PNNL-13877

Pacific Northwest
National Laboratory
Operated by Battelle for the
U.S. Department of Energy

ALARA Analysis of Radiological Control Criteria Associated with Alternatives for Disposal of Hazardous Wastes

R.L. Aaberg*
G.R. Bilyard*
K.M. Branch*
J.C. Lavender**
P.L. Miller*

February 2002

*Pacific Northwest National Laboratory
**Bechtel National

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RL01830

DISCLAIMER

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062;
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service,
U.S. Department of Commerce, 5285 Port Royal Rd., Springfield, VA 22161
ph: (800) 553-6847
fax: (703) 605-6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm


This document was printed on recycled paper.
(8/00)

PNNL-13877

ALARA Analysis of Radiological Control Criteria Associated with Alternatives for Disposal of Hazardous Wastes

R.L. Aaberg*
G.R. Bilyard*
K.M. Branch*
J.C. Lavender**
P.L. Miller*

February 2002

*Pacific Northwest National Laboratory
**Bechtel National

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RL01830

Executive Summary

This ALARA analysis of Radiological Control Criteria (RCC) considers alternatives to continued storage of certain DOE mixed wastes. It also considers the option of treating hazardous wastes generated by DOE facilities, which have a very low concentration of radionuclide contaminants, as purely hazardous waste. Alternative allowable contaminant levels examined correspond to doses to an individual ranging from 0.01 mrem/yr to 10 to 20 mrem/yr. Generic waste inventory data and radionuclide source terms are used in the assessment. Economic issues, potential health and safety issues, and qualitative factors relating to the use of RCCs are considered.

Acronyms

AEA	Atomic Energy Act
ALARA	dose as low as reasonably achievable
CEPCI	Chemical Engineering Plant Cost Index
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CMWIR	Condensed Mixed Waste Inventory Report
D&D	decontamination and decommissioning
DSSI	Diversified Scientific Services, Inc.
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EPA	U.S. Environmental Protection Agency
ER	environmental restoration
FFCA	Federal Facility Compliance Act
FTE	full-time equivalent
IAEA	International Atomic Energy Agency
INEEL	Idaho National Engineering and Environmental Laboratory
LCF	latent cancer fatality
LLMW	low-level mixed waste
MEI	maximally exposed individual (public)
MEW	maximally exposed worker
MITI	Material Inventory and Tracking Information system
MT	metric tons
MWIR	Mixed Waste Inventory Report
NRC	Nuclear Regulatory Commission

ORNL	Oak Ridge National Laboratory
RCC	radiological control criteria
RCRA	Resource Conservation and Recovery Act
STP	Site Treatment Plan
SWMU	solid waste management unit
T_{MAX}	time to reach maximum concentration
TSD	treatment, storage, and disposal facility
WHC	Westinghouse Hanford Company

Acknowledgments

The authors which to thank Andrew Wallo III and Gustavo Vazquez for their guidance and encouragement in this work. Special thanks to Robin L. Hill, who performed an internal peer review, and provided ideas and material for revision. The authors would like to acknowledge the contributions of Jay Lavender, who supported the worker and transportation safety sections; Pete Miller, who wrote on regulatory matters; Gordon Bilyard, who contributed the ecological assessment; and Kristi Branch, who contributed material concerning public perceptions. Thanks also to technical editor Jim Weber and PNNL's document design team, including Colleen Warnecke and Lisa Smith.

Contents

Tables

1.0 Introduction

Currently, most U.S. Department of Energy (DOE) mixed wastes (wastes that contain both radioactive waste and hazardous waste) are stored at DOE sites, awaiting treatment at mixed waste treatment facilities to be built at DOE sites. The premise of this report is that some low-level mixed waste (LLMW) could be treated safely at existing facilities regulated under the Resource Conservation and Recovery Act (RCRA). This would reduce the quantity of LLMW in long-term storage at DOE sites.

The purpose of the report is to provide data and analyses to support ALARA decisions (keeping doses As Low As Reasonably Achievable) for regulating and managing the DOE LLMW. This assessment, although only a waste management feasibility study, is consistent with the philosophy and the principles expressed in Executive Order 12866, "Regulatory Planning and Review," dated October 4, 1993. The Order calls for Federal agencies to assess the costs and the benefits of the various regulatory alternatives, directs that these assessments be conducted using both quantitative and qualitative measures, and encourages an approach that maximizes total benefits. The analysis evaluates cost and dose consequences of waste management strategies, using generic waste inventory data and radionuclide source term assumptions to assess the trade-offs in determining the maximum radionuclide content of purely hazardous waste as compared with mixed waste. The factors thus considered include the economics, the potential health and safety issues, and qualitative factors relating to the use of different radiological control criteria (RCC) to treat certain DOE LLMW as hazardous only. The concept of ALARA is considered for individuals as well as for groups of potential receptors, including rad workers at DOE facilities, hazardous waste workers at treatment, storage, and disposal facilities (TSDs), and the population residing near TSDs.

1.1 Description of the Radiological Control Criteria Concept

The action being evaluated would allow the treatment and disposal of certain LLMW containing very low levels of radioactivity using existing commercial hazardous waste facilities regulated under RCRA. The LLMW containing activity meeting the concentration guidelines (the RCC) effectively meets or exceeds all radiation protection requirements through compliance with RCRA regulations only.

The levels evaluated as possible RCC for hazardous waste in this report, which are acceptable concentrations of residual radioactive material, were developed and documented in a previous PNNL report, funded by DOE (Aaberg et al. 1995), and provide a foundation for the current analysis. Exposure scenarios were used to estimate potential exposures to individual workers at TSD facilities and to members of the general public residing near TSD facilities (exposed via offsite releases). The RCC levels are expressed as concentrations of radionuclides in LLMW, which correspond to a given dose level for a hypothetical maximally exposed individual member of the public (MEI) or maximally exposed worker (MEW). The discrete values evaluated do not constitute the only concentrations that might be selected as RCC. They were selected to bracket an acceptable range of values to be assessed as part of this study.

Dose constraints in Aaberg et al. (1995) were chosen to illustrate various ratios of allowable dose to individual workers and dose to members of the public. The allowable dose to individual workers is equal to or greater than the allowable dose to a member of the public. The dose constraints investigated ranged from 1:1 to 100:1. In the current analysis, concentrations are generally based on multiples of the RCC values with a ratio of worker to public dose of 1:1. The proportionality between a specified dose limit and the RCC allows other dose-to-concentration limits to be inferred or extrapolated.

1.2 Links to Earlier Radiological Control Criteria Study

The Office of Environmental Policy and Assistance (EH-4) has investigated the feasibility of establishing RCC for hazardous waste. The purpose of the project is to determine if it is feasible to define the control criteria in regulated chemical wastes (e.g., RCRA) at which regulation of the waste for its chemical properties provide acceptable control of the radioactive portion of the waste. To be feasible, control of radionuclides afforded by RCRA regulations must provide level of protection for the public equivalent to that stipulated by the regulation based on the Atomic Energy Act. Doses must be ALARA.

The three potential RCC concentration levels investigated for this report are based on the RCC concentration levels of various radionuclides in LLMW presented in Aaberg et al. (1995), with the equal dose criteria applied to individual workers and members of the public, up to 10 mrem. Dose to individual members of the public is not to exceed 10 mrem. Where the limiting dose scenario was based on exposure to a member of the public, rather than a worker, the allowable dose was limited to 10 mrem/yr; thus, concentration was limited to half the value based on the 20-mrem criterion. The magnitude of dose criteria investigated covered the range from 0.01 mrem/yr (RCC Level 1) to 20 mrem/yr (RCC Level 3). The proportionality between a specified dose and the RCC allows other dose-to-concentration levels to be inferred.

The RCCs were derived by evaluating the dose to an individual by radionuclide for both workers and members of the public residing near a TSD. Doses in the worker scenarios were based on various steps in handling waste or residue at a TSD. Concentrations were back-calculated, i.e., starting with a unit concentration in which a dose was calculated, and then the dose concentration ratio was used to determine the concentration that would result in the desired dose level. (See Appendix D for more information.) For offsite individuals, concentrations were back-calculated from the calculated doses from unit releases of radionuclides. In general, the scenarios involving waste treatment workers at TSD facilities were limiting for most radionuclides and RCC levels.

The limiting individual doses are used in this study (along with throughput and labor requirements) to estimate collective dose to workers at various treatment facilities. Collective doses to members of the public were calculated using collective dose factors (from Aaberg et al. 1995) and release factors along with facility throughputs.

1.3 Field Data Collection

As part of the RCC Feasibility Study, the DOE initiated a survey of DOE sites concerning mixed waste inventory, both stored and projected, predominant radionuclides, and the detection capabilities for radioactivity. This survey, known as the DOE Data Call, is summarized in Appendix A of this document. Results of the data call were used to assess the types of waste and radionuclides of importance in LLMW.

The DOE also surveyed a number of TSD facilities to investigate waste- and residue-handling practices. This included both retrospective dose analyses (see M. H. Chew and Associates 1993a, 1993b, 1994, 1995) and reports involving measurement of background radiation and waste-handling procedures (DOE/EH-funded reports by ORISE). Information from the TSD reports was used to determine the potential exposures to workers. The reports cover a number of facility types, including incinerators, cement kilns, and landfills. These reports are cited in Appendix D, "Dose Calculations."

Generic facilities are used to estimate impacts and costs. These reference facilities are considered to be sufficiently representative of TSD facilities to provide a basis for assessing the impacts and costs of the alternatives. Treatment facility characteristics are described in Section 4.3.

1.4 Scope of This Analysis

The premise of this investigation is that protective measures observed in treatment and disposal of hazardous waste regulated under RCRA and TSCA are adequate to assure protection of hazardous waste workers and members of the general public from the potential effects of radiation exposure associated with waste contaminated with very low concentrations of radioactive material.

The current report performs a generic ALARA analysis on the RCCs (Aaberg et al. 1995a) providing exposure and pathway analysis for individuals, and dose factors for population exposure from airborne emissions. Since collective doses for TSD workers and rad workers were not included in the earlier study, they are developed for use in this ALARA analysis.

The waste management options considered in this report address LLMW that is either currently stored or projected to be generated by DOE in the next 30 years. The primary option is assumed to be continued storage of all LLMW at DOE facilities. The alternative involves treating a portion of the mixed waste, for which the residual radionuclide content meets certain control criteria, at existing facilities regulated under RCRA. Three alternative levels of radionuclide content, corresponding to RCC levels, are considered; other levels may be inferred or extrapolated by proportionality between a specified dose limit and the RCC.

The current study considers potential population exposure from processing wastes that meet three dose levels of radionuclide concentration that correspond to doses of 0.01, 1, and 20 mrem to the hypothetical MEW at a hazardous waste TSD facility, or 0.01, 1, and 10 mrem to a member of the general public (offsite). Under the treatment options, waste meeting a chosen RCC level would be treated as hazardous waste, based on the physical form of the waste (aqueous liquid, organic solid, inorganic solid, etc.) and the hazardous contaminants present (organics, metals, etc.).

About 60 radionuclides were considered in the initial RCC assessment; 10 radionuclides (^{3}H, ^{60}Co, ^{90}Sr, ^{99}Tc, ^{137}Cs, ^{129}I, ^{238}U, ^{239}Pu, ^{237}Np, and ^{241}Am) common to several DOE sites are used in unit RCC-level dose calculations. These radionuclides are used to make up a composite source term for example calculations. This subset of radionuclides is used to demonstrate the use of RCC levels with a simplified set of dose calculations.

Dose calculations from the RCC study were expanded to provide estimates of collective dose. The collective worker dose was estimated using the limiting annual dose to the MEW (mrem per full-time equivalent [FTE]) corresponding to each RCC level, the quantity of DOE waste at that RCC level processed by the facility (tons/yr), and the operating labor required by the type of facility (FTE/ton). Collective dose for offsite residents is based on facility emissions (in units of Ci/yr) and a population dose factor (person-rem per Ci emitted). Facility emissions are based on throughput of DOE waste (tons/yr) at each RCC level, the activity of the waste based on the RCC level (pCi/g or Ci/tons), and the release factor (fraction of an individual radionuclide contaminant in airborne emissions from a given process).

In a few cases, the dose to an offsite individual was more restrictive than the worker exposure. For offsite individuals, the RCC concentrations were back-calculated from unit releases of radionuclides. The MEI corresponded to a resident located 500 m from the release of airborne emissions, with inhalation and home-grown food pathways considered. The 500-m distance is based on data from six incineration facilities, with distances from stack to nearest resident ranging from 450 m to 4000 m. The population dose was based on generic meteorology and uniform population density (see Appendix D).

The ALARA analysis was done using an adaptation of a cost/benefit method from ALARA protective measure analysis methods presented in a DOE workshop (Baum et al. 1992; Brown and Stephan 1992). The method includes definition of the problem, overriding factor analysis, benefit calculation, cost calculation, dose estimate, net benefit calculation, and use of a factor-analysis check sheet.

1.5 Structure of This Report

Section 2.0 describes the current Federal regulatory structure for LLMW storage, and for treatment and disposal of hazardous and mixed waste. Section 3.0 describes the example levels of control criteria considered in this report. Section 4.0 describes waste treatment and disposal alternatives. Section 5.0 lists dose consequences, both for human health and ecology.

Section 6.0 describes the ALARA analysis approach, with introductory and background material, plus an overview of the methodology, including economic costs and benefits, dose estimate, overriding factors, net benefit evaluation, and sensitivity analysis. Qualitative factors are also presented, including worker and transportation safety, ecological concerns, public perception, regulatory factors, and future risk for disposal (a groundwater contamination scenario).

Results and conclusions are presented in Sections 7.0 and 8.0, respectively. Section 9.0 is a compilation of references cited.

The appendixes provide greater detail of topics covered in the document. Appendix A includes the text of the DOE data call and summarizes the responses. Appendix B gives the basis for the generic waste inventory used for example dose calculations. Appendix C describes the cost-benefit methods and Appendix D describes dose calculation methods. Appendix E gives details of the groundwater calculations performed in consideration of future risk from disposal. Appendix F provides calculated scenarios of RCRA cell failures.

2.0 Current Regulatory Structure for Treatment and Disposal of Hazardous Waste and Mixed Waste

This section summarizes the current (c. 1996) regulatory requirements for treating and disposing of hazardous and mixed waste. It includes a section hypothesizing on the regulatory implementation of RCC waste.

2.1 Hazardous Waste Treatment and Disposal

Hazardous waste management facilities are subject to extensive regulation under RCRA and analogous legislation in states where the facilities have to be "authorized" under RCRA. Facility standards include requirements for security, preparedness, and contingency planning. The TSD facilities may also be subject to the Clean Air Act, the Clean Water Act, and possibly other environmental regulations, depending on the types of management practices and effluent discharges generated.

Provisions to regulate TSD facilities under these authorities are generally incorporated into facility-specific permits. In essence, TSD facility regulations and associated permit provisions establish standards to ensure that all wastes are accounted for, that no unregulated releases to the environment occur, and that accidental releases are immediately cleaned up.

Some TSD facilities offer a broad range of treatment technologies services; some offer only one technology. Services offered range from technologies to treat or destroy wastes, such as incineration, to technologies for land disposal of wastes after they have been treated. The types of waste streams a TSD facility is authorized to treat depend on the types of treatment technologies offered by the facility and is specified in the permit. The TSD facilities may also be authorized to blend, redistribute, or use certain hazardous waste streams in such beneficial applications as cement production and energy recovery.

A small subset of TSD facilities is authorized to treat both hazardous and radioactive mixed wastes. These facilities are subject to the same basic suite of environmental regulations as other TSDs, and they are also required to have licenses issued by the Nuclear Regulatory Commission (NRC) or Agreement State authority. While the permit and licenses for these facilities incorporate specialized provisions to address radiological concerns, the processes used to treat mixed waste streams are essentially the same as those used by TSDs in general.

2.2 Mixed Waste Treatment and Disposal

Under the current scheme of environmental regulations, radioactive mixed wastes are subject to regulation under the Atomic Energy Act (AEA) and RCRA, amended by the Federal Facilities Compliance Act (FFCA).

- *Atomic Energy Act (AEA)* - Regulates the radioactive component of mixed wastes. This 1954 Act created the Atomic Energy Commission (AEC) to encourage the development and use of nuclear energy and research for the general welfare and of the common defense and security for the United States. The AEA has since become the basis of authority for NRC, DOE, and Environmental Protection Agency (EPA) in regulating radioactive materials defined in the AEA.

- *Resource, Conservation, and Recovery Act (RCRA)* - Regulates the hazardous constituents of mixed wastes. RCRA provides EPA and authorized states the authority to regulate solid and hazardous waste management activities from generation to ultimate disposal.

- *Federal Facilities Compliance Act (FFCA)*.

Regulations issued under these acts generally require that federal facilities managing mixed wastes have site-specifics treatment plans, with permits and licenses issued by the NRC, the EPA, and by authorized state agencies.

2.2.1 Commercial Mixed Waste Management Facilities

Three TSD facilities that are authorized to accept mixed waste are discussed below to illustrate the kinds of capabilities that are available for treatment and disposal of mixed wastes. Other facilities are cited in a DOE publication, *Commercially Available Low-Level Radioactive and Mixed Waste Treatment Technologies* (Garcia 1996).

- *Envirocare of Utah, Inc*. - The Envirocare facility is located in the Great Basin Desert Area of western Utah, approximately 75 miles west of Salt Lake City. Envirocare provides treatment, storage, transportation and disposal for waste streams in excess of 100 cubic feet. Envirocare accepts all nuclides within specific limits (less than NRC Class A), and over 200 waste codes including characteristic and listed wastes. As of 1996, Envirocare was the only permitted solid mixed waste disposal facility in the U.S. The mixed waste disposal cells for hazardous wastes are above-grade, capped embankments designed for lifetimes of at least 1,000 years. Envirocare performs two types of mixed waste treatment:

  - *Stabilization* - State-of-the-art 150 tons per day treatment facility can process soils, sludges (up to 49% aqueous liquids), debris, and process wastes to meet either RCRA characteristic or listed waste treatment standards. Non-thermal treatment technologies include stabilization, chemical fixation, chemical oxidation, chemical reduction, neutralization, and deactivation.

  - *Macroencapsulation* - Low-density polyethylene (LDPE) extrusion technology is used to encapsulate elemental lead and hazardous debris in order to meet both D008 (the waste for lead in 40 CFR 261) and alternative debris treatment standards.

- *Diversified Scientific Services, Inc. (DSSI)* - DSSI provides thermal treatment of liquid mixed, hazardous and/or radioactive waste, and waste brokerage and transportation services. DSSI accepts remedial and as-generated process wastes provided that the waste is a pumpable liquid and one that

DSSI can accept. In liquid form, DSSI can accept all RCRA hazardous waste codes (except D003, F020, F021, F022, F023, F026, and F027), including waste containing small quantities of radio-isotopes with atomic numbers 1 through 83, 88, 90, 92, 94, and 95. DSSI owns and operates an industrial boiler system that produces electrical power from the thermal treatment of liquid wastes classified as mixed, hazardous and/or radioactive. The residue resulting from the treatment process is considered DSSI generated waste and is disposed of by DSSI at an appropriately licensed and permitted disposal facility. Through beneficial recovery of thermal energy, large quantities of hazardous waste that would otherwise be stored produce a useful product while a substantial waste reduction is accomplished.

- *Nuclear Sources and Services, Inc. (NSSI)* - NSSI is a fully permitted RCRA Part B facility which accepts hazardous, mixed, and radioactive wastes for treatment, storage, and disposal. However, NSSI accepts both remediation and as-generated process wastes. However, NSSI accepts private sector wastes only, and DOE, DoD, or other government-generated wastes are accepted only through private sector brokers. NSSI has an authorized drum storage capacity of 4000 drums, and is also a permitted radioactive, mixed, and hazardous waste transporter. Disposal of all residues of wastes received at NSSI is at offsite facilities. NSSI is permitted for all EPA waste codes, all waste forms, and all radionuclides including special nuclear material. The only waste materials not currently acceptable at NSSI are polychlorinated biphenyls (PCBs) above 50 ppm, explosives, and dioxins.

Most RCRA treatment, storage, and disposal facilities are not authorized to accept radioactive wastes; this restriction is specified in the waste acceptance criteria for the facility. It is not known whether this is attributable to regulatory constraints or economic considerations.

2.2.2 Hypothetical Regulatory Implementation of the RCC Approach

One of the key assumptions of the RCC approach is that radiation emitted by RCC wastes would be low enough to be safely accommodated by existing hazardous waste management facilities regulated by RCRA. In essence, the practices and procedures for minimizing exposures to hazardous wastes would have to be deemed adequate for minimizing exposure to RCC quantities of radiation.

The ostensible advantage of this approach would be elimination or reduction of the tier of regulations normally applied to certain radioactive waste management activities, which would be unnecessary for trace amounts of radioactive contaminants in hazardous waste. Cursory review of currently available mixed waste management capabilities, as outlined above, suggests that mixed wastes are readily treatable using common hazardous waste treatment technologies. Because the treatment of these wastes is required only for their hazardous components, RCC wastes would clearly be amenable to treatment with these same technologies.

3.0 Waste Management Alternatives Considered

This section is organized into five parts: introductory material, consisting of an overview of the alternatives and waste inventory; a description of the current practice of storing mixed waste at DOE facilities; and brief descriptions of each of the three RCC sample level alternatives.

3.1 Overview of Alternatives and Waste Inventory

The three RCC alternative treatments all include sending a portion of the existing and projected mixed waste generated at DOE facilities to commercial TSD facilities. The three differ only in the activity levels which would allow control as hazardous waste. The activity levels correspond to dose levels to which the public MEI or MEW is exposed. The three screening levels cover more than three orders of magnitude for workers, from 0.01 to 20 mrem/yr, and three orders of magnitude for the public, 0.01 to 10 mrem/yr. The ranges are believed to encompass activities that would be reasonable to regulate as hazardous. The upper end of the range, 20 mrem/yr, has more than a 100-fold margin of safety compared with the 5000-mrem limit which is applied to general employees of DOE and its contractors by 10 CFR 835.202. The Level 3 RCC corresponds to one-tenth of the primary limit of 100 mrem for the public in 10 CFR 835.101, and is equal to the 10-mrem maximum dose to a member of the public from air releases from DOE activities in 10 CFR 834.201. The three alternative treatments are as follows:

- Treat wastes which meet RCC Level 1 (MEI and MEW dose of 0.01 mrem/yr) at commercial TSD facilities and, for now, store the remainder of waste at existing DOE mixed waste storage facilities.

- Treat wastes which meet RCC Level 2 (MEI and MEW dose of 1 mrem/yr) at commercial TSD facilities, and store the remainder at existing DOE mixed waste storage facilities.

- Treat waste which meet RCC Level 3 (MEI dose of 10 mrem; MEW dose of 20 mrem) at commercial TSD facilities.

Wastes containing activity in concentration greater than RCC Level 3 are outside the scope of this analysis and are excluded from further consideration. Excluded waste would be stored as LLMW in all three alternatives and is, therefore, of no consequence in a comparative analysis.

This analysis tests the notion that certain LLMW could be regulated as purely hazardous waste upon the establishment of a control level for the radioactive constituents. The three sample RCC levels analyzed in this report, which are a variation of the levels presented in Aaberg et al. (1995), are radionuclide concentrations based on potential doses to an MEI. Table 3.1 shows the MEI dose corresponding to each RCC level and the corresponding fraction of non-excluded waste assumed to meet each level. About 86% (by mass) of the total stored inventory and 43% of the projected inventory from the Condensed Mixed Waste Inventory Report (CMWIR) (DOE 1995) falls within Level 3 criteria and

Table 3.1. RCC Level Assumptions Concerning Stored (Candidate) Waste

RCC Level	Dose to Maximally Exposed Individual	Waste Fraction, cumulative
Level 1	0.01 mrem	10%
Level 2	1.0 mrem	40%
Level 3	20 mrem (10 mrem public)	100%

are included. The remainder is excluded because the waste contains excessive activity or constituents (e.g., mercury) which may not be treatable at many commercial TSDs. The subset of DOE mixed waste that is assumed to meet at least RCC Level 3 is based on the screening of large-volume waste streams in the CMWIR. Mixed wastes which contain activity in concentration greater than RCC Level 3 are outside the scope of this report.

Quantities which met Levels 2 and 3 screening were assessed; one-quarter of the stored waste meeting Level 2 (about 10% of the total) was assumed to meet Level 1, based on an overview of Data Call and CMWIR information. The percentage of waste meeting each level is slightly different for projected waste than for the stored waste listed in Table 3.1; the cumulative percentages of waste meeting Levels 1 and 2 are 10.6% and 42.3%, respectively, of the non-excluded waste.

Waste having radioactive constituent concentrations greater than the highest RCC level is assumed to be stored indefinitely in a DOE facility. The fraction meeting a criterion is assumed to be transported to a commercial hazardous waste facility for treatment and disposal. The commercial facility (i.e., the TSD) then would treat and dispose of the waste on location.

For each RCC level, the treatment processes depend only on the physical form of the waste and the hazardous constituents. The only difference in treatment is the quantity which would qualify as hazardous waste. The proportions of the physical forms of the waste (waste matrices) are taken from data in the CMWIR (DOE 1995) and may vary with the RCC level. The chemical nature of the radiological component should have no impact on the treatment because of the trace quantities. The assumption is that no special provisions be made for this waste.

3.2 Continued Storage

The Continued Storage (status quo) alternative involves storing all mixed wastes at DOE facilities for the duration of the 30-year study period. The wastes considered are those which meet Level 3 RCC; waste containing activity in excess of this level is not considered.

At the end of the 30-year period, the waste is still in storage. Treatment and disposal at a DOE facility would be a way to complete the cycle. A variation would be 10 to 20 years of storage, followed by treatment at a DOE mixed waste facility, such as those being included in the Site Treat Plans (STPs) under the FFCA. This alternative is not analyzed in detail, but there are some observations which can be made concerning this possibility. It is assumed that treatment of this waste at a mixed waste treatment facility would be more costly than treatment at a commercial hazardous waste facility because a facility designed to treat radioactive waste would incorporate radiation protection (shielding, additional remote-handling, additional procedures), which would add to the construction and operating costs. If treatment costs were the same, processing at a DOE facility would still be more costly due to the additional cost of storing the waste at a DOE facility until appropriate processing facilities were available.

3.3 Radiological Control Criteria Level 1

The Level 1 RCC corresponds to a dose of 0.01 mrem/yr to the hypothetical MEI, which could be either a worker or member of the public. The Level 1 RCC is based on 1% of the concentration for each radionuclide that was calculated to result in 1 mrem/yr to the MEI, and is based on a scenario analysis (Aaberg et al. 1995). Values for the Level 1 RCCs are given in Table 3.2. The magnitude of the values range from thousandths of pCi/g for ^{60}Co to hundreds of pCi/g for ^{3}H, ^{63}Ni, and ^{93}Zr. For mixtures of radionuclides, the sum of fractions rule[(a)] is applied. Physically, it means that the combined effect of the radionuclide contaminants cannot exceed the dose criterion.

3.4 Radiological Control Criteria Level 2

The Level 2 RCC corresponds to a dose of 1 mrem/yr to the hypothetical MEI or MEW as with RCC Level 1. Values for the Level 2 RCCs are given in Table 3.3. The magnitude of the values range from tenths of pCi/g for ^{60}Co to thousands to tens of thousands of pCi/g for ^{3}H, ^{63}Ni, and ^{93}Zr. Other constraints such as the U.S. Department of Transportation (DOT) limit of 2 nCi/g (based on the 49 CFR 173.403 definition of radioactive material) may provide a practical upper bound on the allowable activity of these isotopes. For mixtures of radionuclides, the sum of fractions rule is applied.

(a) Sum of fractions rule, as applied to waste meeting RCC criteria: to meet the RCC level n, the sum of the ratios of actual concentration of a radionuclide Ê to the RCC Level n limit for radionuclide Ê must be less than or equal to unity:

$$\sum \text{ radionuclide}_i \ \frac{\text{concentration}_i}{\text{RCC level N}_i} \leq 1$$

For example, given RCC Level 1 concentration for Table 3.2, a waste stream containing 3H at 300 pCi/g and 14C at 6 pCi/g it would meet the limit:

$$\frac{300}{650} + \frac{6}{12} \leq 1$$

3.5 Radiological Control Criteria Level 3

The Level 3 RCC corresponds to a dose of 20 mrem/yr to the MEW or 10 mrem/yr to the MEI. For most radionuclides, these concentrations are 20 times the Level 2 concentration. A factor of 10 times the RCC for a radionuclide is used when the exposure scenario which is most restrictive, or most limiting (Aaberg et al. 1995), involves a member of the general public; this is the case for ^{3}H, ^{14}C, ^{35}S, ^{99}Tc, ^{125}I, and ^{129}I.

Level 3 RCCs are given in Table 3.4. The magnitude of the values range from a few pCi/g for ^{60}Co to tens of thousands or more pCi/g for ^{3}H, ^{63}Ni, and ^{79}Se, ^{93}Zr.

Table 3.2. RCC Level 1 Concentrations, pCi/g

Radionuclide	RCC Level 1	Radionuclide	RCC Level 1
^{3}H	6.5×10^{2}	^{147}Pm	6.1×10^{2}
^{14}C	1.2×10^{1}	^{151}Sm	1.3×10^{3}
^{55}Fe	1.4×10^{1}	^{154}Eu	1.1×10^{-2}
^{60}Co	4.5×10^{-3}	$^{226}Ra+D^{(b)}$	6.1×10^{-3}
^{63}Ni	1.7×10^{3}	^{228}Th	2.5×10^{-1}
^{79}Se	5.8×10^{1}	^{230}Th	3.0×10^{-1}
$^{90}Sr+D^{(a)}$	3.6	$^{232}Th+D^{(c)}$	3.4×10^{-3}
^{93}Zr	5.4×10^{2}	^{235}U	3.5×10^{-1}
^{94}Nb	1.4×10^{-2}	$^{238}U+D^{(d)}$	5.0×10^{-1}
^{99}Tc	5.0	$^{237}Np+D^{(e)}$	8.4×10^{-2}
^{106}Ru	1.0×10^{-1}	^{238}Pu	2.8×10^{-1}
^{125}Sb	6.3×10^{-2}	^{239}Pu	2.5×10^{-1}
^{129}I	1.1×10^{-2}	^{241}Pu	1.5×10^{1}
^{134}Cs	1.2×10^{-2}	^{241}Am	1.2×10^{-1}
^{137}Cs	4.6×10^{-2}	--	--

(a) $^{90}Sr+D$ refers to $^{90}Sr+D$ in equilibrium with ^{90}Y.
(b) $^{226}Ra+D$ refers to ^{226}Ra in equilibrium with ^{222}Rn, ^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po, ^{210}Pb, ^{210}Bi, and ^{210}Po.
(c) $^{232}Th+D$ refers to ^{232}Th in equilibrium with ^{228}Ra, ^{228}Ac, ^{228}Th, ^{224}Ra, ^{220}Rn, ^{216}Po, ^{212}Pb, and ^{212}Bi.
(d) $^{238}U+D$ refers to ^{238}U in equilibrium with ^{234}Th and ^{234}Pa.
(e) $^{237}Np+D$ refers to ^{237}Np in equilibrium with ^{233}Pa.

Table 3.3. RCC Level 2 Concentrations, pCi/g

Radionuclide	RCC Level 2	Radionuclide	RCC Level 2
^{3}H	6.5×10^{4}	^{147}Pm	6.1×10^{4}
^{14}C	1.2×10^{3}	^{151}Sm	1.3×10^{5}
^{55}Fe	1.4×10^{3}	^{154}Eu	1.1
^{60}Co	4.5×10^{-1}	$^{226}Ra+D^{(b)}$	1.4×10^{1}
^{63}Ni	1.7×10^{5}	^{228}Th	2.5×10^{1}
^{79}Se	5.8×10^{3}	^{230}Th	3.0×10^{1}
$^{90}Sr+D^{(a)}$	3.6×10^{2}	$^{232}Th+D^{(c)}$	3.4×10^{-1}
^{93}Zr	5.4×10^{4}	^{235}U	3.5×10^{1}
^{94}Nb	1.4	$^{238}U+D^{(d)}$	5.0×10^{1}
^{99}Tc	5.0×10^{2}	$^{237}Np+D^{(e)}$	8.4
^{106}Ru	1.0×10^{1}	^{238}Pu	2.8×10^{1}
^{125}Sb	6.3	^{239}Pu	2.5×10^{1}
^{129}I	1.1	^{241}Pu	1.5×10^{3}
^{134}Cs	1.2	^{241}Am	1.2×10^{1}
^{137}Cs	4.6	--	--

(a) $^{90}Sr+D$ refers to $^{90}Sr+D$ in equilibrium with ^{90}Y.
(b) $^{226}Ra+D$ refers to ^{226}Ra in equilibrium with ^{222}Rn, ^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po, ^{210}Pb, ^{210}Bi, and ^{210}Po.
(c) $^{232}Th+D$ refers to ^{232}Th in equilibrium with ^{228}Ra, ^{228}Ac, ^{228}Th, ^{224}Ra, ^{220}Rn, ^{216}Po, ^{212}Pb, and ^{212}Bi.
(d) $^{238}U+D$ refers to ^{238}U in equilibrium with ^{234}Th and ^{234}Pa.
(e) $^{237}Np+D$ refers to ^{237}Np in equilibrium with ^{233}Pa.

Table 3.4. RCC Level 3 Concentrations, pCi/g

Radionuclide	RCC Level 3	Radionuclide	RCC Level 3
^{3}H	6.5×10^{5}[a]	^{137}Cs	9.2×10^{1}
^{14}C	1.2×10^{4}[a]	^{147}Pm	1.2×10^{6}
^{55}Fe	2.8×10^{4}	^{151}Sm	2.6×10^{6}
^{60}Co	9.0	$^{226}Ra+D$[c]	1.2×10^{1}
^{63}Ni	3.4×10^{6}	^{228}Th	5.0×10^{2}
^{79}Se	1.2×10^{5}	^{230}Th	6.0×10^{2}
$^{90}Sr+D$[b]	7.2×10^{3}	$^{232}Th+D$[d]	6.8
^{93}Zr	1.1×10^{6}	^{235}U	7.0×10^{2}
^{94}Nb	2.8×10^{1}	$^{238}U+D$[e]	1.0×10^{3}
^{99}Tc	5.0×10^{3}[a]	$^{237}Np+D$[f]	1.7×10^{2}
^{106}Ru	2.0×10^{2}	^{238}Pu	5.6×10^{2}
^{125}Sb	1.3×10^{2}	^{239}Pu	5.0×10^{2}
^{129}I	2.2×10^{1}[a]	^{241}Pu	3.0×10^{4}
^{134}Cs	2.4×10^{1}	^{241}Am	2.4×10^{2}

(a) Limiting individual dose is based on 10-mrem to a member of the general public offsite.
(b) $^{90}Sr+D$ refers to $^{90}Sr+D$ in equilibrium with ^{90}Y.
(c) $^{226}Ra+D$ refers to ^{226}Ra in equilibrium with ^{222}Rn, ^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po, ^{210}Pb, ^{210}Bi, and ^{210}Po.
(d) $^{232}Th+D$ refers to ^{232}Th in equilibrium with ^{228}Ra, ^{228}Ac, ^{228}Th, ^{224}Ra, ^{220}Rn, ^{216}Po, ^{212}Pb, and ^{212}Bi.
(e) $^{238}U+D$ refers to ^{238}U in equilibrium with ^{234}Th and ^{234}Pa.
(f) $^{237}Np+D$ refers to ^{237}Np in equilibrium with ^{233}Pa.

4.0 Waste Treatment and Disposal Options

The waste treatment methods and facilities relied on by the alternatives depend on the characteristics of the LLMW which would meet the RCC criteria. This section includes a brief description of the generic LLMW inventory, in addition to a description of the types of commercial treatment facilities which would be used to treat RCC wastes.

4.1 Generic Waste Inventory

A generic waste inventory allows assessment of costs, based on a reasonable mix of waste types and applicable treatment methods. A DOE Data Call requesting information regarding the mix of LLMW was conducted, and responses to this particular question were received from 12 DOE sites (see Appendix A). However, results indicated that the inventory information from many sites was not detailed enough to readily provide the information required. Therefore, the field survey responses and information available in the CMWIR (DOE 1995) were used to define the generic waste mix.

Costs of the treatment of LLMW depend on the type of processing that is required prior to its safe disposal. The processing that is required depends on the physical and chemical forms (or matrix) as well as the hazardous contaminant content. Six waste forms were defined for this analysis: organic liquids, aqueous liquids, organic and inorganic solids, soil, and debris. The proportion of each physical form of waste was based on data from the CMWIR (DOE 1995). Another significant TSD cost factor which is not considered in this analysis is waste volume. Large volumes generated by Federal generators can be negotiated into as much as 50% cost reductions at the TSD.

Table 4.1 lists the breakdown of stored and projected DOE LLMW by physical form and RCC level. The stored waste values represent the quantity (tons) which would be processed on an annual basis to accomplish a 5-year work-off of the existing waste inventory. Cumulative quantities of waste, both currently stored and projections for 30 years, are listed in Table 4.2. These are quantities which meet RCC Level 3 or lower (inventory discussed in Section 3.0). A description of the generic inventory and its development is given in Appendix B.

A list of 10 radionuclides commonly found in DOE wastes based on a survey of DOE sites (Appendix A) is used to provide simplified, example dose calculations. The radionuclide source terms are based on the limiting concentration of an individual radionuclide at each RCC level (see Tables 3.2 - 3.4). Because these radionuclides emit different types of radiation, the dominant exposure pathways and limiting scenarios differ between radionuclides. The example radionuclides with their characteristic emissions and half-lives are listed in Table 4.3.

Table 4.1. Incremental Quantities of Waste Meeting RCC by Physical Form

Waste Form	Annual Quantity of Waste Processed, Incremental by Level					
	Stored Waste,[a] tons			Projected Waste,[b] tons		
	RCC Level 1	RCC Level 2	RCC Level 3	RCC Level 1	RCC Level 2	RCC Level 3
Debris	177	530	9,168	70	210	281
Soils	1,973	5,918	816	9[c]	26[c]	485[c]
Organic solids	144	432	3,615	63	190	136
Inorganic solids	68	203	271	24	73	98
Organic liquids	40	120	160	11	34	45
Aqueous liquids	16	49	65	6	17	22
Total	2,417	7,251	14,094	183	550	1,067

(a) Stored waste to be processed on an annual basis is assumed to be one-fifth of the stored backlog.
(b) Annual generation, or one-fifth of the 5-year projection.
(c) The projected quantity of soils is assumed to be underestimated because environmental restoration wastes from most sites were not included.

Table 4.2. Cumulative Quantities of Waste, Incremental by RCC Level

Waste Type	Quantity of Waste, Incremental by Level, tons		
	RCC Level 1	RCC Level 2	RCC Level 3
Stored[a]	12,100	36,300	70,000
Projected[b]	5,500	16,500	32,000
Total	17,600	53,800	102,000

(a) Stored waste is calculated as quantity processed annually (Table 4.1) times 5 years (to work off backlog).
(b) Projected waste is calculated as quantity generated annually (Table 4.1) times 30 for the 30-year study period.

Table 4.3. Characteristic Emissions from Radionuclides Considered

Emissions from Radioactive Decay	Example	Half-life	Other Examples
Alpha-emitters	^{238}U ^{239}Pu ^{241}Am	4.6 x 10^9 y 24,000 y 433 y	U, Th isotopes
No photon, high radiotoxicity[(a)]	^{90}Sr	28.5 y	^{241}Pu
No photon, low to moderate radiotoxicity	^{3}H	12.3 y	^{14}C, ^{63}Ni, ^{79}Se, ^{93}Zr, ^{99}Tc, ^{147}Pm
Photon < 0.3 MeV	^{129}I	1.6 x 10^7 y	^{55}Fe, ^{125}Te, ^{125}I, ^{144}Ce, ^{151}Sm
Photon > 0.3 - 1 MeV	^{137}Cs	30.1 y	^{7}Be, ^{54}Mn, ^{57}Co, ^{94}Nb, ^{131}I, ^{125}Sb
Photon > 1 MeV	^{60}Co ^{234}Pa[(b)]	5.3 y 6.7 h	^{65}Zn, ^{106}Ru, ^{110}Ag, ^{133}I, ^{134}Cs, ^{152}Eu, ^{154}Eu

(a) Radiotoxicity is dependent on the rates of exposure (e.g., Pu is high for inhalation but not for ingestion) and chemical form of the radionuclide.
(b) Decay product of ^{238}U, included along with ^{234}Th in ^{238}U+D.

Composite source terms for RCC Levels 1, 2, and 3 are presented in Table 4.4. This mixture of radionuclides, based on RCC concentrations and the sum of fractions rule, is used to show example calculations, so the characteristics/pathways of importance for a single radionuclide do not dominate the overall results. One-tenth of the limiting concentration for each RCC level is apportioned among the 10 radionuclides; the quantity of ^{3}H is adjusted so the total does not exceed 2000 pCi/g (the DOT ceiling over which labeling as radioactive is required). Two variations are given for RCC Level 3: in one, a full 10% of the RCCs are used, so the total exceeds 2000 pCi/g; in the other, radionuclides are proportioned differently, while still meeting RCC.

The radionuclides chosen for this generic analysis are from a variety of sources: tritium (^{3}H) and ^{60}Co are activation products; ^{90}Sr, ^{129}I, and ^{137}Cs are fission products; uranium, ^{238}U, reactor fuel, ^{239}Pu, and ^{241}Am are transuranic elements.

4.2 Continued Storage - No Action

The continued storage alternative describes the policy of long-term storage of DOE LLMW. In this alternative, all of the current inventory and projected annual generation of LLMW are stored. The scenario does not consider any LLMW processing once it is stored.

Both routine and non-routine activities are associated with long-term storage of LLMW. Routine activities include waste monitoring, container inspection, sampling, and reporting. These activities occur periodically and are included in the cost of storing the waste. Non-routine activities include waste

Table 4.4. Composite Source Term, Maximum Total 2000 pCi/g

	RCC Composite Source Term, Based on Sum of Fractions Rule, Limited to 2000 pCi/g					
	RCC Level 1 Fraction Conc. L1		RCC Level 2 Fraction Conc. L2		RCC Level 3 Fraction Conc. L3	
Radionuclide	**L1**	**pCi/g**	**L2**	**pCi/g**	**L3**	**pCi/g**
^{3}H	0.07	45.5	0.03	1978	0.002458	1598
^{60}Co	0.14	0.00063	0.18	0.08	0.2	1.8
^{90}Sr + D	0.01	0.036	0.01	3.6	0.01	72
^{129}I	0.01	0.00011	0.01	0.01	0.01	0.22
^{137}Cs	0.43	0.01978	0.43	2.0	0.43	39.6
^{238}U +D	0.19	0.095	0.19	9.5	0.198	198
^{239}Pu	0.04	0.01	0.04	1	0.04	20
^{241}Am	0.05	0.006	0.05	0.6	0.05	12
^{99}Tc	0.01	0.05	0.01	5	0.01	50
^{237}Np + D	0.05	0.0042	0.05	0.4	0.05	8.4
Total	1	45.7	1.000	2000	1.000	2000

repositioning within the storage facility, repackaging of breached waste containers, and decontamination of facility and equipment due to accidents or breached containers. Only routine storage activities are included in the cost analysis.

Low-level mixed waste is assumed to be stored at the DOE site where the waste currently exists or will be generated in the future. The intra-site transportation of the LLMW is assumed to be negligible and is not included in the cash-flow analysis.

4.3 Treatment

Each waste form is subject to a treatment process to destroy, or encapsulate its hazardous component prior to disposal. The process assumed to be applicable to each waste form is indicated in Table 4.5. Although incineration is included as a disposal method for soil, the actual preferred treatment method for soils contaminated with heavy metals would be stabilization.[(a)] To calculate collective worker dose, exposures are evaluated for various waste processing options. Emphasis is placed on treatment methods used for large volumes of waste.

Table 4.5. Treatment Options Appropriate to Each Waste Form

(a) For simplicity for the first iteration, incineration alone was chosen. Since incineration costs more than stabilization, this assumption tends to make the continued storage option more attractive than it would be otherwise.

Waste Form	Treatment Option
Debris	Shred/grout stabilization
Soils	Incineration /stabilization[(a)]
Organic solids	Incineration
Inorganic solids	Stabilization
Organic liquids	Incineration
Aqueous liquids	Neutralization, chemical reduction, stabilization

(a) Incineration is appropriate for soil contaminated with organics; stabilization is more appropriate for contamination with metals.

4.3.1 Incineration of Liquids and Solids

Incineration facility operations at the generic incinerator include waste receiving and analysis, waste staging and storage, incineration of liquids and solids, and stabilization and disposal of residue materials. The refractory-lined rotary kiln incinerator, a slightly inclined cylinder 3 m in diameter and 10 m long, has a capacity of 30,000 metric tons per year. The secondary combustion chamber is a refractory-lined vessel which is used to burn liquid wastes and provide more complete combustion. Residual materials include a glassy slag, which is collected from the discharge end of the kiln in a bin, and fly ash, which is collected as sludge in the wet scrubbers of the air pollution control system.

Other major process equipment includes a shredder for size reduction, an air pollution control system including ionizing wet scrubbers, and a waste water treatment system to handle scrubber sludge. Onsite stabilization of ash residue materials includes a pit and backhoe arrangement for adding and mixing stabilizing materials to prepare for onsite disposal.

The incinerator is assumed to employ 150 persons, of whom 80 are hazardous waste workers. Most of the waste workers (such as incinerator operators) perform jobs that have a low potential for exposure because little time is spent near or in contact with waste, or (as with analytical laboratory personnel) the time spent is near very small quantities of waste materials. Activities which have the highest potential exposure to radioactive materials from waste include waste receiving and sampling, kiln maintenance, fly ash handling, and residue stabilization (Beck and Folz 1993a, 1993b, 1995; and M.H. Chew & Associates 1993a, 1993b, 1994).

4.3.2 Stabilization of Ash and Inorganic Solids

Encapsulation, a fundamental process for improving the containment of waste, is the combined processes of *stabilization* and *solidification*. Stabilization attempts to reduce the solubility or chemical reactivity of a waste by changing its chemical state or by physical entrapment. Solidification attempts to convert the waste into an easily handled solid with reduced hazards from volatilization, leaching, or spillage. Stabilization and solidification are typically discussed together since they have the common

purpose of improving the containment of potential pollutants in radioactive and hazardous wastes (Barth et al. 1990).

The generic process chosen for stabilization/solidification includes the following steps: 1) the input waste stream may be sorted by size based upon process requirements; 2) the waste stream is then blended with additives and put into containers or forms; 3) the waste is cured for solidification, after which it is ready for packaging and/or disposal.

The chemical properties of the waste and the additives used in the process determine whether the process is solidification, stabilization, or both. The additives used in stabilization/solidification (referred to as *stabilization* in the remainder of this section) depend upon the nature and properties of the waste to be treated. Inorganic wastes are typically stabilized using cement-based additives (e.g., Portland cement, with small amounts of fly ash, sodium silicate, bentonite, or other additives) and pozzolanic additives (such as fly ash, pumice, or lime kiln dusts). Although organic wastes may be treated by stabilization, it is not considered in this report, since incineration is the preferred treatment option for organics.

Stabilization can be performed in situ or ex situ. In situ processes mix the additives with the waste in place, with curing at the disposal location. Stabilization can be performed in the waste container by mixing the additives directly in the waste package. An ex situ process, performed at the TSD, is the reference process for this study.

Major equipment used in the stabilization process includes material control equipment, such as feeders with rotating screws, weigh feeder systems, or belt scale systems; material-handling equipment, such as front-end loader/dump-truck operations and belt or screw conveyor systems; and material mixing equipment. Mixing equipment can be either batch mode, such as change-can and muller mixers, or continuous mixing using ribbon blenders or other such devices.

Stabilization can be performed on a wide range of wastes and additives, in situ or at a TSD, and with a wide range of equipment. For the purposes of this report, ex situ stabilization has been assumed to be performed in batch mode on solid material in a commercial facility capable of processing 15,000 tons of waste per year (about 220 ft^3/h), which would employ approximately 30 workers. The equipment assumed to be used in the stabilization process includes front-end loader/dump-truck waste-handling, a weigh batcher system to measure the waste input to the mixer, a weigh feeder system to measure the amount of additives for the batch, belt conveyors to move waste and additives to the muller-type batch mixer, and screw-type conveyors to move the mixture to forms for curing or to a dump-truck for disposal. For TSD worker exposure scenarios, waste-handling operations are assumed to be similar to those at an incineration facility.

4.3.3 Shredding and Grouting of Debris

Shredding and grouting of debris are very similar in concept to stabilization/solidification of ash. The difference is that debris must be sorted for coarse and fine material. The coarse material is volume-reduced. Finally, all the material is stabilized and/or solidified with a grouting agent. Portland cement is assumed to be the grouting agent used in this process.

Typical equipment required to perform shredding and grouting includes a front-end loader/backhoe, a hopper with conveyor system connected to a shaker screen, a crusher and/or shredder, a plug mill or cement mixer, molds to hold and cure the grouted material, and an all-terrain forklift for moving the cured grouted material. A plant with this equipment could treat approximately 10,000 tons per year (EPA 1992) and would employ approximately 45 workers.

4.3.4 Neutralization, Precipitation, and Stabilization of Aqueous Liquids

The reference treatment process for aqueous liquids is one that employs neutralization first and then precipitation before stabilization of the precipitate.

In the neutralization process, an acid or base is added to the waste stream to achieve a neutral pH (range of 6 to 8). The precipitation process involves addition of chemicals to the waste stream to create insoluble compounds, which are separated from the liquid phase. See Section 4.3.2 for a discussion on stabilization of the resulting precipitation solids.

It is assumed that aqueous liquids are treated in batch mode, including the following steps: 1) the waste is pumped into a tank, 2) neutralizing agents are mixed into the waste to achieve the desired pH, and 3) additives are mixed into the neutralized liquid to precipitate solids. The resulting insoluble fraction is solidified. The treated liquid fraction is monitored to ensure compliance with permits, before being sent to the sewer or drain field. Neutralization is required before disposal of liquid waste. The assumed capacity for this process is 50,000 tons (about 13-million gallons) per year.

4.4 Landfill/Disposal

The generic RCRA landfill facility has a capacity of approximately 150,000 t/yr,[(a)] and accepts a variety of bulk and packaged waste materials. Loads of waste are weighed, sampled, and placed into a RCRA cell. Equipment used includes trucks and earth-moving machinery for filling between layers of compacted soil. The position of all waste materials (in three dimensions) is surveyed and tracked. The facility employs approximately 150 workers, of whom 100 would be engaged in waste-handling operations.

4.5 Transportation

Waste is assumed to be transported to the treatment or disposal facility by truck. The hazardous waste constituents, distance to be transported, and waste container (or transportation mode) dictate the cost of transportation. A study by M. H. Chew & Associates (1995) was used as a basis for cost

---

(a) Three landfills are cited in Appendix D, Table D.6; their capacities range from 135,000 to 800,000 tons/yr (the largest in the U.S.). Permitted capacities of 11 landfills for which data was available indicate a range from 800,000 yd^3 to 12 million yd^3, and five facility capacities range from 900,000 tons to 4.4 million tons (*Hazardous Waste Consultant*, Vol. 13, Issue 2, 1995).

calculations. The average transport distance is computed for representative areas based on the number of disposal sites.

A truck is assumed to haul a maximum of 19.2 t (42,320 lb) of waste per shipment. The one-way shipment is based upon an assumed average distance of 1970 km (1230 miles) for mixed waste to reach a suitable treatment facility. Densities of solid and liquid wastes were taken to be 1500 and 1000 kg per cubic meter, respectively. It is assumed that waste would be accumulated in storage at each DOE site until a sufficient quantity is available for shipping.

Labor requirements for transportation of waste are based on a shipping distance of 2124 km (1320 miles), or 1600 tons per year per FTE. The shipping distance could actually range from less than 100 miles to more than 1000; to be conservative for this analysis, a greater distance is used (resulting in higher collective dose and cost). The dose to truck drivers is based on external exposure to the cargo. (Details are given in Appendix D).

5.0 Dose Consequences

This analysis evaluated human exposure for storage and a range of RCC values. Collective doses were evaluated for the human receptors, including workers at DOE LLMW storage facilities, TSD workers, and members of the general public residing near TSD facilities. The analysis also evaluated impacts on the biological and physical environments from small amounts of activity in LLMW.

5.1 Human Health

This section provides an overview of the dose impacts of both continued storage of all DOE LLMW and of treating the alternative RCC levels of DOE LLMW at commercial TSD facilities. Details of the dose calculations are given in Appendix D. The estimated annual and cumulative doses to rad workers, TSD workers, and the general public are presented in this section.

The 30-year cumulative collective dose to the three receptor groups based on the estimated inventory of waste meeting RCC Level 3 is on the order of 10 person-rem. The ICRP has estimated the probability of latent cancer fatality (LCF) to be 4×10^{-4} per person-rem for workers or 5×10^{-4} per person-rem for the general public (ICRP 1991). When these LCFs are applied to results of this analysis, the probability of fatal cancer (caused by exposure to LLMW meeting RCC Level 3 via the scenarios outlined) for the 30-year study period is estimated not to exceed 0.007 LCF for storage workers in the continued storage case (based on ^{137}Cs), or 0.006 LCF (combined for TSD workers and the public) for the treatment of waste at RCC Level 3. The impact on human health from treating low-level mixed waste meeting RCCs as defined would be imperceptible, based on this estimate.

5.1.1 Collective Dose to Radiation Workers

The dose to radiation workers in DOE mixed waste storage facilities is based on external exposure to all LLMW which contain radionuclide concentrations meeting RCC Level 3. The assumptions used in calculating the dose to these storage workers are presented in Appendix D. Dose estimates for the continued storage and treatment alternatives which meet the three levels, based on 10 selected radionuclides, are given in Table 5.1.

The continued storage alternative results in the maximum collective dose potentially received by workers at DOE storage facilities because the waste would remain in storage for the 30-year study period. If RCC Level 1 treatment were implemented, the collective dose to workers at DOE LLMW storage facilities would change imperceptibly because only the low-activity waste would be eliminated from storage. The cumulative collective dose for radiation workers is dependent on the external dose from each radionuclide. The values in Table 5.1 represent the hypothetical dose to rad workers if all stored waste were contaminated with a single radionuclide at the RCC level. The cumulative dose (by nuclide) ranges from essentially zero for ^{3}H, to about 17 person-rem for ^{137}Cs, a gamma-emitter.

Table 5.1. Cumulative Collective Dose to Radiation Workers from Mixed Waste Inventory Containing Individual Radionuclides at the RCC Limiting Concentrations

Collective Dose to Rad Workers, person-rem				
Nuclide	**Continued Storage**	**Treat RCC Level 1**	**Treat RCC Level 2**	**Treat RCC Level 3**
^{3}H	0 [(a)]	0	0	0
^{60}Co	6.5	6.5	6.3	0.3
^{90}Sr +D	10.1	10.1	9.8	0.5
^{99}Tc	2.2E-3	2.2E-3	2.2E-3	1.2E-4
^{129}I	7E-8	7.E-8	7.E-8	4.E-9
^{137}Cs	17.4	17.4	17.0	0.9
^{238}U +D	14.7	14.7	14.4	0.8
^{237}Np	9.5	9.5	9.3	0.5
^{239}Pu	8E-4	8.E-4	8.E-4	4.E-5
^{241}Am	1.3E-4	1.E-4	1.E-4	7.E-6
(a) Based on external dose; effectively zero for ^{3}H.				

For processing of waste meeting Level 2, the dose to the storage worker would be reduced by about 2 or 3 percent. If wastes meeting RCC Level 3 are processed, the only exposure (from non-excluded waste) received by storage workers would occur during the 5-year period when the backlog of stored waste is being processed.

5.1.2 Collective Dose to Treatment, Storage, and Disposal Facility Workers

The individual and collective doses received by TSD workers under the three alternative treatment levels are a function of the quantity and activity of the treated waste. Dose estimates for the alternatives, by radionuclide, are given in Table 5.2. The table indicates that the cumulative collective dose to TSD workers is independent of radionuclide (with the exception of tritium and radioiodine) for treatment of waste meeting each RCC level. This is because the collective dose is based on the most limiting (restrictive) scenario, which for most radionuclides was a TSD worker scenario.

Table 5.2. Cumulative Collective Dose to TSD Workers from Mixed Waste Inventory Containing Individual Radionuclides at the RCC Limiting Concentrations

Nuclide	Collective Dose to TSD Workers, person-rem[(a)]			
	Continued Storage	**Treat RCC Level 1**	**Treat RCC Level 2**	**Treat RCC Level 3**
^{3}H	0	1E-5[(b)]	4.3E-3	0.17
^{60}Co	0	7E-4	0.21	8.3
^{90}Sr +D	0	7E-4	0.21	8.3
^{99}Tc	0	2E-7	6E-5	3E-3
^{129}I	0	7E-6[(b)]	2.E-3	0.08
^{137}Cs	0	7E-4	0.21	8.3
^{238}U +D	0	7E-4	0.21	8.3
^{237}Np	0	7E-4	0.21	8.3
^{239}Pu	0	7E-4	0.21	8.3
^{241}Am	0	7E-4	0.21	8.3

(a) Doses to TSD workers are generally the same because the estimates are based on the limiting worker scenario for each radionuclide.
(b) The values differ for ^{3}H and ^{129}I, because individual dose to a member of the public is most restrictive.

The limiting scenarios are radionuclide-specific: for gamma-emitters such as ^{60}Co and ^{137}Cs, waste disposal (landfill worker, exposed to waste being placed in landfill) is limiting; for alpha-emitters such as ^{238}U, ^{237}Np, ^{239}Pu, waste receiving, in which there is both external exposure and potential for inhalation, is limiting (see Aaberg et al. 1995, Section 3.0.)

For radionuclides in which the individual dose to a member of the public was most restrictive (tritium and radioiodine), the TSD worker doses were reduced. Cumulative collective dose, based on RCC Level 3 (potentially 20 mrem to the MEW), is calculated to be about 8 person-rem for the 30-year study period. The annual dose received by TSD workers would be greatest during the assumed 5-year period in which both stored waste and projected wastes meeting RCCs are processed.

RCCs were based on a limiting dose to an individual (MEI or MEW) for a radionuclide concentration in waste that was applied to the entire throughput of a facility. The anticipated DOE waste throughput (based on 5-year work-off of waste in storage) for the processes considered is projected to be less than the

capacity of the TSD facility types (based on annual waste processing requirements, Table 4.1, and facility capacity, Table D.3). For this reason, individual doses, on which the collective doses are based, will generally be less than the RCC limiting dose (e.g., for Level 2, the MEI/MEW will receive less than 1 mrem/yr). Table 5.3 shows the percentage of throughput for a process for each RCC level. This table shows that the amount of waste processed annually is not likely to exceed the capacity for one TSD. The highest percentage of throughput is for shred/grout processing of stored waste (1% + 4% +61%, or 66% of assumed capacity). The percentage of throughput is an indicator of the potential fraction of the dose limit. Treatment of wastes at multiple facilities will not affect the collective dose, but will limit the individual dose.

5.1.3 Collective Dose to Offsite Residents

Collective dose to offsite residents for the RCC Levels 1, 2, and 3 are given in Table 5.4. There is assumed to be no dose to the general public associated with the continued storage alternative. The collective dose to offsite residents, which depends on the quantity and type of waste, is determined by the processing and emission factors, atmospheric dispersion, population density, and environmental pathways (food chain).

Unit dose factors (person-rem/Ci released, as found in Aaberg et al. 1995) are based on uniform population density (80 persons/km^2) and generic meteorology; release factors for various processes are given in Appendix D, "Dose Calculations."

Table 5.3. Percentage of Capacity of a Single Reference TSD Facility Based on Annual Processing Rate of DOE Hazardous Waste, greatest fraction of MEW dose possible

	Percentage of Facility Capacity (annual), Incremental by RCC Level					
	Stored Waste (1/5 inventory per year)			**Projected Waste (annual generation)**		
Treatment	**RCC Level 1**	**RCC Level 2**	**RCC Level 3**	**RCC Level 1**	**RCC Level 2**	**RCC Level 3**
Incineration	7%	22%	15%	0.3%	0.8%	2%
Shred/grout	1%	4%	61%	0.5%	1%	2%
Stabilization	0.5%	1%	2%	0.2%	0.5%	0.7%
Neutralization	<0.1%	0.1%	0.1%	<0.1%	<0.1%	<0.1%
Landfill	2%	5%	9%	0.1%	0.4%	0.7%

Table 5.4. Cumulative Collective Dose to the Public from Mixed Waste Inventory Containing Individual Radionuclides at the RCC Limiting Concentrations

Nuclide	Collective Dose to the Public, person-rem			
	Continued Storage	Treat RCC Level 1	Treat RCC Level 2	Treat RCC Level 3
^{3}H	0	1E-2	0.1[(a)] (3.1)[(b)]	0.23 (37)
^{60}Co	0	1E-5	3E-3	6E-2
^{90}Sr +D	0	4E-3	2E-2	0.4
^{99}Tc	0	2E-2	5.2	28 (61)
^{129}I	0	4E-3	0.9	14
^{137}Cs	0	2E-5	7E-3	0.2
^{238}U +D	0	6E-4	7E-2	3.9
^{237}Np	0	3E-4	9E-2	2.0
^{239}Pu	0	9E-4	0.27	6.0
^{241}Am	0	4E-4	0.13	3.0

(a) Value is based on 2000 pCi/g ^{3}H and ^{99}Tc in waste.
(b) Values in parentheses are based on RCC value for ^{3}H and ^{99}Tc which would result in 10 mrem to the MEI.

Based on these assumptions, the annual collective dose received by residents within 80 km of TSD facilities would be greatest during the assumed 5-year period in which both stored and projected waste that meets RCCs are processed. The cumulative collective dose for the 30-year time horizon does not exceed 10 person-rem.

5.2 Ecological and Natural Resource Impacts

Properly operating TSD facilities must not release hazardous and/or radioactive materials to the environment. Routine emissions from facilities should cause no significant contamination of environmental media or exposure of living ecological resources during normal operations. However, a potential for accidental release of hazardous and/or radioactive materials always exists, however small. The following discussion is limited to impacts that could result from accidental releases of radioactive fractions from processing facilities. Potential groundwater contamination is addressed in Appendix F.

5.2.1 Assumptions

Releases of hazardous and/or radioactive materials from solid waste management units (SWMUs) of a TSD must be cleaned up as part of a RCRA corrective action. (For routine and systematic releases, not related to SWMUs, CERCLA action may be implemented.) The specific cleanup activities and the end-state conditions that are mandated under the corrective action will be highly dependent on the type,

quantity, and condition of the release, as well as the characteristics of the affected environment. It is likely, however, that the corrective action specifications will account for existing and potential uses of the affected environment by humans and living ecological resources and will not preclude any such uses at any time in the future after the release is cleaned up. The trend is for consideration of land use in setting cleanup levels. In some cases, cleanup levels will be based on a residential scenario.

If an accidental release of radioactive materials does occur, living ecological resources could be exposed and impacted. The following assessment of potential impacts to living ecological resources assumes that 100 percent of the ionizing radiation to which plants and animals are exposed (via environmental media) is absorbed by those plants and animals (i.e., the exposure rate equals the dose rate). This assumption is highly conservative, especially for small organisms which are likely to absorb only small proportions of gamma radiation. (See Baker and Soldat [1992] for detailed information on calculation of dose rates for exposure to radionuclides.) Thus, actual dose rates will be much lower than assumed below for most plants and animals.

5.2.2 Assessment

Dose limits for the protection of plants and animals have been proposed for codification as part of 10 CFR 834, "Radiation Protection of the Public and the Environment" (61 FR 6799). A dose limit of 1.0 rad/day is proposed for native aquatic animal organisms that are exposed to radiation or radioactive material discharged in liquid waste to natural waterways. (This limit is based on information in DOE 1990b and NCRP 1991.) A dose limit of 0.1 rad/day is proposed for terrestrial animals, and a dose limit of 1.0 rad/day is proposed for terrestrial plants. (These limits are based on the results of a June 1994 Department of Energy workshop [see Barnthouse 1995] on the effects of ionizing radiation on terrestrial plants and animals, during which information in IAEA [1992b] was reviewed and evaluated.)

Given the above standards, the highest daily exposure rate considered in this analysis (i.e., 5.5E-05 rad/d) is about 2.5 orders of magnitude lower than any applicable existing or proposed standard for the protection of aquatic or terrestrial organisms. Hence, it is highly unlikely that substantive environmental or ecological impacts to terrestrial or aquatic organisms will result from exposure to ionizing radiation from the LLMW under consideration in this report. Thus, such impacts are not included in this ALARA analysis.

6.0 ALARA Analysis Approach

This section describes the cost-benefit method, economic costs and benefits, estimated doses, and overriding factors in comparing the alternatives for ALARA considerations. The bounding net benefit evaluation is based on upper- and lower-level values placed on the collective radiation dose received for each alternative. Parameter sensitivity is described, and qualitative factors are discussed.

6.1 Cost-Benefit Methodology Overview

A cost-benefit methodology adapted from a DOE ALARA workshop (Baum et al. 1992; Brown and Stephan 1992) was used to analyze and compare the current practice of continued storage with each of the three RCC level alternatives. This cost-benefit analysis differed from the typical ALARA cost-benefit analysis in that it involved a regulatory change, rather than a change in work practice. To adequately represent the costs of such a policy change, life-cycle costs were developed for each alternative. The life-cycle costs were computed on an incremental basis, i.e., the cost elements considered for the analysis were those main factors that changed between the alternatives.

There were four cost elements evaluated for each alternative: treatment, disposal, transportation, and DOE storage costs. Thirty-year cost estimates were generated by year for each element of each alternative. The yearly cost elements were computed by multiplying the estimated unit cost factor (1995 dollars per cubic meter of waste) for each element by the quantity of waste (cubic meters) for that element and year. This calculation was performed for all cost elements and alternatives to obtain the costs used in the life-cycle cost calculations by alternative.

These costs by element and year were discounted at a rate of 3% and summed to generate a single sum equivalent (present worth) expressed in 1995 dollars for each alternative. The differences in present worth between alternatives were compared.

6.2 Economic Costs

The analysis is based on four cost elements: storage, transportation, treatment, and disposal. Storage is the only cost in the continued storage alternative, and the predominant cost element in treating waste meeting RCC Level 1. As the activity in hazardous waste meeting RCC Level 1 was increased, the quantity of waste stored, and thus the cost of storage, decreased. At RCC Levels 2 and 3, more waste would be transported, treated, and disposed as the RCC level increased, and less volume would be stored.

6.3 Economic Benefits

In this analysis, the economic benefit of implementing RCC levels is solely due to the savings associated with the reduction of storage cost. This is a result of reduced volume of storage required as the RCC level is increased because the cost of treatment is less than that of continued storage. The benefit is,

therefore, the difference in cost between the continued storage alternative and the treatment alternatives based on RCC Levels 1, 2, and 3.

6.4 Dose Estimate

Estimating dose that would meet given RCC levels involves comparing dose commitment from continued storage with dose commitment which would result from the implementation of RCCs. The dose associated with continued storage at DOE facilities involves maintenance of mixed waste storage facilities and inventory. The dose estimate is based on labor requirements, time spent in the proximity to waste, and particular radionuclide contaminant and its activity. Only waste which would potentially meet the RCC Level 3 is considered; other dose from mixed waste is not considered because it would be identical for all cases.

With RCCs implemented, the quantity of material stored at DOE facilities, and thus the number of workers, would be reduced. The dose from the remaining waste (both quantity and activity) is calculated based on the RCC level. For example, if waste meeting RCC Levels 1 and 2 is treated, RCC Level 3 waste would remain at DOE storage facilities.

6.4.1 Continued Storage

Collective dose for the continued storage option is based on external exposure to sealed packages containing mixed waste. The exposure scenario is based on exposure of an individual for 25% of the time at work, or 500 hours per year.

6.4.2 Using RCC Level 1 Alternative

If the RCC Level 1 alternative were adopted, the total collective dose would be nearly the same as for continued storage. Most of the volume of waste and most of the activity would remain in waste in mixed waste storage facilities at DOE sites. Doses to TSD workers are based on the dose limit of 0.01 mrem per worker for RCC Level 1, modified by the amount of RCC Level 1 waste processed (tons) and the labor requirements for the facility (person-years or FTE per ton). (See Appendix D for a discussion of the calculation of collective dose for TSD workers.) Population dose is estimated using unit dose factors from Aaberg et al. (1995), and the amount of material potentially released by a facility. (The activity released is based on quantity of waste processed, the RCC limiting concentration for the radionuclide, and the release factor for the radionuclide, described in Appendix D.)

6.4.3 Using RCC Level 2 Alternative

With the RCC Level 2 Alternative, the dose calculation method is the same as for Level 1. The difference is that additional waste with a greater concentration of radionuclides would be processed, and less would be stored.

6.4.4 Using RCC Level 3 Alternative

The Level 3 alternative would potentially allow much of the waste from storage (all of the non-excluded waste in this study) to be treated at TSD facilities. Storage of waste would occur during the initial 5-year period in which the existing backlog of stored waste would be processed.

6.5 Overriding Factors

Overriding factors involve an impact which cannot be ignored, such as the violation of a state or Federal law, if the ALARA protective measure is not taken. These factors may affect implementation by preventing implementation that is cost-effective, or requiring a measure that is not cost-effective. Factors to be considered include complying with a DOE Order, Federal regulation, or state law; creating an unsafe condition that could lead to worker injury; adding a significant quantity of land-banned materials to a facility; or causing workers to exceed dose limits (Brown and Stephan 1992).

6.6 Bounding Net Benefit Evaluation

The bounding net benefit is evaluated for the RCC alternatives by considering the effect of the treatment and disposal on the total, 30-year cumulative collective dose (see Section 5.0), evaluated at $2000 per person-rem and $10,000 per person-rem, respectively (Baum et al. 1992). The bounding net benefit evaluation is performed on the total cumulative dose, comparing the continued storage alternative with each RCC waste treatment alternative.

6.7 Parameter Value Sensitivity Analysis

Sensitivity analyses were performed separately for the dose and cost portions of the analysis. Factors such as storage and treatment cost factors and waste volumes were addressed.

A summary of cases used to assess the sensitivity of the doses calculated to various parameters is given in Table 6.1.

Table 6.1. Parameters Included in the Sensitivity Study

Category and Parameter	Receptor	Comments
Radionuclide Inventory		
Single Radionuclide: ^{3}H, ^{90}Sr, ^{137}Cs, ^{129}I, $^{238}U+D$, ^{239}Pu, ^{241}Am, each at RCC limit	All	Dose for alternatives depends on radionuclide characteristics.
Composite source term: mix of ^{3}H, Sr, Cs, U instead of single isotope	All	Mixture yields overall balance; gamma-emitters affect dose from storage; ^{3}H affects population dose.
Waste Quantity & Treatment		
Treatment of soils: stabilized instead of incinerated	General Population	Lowers population dose. No change in alternative with lowest dose.
Projected soil quantity: Increased by 10 times	General Population	Increased waste mass increases population dose.
Scenarios		
Storage worker exposure hours: base case 25% (500 h/yr), increased to 75%	Radiation workers, storage facility	Assumptions concerning rad workers are significant in determining alternative yielding minimum dose.
Collective TSD worker scenarios from Aaberg et al. (1995), take into account low-exposure jobs	TSD workers	Less conservatism decreases collective worker dose by about a factor of 10.
Release factors: increased by 10 times (maximum of 1.0 for tritium and radioiodine)	General Population	Increases population dose.
Population Density: base case 80/km^2; increased to 160/km^2	General Population	Direct multiplier on population dose (ignoring urban/rural food pathways assumptions).

6.8 Qualitative ALARA Factors

Qualitative factors discussed in this section include worker and transportation safety, ecological and natural resource impacts, regulatory factors, public perceptions and concerns, and future risk for disposal.

6.8.1 Worker and Transportation Safety

Labor requirements are used to project worker illnesses/accidents and fatalities for storage facilities and waste treatment alternatives, based on National Safety Council data (NSC 1995). Transportation safety is considered for the offsite treatment alternatives, which require transport of wastes to a TSD,

based on 176,000 km (110,000 mi) per FTE-year and accident rates from Cashwell et al. 1986 (see Appendix E, "Worker & Transportation Safety").

6.8.2 Ecological and Natural Resource Impacts

Analysis of the effects on plant and animal populations are qualitative because radionuclide impact analysis on human health will usually bound the impact on biota and because the range of dose criteria being considered is well below exposures where effects would be observed on biota.

6.8.3 Regulatory Factors

The success of a policy for radiological control criteria for hazardous waste disposal would largely be premised on its acceptance by the public, the regulatory agencies, and the waste disposal industry. Some qualitative regulatory factors are offered herein for consideration.

There are hundreds of facilities that have EPA authorization to treat, store, or dispose of RCRA hazardous wastes. These facilities are authorized to operate (have a permit or are granted "interim status") because they meet the broad range of administrative, technical, and financial assurance requirements established under RCRA regulations for management of hazardous waste (40 CFR 264). These would conceivably be the facilities that would be used for disposal of hazardous wastes that meet the RCC for such wastes.

While the RCRA minimum technical standards for management of hazardous waste would likely provide an appropriate degree of public health and environmental protection for disposal of very low-level mixed wastes, there are currently very few TSD facilities that can accept wastes that are both hazardous and "radioactive."[(a)] Most TSDs clearly stipulate that they will not accept any radioactive mixed wastes because they are not licensed by the NRC to handle radioactive waste.

6.8.4 Public Perceptions and Concerns

Public perceptions and resulting concerns about the implementation of RCC and shipment of wastes at the RCC levels have the potential to affect the social, political, and economic costs of such actions. Proposed actions that are considered unacceptable by a significant element of the society can face organized opposition that increases the time and effort required to complete each step of the decision-making and implementation processes. The key questions are whether a proposed alternative will be considered acceptable, whether a lack of acceptance would be translated into opposition, and what impact opposition would have on the proposed action and its proponents.

(a) It is recognized that all waste contains some quantity of natural radioactive material which in some cases is greater than RCC levels being evaluated.

Recent research has emphasized the importance of "framing" to public perception and judgments about the acceptability and unacceptability of technological decisions and actions (Douglas and Wildavsky 1982; Margolis 1996). This research has shown that the way a problem or issue is initially framed strongly influences subsequent perceptions and response. Similarly, Pijawka and Mushkatel (1992) and the Secretary of Energy's Advisory Board (SEAB 1993), among others, have shown that previous experience, reputation, and existing levels of trust and confidence (or distrust and suspicion) affect in a powerful way the initial framing process and subsequent perceptions and response.

Since commercial TSDs have a vested interest in implementation of this proposal, they could offer insight and experience in handling potential organized opposition, both public and regulatory, to these types of actions. They may, however, wish to avoid additional negative publicity.

6.8.5 Future Risk of Disposal

The long-term performance of a RCRA cell will determine the potential consequences from disposal of radioactive materials. Future consequences of release of contaminants from a RCRA landfill could include contamination of underlying soil and groundwater, which would require remediation. Potential risk to workers as a result of performing a remediation project include exposure to radioactive materials in the landfill.

6.8.6 Risk to Workers from Corrective Action

Remediation could involve the exhumation of wastes to repair a section of liner at a landfill containing hazardous waste. This scenario was examined in Aaberg et al. (1995) but was not a limiting scenario for any radionuclide. Since the excavation or stabilization in place of buried waste to accomplish repairs would be a deliberate act by trained workers rather than an accidental intrusion, protective measures would be taken. Workers would wear protective clothing and equipment, which would minimize the potential for internal dose. External dose would be low because the exposure time would be minimal; the limiting scenario for landfill workers, which would result in the lowest concentration for a given acceptable dose level, involved nearly full-time exposure to buried waste.

6.8.7 Contaminant Release to Groundwater Scenario

Potential groundwater contamination based on disposal of waste in a RCRA landfill is considered in generic wet and dry sites. Given a concentration of a given radionuclide in waste, the peak concentration in groundwater and time at which it occurs are calculated using RESRAD. This is a conservative

screening analysis because it is based on a nondispersing medium. The concentration peaks tend to be earlier and higher than would be calculated with dispersion. (Details are covered in Appendix F, "RCRA Cell Failure Scenarios.")

7.0 Results

The results, both economic and dose assessment, for treatment or long-term storage of wastes potentially meeting the RCC Level 3 criterion are described briefly in Sections 7.1 through 7.4, followed by a comparison of the alternatives in Section 7.5. Resulting doses are compared between alternatives based on both individual radionuclides and the composite source term (see Table 4.4).

7.1 Using Existing Activity - Continued Storage

The long-term storage of all existing and future LLMW meeting RCC Level 3 would cost $1.8 billion, and would result in an estimated collective exposure (all to DOE workers) of 12.3 person-rem for 30 years, based on the composite source term.

7.2 Using RCC Level 1 Alternative

The long-term storage of all existing and future LLMW above RCC Level 1 would cost $1.6 billion, and result in an estimated collective exposure (all to DOE workers) on the order of 12 person-rem. Transportation, treatment, and disposal of the waste meeting RCC Level 1 would cost $14 million, and would result in a collective dose of less than 0.001 person-rem to TSD workers and 0.001 person-rem to members of the public, offsite from TSD facilities, based on the composite source term.

7.3 Using RCC Level 2 Alternative

The long-term storage of all existing and future LLMW above RCC Level 2, would cost $1.2 billion, and result in an estimated collective exposure to DOE workers at mixed waste storage facilities of 12 person-rem. Transportation, treatment, and disposal of the waste meeting RCC Level 1 would cost $57 million, and result in collective dose of 0.16 person-rem to TSD workers and 0.02 person-rem to members of the public, offsite from TSD facilities, based on the composite source term.

7.4 Using RCC Level 3 Alternative

In the Level 3 alternative, all the mixed waste considered in this analysis would be treated and disposed as hazardous waste. The cost transportation, treatment, and disposal of wastes meeting RCC Level 3 would cost an estimated $140 million (1995). There would be no additional mixed-waste storage capacity required, after the existing backlog of waste was treated and disposed. The collective dose to storage workers at DOE mixed waste facilities would be minimized, at less than 0.7 person-rem for the study period. The dose to TSD workers (8 person-rem) and population (2 person-rem) is calculated as an example. Actual values would depend on the allocation of activity among the various radionuclides. The total cumulative collective dose for the 30-year study period is about 11 person-rem.

7.5 Comparison of RCC Alternatives for Different Levels

A summary of results of both quantitative and qualitative factors involved in this analysis is presented in Table 7.1. The following subsections provide a comparison of the economic costs and benefits, dose estimates, overriding factors, bounding net benefit evaluation, parameter value sensitivity analysis, and qualitative factors.

7.5.1 Economic Costs and Benefits

Economic costs occur for storage of LLMW and transportation, treatment, and disposal of wastes meeting control criteria. Storage is the primary cost driver for this study. Storage costs accrue each year for management and operation (M&O) of the storage facility. The tasks performed under M&O are discussed in Section 4.2 and Appendix C. The only way to reduce the cost of storage is to discontinue storing the waste.

The results in Table 7.1 show that the more waste that is transported, treated, and disposed by commercial vendors, the less the RCC alternative costs. Since RCC Level 3 allows more waste to be treated by commercial vendors, it has the least overall cost of the RCC alternatives. The alternative of treating all waste meeting RCC Level 3 is estimated to be about $1.5 billion less than storing the waste

Table 7.1. Summary of Results of the RCC ALARA Study

Factor	Cost of Alternative, $ millions			
	Continued Storage	**RCC Level 1**	**RCC Level 2**	**RCC Level 3**
Quantitative				
Storage	$1,800	$1,590	$1,090	$133
Treatment	$0	$ 8	$32	$67
Transportation	$0	$ 2	$ 8	$19
Disposal	$0	$ 4	$17	$51
Dose[a]	$0.1	$0.1	$0.1	$ 0.1
Totals	**$1,800**	**$1,600[b]**	**$1,200**	**$270**
Qualitative[c]				
Regulatory	-	+	+	+
Ecological	~	~	~	~
Public	~	-	-	-

(a) Dose evaluated at $10,000 per person-rem, rounded to one significant figure.
(b) Totals may not sum exactly due to rounding.
(c) Qualitative results are designated as positive (+), negative (-), or neutral (~) to implementation of control criteria.

for the next 30 years, which is the most expensive option. Treatment of RCC Level 1 and RCC Level 2 are intermediate in cost, between the two extremes, saving $200 million and $600 million over the cost of continued storage, respectively.

Savings that could be achieved by implementing RCC depend upon the quantity of waste which would meet the chosen RCC level. It is assumed that a sufficient quantity of waste is available at each level to justify the expense of setting up and implementing the program.

7.5.2 Dose Estimate

The most important observation concerning the collective doses calculated for the continued storage and the alternatives (see Section 5.0) is that the processing of waste meeting RCC Level 3, as defined, would have a minimal impact on collective dose. The collective dose for any of the alternatives outlined is on the order of tenths of person-rem per year.

While there may be some potential for reduction of dose based on treatment of RCC waste, the values are very small. Based on an upper bound on $10,000 per person-rem, the dose-related costs are at least 5 orders of magnitude below storage- and treatment-related costs.

The cumulative doses for the 30-year study period, based on the hypothetical bounding case of waste (both stored and projected) contaminated with the RCC limiting concentration of each of 10 example radionuclides, are given in Table 7.2. Radionuclides with higher external dose factors (and half-lives such that there is substantial activity remaining at the end of the storage period), such as ^{137}Cs, contribute more to the dose for the continued storage alternative. The dose to rad (storage) workers shown in Table 7.2 results from the activity of waste that is not treated, but continues to be stored. For RCC Level 3, the dose to storage workers is from the 5-year period required to work off the backlog of stored waste.

Radionuclides such as ^{3}H, ^{99}Tc, and ^{129}I, with RCCs limited by dose to offsite receptors, contribute a greater dose for the RCC treatment alternatives. The alternative yielding the lowest overall collective dose is dependent on the mix of radionuclides in the waste. Table 7.3 illustrates the use of a composite source term[(a)] of a mix of those radionuclides. With this source term, cumulative collective dose does not vary much by alternative. The lowest collective dose calculated for this example results from processing and treating the maximum amount of waste, RCC Level 3.

(a) Composite source term is taken to include each radionuclide at a fraction of its RCC value, but limited to 2000 pCi/g, defined in Table 4.4.

Table 7.2. 30-Year Cumulative Collective Dose to All Receptors Based on Waste Inventory Containing Individual Radionuclides at the RCC Limiting Concentrations

	Dose by Receptor Category, person-rem			
Nuclide and Receptors	**Continued Storage**	**Treat RCC Level 1**	**Treat RCC Level 2**	**Treat RCC Level 3**
^{3}H				
Radiation Workers	0	0	0	0
TSD Workers	–	1E-5	4E-3	0.2
General Population	–	0.01	0.1(3.1)[a]	0.1(37)[b]
Total for ^{3}H	**0.00**	**0.01**	**0.1(3.1)**	**0.3(37)**
^{60}Co				
Radiation Workers	6.5	6.5	6.3	0.3
TSD Workers	–	7E-4	0.2	8.3
General Population	–	1E-5	3E-3	6E-2
Total for ^{60}Co	**6.5**	**6.5**	**6.5**	**8.7**
^{90}Sr +D				
Radiation Workers	10.1	10.1	9.8	0.5
TSD Workers	–	7E-4	0.2	8.3
General Population	–	4E-3	0.02	0.4
Total for ^{90}Sr+D	**10.1**	**10.1**	**10.1**	**9.3**
^{99}Tc				
Radiation Workers	2E-3	2E-3	2E-3	1E-4
TSD Workers	–	2E-7	6E-5	3E-3
General Population	–	2E-2	5.2	28 (61)[b][c]
Total for ^{99}Tc	**2E-3**	**2E-2**	**5.2**	**28 (61)**
^{129}I				
Radiation Workers	7E-8	7E-8	7E-8	4E-9
TSD Workers	–	7E-6	2E-3	8E-2
General Population	–	4E-3	0.9	13.5[b]
Total for ^{129}I	**7E-8**	**4E-3**	**1**	**14**
^{137}Cs				
Radiation Workers	17.4	17.4	17.0	0.9
TSD Workers	–	7E-4	0.2	8.3
General Population	–	2E-5	7E-3	0.2
Total for ^{137}Cs	**17.4**	**17.4**	**17.2**	**9.4**
^{238}U +D				
Radiation Workers	14.7	14.7	14.4	0.8
TSD Workers	–	7E-4	0.2	8.3
General Population	–	6E-4	7E-2	3.9
Total for ^{238}U + D	**14.7**	**14.7**	**14.6**	**13.0**
^{237}Np				
Radiation Workers	9.5	9.5	9.3	0.5
TSD Workers	–	7E-4	0.2	8.3

	Dose by Receptor Category, person-rem			
Nuclide and Receptors	**Continued Storage**	**Treat RCC Level 1**	**Treat RCC Level 2**	**Treat RCC Level 3**
General Population	–			
Total for ^{237}Np	**9.5**	**9.5**	**9.6**	**10.8**
^{239}Pu				
Radiation Workers	8E-4	8E-4	8E-4	4E-5
TSD Workers	–	7E-4	0.1	8.3
General Population	–	9E-4	0.3	6.0
Total for ^{239}Pu	**8E-4**	**2E-3**	**0.4**	**14.3**
^{241}Am				
Radiation Workers	1E-4	1E-4	1E-4	7E-6
TSD Workers	–	7E-4	0.1	8.3
General Population	–	4E-4	0.1	3.0
Total for ^{241}Am	**1E-4**	**1E-3**	**0.3**	**11.3**

(a) The baseline case concentration for ^{3}H at RCC Levels 2 and 3 is 2000 pCi/g, the DOT limit for labeling as radioactive; the values in parentheses are based on the RCC limits of 6.5E+4 pCi/g and 6.5 x 10^{5} Ci/g for Levels 2 and 3, respectively.

(b) Level 3 is defined so that the dose to the offsite MEI is 10 mrem/hr.

(c) Dose based on 2000 pCi/g; value in parentheses based on concentration of ^{99}Tc for Level 3 of 5000 pCi/g.

Table 7.3. Cumulative Collective Dose to All Receptors for Source Term Containing RCC Limiting Concentrations, Based on Sum-of-Fractions for Radionuclides and Person-Rem Limit of 2000 pCi/g

Receptor	Continued Storage	Treat Level 1	Treat Level 2	Treat Level 3
Radiation Workers	12.3[(a)]	12.3	12.0	0.65
TSD Workers	–	5E-4	0.16	8.1
General Population	–	0.003	0.22	2.2
Total	12.3	12.3	12.4	10.9

(a) Value for continued storage based on source term for RCC Level 3.

Continued Storage

The dose estimate for continued storage ranges from approximately zero for radionuclides which are not gamma-emitters to about 17 person-rem for ^{137}Cs, distributed over a period of 30 calendar years. Individual doses resulting from continued storage of the waste which meets RCC Level 3 would be less than 20 mrem/year, based on external exposure.

RCC Level 1

For the RCC level 1 alternative, a dose of less than 0.001 person-rem for the entire 30-year study period would be received by TSD workers, based on Level 1 concentrations in the stored and projected waste inventory. The collective dose potentially received by members of the general public would be about 0.001 person-rem.

RCC Level 2

For the RCC Level 2 alternative, a collective dose on the order of tenths of a person-rem for the entire 30-year study period could potentially be received by TSD workers. Collectively, the general public living in the vicinity of TSDs could receive up to tenths of a person-rem during the 30-year period, depending on the mix of radionuclides treated. Although more of the waste is processed at TSD facilities, it would not amount to a very great dose reduction for storage workers because the higher-activity waste meeting Level 3 would remain in storage.

RCC Level 3

For the RCC Level 3 alternative, the collective dose to workers at DOE mixed waste storage facilities would be decreased, primarily because there would be less waste in long-term storage, resulting in fewer workers employed at DOE storage facilities. A collective dose on the order of 8 person-rem for the entire 30-year study period could potentially be received by TSD workers, based on RCC Level 3 concentrations, based on the conservative assumptions in this analysis. Collectively, the general public living in the vicinity of TSDs could potentially receive between 1 and 10 person-rem during the 30-year period, depending on the mix of radionuclides treated.

7.5.3 Overriding Factors

A potential overriding factor is the ban on land-disposal prohibited waste (including mixed waste) except "for the purpose of the accumulation of such quantities of hazardous waste as are necessary to facilitate proper recovery, treatment, or disposal" (EPA 1996). EPA has extended its policy on enforcement, ("Policy on Enforcement of RCRA Section 3004(j) Storage Prohibition at Facilities Generating Mixed Radioactive/Hazardous Wastes") confirming that storage of mixed waste subject to LDRs is unlawful, even in the absence of treatment and disposal capacity. The policy states, however, that violators who 1) are faced with an impossibility of complying with the RCRA regulations and 2) are storing their wastes in an environmentally responsible manner will be a low enforcement priority for EPA (EPA 1996).

While the treatment of wastes meeting an RCC level would not eliminate the quantity of waste stored in violation of RCRA Section 3004(j), it would reduce the quantity subject to enforcement action.

7.5.4 Bounding Net Benefit Evaluation

The bounding net benefit was evaluated for a range of values in typical cost/benefit analyses. A conservative value of $10,000 per person-rem is used in Table 7.4 to illustrate the magnitudes of the values of the RCC treatment alternatives. Table 7.4 is actually a version of Table 7.2, which gives cumulative collective doses by radionuclide. The values in Table 7.4 are calculated by taking the total dose by radionuclide for an RCC level, subtracting the dose for continued storage, and multiplying the results by $10,000 per person-rem. Although the result is negative (higher dose from treatment) for most radionuclides, there is a dose savings associated with treatment of waste containing ^{90}Sr, ^{137}Cs, and ^{238}U, which exist in much DOE waste.

Table 7.4. Monetary Equivalent of Dose Savings Compared with Continued Storage

	Dollar Equivalent of Difference in Dose Between RCC Levels at $10,000 per person-rem[a]		
Radionuclide	**RCC Level 1**	**RCC Level 2**	**RCC Level 3**
^{3}H	(< $100)[b]	($1000)	($2,200)
^{60}Co	(< $100)	($500)	($22,000)[c]
^{90}Sr + D	(< $100)	$140	$8300
^{99}Tc	(<$100)	($52,000)	($280,000)
^{129}I	(< $100)	($9000)	($140,000)
^{137}Cs	(< $100)	$2000	$80,000
^{238}U + D	(< $100)	$800	$17,000
^{237}Np	(<$100)	($670)	($12,000)
^{239}Pu	(< $100)	($4000)	($140,000)
^{241}Am	(< $100)	($3000)	($110,000)

(a) Parentheses indicate negative values, or greater cost for RCC alternatives.
(b) The dose for treating RCC Level 1 waste is indistinguishable from the Continued Storage case; dose to rad workers is essentially the same, with an additional dose less than 10^{-3} person-rem to other receptors.
(c) The dose for treatment of ^{60}Co is greater than for storage; largely because its relatively short half-life reduces the dose to rad workers from stored waste which has been stored for up to nearly six half-lives.

The implementation of RCCs would result in the distribution of collective dose to different receptors. The predominant receptors in the continued storage alternative are workers at DOE facilities; receptors for the three RCC waste treatment alternatives include TSD workers and members of the general public.

- Lower-Level Evaluation (at $2000 per person-rem). The cost or savings for each alternative is illustrated using the hypothetical case of the entire waste inventory (stored and projected) of each example radionuclide at the RCC limiting concentration for each alternative. For RCC Level 1, there is an insignificant change in dose compared with the continued storage alternative. At RCC Level 2, and using a $2000 per person-rem equivalent for dose consequences, monetary equivalent of the change in dose would range from an increased cost of about $10,000 ($^{99}Tc$) to a reduction of about $400

(^{137}Cs). For RCC Level 3, the cost or savings range from an extra cost of $55,000 (based on ^{99}Tc) to savings of $20,000. When a composite source term mixture given in Table 4.4 is used as an example, the savings appear to be on the order of $3,000 for RCC Level 3.

- Upper-Level Evaluation (at $10,000 per person-rem). The monetary equivalent of collective dose, illustrated in Table 7.4, shows potential additional cost or savings for each RCC alternative as compared with continued storage, based on $10,000 per person-rem. For cases in which the collective dose is greater for treatment of RCC wastes than for continued storage, the values are in parentheses.

A value of $10,000 per person-rem results in a maximum cost or savings on the order of $100,000 over the 30-year analysis period, depending on radionuclide mix. The greatest reduction in collective dose is seen for relatively long-lived gamma-emitting radionuclides, such as ^{137}Cs, which would potentially produce a dose to storage workers in the continued storage case. For the composite source term, the savings would be on the order of $10,000 to $50,000.

Because the collective doses for each of the alternatives are very small and the costs of storage and treatment are large, the monetary equivalents of the doses are insignificant in comparison to other costs involved in the implementation of an RCC for DOE waste. Whereas the costs of storage and treatment would involve many millions of dollars, the monetary value corresponding to dose is on the order of only hundreds or thousands of dollars.

7.5.5 Parameter Value Sensitivity Analysis

Sensitivity analyses were performed for economic parameters, detailed in parts of Appendix C, and for dose consequences, discussed in depth in Appendix D.

Economics

A sensitivity analysis was performed on the economic parameters used in this study. No sensitivity case was found to change the comparative results of the economic costs. See Appendix C, Section C.5 for a complete discussion of the economic sensitivity analysis. See Appendix C, Section C.3 for a discussion and rationale of the assumptions used in the economic analysis.

Dose Consequences

Dose consequences for the sensitivity cases are based on the composite source term rather than on individual radionuclides, both to simplify the presentation and to show trends rather than emphasize differences based on individual radionuclide characteristics. A discussion of sensitivity cases are presented in Appendix D, "Dose Calculations." Parameters of interest are listed in three groups: radionuclide inventory, waste quantity and treatment, and scenario assumptions (see Table 6.1). For all the parameter variations considered, dose to each receptor type and for each alternative is given. This exercise shows that the cumulative collective doses to workers and members of the public are calculated to be less than

100 person-rem for the 30-year study period. The monetary equivalent of the dose consequences would be minor in comparison to the storage and treatment costs.

7.5.6 Qualitative ALARA Factors

Qualitative (nonquantified) factors that are germane to the ALARA analysis include worker and transportation safety, ecological impacts, regulatory compliance, public perceptions of risk, and future risk to workers and the public.

Worker and Transportation Safety

The greatest number of labor-hours (thus, the greatest number of worker accidents and injuries) would result from the continued storage alternative. Roughly 9,000 FTE-years would be required to manage all the DOE mixed waste (both stored and projected) to meet at least RCC Level 3 in the next 30 years. Worker and transportation safety is presented in Appendix E.

Ecological and Natural Resource Impacts

As discussed in Section 5.2, the highest daily exposure rate considered in this analysis is 5.5E-05 rad/day; no observable effects would be anticipated for animals at chronic dose rates of 0.1 R/day or for plants at 1 R/day (IAEA 1992). Because it is highly unlikely that substantive environmental or ecological impacts to terrestrial or aquatic organisms will result from exposure to ionizing radiation from the LLMW under consideration in this report, such impacts are not discussed in this ALARA analysis.

Regulatory Factors

The adaptation of RCC for mixed waste would be a positive step from a regulatory standpoint, in that the regulation of wastes meeting the criteria would be simplified. A favorable consequence of this would be greater availability of treatment capacity for these wastes. Site Treatment Plans would have to be reconsidered and renegotiated.

Public Perceptions and Concerns

Research and practical experience have shown that public perceptions and concerns about options involving hazards and risk frequently do not correspond well with probabilistic analyses of risk (Covello 1983; Slovic 1986) and that such concerns are relatively impervious to technical information or expert assurances of safety. One line of research (Slovic 1986; Slovic et al. 1991) has identified attributes of events or materials that are associated with perceptions of risk and concern. The proposed RCCs involve a number of these attributes:

- The hazard is not readily detectable by the senses.

- Exposure to the hazard is involuntary.

- The hazard is not a common material or occurrence but manmade and involves radioactivity and waste materials.

- Exposure to the hazard could remain unknown.

Another line of research has identified social and organizational attributes that affect perceptions of risk and concern and the acceptability of a proposed option or alternative. In addition to the technical aspects of the proposed activity or hazard and its potential impacts, consideration of the characteristics of the decision-making process, the nature of the relationship of the proponent, operator, and regulator with the broader community, and the institutional safeguards and mechanisms for ensuring accountability have been found to structure the public's assessment process (Wynne et al. 1993). Judgments about these factors affect the credibility of and trust in the organizations providing information and proposing to undertake actions or make decisions. When the organization or group of organizations conducting the analyses and initiating the decision-making process has low initial credibility and a perceived vested interest in the outcome, such as significant cost savings, the persuasive power of technical risk assessment information is diminished and the potential for adverse public response increases (Kasperson 1983; Pijawka and Mushkatel 1992).

In a climate of low trust, efforts to modify established standards, requirements, or agreements are likely to be met with suspicion and opposed, particularly if the modification is clearly a relaxation of standards or a broadening of scope (Mitchell 1992). Although the public response to disposal of this waste at existing commercial TSD facilities will be influenced by the credibility and trust levels of the facility operator and regulator, acceptance of this waste may be seen as violating the terms under which the facility was accepted by the community, thereby raising questions about accountability, decision-making, and public safety. Similarly, a major transportation campaign involving radioactive waste could evoke public concern and opposition that would significantly increase the costs of the program.

One of the important consequences of public concern and opposition is an increase in the cost of an alternative. Efforts to address public concern and overcome opposition can require extensive studies and elaborate documentation, increased safety measures, and intensive outreach.

Future Risk for Disposal

The consequences to workers from remediation of a leaking RCRA disposal cell would be very limited, compared with limiting individual doses for other exposure scenarios. The individual doses from landfill excavation are about 1% of the doses from the most limiting scenario, on which the RCC levels are based. This means that the collective dose from landfill excavation would be negligible. The probability of such an intrusion occurring is based on liner failure after disposal of DOE waste.

A groundwater release accident scenario, with consequences calculated using RESRAD, a computer code (Yu et al. 1993), is presented in Appendix F.

8.0 Conclusions

The results of this study provide strong evidence to consider adoption of an RCC limit which would encompass a significant portion (at least 10%, as assumed for Level 1) of the DOE LLMW wastes studied, would save money, and may actually decrease the collective dose received over the study period. These results are insensitive to the cost factors and waste volumes used in this analysis. Adoption of an RCC limit is consistent with ALARA, limiting collective dose. Therefore, policy relating to establishing a RCC level should be further pursued as a credible way to lower the collective dose and costs of waste management operations. In addition, the highest RCC limit considered (i.e., least restrictive) offers the most potential for economic savings, without a significant increase in the risk to human health and the environment.

Large economic savings could be realized by implementing RCC Level 3. Potential cost savings must be tempered with the anticipated cost to change the procedural and regulatory framework to implement a RCC approach. Implementation costs were not analyzed in this report. These costs would most likely include legal fees, additional policy studies, public involvement workshops, implementation studies, potential court challenges, etc. Public perception, which may not be founded on the facts and which could be an obstacle to any policy change regarding mixed waste, was not included in a quantitative manner in this analysis.

9.0 References

61 FR 6799. February 22, 1996. Department of Energy, "Radiation Protection of the Public and the Environment."

Aaberg, R. L., D. A. Baker, M. F. Jarvis, K. Rhoads, and W. E. Kennedy, Jr. 1995. *Radiation Dose Assessment Methodology and Preliminary Dose Estimates to Support U.S. Department of Energy Radiation Control Criteria for Regulated Treatment and Disposal of Hazardous Wastes and Materials*. PNL-9405, Pacific Northwest National Laboratory, Richland, Washington. Prepared for the U.S. Department of Energy, Office of Environmental Safety and Health, Washington, D.C.

Baker, D. A., and J. K. Soldat. 1992. *Methods for Estimating Doses to Organisms from Radioactive Materials Released into the Aquatic Environment.* PNL-8150, Pacific Northwest Laboratory, Richland, Washington.

Barth, E. F., et al. 1990. *Stabilization and Solidification of Hazardous Wastes*. Noyes Data Corporation, Park Ridge, New Jersey.

Barnthouse, L. W. 1995. *The Effects of Ionizing Radiation on Terrestrial Plants and Animals: A Workshop Report*. ORNL/TM-13141, Martin Marietta Energy Systems, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Baum, H. R. Brown, B. Dionne, B. Mann, and S. Maschulli. 1992. *Operational Exercises on Cost-Benefit Methodologies.* Presented at Department of Energy ALARA Workshop, April 21-22, 1992. Brookhaven National Laboratory, Upton, New York.

Beck, W. L., and G. R. Foltz. 1993a. *Exposure Pathway Assessment Report for Laidlaw Environmental Services, Roebuck, South Carolina*. ORISE 95/C-69, prepared for U.S. Department of Energy by the Environmental Survey and Site Assessment Program, Oak Ridge Institute for Science and Education, Oak Ridge, Tennessee.

Beck, W. L., and G. R. Foltz. 1993b. *Exposure Pathway Assessment Report for Rollins Environmental Services Site, Baton Rouge, Louisiana*. ORISE 93/J-175, prepared for U.S. Department of Energy by the Environmental Survey and Site Assessment Program, Oak Ridge Institute for Science and Education, Oak Ridge, Tennessee.

Brown, R. L., and C. J. Stephan. 1992. *Cost/Benefit Analysis at Westinghouse Hanford Company*. Presented at Department of Energy ALARA Workshop, April 21-22, 1992. Brookhaven National Laboratory, Upton, Long Island, New York.

Cashwell, J. W., K. S. Neuhause, P. C. Reardon, and G. W. McNair. 1986. *Transportation Impacts of the Commercial Radioactive Waste Management Program*. SAND85-2715, Sandia National Laboratories, Albuquerque, New Mexico.

Chew, M. H., and Associates. 1993a. *Radiological Dose Assessment of the Treatment, Storage, and Disposal of Department of Energy Waste by Chemical Waste Management, Inc., Emelle, Alabama*. Compiled for the Department of Energy, Office of Environmental Restoration and Waste Management by M. H. Chew and Associates, Inc., under contract to BDM International, Inc.

Chew, M. H., and Associates. 1993b. *Radiological Dose Assessment of the Treatment, Storage, and Disposal of Department of Energy Waste by Environmental Systems Company, El Dorado, Arkansas*. Compiled for the Department of Energy, Office of Environmental Restoration and Waste Management by M. H. Chew and Associates, Inc., under contract to BDM International, Inc.

Chew, M. H., and Associates. 1994. *Radiological Dose Assessment of the Treatment, Storage, and Disposal of Department of Energy Waste by Rollins Environmental Services Site, Deer Park, Texas*. Compiled for the Department of Energy, Office of Environmental Restoration and Waste Management by M. H. Chew and Associates, Inc., under contract to BDM International, Inc.

Chew, M. H., and Associates. 1995. *Interim Report: Waste Volume Projections and Disposal Costs Associated with Changing Discrimination Levels*. Prepared for U.S. Department of Energy, Office of Waste Management, Washington, D.C.

Covello, V. 1983. "The Perception of Technological Risks: A Literature Review." *Technologia Forecasting and Social Change* 23:285-297.

Douglas, M., and A. Wildavsky. 1982. *Risk and Culture: An Essay on the Selection of Technological and Environmental Dangers*. University of California Press, Berkeley, California.

Executive Order 12866. October 4, 1993. "Regulatory Planning and Review."

Garcia, R. S. 1996. *Commercially Available Low-Level Radioactive and Mixed Waste Treatment Technologies*. DOE/LLW-240, prepared for the U.S. Department of Energy by Idaho National Engineering Laboratory, Idaho Falls, Idaho.

International Atomic Energy Agency (IAEA). 1992. *Effects of Ionizing Radiation on Plants and Animals at Levels Implied by Current Radiation Protection Standards.* International Atomic Energy Agency, Vienna, Austria.

Kasperson, R. E. 1983. "Acceptability of Human Risk." *Environmental Health Perspectives* 52:15-20.

Margolis, H. 1996. *Dealing with Risk: Why the Public and the Experts Disagree on Environmental Issues*. University of Chicago Press, Chicago, Illinois.

Mitchell, J. V. 1992. "Perception of Risk and Credibility at Toxic Sites." *Risk Analysis* 12(1):19-26.

National Council on Radiation Protection and Measurements (NCRP). 1991. *Effects of Ionizing Radiation on Aquatic Organisms.* NCRP Report 109, National Council on Radiation Protection and Measurements, Bethesda, Maryland.

National Safety Council (NSC). 1995. *Accident Facts, 1995 Edition*. National Safety Council, Itasca, Illinois.

Pijawka, D., and A. H. Mushkatel. 1992. "Public Opposition to the Siting of the High-Level Nuclear Waste Repository: The Importance of Trust." *Policy Studies Review* 10(4):180-194.

Resource Conservation and Recovery Act (RCRA) of 1976. 42 USC 6901 et seq., as amended.

Secretary of Energy's Advisory Board (SEAB). 1993. *Task Force Report: Earning Public Trust and Confidence*. Vol 2. U.S. Department of Energy, Washington, D.C.

Slovic, P. 1986. "Informing and Educating the Public About Risk." *Risk Analysis* 4(4):403-415.

Slovic, P., J. H. Flynn, and M. Layman. 1991. "Perceived Risk, Trust, and the Politics of Nuclear Waste." *Science* 236:280-285.

Wynne, B., C. Waterton, and R. Grove-White. 1993. *Public Perceptions and the Nuclear Industry in West Cumbria*. Center for the Study of Environmental Change, Lancaster University, Lancaster, U.K.

U.S. Department of Energy (DOE). 1990. *Radiation Protection of the Public and the Environment.* DOE Order 5400.5, U.S. Department of Energy, Washington, D.C.

U.S. Department of Energy (DOE). 1995. *Condensed Mixed Waste Inventory Report* (CMWIR), database. (Accessed from Internet, August 1995)

U.S. Environmental Protection Agency (EPA). 1996. "EPA Extends Policy for Some Stored Mixed Wastes (4/96)" [Online]. Available: http://www.epa.gov/radiation/mixed-waste/mw_pg14.htm#enf

U.S. Environmental Protection Agency (EPA). *Silicate Technology Corporation's Solidification/ Stabilization Technology for Organic and Inorganic Contaminants in Soils: Applications Analysis Report*. EPA/540/AR-92-010, EPA, Washington D.C.

Yu, C., A. J. Zielen, J. J. Cheng, Y. C. Yuan, L. G. Jones, D. J. DePoire, Y. Y. Wang, C. O. Loureiro, E. Gnanapragasam, E. Faillace, A. Wallo III, W. A. Williams, and H. Peterson. 1993. *Manual for Implementing Residual Radioactive Material Guidelines Using RESRAD, Version 5.0.* ANL/EAD/LD-2, prepared by Argonne National Laboratory, Argonne, Illinois, for the U.S. Department of Energy.

Appendix A

Radiological Control Criteria - Data Call Background

Appendix A

Radiological Control Criteria - Data Call Background

The characterization of regulated chemical wastes produced by facilities of the DOE is a key element in establishing the feasibility for establishing RCC for such regulated wastes. A data call was sent to DOE facilities in order to obtain a good idea as to the types of wastes that could potentially be handled by commercial facilities. This appendix presents information obtained from the data call.

Section A.1 gives an outline of the data call and a summary of the questions presented in it; Section A.2 summarizes responses from the various DOE sites which responded to the data call.

Two key questions from the data call for the development of RCC concern cost savings (question 6) and detection capabilities, predominant nuclides, and waste concentrations (question 7). An augmented version of the INEL summary of question 6 and a summary of responses to question 7 are incorporated into Section A.2. A synopsis of the responses to other questions and the INEL summaries are included for completeness.

A.1 Data Call and Screening Criteria

Structure of the Data Call

The major sections of the data call are Background, Base Case Data Assumptions, Alternative One to Base Case Data Assumptions, Alternative Two to Base Case Data Assumptions, Consideration of Other Criteria, and General Questions about Handling Hazardous Waste.

Part A - Base Case Data and Assumptions

Table 1 in Part A of the data call presents potential RCC values which correspond to RCC Level 2, based on a dose of 1 mrem to a maximally exposed individual (MEI). This set of concentrations from the data call is referred to here as Case A. A series of questions is asked, assuming that the values in Case A were established as the RCC for hazardous wastes. The topics are in three categories, listed below:

- Waste quantity and radionuclide content - Questions 1 though 4 deal with waste quantity, treatment requirement, predominant radionuclides, activity, and physical and chemical forms of hazardous waste.

- Measurements of radionuclides in hazardous waste - Questions 5-7 deal with the ability to detect at the given concentrations, suitability of laboratory techniques available, and use of onsite or commercial laboratory.

- Costs associated with hazardous waste disposal - Questions 8 and 9 concern cost savings and other benefits.

Part B - Alternative One to Base Case Data and Assumptions

In Part B, Table 2 of the data call presents potential RCC values which correspond to RCC Level 1, based on a dose of 0.01 mrem to an MEI. This set of concentrations from the data call is referred to here as Case B. The same series of questions (as noted above) is asked but it is assumed that the values in Case B were established as RCC.

Part C - Alternative Two to Base Case Data and Assumptions

Table 3 in Part C of the data call presents potential RCC values which correspond to RCC Level 3, based on a dose of 20 mrem to an MEI. This set of concentrations from the data call is referred to here as Case C. The same series of questions (as noted above) is asked, but it is assumed that the values in Case C were established as RCCs.

Part D - Considerations of Other Criteria

The questions in Part D ask about the impact of 1) a 2000 pCi/g maximum concentration, 2) U and Th concentrations limited to 500 ppm, and 3) break point where verification of quantities becomes extremely difficult.

Part E - General Questions about Handling Hazardous Waste

The questions in Part E ask which TSD facilities were used, what quantities of waste were shipped to TSDs, and the physical form, chemical form, and treatment method of the wastes shipped.

The text of the data call is included below. A summary of the responses is found in Section A.2.

Text of Data Call

Screening Level Assessment in Support of Radiation Control Criteria for Hazardous Waste

Background

The Office of Environmental Guidance is conducting a project to assess the feasibility of establishing radiation control criteria for hazardous waste. The purpose of the project is to determine if it is feasible to define control criteria (concentrations of residual radioactive material) in regulated chemical wastes (e.g., the Resource Conservation and Recovery Act, RCRA) at which regulation of the waste for its chemical properties provide acceptable control of the radioactive portion of the waste. To be feasible, control of radionuclides afforded by RCRA regulations must provide an equivalent level of protection for the public as that provided by Atomic Energy Act based regulation; doses must be as low as in reasonably achievable.

The project is being conducted in a phased approach that, if the control criteria concept is feasible, will result in DOE working with EPA and NRC and other concerned parties to develop and implement radiation control criteria. These phases include:

I. **Identify Regulatory Limits and Constraints** applicable to radiological control criteria.

II. **Analyze hazardous waste Treatment, Storage and Disposal Facility Procedures and Controls** that would be in place at permitted facilities.

III. **Complete Pathway and Exposure Analyses** to identify potential sources of dose and risk.

IV. **Develop Screening Criteria** to support characterizing potential waste streams.

V. **Characterize Waste Streams** to identify potential source term.

VI. **Conduct ALARA and NEPA Analyses** to support the determination as to whether radiological control criteria are feasible and determine possible levels (concentrations).

VII. **Determine Appropriate Action** jointly with EPA and NRC.

A key element in the process of estimating potential the doses or risks and completing the ALARA (As Low As is Reasonably Achievable) analysis and the National Environmental Policy Act (NEPA) Analyses for the various alternatives (Phase VI), is determining the quantity of residual radioactive material potentially in waste regulated for its non-radioactive hazardous components (Phase V). In order

to calculate expected doses under the various alternative control criteria, it is necessary to identify the potential radioactive source term in hazardous waste. The data requested in the attached document are needed to establish this source term at various screen levels.

Respondents should provide their best estimate of the quantities, characteristics and costs relating to screen criteria identified below. It may not be possible to complete the final phases of the radiation control criteria project without such data. Please provide complete and timely answers to the attached questions.

A. Base Case Data Assumptions

Answer the questions listed below assuming that numerical control criteria for radionuclides in hazardous waste materials regulated under RCRA and TSCA were established at the concentrations given in Table 1 (Base Case).

Additional assumptions include:

- Wastes for disposal and waste residues from treatment facilities will ultimately be sent to RCRA or TSCA regulated disposal facilities (not recycle),

- Analytical techniques and equipment are available to measure (or permit the calculation of) radionuclides at least to 50% but ideally 10% or less of the levels given in the Table 1 and data must be reported in a manner consistent with the requirements in Chapter 7 (including 7.3.4) of DOE/EH-73T,[(a)]

- When several radionuclides are present, control criteria shall be determined using the sum of the fractions rule (see DOE 5400.5, Section II.3.a(c)(3)).

Waste Quantity and Radionuclide Content

A.1 How much additional hazardous waste (mass and volume) is likely to be shipped (on average) from your site to TSD facilities for disposal during a 12 month period?

(a) DOE Environmental Regulatory Guide for Radiological Effluent Monitoring and Environmental Surveillance, 1/91.

Table 1. Base Case Numerical Control Criteria

Radionuclide	pCi/g	Bq/kg
H-3	6.5E+04	2.4E+06
Be-7	5.9E+01	2.2E+03
C-14	1.2E+03	4.4E+04
Na-22	7.2E-01	2.7E+01
P-32	1.6E+03	5.9E+04
S-35	4.0E+04	1.5E+06
Sc-46	6.4E-01	2.4E+01
V-48	5.4E-01	2.0E+01
Cr-51	1.2E+02	4.4E+03
Mn-54	2.2E+00	8.1E+01
Fe-55	1.4E+03	5.2E+04
Co-56	2.4E-01	8.9E+00
Co-57	6.6E+01	2.4E+03
Co-58	1.9E+00	7.0E+01
Co-60	4.5E-01	1.7E+01
Ni-63	1.7E+05	6.3E+06
Zn-65	1.8E+00	6.7E+01
Ge-68	2.9E+02	1.1E+04
As-74	4.2E+00	1.6E+02
Se-75	1.6E+01	5.9E+02
Se-79	5.8E+03	2.1E+05
Sr-90	7.8E+02	2.9E+04
Sr-90+D	3.8E+02	1.4E+04
Y-88	4.0E-01	1.5E+01
Zr-93	5.4E+04	2.0E+06
Nb-94	1.4E+00	5.2E+01
Tc-99	5.0E+02	1.9E+04
Ru-100	1.0E+01	3.7E+02
Ag-110m	5.5E-01	2.0E+01
Sn-113	3.1E+02	1.1E+04
Sb-124	5.7E-01	2.1E+01
Sb-125	6.3E+00	2.3E+02

Table 1. (contd)

Radionuclide	pCi/g	Bq/kg
Te-125m	2.2E+02	8.1E+03
I-125	2.5E+01	9.3E+02
I-126	5.5E+00	2.0E+02
I-129	1.1E+02	4.1E+03
I-131	1.0E+01	3.7E+02
Cs-134	1.2E+00	4.4E+01
Cs-137	4.6E+00	1.7E+02
Ce-144	4.3E+02	1.6E+04
Pm-147	6.1E+04	2.3E+06
Sm-151	1.3E+05	4.8E+06
Eu-152	1.1E+00	4.1E+01
Eu-154	1.1E+00	4.1E+01
Eu-155	1.6E+02	5.9E+03
Hg-203	2.7E+01	1.0E+03
Bi-207	9.3E-01	3.4E+01
Ra-226	9.3E+01	3.4E+03
Ra-226+D	1.4E+01	5.2E+02
Th-228	2.5E+01	9.3E+02
Th-229	4.4E+00	1.6E+02
Th-230	3.0E+01	1.1E+03
Th-232	6.8E+00	2.5E+02
Th-232+D	3.4E-01	1.3E+01
U-232	1.2E+01	4.4E+02
U-233	6.3E+01	2.3E+03
U-234	6.4E+01	2.4E+03
U-235	3.5E+01	1.3E+03
U-238	6.9E+01	2.6E+03
U-238+D	5.0E+01	1.9E+03
NP-237	1.3E+01	4.8E+02
Np-237+D	8.4E+00	3.1E+02
Pu-238	2.8E+01	1.0E+03
Pu-239	2.5E+01	9.3E+02
Pu-240	2.5E+01	9.3E+02

Radionuclide	pCi/g	Bq/kg
Pu-241	1.5E+03	5.6E+04
Am-241	1.2E+01	4.4E+02

Sr-90+D refers to Sr-90 in equilibrium with Y-90.
Ra-226+D refers to Ra-226 in equilibrium with Rn-222, Po-218, Pb-214, Bi-214, Po-214, Pb-210, Bi-210, and Po-210.
Th-232+D refers to Th-232 in equilibrium with Ra-228, Ac-228, Th-228, Ra-224, Rn-220, Po-216, Pb-212, and Bi-212.
U-238+D refers to U-238 in equilibrium with Th-234 and Pa-234.
Np-237+D refers to Np-237 in equilibrium with Pa-233.

A.1.1 If possible, indicate, what proportion of the total amount of waste shipped during the 12 month period will be disposed of directly and what proportion will require treatment.

A.2 What will be the predominant[(a)] radionuclides present in this incremental portion of hazardous waste to be shipped from your site for disposal?

A.3 What is the best estimate of radionuclide concentrations or the total activity (curie or Bq) amounts of each radionuclide in hazardous waste to be shipped over a 12 month period?

A.4 What will be the typical forms (physical [e.g., aqueous, solid, sludge, liquid] and chemical [e.g., organic, inorganic, acid, base] of hazardous waste shipped from your site?

Measurements of Radionuclides in Hazardous Waste

A.5 Will the radionuclides in hazardous waste for disposal at your facility be detectable at the concentrations given in Table 1 and considering the assumptions stated above?

A.6 Will conventional laboratory techniques be suitable or would significant procedure or method change be required to measure radionuclides in hazardous waste at the concentrations given in Table 1 (and assumptions)? (List those radionuclides or waste forms requiring the new analytical procedures or equipment.)

A.7 Will analyses of radionuclides in hazardous waste be performed at an existing onsite DOE laboratory or at a commercial laboratory?

Costs Associated With Hazardous Waste Disposal

A.8 What will be the expected cost saving or increase in cost (separate analytical and disposal) that would result from the establishment of the radionuclide control criteria consistent with

(a) Radionuclides contributing significantly to the potential dose (> 5% of the total dose). The radionuclides listed should account for at least 90% of the potential dose.

concentrations in Table A.l compared to your current waste disposal and management practices?

A.9 What other benefits or costs would result from establishing radionuclide control criteria at the Base Case levels given in Table 1?

B. Alternative One to Base Case Data Assumptions

Answer the questions listed below assuming that numerical control criteria for radionuclides in hazardous wastes regulated under RCRA and TSCA were established at concentrations 1/100th of the Base Case as given in Table 2 (Alternative One).

Additional assumptions include:

- Wastes for disposal and waste residues from treatment facilities will ultimately be sent to RCRA or TSCA regulated disposal facilities (not recycle),

- Analytical techniques and equipment are available to measure (or permit the calculation of) radionuclides at least to 50% but ideally to 10% or less of the levels given in the Table 2 and data must be reported in a manner consistent with the requirements in Chapter 7 (including 7.3.4) of DOE/EH-173T,

- When several radionuclides are present, control criteria shall be determined using the sum of the fractions rule (see DOE 5400.5, Section II.3.a(c)(3)).

Table 2. Alternative One to Base Case Numerical Control Criteria
(Base Case Criteria times 0.01)

Radionuclide	pCi/g	Bq/kg
H-3	6.5E+02	2.4E+04
Be-7	5.9E-01	2.2E+01
C-14	1.2E+01	4.4E+02
Na-22	7.2E-03	2.7E-01
P-32	1.6E+01	5.9E+02
S-35	4.0E+02	1.5E+04
Sc-46	6.4E-03	2.4E-01
V-48	5.4E-03	2.0E-01
Cr-51	1.2E+00	4.4E+01
Mn-54	2.2E-02	8.1E-01
Fe-55	1.4E+01	5.2E+02
Co-56	2.4E-03	8.9E-02
Co-57	6.6E-01	2.4E+01
Co-58	1.9E-02	7.0E-01
Co-60	4.5E-03	1.7E-01
Ni-63	1.7E+03	6.3E+04
Zn-65	1.8E-02	6.7E-01
Ge-68	2.9E+00	1.1E+02
AS-74	4.2E-02	1.6E+00
Se-75	1.6E-01	5.9E+00
Se-79	5.8E+01	2.1E+03
Sr-90	7.8E+00	2.9E+02
Sr-90+D	3.8E+00	1.4E+02
Y-88	4.0E-03	1.5E-01
Zr-93	5.4E+02	2.0E+04
Nb-94	1.4E-02	5.2E-01
Tc-99	5.0E+00	1.9E+02
Ru-100	1.0E-01	3.7E+00
Ag-110m	5.5E-03	2.0E-01
Sn-113	3.1E+00	1.1E+02
Sb-124	5.7E-03	2.1E-01
Sb-125	6.3E-02	2.3E+00

Table 2. (contd)

Radionuclide	pCi/g	Bq/kg
Te-125m	2.2E+00	8.1E+01
I-125	2.5E-01	9.3E+00
I-126	5.5E-02	2.0E+00
I-129	1.1E+00	4.1E+01
I-131	1.0E-01	3.7E+00
Cs-134	1.2E-02	4.4e-01
Cs-137	4.6e-02	1.7E+00
Ce-144	4.3E+00	1.6E+02
Pm-147	6.1E+02	2.3E+04
Sm-151	1.3E+03	4.8E+04
Eu-152	1.1E-02	4.1E-01
Eu-154	1.1E-02	4.1E-01
Eu-155	1.6E+00	5.9E+01
Hg-203	2.7E-01	1.0E+01
Bi-207	9.3E-03	3.4E-01
Ra-226	9.3E-01	3.4E+01
Ra-226+D	1.4E-01	5.2E+00
Th-228	2.5E-01	9.3E+00
Th-229	4.4E-02	1.6E+00
Th-230	3.0E-01	1.1E+01
Th-232	6.8E-02	2.5E+00
Th-232+D	3.4E-03	1.3E-01
U-232	1.2E-01	4.4E+00
U-233	6.3E-01	2.3E+01
U-234	6.4E-01	2.4E+01
U-235	3.5E-01	1.3E+01
U-238	6.9E-01	2.6E+01
U-238+D	5.0E-01	1.9E+01
NP-237	1.3E-01	4.8E+00
Np-237+D	8.4E-02	3.1E+00
Pu-238	2.8E-01	1.0E+01
Pu-239	2.5E-01	9.3E+00
Pu-240	2.5E-01	9.3E+00

Table 2. (contd)

Radionuclide	pCi/g	Bq/kg
Pu-241	1.5E+01	5.6E+02
Am-241	1.2E-01	4.4E+00

Sr-90+D refers to Sr-90 in equilibrium with Y-90.
Ra-226+D refers to Ra-226 in equilibrium with Rn-222, Po-218, Pb-214, Bi-214, Po-214, Pb-210, Bi-210, and Po-210.
Th-232+D refers to Th-232 in equilibrium with Ra-228, Ac-228, Th-228, Ra-224, Rn-220, Po-216, Pb-212, and Bi-212.
U-238+D refers to U-238 in equilibrium with Th-234 and Pa-234.
Np-237+D refers to Np-237 in equilibrium with Pa-233.

Waste Quantity and Radionuclide Content

B.1 How much additional hazardous waste (mass and volume) is likely to be shipped (on average) from your site to TSD facilities for disposal during a 12 month period?

B.1.1 If possible, indicate what proportion of the total amount of waste to be shipped during the 12 month period will be disposed of directly and what proportion will require treatment.

B.2 What will be the predominant radionuclides present in this incremental portion hazardous waste to be shipped from your site for disposal?

B.3 What is the best estimate of radionuclide concentrations or the total activity (curie or Bq) amounts of each radionuclide in hazardous waste to be shipped over a 12 month period?

B.4 What will be the typical forms (physical [e.g., aqueous, solid, sludge, liquid] and chemical [e.g., organic, inorganic, acid, base] of hazardous waste shipped from your site?

Measurements of Radionuclides in Hazardous Waste

B.5 Will the radionuclides in hazardous waste for disposal at your facility be detectable at the concentrations given in Table 2 and considering the assumptions stated above?

B.6 Will conventional laboratory techniques be suitable or would significant procedure or method change be required to measure radionuclides in hazardous waste at the concentrations given in Table 2 (and assumptions)? (List those radionuclides or waste forms requiring the new analytical procedures or equipment.)

B.7 Will analyses of radionuclides in hazardous waste be performed at an existing onsite DOE laboratory or at a commercial laboratory?

Costs Associated With Hazardous Waste Disposal

B.8 What will be the expected cost saving or increase in cost (separate analytical and disposal) that would result from the establishment of the radionuclide control criteria given in Table 2 compared to your current waste disposal and management practices?

B.9 What other benefits or costs would result from establishing radionuclide control criteria at the levels given in Table 2?

B.10 What would be the impact of eliminating the requirement to apply the "sum of the fractions" rule when using radiation control criteria at this level (i.e., each radionuclide concentration applied independently) ?

C. Alternative Two to Base Case Data Assumptions

Answer the questions listed below assuming that numerical control criteria for radionuclides in hazardous wastes regulated under RCRA and TSCA were established at concentrations 20 times the Base Case as given in Table 3 (Alternative Two).

Table 3. Alternative One to Base Case Numerical Control Criteria
(Base Case Criteria times 20)

Radionuclide	pCi/g	Bq/kg
H-3	1.3E+06	4.8E+07
Be-7	1.2E+03	4.4E+04
C-14	2.4E+04	8.9E+05
Na-22	1.4E+01	5.3E+02
P-32	3.2E+04	1.2E+06
S-35	8.0E+05	3.0E+07
Sc-46	1.3E+01	4.7E+02
V-48	1.1E+01	4.0E+02
Cr-51	2.4E+03	8.9E+04
Mn-54	4.4E+01	1.6E+03
Fe-55	2.8E+04	1.0E+06
Co-56	4.8E+00	1.8E+02
Co-57	1.3E+03	4.9E+04
Co-58	3.8E+01	1.4E+03
Co-60	9.0E+00	3.3E+02
Ni-63	3.4E+06	1.3E+08
Zn-65	3.6E+01	1.3E+03
Ge-68	5.8E+03	2.1E+05
AS-74	8.4E+01	3.1E+03
Se-75	3.2E+02	1.2E+04
Se-79	1.2E+05	4.3E+06
Sr-90	1.6E+04	5.8E+05
Sr-90+D	7.6E+03	2.8E+05
Y-88	8.0E+00	3.0E+02
Zr-93	1.1E+06	4.0E+07
Nb-94	2.8E+01	1.0E+03
Tc-99	1.0E+04	3.7E+05
Ru-100	2.0E+02	7.4E+03
Ag-110m	1.1E+01	4.1E+02
Sn-113	6.2E+03	2.3E+05
Sb-124	1.1E+01	4.2E+02
Sb-125	1.3E+02	4.7E+03

Table 3. (contd)

Radionuclide	pCi/g	Bq/kg
Te-125m	4.4E+03	1.6E+05
I-125	5.0E+02	1.9E+04
I-126	1.1E+02	4.1E+03
I-129	2.2E+03	8.1E+04
I-131	2.0E+02	7.4E+03
Cs-134	2.4E+01	8.9E+02
Cs-137	9.2E+01	3.4E+03
Ce-144	8.6E+03	3.2E+05
Pm-147	1.2E+06	4.5E+07
Sm-151	2.6E+06	9.6E+07
Eu-152	2.2E+01	8.1E+02
Eu-154	2.2E+01	8.1E+02
Eu-155	3.2E+03	1.2E+05
Hg-203	5.4E+02	2.0E+04
Bi-207	1.9E+01	6.9E+02
Ra-226	1.9E+03	6.9E+04
Ra-226+D	2.8E+02	1.0E+04
Th-228	5.0E+02	1.9E+04
Th-229	8.8E+01	3.3E+03
Th-230	6.0E+02	2.2E+04
Th-232	1.4E+02	5.0E+03
Th-232+D	6.8E+00	2.5E+02
U-232	2.4E+02	8.9E+03
U-233	1.3E+03	4.7E+04
U-234	1.3E+03	4.7E+04
U-235	7.0E+02	2.6E+04
U-238	1.4E+03	5.1E+04
U-238+D	1.0E+03	3.7E+04
NP-237	2.6E+02	9.6E+03
Np-237+D	1.7E+02	6.2E+03
Pu-238	5.6E+02	2.1E+04
Pu-239	5.0E+02	1.9E+04
Pu-240	5.0E+02	1.9E+04

Radionuclide	pCi/g	Bq/kg
Pu-241	3.0E+04	1.1E+06
Am-241	2.4E+02	8.9E+03

Sr-90+D refers to Sr-90 in equilibrium with Y-90.
Ra-226+D refers to Ra-226 in equilibrium with Rn-222, Po-218, Pb-214, Bi-214, Po-214, Pb-210, Bi-210, and Po-210.
Th-232+D refers to Th-232 in equilibrium with Ra-228, Ac-228, Th-228, Ra-224, Rn-220, Po-216, Pb-212, and Bi-212.
U-238+D refers to U-238 in equilibrium with Th-234 and Pa-234.
Np-237+D refers to Np-237 in equilibrium with Pa-233.

Additional assumptions include:

- Wastes for disposal and waste residues from treatment facilities will ultimately be sent to RCRA or TSCA regulated disposal facilities (not recycle),

- Analytical techniques and equipment are available to measure (or permit the calculation of radionuclides at least to 50% but ideally to 10% or less of the levels given in the Table 3 and data must be reported in a manner consistent with the requirements in Chapter 7 (including 7.3.4) of DOE/EH-173T,

- When several radionuclides are present, control criteria shall be determined using the sum of the fractions rule (see DOE 5400.5, Section II.3.a(c)(3)).

Waste Quantity and Radionuclide Content

C.1 How much hazardous waste (mass and volume) is likely to be shipped (on average) from your site to TSD facilities for disposal during a 12 month period?

C.1.1 If possible, indicate what proportion of the total amount of waste to be shipped during the 12 month period will be disposed of directly and what proportion will require treatment at a TSD?

C.2 What will be the predominant radionuclides present in the incremental portion of hazardous waste to be shipped from your site for disposal?

C.3 What is the best estimate of radionuclide concentrations or the total activity (curie or Bq) amounts of each radionuclide in hazardous waste to be shipped over a 12 month period?

C.4 What will be the typical forms (physical [e.g., aqueous, solid, sludge, liquid] and chemical [e.g., organic, inorganic, acid, base] of hazardous waste shipped from your site?

Measurements of Radionuclides in Hazardous Waste

C.5 Will the radionuclides in hazardous waste for disposal at your facility be detectable at the concentrations given in Table 3 and considering the assumptions stated above?

C.6 Will conventional laboratory techniques be suitable or would significant procedure or method change be required to measure radionuclides in hazardous waste at the concentrations given in Table 3 (and assumptions)? (List those radionuclides or waste forms requiring the new analytical procedures equipment.)

C.7 Will analyses of radionuclides in hazardous waste be performed at an existing onsite DOE laboratory or at a commercial laboratory?

Costs Associated With Hazardous Waste Disposal

C.8 What will be the expected cost saving or increase in cost (separate analytical & disposal) that would result from the establishment of the radionuclide control criteria given in Table 3 compared to your current waste disposal and management practices?

C.9 What other benefits or costs would result from establishing radionuclide control criteria at the levels given in Table 3?

D. Considerations of Other Criteria

D.1 What would be the impact on the estimates and data provided for the base case and the two alternative cases if the combined activity in any waste was limited to 2000 pCi/g (7.4×10^4 Bq/kg) as shown in Table 4? This requirement will reduce any individual radionuclide limit that is greater than 2,000 pCi/g to 2,000 pCi/g and further restrict the total activity from all radionuclides to 2,000 pCi/g.

D.2 What would be the impact on the estimates and data provided if uranium and thorium concentrations in the base case and the two alternative cases was limited to 500 ppm as shown in Table 4?

D.3 Is there a "break point" in the numerical control criteria where the quantity of hazardous waste to be shipped for disposal from your facility will significantly change or the where measurement or verification become extremely difficult or impossible?

Table 4. Other Restrictions to be Considered

Type of Restriction	Limit
Total Activity limit	2000 pCi/g ($7.4 \times l0^4$ Bq/kg)

Source Material limited to 500 ppm (e.g., Natural Uranium (500 ppm) ^{232}Th (500 ppm))	1700 pCi/g (6.2 x 10^4 Bq/kg) 540 pCi/g (2.0 x 10^4 Bq/kg)

E. General Questions About Handling Hazardous Waste

E.1 List the commercial TSD facilities that received hazardous waste from your site during the past 12 months, and indicate the proportion of wastes disposed of directly and the proportion treated before disposal.

E.2 Provide your best estimate of the total amount (mass and volume) of hazardous waste shipped from your site during the past 12 months for disposal or treatment. Provide the following descriptions of that waste to the extent possible:

E.2.1 What was the physical form? (e.g., liquid, solid [metal, wood, paper, soil, rubble, building trash], sludge, or gas [compressed or sorbed]). Provide a breakdown if different forms were shipped.

E.2.2 What was the chemical form? (e.g., [organic or inorganic, mixed; acidic or basic, neutral]). List chemical constituents by physical form. Provide volume and mass estimates by RCRA waste designation codes.

E.2.3 What was the treatment method used? (e.g., incineration, fuel substitution, recycle, burial, chemical treatment.) Provide a percentage of the amount of waste shipped (E.2) for each method.

A.2 Summary of Responses

Detailed responses from 21 of 23 DOE sites (or contractors) have been received from INEL. Some responses were not available, and there are some cases in which the format was not followed (NTS and LLNL) or pieces of the response were missing. The most important survey questions in the content of the RCC ALARA analysis, are questions 6 and 7, which deal with waste quantities, radionuclide concentrations, and costs. These questions are covered in greater detail that the others. A synopsis of what can be learned from the available responses follows:

1. Information from 16 sites was summarized by INEL. Nine of the 18 sites from which information was reported gave activity in waste in terms of concentration (for low-level waste [LLW]) of hazardous/mixed waste or for both); others reported activity per year.

   The numbers and quantities of radionuclides vary greatly among DOE sites. The number of radionuclides in LLW varies from one (^{3}H) for Pinellas to 82 for Oak Ridge. Several sites reported 30 or more radionuclides in either LLW or mixed waste.

2 & 3. Instrumentation information was summarized by INEL for 12 respondents.

4. Sampling frequency was summarized by INEL for 14 respondents.

5. Analysis information was summarized by INEL for 12 respondents.

6. This question includes eight parts: a) increased quantity to be treated as non-rad waste; b) percent requiring treatment; c) quantity and type of treatment offsite; d) physical forms and e) chemical forms of waste; f) estimated cost savings; g) analytical cost changes, and h) other benefits. Parts a), b), and f) were summarized by INEL for 10 respondents. Some additional information was incorporated into three tables (Attachments, Tables A.1, A.2, and A.3) corresponding to Cases A, B, and C.

   Assessing the overall impact of the proposal to treat some DOE waste as RCRA waste is complicated because the responses are not uniform. Observations concerning the submittals (see Tables A.1, A.2, A.3) are listed below:

   - For some entries, waste quantities are given in mass only (ANL E, SNL/CA) or percentage (SLAC), without indication of the relative amount.

   - The waste listed for SNL/A (New Mexico) is mostly LLW; other sites do not include the LLW component of the waste streams.

Table A.1. Radiation Control Criteria Questionnaire: Question 6, Case A Response Summary (all physical and chemical forms)

Site	Increased Quantity, Mass (kg)	Increased Quantity, Volume (m^3)	Percent Requiring Treatment	Cost Savings Estimate	Notes Concerning Costs, Waste Form
LBL	2,688 (56%)	9.3	100%	$35,000	Narrative of response to question 6, a-f is missing.
RFP	0	0	0	0	No wastes meet case A criteria.
ORNL	4,186,600 (7%)		100%	$1 to $10 M	Cost estimate requires better quality data; this waste mostly soils.
PNL	900-1500 (15 - 25%)	16.5 - 27.5	100%	$110,000	Saving $800/drum disposal cost (~138 drums 55-gal or 0.2 m^3).
SLAC	100%		0%	$50,000	Liquid waste, containing ^3H.
LEHR			unknown	$40,000	No specifics given.
UMTRA	0	0		0	No wastes meet case A criteria.
SNL/A	12010 (11560 LL + 450 MW)	30	4% LL; 100% MW	$13,500	Mostly solids & debris; Note: 96% LLW, non-hazardous.
ITRI	806	0.766	100%	$16,200	Liquid Waste; scintillation counting cocktail.
PTX		38	12.4%	$42,000 $4,600/yr	Mostly heterogeneous solids.
ANL E	667	0.63	100%	$2,500	No details.

Site	Increased Quantity, Mass (kg)	Increased Quantity, Volume (m^3)	Percent Requiring Treatment	Cost Savings Estimate	Notes Concerning Costs, Waste Form
SRS	3.3176 E5	210.4	100%	$550,000	Savings $3500/drum (liquid) and $1400/drum (solid); Cost by waste stream; > 80% lead shielding & Cd-coated filter frames, disposal costs unknown.
SNL/CA	3195.535	2.799			Treatment costs unknown.
INEL					No response to this question.
LANL	(7.7E+4)[a]	(150)[a]		(~ $400 K) ~500 drums x $800/drum	Estimate inferred from LANL response, Tables A.1 and A.2. Cost estimate deduced from PNL per drum costs.
GJPO	~6				Not significantly affected by Case A.
Mound	--				Waste hydraulic oil with kerosene, PCBs, and ^3H; Facility is being built.
LLNL	--				LLW Characterization data; no quantities or costs given.
PNLS	NA				No mixed waste; maybe for D&D.
KCP	NA				Not applicable.
NTS	--				No response.

(a) Based on 70% of suspect waste in Table A.2 (110,690 kg, 213.7 m^3); percentage based on the waste breakdown given in Table A.1.

Table A.2. Radiation Control Criteria Questionnaire: Question 6, Case B
Response Summary (all physical and chemical forms)

Site	Increased Quantity, Mass (kg) (percent)	Increased Quantity, Volume (m^3)	Percent Requiring Treatment	Cost Savings Estimate	Notes Concerning Costs, Waste Form
LBL	864 (18%)	3	100%	$11,000	
RFP	0	0	0	0	
ORNL	0				
PNL	600 - 900 (10-15%)	11 - 16.5	100%	$66,000	Saving $800/drum disposal cost
SLAC	20%	0.2	0%	$5,000	
LEHR	100 kg		unknown	-$45,000	
UMTRA	0	0		0	
SNL/A	9570	24		$13,500	~96% LLW, non-hazardous
ITRI	0	0		0	
PTX	0	0		0	
ANL E	212	0.23	100%	$2110	Liquid waste
SRS	6.377 E4	146.2	100%	$230,000	Detailed cost by waste stream; 2/3 Cd-coated filter frames, disposal cost unknown
SNL/CA	641.82	0.6757			
INEL					No response to this question
LANL	(3E+4)[(a)]	(58)[(a)]		(~ $230 K) ~290 drums x $800/ drum	Estimate inferred from LANL response, Tables A.1 and A.2
GJPO	-				Not affected by Case B
Mound	-				
LLNL	-				LLW Characterization data; no quantities or costs given
PNLS	NA				No mixed waste
KCP	0				
NTS	-				No response

(a) Based on 27% of suspect waste in Table A.2 (110,690 kg, 213.7 m^3); percentage based on the waste breakdown given in Table A.2.

Table A.3. Radiation Control Criteria Questionnaire: Question 6, Case C
Response Summary (all physical and chemical forms)

Site	Increased Quantity, Mass (kg)	Increased Quantity, Volume (m^3)	Percent Requiring Treatment	Disposal Cost Savings Estimate	Notes Concerning Costs, Waste Form
LBL	3922 (82% MW)	13.6	100%	$49,500	
RFP	2 (+ 50% LLW)		100%	substantial	
ORNL	58,823,600 (99.88%)		100%	$1 to $20 M	~90 % solids - Ash, concrete, soils, sludge, sediment plus 7% soils as Case A, above
PNL	1500 - 2100 (25-35%)	27.5 - 38.5	100%	$154,000	Cost savings based on $800/drum
SLAC	100%			$50,000	
LEHR	unknown		unknown	$40,000	
SNL/A	15780 (14560 LL + 1220 MW)	90	8% LL 100% MW	$135,000	>90% LLW, non-hazardous
ITRI	806	0.775	100%	$16,200	Scintillation counting cocktail
PTX		110.5	70.8%	$128,000 $9,200/yr	Mostly heterogeneous solids
UMTRA	0	0		0	
ANL E	717	0.68	100%	$3930	
SRS	3.3236 E5	211.6	100	$558,000	Detailed cost by waste stream
SNL/CA	3478.54	3.679			
INEL					No response to this question
LANL	(8.8E+4)[(a)]	(170)[(a)]		(~ $680 K) ~850 drums x $800/drum	Estimate inferred from LANL response, Tables A.1 and A.2
GJPO	125,000				Most waste meets Case C criteria; mostly contaminated soil
Mound	-				Treatment facility being built
LLNL	-				LLW Characterization data; no quantities or costs given
PNLS	NA				Not applicable
KCP		2 drums			Heterogeneous solids, ^{147}Pm
NTS	-				No response

(a) Based on 80% of suspect waste in Table A.2 (110,690 kg, 213.7 m^3); percentage based on the waste breakdown given in Table A.1.

- It appears that wastes from remediation efforts (contaminated soils) are included in the ORNL submittal; responses from others sites do not appear to include this type of waste.

- Response from WHC (Hanford), which is not yet available, is expected to show a significant quantity of RCRA waste which could potentially be handled as non-rad.

The inclusion of D&D and remediation wastes and LLW in the quantities could have a very large impact on the quantities of wastes categorized as Non-rad (RCRA) or mixed waste.

6c. Offsite waste treatment capacity would appear to be an important consideration for Oak Ridge wastes; the quantity of waste requiring treatment for Case A is more than 4,000 tons.

6f. For many sites, the relative economic impact appears to be relatively small (less than the cost of employing one full-time worker); adding site cleanup activities may modify that conclusion.

For Case B: At least 7 DOE sites (RFP, ORNL, UMTRA, ITRI, PTX, GJPO, and KCP) would have no additional non-rad hazardous wastes if Case B limits were adopted.

For Case C: With the exception of UMTRA, all the DOE sites reporting have some waste eligible to be considered hazardous waste under Case C. This would be most important for ORNL, from which almost 60,000 tons of waste would be eligible for disposal as hazardous waste, at a savings of $1M to $20M. Offsite waste treatment capacity may be an important consideration for this quantity of wastes.

7. Question 7 Consists of five parts: a) detectability at the concentrations in Table 1; b) adequacy of conventional laboratory techniques; c) type of lab: onsite (DOE) or offsite commercial lab; d) predominant nuclides for offsite shipments; and e) estimate of average concentration or activity of each predominant radionuclide.

The response is given in two parts: 1) a summary response to each question by DOE site and 2) A listing of potential radionuclides in RCRA waste for each DOE site. This information is given in Tables A.4 and A.5, and a key explaining the symbols used, attached. Some observations concerning the submittals are listed below:

7a & b.

Concerning detection of various radioduclides:

- Note that Detection Limits (DLs) for predominant radionuclides ^{232}Th + D and ^{239}Pu at Pantex do not meet Table 1 criteria.

- DLs at the Mound facility for several potential radionuclide contaminants (^{60}Co, ^{137}Cs, ^{226}Ra, ^{228}Th, ^{230}Th, ^{232}Th, ^{234}U, and ^{238}U) do not meet Table A.1 criteria.

- DLs for some radionuclides potentially in ORNL waste (^{90}Sr, ^{137}Cs, ^{239}Pu) do not meet the Table A.1 criteria.

7c. Onsite (DOE and contractor) labs are planned to be used by 15 respondents; both or either (onsite/offsite) by three, and only one site (LEHR) specified all offsite commercial lab analyses.

7d. Not surprisingly, many of the DOE sites have the same or similar predominant radionuclides in their hazardous waste streams, as illustrated in Table 7.2. Radionuclides identified as predominant at 4 or more DOE sites for Case A include ^{3}H (12 sites), ^{239}Pu (7 sites); ^{238}U and ^{14}C, (each, 5 sites), ^{137}Cs, ^{238}Pu, and ^{241}Am (each, 4 sites).

7e. There is some confusion with differing units. The survey allowed reporting in either Ci/yr or concentration units; the units intended are not always specified, and comparisons of results for facilities using unlike units may be difficult. When radionuclide content is specified in Ci, the radionuclide concentration calculated from the mass of waste meeting the Table 1 criteria (Table 1, question 6a) does not always meet Table 1 concentrations. There may be some disconnects in the sources of mass and concentration data. Discrepancies between the waste concentrations and Table 1 limits are noted in Table 4 for ITRI and SR.

Table A.4. Summary of Responses to Data Call Question 7

No.	Site	DETECT @ TBL A Concentration?	b. Conventional Techniques?	c. Onsite or Commercial Lab?	d. Predominant Nuclides for Offsite Shipment	e. Est. Ave. Rad Concentration or Activity in 7d.
1	INEL	Most detectable ABC; ND for B: ^{22}Na, ^{56}Co, ^{60}Co, ^{65}Zn, ^{88}Y, ^{94}Nb, ^{99}Tc, ^{110m}Ag, ^{124}Sb, ^{147m}P, ^{152}Eu, ^{154}Eu ND ABC: ^{125}I	Yes-except those nuclides listed; depends on matrix, sample geometry, counting times, and detector system.	Onsite	Not indicated; refer to individual waste generators	Not indicated; refer to individual waste generators
2	ORNL	A: ND ^{90}Sr, ^{137}Cs, ^{232}Th, ^{239}Pu; B: No response; C: All detectable	New techniques for nuclides listed	Both	A: ^{99}Tc, ^{228}Th, ^{238}U/^{234}Th/^{234m}Pa; ^{237}Np; C: ^{99}Tc, ^{230}Th, ^{234}U, ^{238}U+D (^{234m}Pa), ^{237}Np	A,C: Activity, pCi/g; ^{99}Tc 6.1, 1570; ^{230}Th (.9), 24;[a] ^{228}Th .52; (7.7); ^{234}U (-), 145; ^{238}U 4.6, 201; ^{234}Th 17, 285; ^{234}Pa.1, 588; ^{237}Np 3.1, 12; ^{238}Pu 0.5, (-); ^{239}Pu 0.03, 4.96; ^{241}Am 0.016, 0.29
3	PNL	A: ^{125}I, ^{129}I (ex. aq l) [^{228}Th, ^{230}Th, ^{232}Th ^{237m}Np ^{238m}Pu ^{239}Pu, ^{240}Pu, ^{241m}A (solids)]	New methods for listed items	Onsite	^{3}H, ^{14}C, ^{54}Mn, ^{55}Fe, ^{60}Co, ^{90}Sr+D, ^{106}Ru, ^{137}Cs, ^{154}Eu, ^{232}Th, ^{238}U, ^{238}Pu, ^{239}Pu, ^{241}Am	Ci/yr from q. 1: ^{3} H 2E-2; ^{14}C .17; ^{54}Mn 6E-4; ^{55}Fe 8.8E-4; ^{60}Co 3.4E-3; ^{90} Sr+D, 4.5E-5; ^{106}Ru 4.5E-5; ^{137}Cs 0.1; ^{154}Eu 4E-3, ^{232}Th 3.5E-4; ^{238}U 6.5E-5, ^{238}Pu 5.2E-5; ^{239}Pu 8.9E-4; ^{241}Am 4.7E-5
4	SNL/A	Yes	No new methods	Either	^{3}H; ^{3}H + ^{63}Ni for C	Ci, Case A, B, C;[b] ^{3}H: 6.4E-3, 1.2E-4, 9.7E-3; ^{63}Ni: (-), (-), 6.4E-3

Table A.4. (contd)

No.	Site	DETECT @ TBL A Concentration?	b. Conventional Techniques?	c. Onsite or Commercial Lab?	d. Predominant Nuclides for Offsite Shipment	e. Est. Ave. Rad Concentration or Activity in 7d.
5	LANL	Gamma emitters OK; for most waste streams, additional liquid scintillation & alpha spectroscopy	Most items could be surveyed with conventional techniques.	Most likely on-site with new facility.	^{3}H, ^{137}Cs, ^{235}U, ^{238}U; ^{238}Pu, ^{239}Pu; ^{241}Am	Conc. (pCi/g) A,B,C: ^{3}H: 4830, 107, 2.15E4 ^{137}Cs: .285, .011, 10; ^{235}U: 4.8, .039, 11.5; ^{238}U: 12.6, .065, 91; ^{238}Pu: 5.85, .034, 18; ^{239}Pu: 3.37, .039, 46; ^{241}Am: 3.35, .0043, 19.6
6	LBL	Yes - all cases	None	Onsite	^{3}H, ^{14}C, ^{35}S; (^{125}I, ^{238}U, ^{237}Np, ^{239}Pu, ^{241}Am)	Ci for case A, B, C: ^{3}H: 5E-2, 1E-4, 0.1 ^{14}C: 2E-5, 2E-6, 2E-3 ^{35}S: 7E-5, 7E-5, 7E-4
7	LEHR	Yes - Case A; Case B questionable for ^{14}C, ^{129}I, ^{137}Cs, ^{144}Cm, ^{207}Bi, ^{226}Ra, ^{238}U	Case B, new methods for ^{137}Cs, ^{207}Bi, ^{226}Ra, ^{234}U	Offsite - all nuclides	^{90}Sr, ^{137}Cs, ^{226}Ra	(Case A) activity, Ci ^{3}H < 10E-10 ^{90}Sr < 10E-10 ^{137}Cs <2E-12 ^{226}Ra < 2E-11
8	ITRI	All detectable	Mostly existing methods; new methods for ^{239}Pu	All onsite	^{3}H, ^{14}C, ^{63}Ni, ^{239}Pu	A: ^{3}H: 200 mCi/ml; C14 110 pCi/ml; ^{63}Ni 1200 pCi/ml; ^{239}Pu 1300 pCi/ml?[(c)]
9	GJPO	Detectable at Case C (20 x Table A);	No new methods or equipment for Case C	All Onsite Analyses	^{226}Ra, ^{230}Th, ^{232}Th in solid waste; ^{232}TH, ^{234}U, ^{238}U in soils	Case C: 4 types, units pCi/g: Org. .05 pCi/g or less UMTRA s ^{226}Ra 25, ^{230}Th 25, ^{232}Th 1.; GJPORAP ^{226}Ra 13, ^{230}Th 11, ^{232}Th 0.7; Sandia soil ^{232}Th 2.2, ^{234}U 150, ^{238}U 140, Total U 2-1500 pCi/g
10	MOUND	A: detectable ^{3}H & Pu; others need development; LLDs noted for Q5 (Aq) seem low (perhaps units should be µCi/g not pCi/g) ^{3}H .4; ^{239}Pu 5E-6	No new methods for ^{3}H and Pu; new methods for others	Specific rad onsite	^{3}H, ^{238}Pu, ^{239}Pu, ^{240}Pu	Not available

Table A.4. (contd)

No.	Site	DETECT @ TBL A Concentration?	b. Conventional Techniques?	c. Onsite or Commercial Lab?	d. Predominant Nuclides for Offsite Shipment	e. Est. Ave. Rad Concentration or Activity in 7d.
11	UMTRA	A: detectable	No new methods, Cases A & C	Both	^{226}Ra+D (^{230}Th, ^{234}U, ^{235}U, ^{238}U) (No offsite shipments)	Ci, A & C from Table: ^{226}Ra 8739, ^{230}Th (8739), U isotopes (874) (No offsite shipments)
12	KC	Not applicable[(d)]				
13	SLAC	A&C: Detectable; B: ND ^{7}Be;	New methods for Case B: ^{7}Be (H3)	Yes	^{3}H	20,000 pCi/L ^{3}H
14	PTX	^{3}H and ^{238}U Detectable; Th and Pu not for cases A,B,C	New methods for ^{232}Th + D; ^{239}Pu, all cases	Onsite	^{3}H, ^{232}Th+D, ^{238}U+D, ^{239}Pu	not given
15	RFP	(^{235}U) ^{238}U, ^{239}Pu OK; ^{241}Am questionable A;	No new methods for A; New methods for Case B	Onsite (Case A); unknown (Case B)	(^{235}U) ^{238}U, ^{239}Pu, ^{241}Am	range: 2.3E-7 to 29 pCi/g for isotopes of concern
16	PNLS	yes, detectable	No new methods or equipment	Onsite	^{3}H	Case A, B, C: ^{3}H 5-1000 pCi/l
17	SR	Liq.: all predominant nuclides detectable for case A (ND for ^{22}Na, ^{56}Co, ^{58}Co, ^{60}Co, ^{65}Zn, ^{88}Y, ^{94}Nb, ^{106}Ru, ^{110m}Ag, ^{125m}Te, ^{125}I, ^{152}Eu, ^{154}Eu, ^{207}Bi, ^{226}Ra+D, ^{229}Th, ^{232}Th+D; few nuclides detectable for case B; Solids: detectable for Case A except ^{241}Am	None for A; new methods for B	Onsite	Liquid matrix: ^{3}H, ^{14}C, ^{90}Sr, ^{137}Cs, ^{238}U, ^{238}Pu, ^{241}Am; Solids: not listed	ABC: liquids, pCi/g: ^{3}H 1.2E4; C14 < DL ^{90}Sr 1.2E-2; ^{137}Cs 50. ? [(e)] ^{238}U 39.; ^{238}Pu 0.3; ^{241}Am 5.5E-5
18	LLNL	Not submitted[(f)]	Information not submitted	Iinformation not submitted	Information given as characterization for 9 waste streams	Iinformation submitted by waste stream
19	ANL	Detectable for A,C; many not for B (OK for ^{3}H, ^{63}Ni, Th, U, Np Pu, Am)	No new Methods for A	Onsite	^{3}H for A,C; ^{3}H + ^{14}C for Case B	A: 1E-7 Ci ^{3}H; B: 1.4E-10 Ci ^{3}H, 5.3E-11 Ci ^{14}C

Table A.4. (contd)

No.	Site	DETECT @ TBL A Concentration?	b. Conventional Techniques?	c. On-site or Commercial Lab?	d. Predominant Nuclides for Offsite Shipment	e. Est. Ave. Rad Concentration or Activity in 7d.
20	SNL/CA	Detectable for all cases	No new methods	Onsite	A: ^{3}H, ^{14}C, ^{147}Pm, ^{238}U B: ^{3}H, ^{207}Bi, ^{238}U C: same as A	^{3}H 100 Ci; ^{14}C 6E-6 Ci; ^{147}Pm 2.5 mCi; ^{238}U 0.022 mCi
21	BNL	Not available				
22	ETEC	No response[(g)]				
23	NTS	Not available[(h)]				
3a	WHC	Not available				

(a) Parentheses indicate this radionuclide is not predominant for this case.
(b) Response table for Question 7 from SNL/A (NM) includes only first page (^{3}H through ^{152}Eu).
(c) Note that the Table A limit for ^{239}Pu is 25 pCi/g
(d) In the response from KSP, it is stated that hazardous waste generated at the Kansas City Plant, has no radiological contamination; sealed and plated sources; KCP accepts only material and equipment which meets the DOE order 5400.5 limits for unrestricted release.
(e) Note that the Table A limit for ^{137}Cs is 4.6 pCi/g
(f) Submittal by LLNL consisted of characterization of nine waste streams.
(g) Submittal by ETEC was deemed unnecessary by the Program Manager for Facility Programs. All facilities used for nuclear at ETEC have been declared surplus, and is nearly done with decommissioning.
(h) NTS letter refers to "Performance Objective Criteria"; a document which was unavailable at this writing.

Table A.5. Summary Response by Nuclide to Question 7

Nuclide	pCi/g	INEL 1	ORNL 2	PNL 3	SNL/A 4	LANL 5	LBL 6	LEHR 7	ITRI 8	GJPO 9	Mound 10	UMTRA 11	KC1 2	SLAC 13	PTX 14	RFP 15	SR 16	LLNL 17	AN L 18	SNL/CA 19	WHC 3a	PNLS 20
^{3}H	65,000.			A	A	A	A		A		A			A	A		A		A	A		A
^{7}Be	59.																					
^{14}C	1200.			A			A		A								A		B	A		
^{22}Na	0.72																					
^{32}P	1600.																					
^{35}S	40,000.						A															
^{46}Sc	0.64																					
^{48}V	0.54																					
^{51}Cr	120.																					
^{54}Mn	2.2			A																		
^{55}Fe	1400.																					
^{56}Co	0.24																					
^{57}Co	66.																					
^{58}Co	1.9																					
^{60}Co	0.45			A							<											
^{63}Ni	170,000.				C				A													
^{65}Zn	1.8																					
^{68}Ge	290.																					
^{74}As	4.2																					
^{75}Se	16.																					
^{79}Se	5800.																					
^{90}Sr	780.		<					A									A					
^{90}Sr+D	360.			A													A					
^{88}Y	0.40																					
^{93}Zr	54,000.																					
^{94}Nb	1.4																					
^{99}Tc	500.		A																			
^{106}Ru	10.			A																		
^{110m}Ag	0.55																					
^{113}Sn	310.																					

Table A.5. (contd)

Nuclide	pCi/g	INEL 1	ORNL 2	PNL 3	SNL/A 4	LANL 5	LBL 6	LEHR 7	ITRI 8	GJPO 9	Mound 10	UMTRA 11	KC1 2	SLAC 13	PTX 14	RFP 15	SR 16	LLNL 17	AN L 18	SNL/CA 19	WHC 3a	PNLS 20
^{113}Sn+D	18.																					
^{124}Sb	0.57																					
^{125}Sb	6.3																					
^{125m}Te	220.																					
^{125}I	25.			s																		
^{126}I	5.5																					
^{129}I	1.1			s																		
^{131}I	10.																					
^{134}Cs	1.2																					
^{137}Cs	4.6		<	A		A		A			<						A					
^{144}Ce	430.																					
^{144}Ce+D	25.																					
^{147}Pm	61,000.																			A		
^{151}Sm	130,000.																					
^{152}Eu	1.1																					
^{154}Eu	1.1			A																		
^{155}Eu	160.																					
^{203}Hg	27.																					
^{207}Bi	0.93																			B		
^{226}Ra	93.							A		C	<											
^{226}Ra+D	0.61										<	A										
^{228}Th	25.		A	s							<											
^{229}Th	4.4																					
^{229}Th+D	3.5																					
^{230}Th	30.		C	s						C	<											
^{232}Th	6.8		<	As						C	<											
^{232}Th+D	0.34														A							
^{232}U	12.																					
^{233}U	63.																					
^{234}U	64.		C							C	<											

Table A.5. (contd)

Nuclide	pCi/g	INEL 1	ORNL 2	PNL 3	SNL/A 4	LANL 5	LBL 6	LEHR 7	ITRI 8	GJPO 9	Mound 10	UMTRA 11	KC1 2	SLAC 13	PTX 14	RFP 15	SR 16	LLNL 17	AN L 18	SNL/CA 19	WHC 3a	PNLS 20
^{235}U	35.					A										A						
$^{235}U+D$	34.																					
^{238}U	69.			A		A	C			C	<					A	A			AB		
$^{238}U+D$	50.		A												A							
^{237}Np	13.		A	s																		
$^{237}Np+D$	8.4																					
^{238}Pu	28.			As		A					A						A					
^{239}Pu	25.		<	As		A		A	A		A				A	A						
^{240}Pu	25.			s							A											
^{241}Pu	1500.																					
^{241}Am	12.			As		A										A	A					

8. Is there a breakpoint for numerical control criteria?

   The 18 responses (starting from B, lowest concentration) are widely distributed. At the lowest concentrations, there is concern about analytical capabilities. At moderate concentrations, the actual concentration of waste is considered.

Breakpoint	No. Responses, Sites	Reason
Case B	3 (ANL, PTX, UMTRA)	Analytical
B - A	2 (PNL, LBL)	Waste volume
Case A	3 (INEL, ORNL, SR)	Achievable; method & representative samples
A - C	2 (SNL/A, GJPO)	Waste volume
Case C	1 (RFP)	RFP waste meets criteria
None or unknown	6 (PNLS, SLAC, Mound, SNL/CA, ITRI, LANL)	
Nuclide dependent	1 (LEHR)	Background

9. The consensus among the DOE sites is that eliminating sum of fractions rule for Case B would have very little impact. ORNL indicates only aqueous liquid wastes would benefit; INEL insists that Case B is not generally achievable.

10. The idea of a 2000 pCi/g cutoff seems to have been misinterpreted by some sites as an allowable limit, rather than truncation, for radionuclides with limits greater than 2000 pCi/g.

Impact	No. Responses, Sites	Reason
Unknown	1 LEHR	
None	3 SLAC, Mound, UMTRA	
Little	1 SNL/CA	Most waste contains one radionuclide
Favorable	1 PNLS	
Reduce some	1 ANL E	
Reduce greatly	1 LBL	
Greatest for ^{3}H	1 ITRI	
Eliminate placarded		
(DOT) waste	1 SRS	
Misunderstood?	8 PNL, ORNL, RFP, INEL, GJPO, SNL/A, PTX, LANL	

11. In general, the 500 ppm limit for U and Th would have a small effect:

Impact	No. Responses, Sites
Unknown	2 LEHR, RFP
Little or None	11 SLAC, PNL, ORNL, LBL (cases A, B) , INEL, Mound, UMTRA, ITRI, LANL, ANL E, SRS
Misunderstood?	4 PTX, GJPO, SNL/CA (little impact unless materials reclassified as waste), SNL/A

Description of Tables A.4 and A.5

Table A.4 provides a summary of responses to Question 7 by DOE site. Table A.5 lists all radionuclides, and in one column for each DOE site, indicates potential radionuclides in LLW and hazardous wastes. Predominant nuclides potentially present in RCRA waste are shown.

Key to Table A.5, response by DOE site:

C If a radionuclide may be in waste from the facility (according to the response to question 1; in either hazardous or low level waste), the entry is highlighted (with REDLINE,).

C The predominant radionuclides for each facility (according to question 7) are noted by characters "A", "B" or "C", representing the case for which they are predominant radionuclides in the potentially "nonradioactive" RCRA waste stream. (In most cases, predominant nuclides in case A are predominant in other cases; in such cases, only A is noted.)

C Bold type "**A**" is used to show where different techniques must be used to meet Case A criteria for the predominant radionuclides.

C When the Table A value for nuclides which may potentially be found in waste streams is less than the detection limit, the symbol "< " is given; when specific (matrix related) exceptions to ability to detect are noted, the symbol "s " is given.

C Notes for specific DOE sites:

- NEL: Predominant radionuclides not indicated for question 7

- ORNL: Most waste is between levels A and C; does not include in-place environmental restoration or decommissioning wastes

- PNL: Specific exceptions to DL noted by s; denotes exception to detection level in a particular matrix.

- SNL/A (NM): Response to question 7 given only through ^{152}Eu; other page of table is missing.

- LANL: Waste streams are dominated by low-energy beta emitters and/or alpha emitters; determination of content would require far more analyses by liquid scintillation and /or alpha spectroscopy

- LEHR: Some radionuclides potentially occurring in waste streams are not summarized in Table A.1.

- KC: Question 7 was deemed not applicable by KCP.

- SR: Waste may include fission products, activation products, tritium Pu, Np, Cm, Am, Cf, and other actinides not specifically identified on the summary.

- LLNL: Information was not in the specified format, and predominant radionuclides were not identified as such. Nuclides other than those noted may be present.

- PNLS: Tritium only.

- WHC (Hanford): Response not available

- ETEC: No response given

- NTS: Information not available.

- No specific comments are given for LBL, ITRI, GJPO, MOUND, UMTRA, SLAC, PTX, RFP, ANL, and SNL/CA.

Appendix B

Development of Generic Waste Inventory

Appendix B

Development of Generic Waste Inventory

To determine the potential applicability of RCC, it was necessary to define the low-level mixed waste (LLMW) inventory that meets each set of RCC. A DOE data call requesting information from DOE sites was conducted by DOE-EM and DOE-EH (see Appendix A). However, results indicated that the inventory information from many sites was not detailed enough to readily provide the information required to define the inventory that meets values for RCC. Therefore, the survey responses and information available in the Condensed Mixed Waste Inventory Report (CMWIR) (DOE 1995) were used to define the generic waste mix. This appendix details how information from CMWIR was used to define waste volumes by matrix (physical form) and RCC level for this study.

The CMWIR was used to approximate the quantity of LLMW for each site and for each waste form that met the RCC at different levels (Cases A and C in the data call). Some of the waste was excluded because its radionuclide concentration was higher than RCC Level 3 (Case C) and, thus, were outside the bounds of where RCC are to be applied. The RCC Level 1 (Case B) concentrations were not evaluated because the volume that was predicted from the survey responses to meet the Level 1 criteria was small for the effort required. Instead, one-quarter of the RCC Level 2 quantity (about 10% of the total quantity of LLMW) was assumed to meet Level 1 criteria. The generic LLMW was evaluated by indicating the volumes that contained radionuclide concentrations below Level 2 (Case A), concentrations above Level 2 but below Level 3 (Case C), and above Level 3 (excluded).

B.1 Defining the Generic Inventory

The relative mix of waste forms varies from site to site in the DOE complex. Site-specific inventory information from the CMWIR (DOE 1995), for both stored LLMW and 5-year projections (post-1993), was compiled to develop the generic DOE inventory. The waste data source contained total stored LLMW as of 1992, and projected generation from 1993 through 1997. For the cost analysis, stored waste as of 1995 was defined as the 1992 storage total, plus three years of estimated "annual" generation. Annual generation is defined as the average yearly generation (projected 1993-1997 total divided by 5). It was assumed that processing stored waste would take 5 years to complete, and that this "catching up" with the backlog would be done in parallel to the processing of the projected waste generated during the 5 years.

A flowchart indicating how data from the CMWIR was evaluated is given in Figure B.1. This figure illustrates the logic used to determine the quantity of waste allocated to each RCC level. The boxes in the flowchart represent data sets; the arrows labeled A, B, C and D represent processes performed on the data such as sorting or evaluating categories.

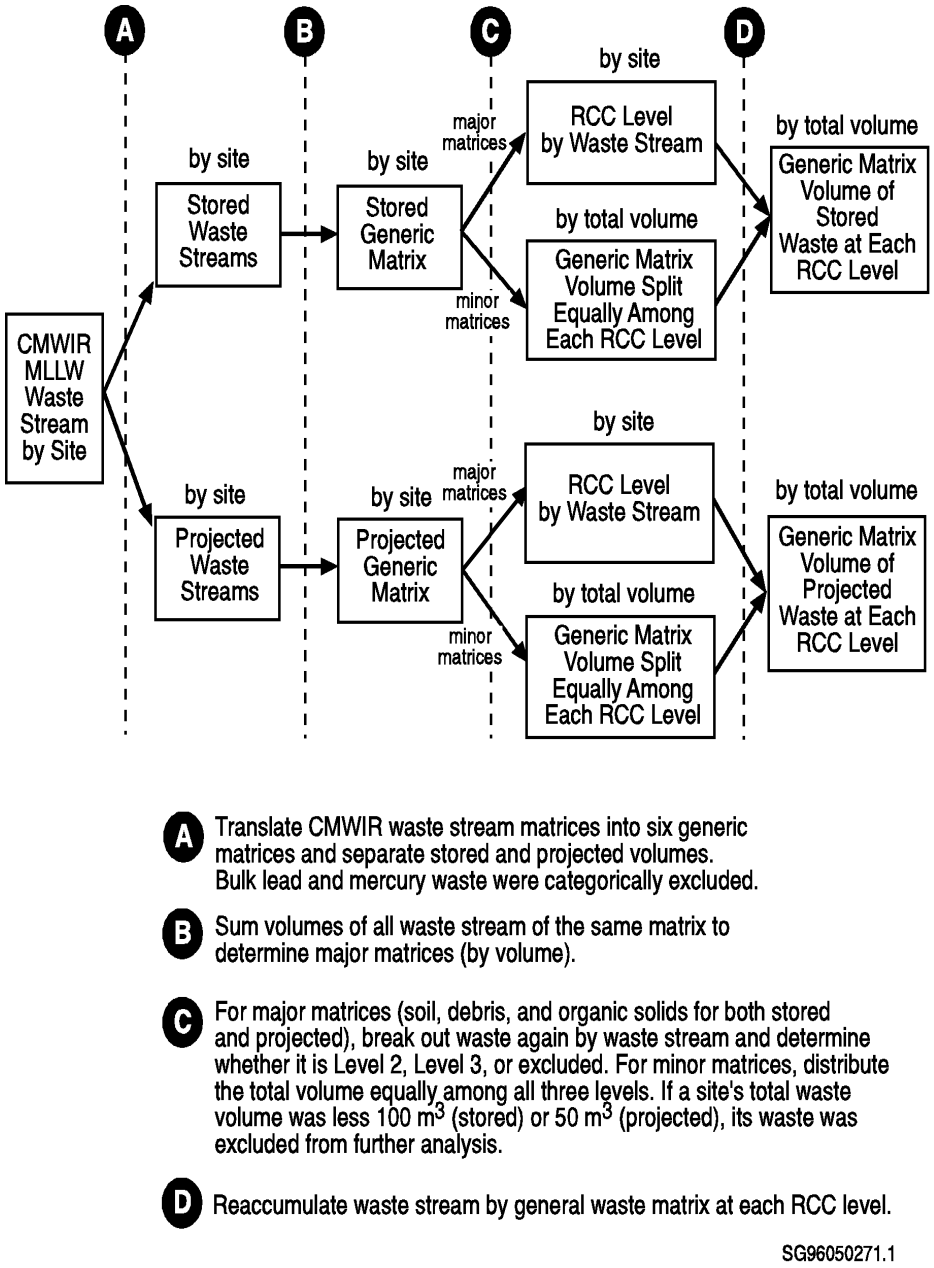

Figure B.1. Use of CMWIR in Assessing Generic Waste Matrix by RCC Level

In process A in Figure B.1, waste stream matrices are defined as one of six generic matrices with separate stored and projected volumes. Bulk lead and mercury waste are categorically excluded. In process B, the volumes of all waste streams were summed to determine which physical forms were the most important. In process C, generic composition was restricted to the LLMW that appeared to be a candidate for RCC consideration. For example, wastes included in the CMWIR which were obviously not potential RCC candidates due to their known high contamination levels were not considered in the development of the generic mix of waste forms. These processes comprised the first-level screening of CMWIR data.

There are, however, some limitations to this data: waste from environmental restoration (ER) is not included, and decontamination and decommissioning (D&D) waste is incomplete. As a consequence, projected quantities of soil and debris may be understated.

The composition of generic stored and projected DOE LLMW, as determined by the above methodology, is shown in Table B.1.

Table B.1. Composition of Generic DOE LLMW Eligible Potentially for RCC Consideration

Physical Form	Stored	Projected
Organic liquid	0.02	0.05
Aqueous liquid	0.01	0.02
Organic solid	0.23	0.26
Inorganic solid	0.03	0.08
Soil	0.34	0.16
Debris	0.37	0.43

The following observations can be made concerning the origin of waste, based on information in the CMWIR (DOE 1995):

- Three sites generated 81% of the stored generic waste: Oak Ridge (43%), Middlesex (NJ) Municipal Landfill (28%), and Portsmouth (10%).

- Soil and debris make up the bulk of the stored waste. The soil comes primarily from Middlesex (82%). The debris comes primarily from Oak Ridge (68%) and Idaho National Engineering and Environmental Laboratory (INEEL) (16%). Organic solids, also a significant contributor to the stored waste composition, originate primarily from Oak Ridge (71%) and Portsmouth (16%).

The major types of the generic projected LLMW are the same as the stored waste: debris, soil, and organic solids. However, a greater volume of the projected waste is expected to be debris. Seventy-seven percent of the future waste volume is expected to originate from four sites: Portsmouth (39%), Savannah River (17%), Argonne-East (11%), and Hanford (10%). Most of the debris will originate from Portsmouth (53%), Savannah River (18%), and Hanford (12%). Major contributors to the LLMW soil volume will include Argonne-East (64%) and Energy Technology Engineering Center (25%). The majority of organic solids are expected from Portsmouth (50%), Hanford (15%), and Savannah River (13%) (DOE 1995).

B.2 Determining Volumes Corresponding to Alternative RCC Levels

The quantity of waste qualifying for treatment under various RCC levels is a key part of the analysis. A second level of screening, shown as process D in Figure B.1, was conducted to determine the volume of the total LLMW inventory that meets each set of RCC. This second level screening was difficult to accomplish in a straightforward fashion.

The CMWIR was used to approximate 1) the quantity of LLMW at each site meeting the RCC at different levels (Case A and Case C in the data call), and 2) the volume that was excluded because its radionuclide concentration was higher than Level 3 (Case C). The Level 1 (Case B) concentrations were not evaluated because the volume that was predicted from the responses from the data call to meet the Level 1 criteria was small with respect to the effort required. The generic LLMW was evaluated by indicating the volumes that contained radionuclide concentrations below Level 2 (Case A), those above Level 2 but below Level 3 (Case C), and those above Level 3 (excluded). The total volume of waste meeting Level 3 criteria is the sum of the indicated Level 2 plus Level 3 volumes.

The evaluation of the approximate LLMW inventory at each RCC level was done on a site-specific and matrix-specific basis. The sites that contributed the greatest volumes to the generic LLMW inventories are shown in Tables B.2 and B.3. A contribution cutoff point of 100 m^3 was used for the stored LLMW, and 50 m^3 was used for the projected LLMW volume. These cutoff points contain the sites that account for greater than 97% of the complex-wide volume of each matrix. Comments concerning the data follow the tables.

Only the matrices that comprised the majority of the waste volume were investigated in more detail. These matrices include the debris, soil, and organic solids for both the stored and projected wastes. The site-specific LLMW that is a major contributor (greater than or equal to 15%) to the debris, soil, or organic liquid matrices is shown in Table B.4.

Evaluating the RCC levels of the matrix volumes from specific sites involved a review of the CMWIR data for information on the various waste batches that make up the matrix. The LLMW included in the waste matrix from a site may be composed of one or more batches. The batches from some sites were easily evaluated. Others required a review of the survey results and some judgment. Difficulties encountered with the evaluation and how they were resolved are included in Sections B.3 and B.4.

Table B.2. Major Contributors to Stored LLMW by Waste Form

Site	Fraction of Complex-Wide LLMW Volume Found at Each Site[a], Divided by Waste Form						Total Volume, m^3	Fraction of Total DOE Volume
	OL	AL	OS	IS	S	D		
All							88,309	
Oak Ridge K-25 Site[b]	0.10	0.38	**0.47**[c]	0.13	0.00	**0.49**	26,474	0.30
Middlesex Sampling Plant	0.00	0.00	0.00	0.00	**0.82**	0.00	24,480	0.28
Oak Ridge Y-12 Plant	0.17	0.01	**0.24**	0.01	0.02	**0.19**	11,905	0.13
Portsmouth Gaseous Diffusion Plant	0.13	0.07	**0.16**	0.05	0.14	0.01	8,420	0.10
Idaho National Engineering and Environmental Laboratory	0.01	0.15	0.06	0.03	0.00	**0.16**	6,724	0.08
Savannah River Site	0.04	0.07	0.02	0.49	0.00	0.09	4,737	0.05
Fernald Environmental Management Project	0.09	0.08	0.01	0.15	0.00	0.00	937	0.01
Weldon Spring Site	0.03	0.02	0.00	0.02	0.00	0.02	888	0.01
Rocky Flats Plant	0.08	0.04	0.02	0.00	0.00	0.01	830	0.01
Energy Technology Engineering Center	0.00	0.00	0.00	0.00	0.02	0.00	619	0.01
Los Alamos National Laboratory	0.05	0.04	0.00	0.00	0.00	0.01	491	0.01
Paducah Gaseous Diffusion Plant	0.16	0.04	0.00	0.02	0.00	0.00	458	0.01
Oak Ridge National Laboratory	0.06	0.00	0.00	0.05	0.00	0.00	318	0.00
Hanford Site	0.00	0.00	0.00	0.00	0.00	0.01	219	0.00
Lawrence Livermore National Laboratory	0.03	0.05	0.00	0.00	0.00	0.00	172	0.00
Pantex Plant	0.00	0.00	0.00	0.01	0.00	0.00	133	0.00
Total	0.96	0.96	0.99	0.97	1.00	1.00		

(a) OL = organic liquid, AL = aqueous liquid, OS = organic solid, IS = inorganic solid, S = soil, D = debris.
(b) Oak Ridge sites (K-25, Y-12, and ORNL) are listed separately.
(c) **Bold** font indicates a major contributor (>15%) to a major matrix of the generic DOE LLMW.

Table B.3. Major Contributors to 5-year Projected LLMW by Waste Form

Site	Fraction of Complex-Wide LLMW Volume Found at Each Site[a], Divided by Waste Form						Total Volume, m^3	Fraction of Total DOE Volume
	OL	AL	OS	IS	S	D		
All							15,045	
Portsmouth Gaseous Diffusion Plant	0.27	0.21	**0.50**[b]	0.12	0.04	**0.53**	5,874	0.39
Savannah River Site	0.01	0.00	0.13	0.69	0.00	**0.18**	2,514	0.17
Argonne National Lab-East	0.00	0.00	0.00	0.00	**0.64**	0.01	1,629	0.11
Hanford Site	0.00	0.00	**0.15**	0.00	0.04	0.12	1,467	0.10
Lawrence Livermore National Laboratory	0.41	0.56	0.01	0.03	0.01	0.05	860	0.06
Rocky Flats Plant	0.00	0.06	0.08	0.04	0.00	0.06	762	0.05
Energy Technology	0.00	0.00	0.00	0.00	**0.25**	0.00	600	0.04
Pantex Plant	0.01	0.00	0.07	0.01	0.00	0.01	342	0.02
Idaho National Engineering and Environmental Laboratory	0.00	0.01	0.00	0.07	0.00	0.03	277	0.02
Los Alamos National Laboratory	0.18	0.14	0.01	0.00	0.00	0.01	274	0.02
Lawrence Berkeley Laboratory	0.00	0.00	0.04	0.00	0.00	0.00	150	0.01
Sandia National Laboratory	0.09	0.00	0.00	0.00	0.00	0.00	73	0.00
Total	0.98	0.98	0.98	0.97	0.98	0.99		

(a) OL = organic liquid, AL = aqueous liquid, OS = organic solid, IS = inorganic solid, S = soil, D = debris
(b) **Bold** font indicates a major contributor (>15%) to a major matrix of the generic DOE LLMW.

After the RCC levels were determined, the volumes of each of the major matrices were evaluated. The evaluation of the minor matrices that make up the generic LLMW was done by dividing the total volume equally among each of the three levels (2, 3, and excluded). The final results are indicated in Table B.4.

B.3 Status of Stored Waste

Status of debris at Oak Ridge National Laboratory (ORNL) and INEEL and organic solids at ORNL and Portsmouth are noteworthy for their assignments of RCC levels:

- ORNL debris - Most of the waste is from B/C pond remediation. Activity levels are not known. The survey results indicate a large volume of Oak Ridge waste meets Level 3 and ~10% of the Level 3 quantity meets Level 2. It was decided to assign all the debris waste to Level 3.

Table B.4. Volumes of Generic LLMW at each RCC Level (Footnotes indicate the manner in which batches of LLMW within the matrix are apportioned.)

Stored RCC	Debris[a]	Soil[b]	Organic Solid[c]	Inorganic Solid[d]	Organic Liquid[d]	Aqueous Liquid[d]
Level 2	1,739	26,232	1,764	883	663	257
Level 3	29,031	1,752	14,721	883	663	257
Excluded	1,739	1,752	4,172	883	663	257
Total	32,509	29,736	20,657	2649	1989	771
Projected RCC	**Debris**	**Soil**	**Organic Solid**	**Inorganic Solid**	**Organic Liquid**	**Aqueous Liquid**
Level 2	904	115	1056	407	225	112
Level 3	908	1615	566	407	225	112
Excluded	4710	715	2223	407	225	112
Total	6522	2445	3845	1221	675	336

(a) Large contributors designated Level 3 and the remaining volume equally apportioned among the three levels.
(b) Middlesex volume assigned Level 2 and the remaining volume equally apportioned among the three levels.
(c) Excluded Portsmouth volume, most of ORNL designated Level 3 but some designated Level 2; the remainder equally apportioned among the three levels.
(d) These small-volume matrices equally apportioned among the three levels.
(e) All large-volume contributors excluded because of uncertainty in the radionuclide concentrations, except for Portsmouth light bulbs (assigned Level 2) and Savannah River vitrified waste (assigned Level 3); the remaining volume equally apportioned among the three levels.
(f) Portsmouth waste excluded because of uncertainty in radionuclide concentrations; Savannah River assigned Level 2; Hanford lab packs and all remaining volume equally apportioned among the three levels.
(g) Argonne-East waste assigned to Level 3 and ETEC waste excluded because of uncertainty in radionuclide concentrations; the remaining volume equally apportioned among the three levels.

- INEEL debris - This waste is miscellaneous debris (e.g., office furniture, equipment). The reported contamination levels hover around Level 3. The batch was assigned Level 3.

- ORNL organic solids - Consists of more B/C pond remediation waste and a small and a large batch of wastewater treatment sludge. No activity levels reported. Again, to reflect the ORNL survey results, the B/C pond and the larger wastewater sludge volume was assigned Level 3. The smaller wastewater sludge was assigned Level 2.

- Portsmouth organic solids - Consists of a batch of lab waste that is suspected to contain a broad range of activity levels. No activity information was provided in CMWIR. Because of the expectation of a wide range of activities, the waste was excluded.

B.4 Assignment of RCC Levels for Projected Waste

The assignment of RCC levels for projected waste is noteworthy for the following sites and waste types:

- Argonne East soil - Appears to have TRU and U/Th in nCi/g levels and, therefore, suspected to be above Level 3 levels. It was excluded from consideration.

- ETEC soil - Very little detail on the waste stream; therefore, it was excluded.

- Oak Ridge sites - The only projected waste listed in the CMWIR for Oak Ridge sites was remotely handled aqueous waste, which was excluded. Oak Ridge would, however, be expected to generate some RCC waste.

- Portsmouth debris - Consists of a large batch of ER debris from an old storage area and a smaller batch of light bulbs. No activity information. It was assumed that the light bulbs met Level 2, excluded the ER waste.

- Savannah River debris - Two batches: one of lab coats, booties, rags, labware, etc., and the other of vitrified forms with depleted uranium. No activity information in CMWIR. The lab waste was excluded because it was assumed to contain a broad range of activities, which were assumed to put it over Level 3 levels. For the vitrified forms, Level 3 was assumed. The immobility and low concentration of the depleted uranium in the glass form was assumed to make it acceptable to EPA for disposal in a hazardous waste landfill.

- Hanford debris - Numerous small batches. Available activity information is (essentially) the acceptance criteria for the storage facility. These reported activities are Level 2 and above Level 3 levels. It was decided that the whole Hanford debris contribution would be excluded.

- Portsmouth organic solids - Most is in three batches. There is no activity information and no basis for putting into any level. Therefore, it was excluded from consideration.

- Hanford organic solids - All batches are organic lab packs. Lower activity levels are suspected in such waste. The entire Hanford matrix was divided equally among the three levels (2, 3, and excluded).

Appendix C

Cost-Benefit Analysis Methods

Appendix C

Cost-Benefit Analysis Methods

This appendix describes the methods used to perform the economic and cost-benefit analyses. The definitions, assumptions, and parameters used, and the computations and cost-benefit methodology are discussed.

C.1 Overview

The purpose of this ALARA analysis was to assess and compare the economic and dose impacts to society for continued storage versus three RCC levels chosen as alternatives. A cost-benefit approach was adopted for this study to be consistent with the standard economic method used in most ALARA analyses. ALARA analyses typically change work practices and/or add protective measures.

This analysis deals with a potential change in regulating DOE-owned mixed wastes. The change involves classifying certain LLMW that meets control criteria (RCC levels) as hazardous waste, thus allowing transport, treatment, and disposal of such waste by commercial hazardous waste vendors. This analysis investigates the costs and benefits resulting from implementing alternative levels of control criteria.

C.2 Definitions

Cash-flows

Cash-flows are sums of money tied to particular time periods. Because money has a "time value," the value of a sum of money depends upon when it is given or received. Cash-flows allow for quantitative analyses to be performed on sums of money that span different time periods.

The concepts of time value of money and cash-flows are fundamental to engineering economic analysis. See White et al. (1984) for a complete description of engineering economics.

In this ALARA analysis, cash-flows needed to be computed by year for each cost element and alternative of the analysis. Cash-flows were generically computed by using volumes and units cost factors, as shown in Equation (C.1):

$$\text{cash flow}_{aet} = \text{volume}_{aet} * \text{unit cost factor}_{e} \quad \text{(C.1)}$$

where

cash flow_{aet} = cash flow for alternative (a) of cost element (e) in year (t)

volume_{aet} = volume for alternative (a) of cost element (e) in year (t)

$\text{unit cost factor}_{e}$ = unit cost factor for cost element (e)

The time-phased cash-flows were computed by multiplying the time-phased volumes by the corresponding unit cost factor for the particular cost element analyzed. The cost elements include storage, transportation, treatment, and disposal. Further discussion regarding the cash-flows for each cost element are described in Section C.3.

Discount Rate

The discount rate is used to move constant worth amounts of money (cash-flows) backward and forward in time. In particular, the discount rate was used to compute present worth for each alternative. The real discount factor (independent of inflation) used for the analysis was 3% (OMB 1996).

Present Worth

The present worth method converts all cash-flows to a single sum equivalent at the beginning of the analysis. The alternative with the largest positive present worth is chosen as the most cost-effective comparison. Equation (C.2) gives the formula to compute present worth for each analysis alternative:

$$\text{present worth}_{a} = \sum_{e}\sum_{t} \text{cash flow}_{aet}(1 + i_r)^{-t} \quad \text{(C.2)}$$

where

e / cost element subscript

t / time subscript (in years)

i_r / yearly real discount rate

cash flow_{aet} / cash flow of alternative (a) for cost element (e) in year (t)

C.3 Economic Assumptions

The following assumptions were used to perform this economic analysis.

- The processing costs for waste meeting each RCC level are the same as that for any other commercial hazardous waste. This is the basic assumption that wastes meeting RCCs may be handled the same as any other hazardous waste.

- DOE storage capacities are sufficient for the volumes of waste analyzed in this report. If this assumption is false, incrementally more cost would be assigned to the continued storage option if more capacity was needed, since this option requires the most storage capacity. In addition, credit could be given for reclaimed storage if some level of RCC were implemented, which would make the RCC alternatives more cost-effective.

- The analyzed waste is suitably packaged for transportation and storage by the generators prior to shipment to a commercial TSD. Analysis of the LLMW source data indicates that minor portions of the waste are not packaged. This should be of little consequence in a comparative analysis, since the alternatives that involve both continued storage and treatment of waste meeting RCC require waste to be packaged. Thus, the packaging costs differences between alternatives are canceled. The cost differences for packaging for storage versus packaging for transportation are assumed negligible.

- No repackaging of waste is required for the duration of the study. If this assumption is false, the cost of the continued storage alternative would be underestimated.

- Up-front analytical costs (not included) are of no consequence to the comparative economic analysis. Since DOE will have to perform the analytical work before storage or offsite shipment, the analytical costs will cancel. The only analytical cost included is the periodic analysis of stored waste, which is imbedded in the unit cost for storage.

- DOE storage costs are made up of two components. The first is a one-time fee paid by the generator for adding new waste to the mixed-waste storage system. This fee goes to off-set some of the operating cost occurred in that year. The second cost is the ongoing maintenance and management cost that is paid by DOE-HQ. These two components have different rates. The one-time storage fee was determined by multiplying the newly generated storage volume by the one-time unit storage cost factor. Ongoing storage cost was obtained by multiplying the ongoing storage unit cost factor by the ongoing storage volume. The total storage cost was obtained the summing the two storage cost components.

- The transportation costs for both solid and liquid wastes were computed as follows: A conservative one-way average transport distance was computed for transporting waste from DOE to a suitable commercial hazardous waste treatment and disposal vendor. Each truck is loaded the maximum weight limit. A rate schedule from a transportation company was used to estimate the total cost for shipment. The unit cost factors were determined by using appropriate densities for both solid and liquid waste. The unit cost factors are given in Table C.1. The total transportation cost was obtained by multiplying the transported volume by the unit cost factor for transportation. The derivation of the one-way shipment costs is given in an interim report by M. H. Chew & Associates (Chew 1995).

- Treatment costs were calculated by multiplying the waste volume (in cubic meters) by the unit cost factor for that treatment option. Wastes and their associated volumes were identified as one of six different categories: debris, soils, organic solids, inorganic solids, organic liquids, and aqueous liquids. Treatment options were devised for each of these waste types, as discussed in Section 4.2. Many of the treatment options have more than one treatment process associated with them; intra-treatment volume changes were accounted for with an adjustment factor applicable for each process.

- Disposal costs were calculated by multiplying the disposal volume by the disposal unit cost factor. The disposal volume was the final volume computed from the treatment option.

Table C.1. Treatment Technology Descriptions and Parameters

Waste Matrix	Technology	Unit Cost, $/unit	Assumed Density, kg/m^3	Unit Cost, $/m^3	Unit Cost, $/m^3 (1995)
Organic Solid	Incineration	$400/ton[(a)]	1200	$530/m^3 (1991)	$560.22/ m^3
Soil	Incineration	$400/ton[(a)]	1500	$660/m^3 (1991)	$697.63/ m^3
Debris	Shred/Grout	$220/ton[(b)]	1550	$380/m^3 (1991)	$401.66/ m^3
Organic Liquid	Incineration	$600/55-gal drum[(a)]	1000	$2730/m^3 (1991)	$2885.65/m^3
Incinerator Ash	Stabilization	$200/ton[(a)]	300	$70/m^3 (1991)	$73.99/m^3
Aqueous Liquid	Chemical Oxidation/ Neutralization	$139/55-gal drum[(c)]	1000	$667.63/m^3 (1985)	$788.64/ m^3
Aqueous Liquid	Chemical Precipitation	$116.50/55-gal drum[(c)]	1000	$559.56/m^3 (1985)	$660.98/ m^3
Inorganic Solids	Stabilization	$200/ton[(a)]	1200	$270/m3 (1991)	$285.39/ m^3
Stabilized Waste	Disposal	$77/55-gal drum[(b)]	-	$350 /m3 (1992)	$373.15 /m^3
Liquid	Transportation	$2386 /shipment[(d)]	1000	$124.04 /m^3 (1995)	$124.04 /m^3
Solid	Transportation	$2386 /shipment[(d)]	1500	$186.05 /m^3 (1995)	$186.05 /m^3

(a) The stabilization cost is adjusted to reflect occasional need to shred material.
(b) Chemical Waste Management, Inc., Arlington, OR Treatment Center, Price schedule for September 1, 1992. WesComp, Inc., offers destructive incineration of both solids and liquids.
(c) M. H. Chew & Associates assumes a maximum weight of 42,320 lb/shipment.
(d) Converted M. H. Chew & Associates conservative $2386/shipment cost using assumption in footnote (c) for both liquid and solid waste.

C.4 Parameters

The parameters used in the cost-benefit analysis were the time horizon, the unit cost factors, and the waste volume.

C.4.1 Time Horizon

The time horizon used for this life-cycle analysis was arbitrarily chosen to be 30 years. The time horizon was selected to ensure that enough time was given to show a steady-state condition for waste processing and reflect the cost differences between alternatives.

C.4.2 Unit Cost Factors

Unit cost factors are costs per cubic meter of waste for storage, transportation, treatment, and disposal of waste. This section discusses the development of the unit cost used in this analysis. In addition, it describes the treatment processes used for each waste form: i.e., for organic liquid, aqueous liquid, organic solid, inorganic solid, soil, and debris. Included in this section are the assumptions regarding volumetric changes of waste due to treatment. These changes are given as factors; they are multiplied by the volume to be treated to obtain the resulting volume after treatment. All factors must be considered when determining final volume from a treatment train consisting of two or more processes.

Organic liquids are incinerated, the ash is stabilized, and the stabilized form is then packaged for disposal. Incineration destroys the organic constituents and thus reduces the waste volume. Incineration reduces the volume to 5% of the original volume, and stabilization of the ash increases the ash volume by a factor of 1.43.

The treatment process chosen for *aqueous liquids* is neutralization, followed by precipitation, stabilization of the solids, and packaging for disposal. The neutralization step modifies the pH. Precipitation results in insoluble solid phases, which can be separated from the liquid phase. The solid material is stabilized in preparation for disposal. The volume change due to neutralization is minimal. The assumed precipitation volume is reduced to 75% of the original volume and the stabilization then increases the precipitated volume by a factor of 1.43.

Organic solids and soils are also incinerated to destroy the hazardous organic constituents. The ash is then stabilized and packaged for disposal. The original waste volume decreases to 70% of the original volume through incineration. Stabilization increases the ash volume by a factor of 1.43.

Inorganic solids and debris waste streams are stabilized. The debris treatment unit cost is adjusted to include shredding for a portion of the debris waste. Shredding is used to reduce the volume of the debris before it is stabilized. Stabilization technologies are used to immobilize the inorganic hazardous constituents in the waste such as heavy metals. The stabilization of inorganic solids results in a volume increase of 1.67 times the original volume. For debris, the volume increases by factor of 2. Stabilized volumes are very dependent on the type of waste that is stabilized. A larger waste-to-binder ratio is allowed for homogeneous waste streams such as inorganic solids, compared to heterogeneous streams such as debris.

The treatment cost for disposing of *hazardous waste* is largely determined by the physical matrix of the waste (i.e., soil, debris, organic liquid, etc.). Many unit costs for treatment were taken from "Mixed Waste Management Options" DOE/LLW-134 (Kirner et al. 1991), and were developed for facilities processing comparatively large volumes of waste, generally over thousands of gallons of liquid waste or tons of solid waste. Note that the costs of chemical oxidation/neutralization and chemical precipitation of aqueous liquids were obtained from Hsieh and Erdogan (1988), since the corresponding values in DOE/LLW-134 appear to be low for the treatment of aqueous liquids as described in this document. Table C.1 shows the unit costs and corresponding reference for each treatment technology used.

The densities of waste used to determine a consistent unit cost were determined by examining the waste forms at each of the sites. In most cases, the density of the waste contributing the most to a particular type was used as the "generic" density. Conversions used to obtain the unit costs per cubic meter are given in Table C.2.

Table C.2. Unit Conversions

English Unit	Metric Equivalent
2000 lb	1 ton
2.205 lb	1 kg
264.172 gal	1 m^3
55-gal drum	0.22 m^3
35.31 ft^3	1 m^3

The referenced unit costs given in Table C.1 were converted to 1995 dollars using the Chemical Engineering Plant Cost Index (CEPCI), as shown in Table C.3. Several different indices are available for such conversions. The CEPCI was chosen to represent the hazardous waste treatment sector over any indices found in the construction industry or published by the government. The 1995 index value was the actual CEPCI value reported for the period through July 1995.

For this study, the waste treatment from one source is used for comparability. The incineration costs seem to be high; lower costs are available. A vendor was contacted to verify that the incineration costs were reasonable. The vendor stated that the $400/ton for incineration of solid waste and $600/ton for liquid did not seem unreasonable. The cost depends on the specific type of container used. For waste sent to the vendor's facility, bulk soil would cost around $0.45/lb or $900/ton. This cost includes stabilization of the ash if needed and disposal. Liquids in drums could cost approximately $0.50/lb or $220/ton. Discussions with a vendor indicate that the costs from the above source should be reasonable to use for this study.[(a)]

Table C.3. Index Values for Cost Conversion to 1995 Dollars

Year	CEPCI Value
1995	381.9[(a)]
1992	358.2[(a)]
1991	361.3[(a)]
1985	325.3[(b)]
1984	322.7[(b)]
1982	314.0[(b)]
1979	238.7[(b)]

(a) United States Pollution Control, Inc. (USPCI), Clive Incineration Facility, Grantsville, Utah, December 1995, 801-884-6841.

1978	218.8[(b)]
1977	204.1[(b)]
(a) Chemical Engineering, November 1995, p. 232. (b) Chemical Engineering, March 1988, p. 9.	

The cost to incinerate organic liquids seems high. Other sources used to verify these unit costs are provided in Table C.4. Although these costs are not used in the study, they verify the unit costs used here and aid in the study or are used here in selecting values for sensitivity studies.

Table C.4. Selected Sources for Cost Verification

Waste Matrix	Technology	Unit Cost, $/unit	Assumed Density, kg/m^3	Unit Cost, $/m^3	Unit Cost, $/m^3 (1995)
Organic Liquids	Incineration	$105/55-gal drum[(a)]	--	$408/m^3 (1984)	$483/m^3
Organic Liquids	Incineration	$265/ton[(b)]	1000	$290/m^3 (1978)	$506/m^3
Organic Liquids	Incineration	$0.08/lb[(c)]	1000	$180/m^3 (1979)	$288/m^3
Organic Liquids	Incineration	$425/55 gal drum[(d)]	--	$1930/m^3 (1992)	$2058/m^3
Solid Waste	Incineration	$880/55 gal drum[(d)]	--	$4000/m^3 (1992)	$4265/m^3
Solid Waste	Sanitary Landfill	$0.16/lb[(e)]	~1200	$420/m^3 (1977)	$786/m^3

(a) Hsieh and Erdogan. 1988.
(b) Noyes, *Control of Organic Substances in Water and Wastewater*. 1987. This information provided by the Illinois Institute of Natural Resources, published by USEPA in 1978.
(c) Noyes, *Control of Organic Substances in Water and Wastewater*. 1987. Costs were published by the Manufacturing Chemists Association (MCA) in 1979. The cost excludes pretreatment and transportation.
(d) Chemical Waste Management, Inc. Arlington, OR/Treatment Center. Price Schedule for September 1, 1992. WesComp Inc. offers destructive incineration of both solids and liquids.
(e) Noyes, *Control of Organic Substances in Water and Wastewater*. 1987. Sanitary Landfill costs were published for Allegheny County in Pennsylvania in 1977.

Treatment unit costs are difficult to estimate because of the different variables on which commercial facilities base their costs. Parameters in the cost a commercial facility will charge DOE to treat/dispose of the waste include the type of container in which the waste is packaged, the specific hazardous components of the waste, and the total amount of waste a facility will receive from DOE. For this analysis, all waste is assumed to be packaged in 55-gallon drums. It would cost comparatively less if the waste were sent as bulk waste streams.

C.4.3 Volumes

Waste quantities were derived for each year of the study for each alternative. The waste volume for the continued storage alternative includes the 1995 stored waste, defined as stored waste as of 1992 plus three-fifths of the 1993-1997 projected waste from the CMWIR. The annual rate of accumulation of waste for years 1996 through 2028 was estimated as one-fifth of the five-year (1993-1997) CMWIR projected waste volumes.

Yearly waste volumes were computed by treatment process for each RCC level. Two volumes were computed for each RCC alternative: the volume that met the RCC level which would be treated, and the volume that exceeded the RCC level which would be stored. Table C.5 lists stored and projected waste volumes used. Also included in Table C.5 are the factors used to allocate waste by RCC level (factor times the corresponding volume equals the waste quantity meeting the respective RCC level). As previously mentioned, it was assumed that the 1995 waste backlog would be spread equally over the first 5 years of the study. The stored volume each year by RCC level is the total volume projected minus the treated RCC volume.

C.5 Sensitivity Analyses

Sensitivity analyses were performed to determine the impacts of results or decisions on data and assumptions used in an analysis. Sensitivity can be analyzed by varying one or more parameters at a time. Typically, the results of each sensitivity case are compared with the baseline to determine the impact (if any) on the results from the baseline.

Sensitivity analyses were performed to determine the effects of varying the parameters in question to all of the alternatives and, thus, the final result. Table C.6 shows the major sensitivity cases analyzed, identified by case number, which are discussed in the remainder of this section.

Table C.5. Waste Inventory Volumes and Allocation Factors Used in the RCC Economic Analysis

Category	Factor	Value	Units
Stored Inventory:	Organic Liquids	1,326	m^3, as of 1992
	Aqueous Liquids	514	m^3, as of 1992
	Organic Solids	16,485	m^3, as of 1992
	Inorganic Solids	1,766	m^3, as of 1992
	Soils	27,984	m^3, as of 1992
	Debris	30,770	m^3, as of 1992
Projected Volumes:	Organic Liquids	450	m^3/year, total 1993-1997
	Aqueous Liquids	224	m^3/year, total 1993-1997
	Organic Solids	1,622	m^3/year, total 1993-1997
	Inorganic Solids	814	m^3/year, total 1993-1997
	Soils	1,730	m^3/year, total 1993-1997
	Debris	1,812	m^3/year, total 1993-1997
Allocation Factors:	Level 1 - 0.01 mrem	10%	estimated fraction that meets RCC level
	Level 2 - 1 mrem	40%	estimated fraction that meets RCC level
	Level 3 - 20 mrem	100%	estimated fraction that meets RCC

The parameter that sets the basis for comparison between each alternative is the storage cost. Storage cost has been modeled as two components: first-time charges and annual charges. A one-time fee is charged for waste which does not meet a particular RCC level as it enters waste management operations in the first year. This fee helps offset the cost of operations for that year. Once that waste has been accepted, an ongoing storage fee is charged for each additional year.

Case 1. The baseline (case 1) gives the most likely estimate of the comparative economic analyses performed. It consists of the best estimates of all of the cost factors, volumes, economic rates, and hazardous waste allocation fractions for each RCC Level. See Section 7.0 for a discussion of the results for the baseline case.

Case 2. In the first sensitivity case (2), the one-time fee was set to $0 per cubic meter; the break-even point (where the present worth is the same for continued storage and one or more alternatives) is approximately $76 per cubic meter. A cost of $76 per cubic meter is approximately equivalent to the cost of ash stabilization and one-tenth the estimated cost for ongoing storage. This combination of storage values was considered to be too low to represent a possible scenario that would change the results found in the baseline case.

Table C.6. Economic Sensitivity Cases

Sensitivity Case/ Description	Present Worth of Alternative, $ millions			
	Storage	Level 1	Level 2	Level 3
Case 1: Baseline (One-Time $4246, Ongoing $828)	1,800	1,600	1,200	270
Case 2: Storage: $0 One-Time, $76 Ongoing, Break-even	1,800	1,600	1,200	270
Case 3: Storage: $0 Ongoing, $5100 One-Time, Break-even	140	140	140	140
Case 4: Storage: 8.50% of Both Costs, Break-even	150	150	150	150
Case 5: Cost Factor of 12 Excluding Storage, Break-even	1,800	1,600	1,200	270
Case 6: Rate: 10% Discount	1,800	1,600	1,200	270
Case 7: Volume: 10% of Original	180	160	120	27
Case 8: Volume: 200% of Original	3,500	3,200	2,300	540
Case 9: Volume: 10% of Soil & Debris	870	790	560	120
Case 10: Volume: 400% of Soil & Debris	4,700	4,300	3,100	770

Case 3. Alternatively, in Case 3 the ongoing costs were set to $0 per cubic meter, and the one-time break-even cost was determined to be approximately $5100 per cubic meter. At these values, the Level 3 alternative became more expensive than continued storage. Again, this combination of storage values was considered to be too low to realistically represent a credible scenario, since the estimated baseline ongoing storage cost is estimated at $828 per cubic meter per year.

Case 4. A final storage-cost sensitivity case (4) included a reduction of both storage cost factors by the same percentage to find the break-even point. This showed that if both storage costs were reduced to approximately 8.5% of the baseline values, Level 3 would begin to be more costly than continued storage. These values also appear to be too low to be considered credible. It is concluded that the storage sensitivity cases are unrealistic.

Case 5. The next set of parameters analyzed was the other nonstorage cost factors, which were changed as a group in Case 5. For the alternative of treatment of the RCC Level 1 waste, the nonstorage cost factors must be multiplied by a factor of 12 to be as costly as continued storage. This means that the baseline factors must be over an order of magnitude low before storage becomes more economically attractive than Level 1. It is highly unlikely that the baseline cost factors would be that low, based on the reference cost data.

Case 6. Case 6 analyzed the discount rate. The discount rate was changed from its baseline value to 10%. In this case, the storage alternative was still the most costly.

Case 7 - 10. Finally, the storage and projected volumes were changed as a group with the same percentage, for Cases 7 through 10. In Cases 7 and 9, the volume of all waste and the volume of soil and debris waste were changed to 10% of the baseline values, respectively. For both of these cases, the storage option continued to be the most expensive alternative. In Case 8, the volume of waste was

increased to 200% of the baseline case. In Case 10, the volume of the soils and debris volumes were increased by 400% of the baseline. Continued storage remained the most expensive alternative.

C.6 Cost-Benefit Analysis

The basic cost-benefit analysis employed here depicts costs and savings to the government associated with obtaining benefits and the associated *dis-benefits* (or disadvantages) occurring to society for various alternatives analyzed. Costs and savings to the government are compared against benefits and dis-benefits to society measured in comparable dollars. When the benefits and disadvantages cannot be estimated in dollars, they are assessed as qualitative factors (see Section 6.0).

In this study, costs are associated with transportation, treatment, and disposal of waste meeting the RCC levels. Savings are associated with reduced storage costs of waste meeting the RCC levels. The benefit is reduced collective dose. The intangible factors include worker and transportation safety, regulatory feasibility, ecological and natural resource impacts, and public perceptions.

C.7 References

Hsieh, H., and Erdogan, H. 1988. "Cost Estimates for Several Hazardous Waste Disposal Options," *Hazardous Waste & Hazardous Materials* 5 (4).

Kirner, N., G. Faison, and C. Owens. 1991. *Mixed Waste Management Options*. DOE/LLW-134, U.S. Department of Energy, Washington, DC.

M. H. Chew and Associates. 1995. *Waste Volume Projections and Disposal Costs Associated with Changing Discrimination Levels*, Interim Report. Prepared for U.S. DOE Office of Waste Management, M. H. Chew and Associates, Inc.

Office of Management and the Budget (OMB). 1996. Circular No. A-94, Appendix C, February 6, 1996 [http:// www.whitehouse.gov/WH/EOP/OMB/html/circulars/a094.html].

U.S. Department of Energy (DOE). 1995. *Condensed Mixed Waste Inventory Report* (CMWIR), database. (Accessed from Internet, August 1995.)

White, J. A., M. H. Agee, and K. E. Case. 1984. *Principles of Engineering Economic Analysis.* 2nd ed. John Wiley & Sons, New York.

Appendix D

Dose Calculation Methods

Appendix D

Dose Calculation Methods

RCC limiting concentrations used as a basis for this analysis were derived from individual doses to TSD workers and the offsite MEI from airborne pathways. In this appendix, the calculation of collective dose is described for three groups of receptors: DOE workers onsite at mixed waste storage facilities, TSD workers, and members of the general public offsite. In addition, sensitivity of cumulative collective dose to certain radionuclide inventory, waste quantity, and scenario parameters were evaluated.

Dose factors and scenario assumptions are taken from Aaberg et al. (1995), and a spreadsheet was used to perform the dose calculations. The annual and cumulative doses, based on waste quantities and categorization (as RCC Levels 1, 2, or 3), are derived from mixed waste inventory information for both currently stored and projected wastes.

D.1 Cumulative Waste Quantities

The cumulative quantity of waste stored or processed (Table 4.2) at each RCC level is used as a basis for life-cycle comparisons. For ease of accounting, calculations are performed separately for currently stored and projected waste. The cumulative quantity of stored waste is in terms of the amount stored, integrated over the 30-year study period (units of ton-yr). Projected waste continues to be accumulated annually and is stored for the remainder of the period. The integrated waste quantity accounts for storage and maintenance of the same waste for multiple years.

D.1.1 Waste Storage

In the continued storage alternative, the storage of all waste (quantity *S* tons) continues throughout the analysis period, and projected waste (quantity *P* tons) accumulates annually. The waste quantities are divided into three RCC levels, designated as L1, L2, and L3. The parameter of interest is cumulative stored quantity, in terms of ton-yr. For stored waste, this is defined as:

$$S_{Ln} \ (\ T \ ' \ 30S_{Ln} \ ton\&yr \qquad (D.1)$$

where S_{Ln} is the quantity of stored waste meeting Level *n,* in tons, and T is the duration of storage assumed for the analysis, 30 years.

For waste accumulated throughout the analysis period, the waste received in the first year is stored for 30 years; the second batch, 29 years, and so on. The cumulative quantity of projected waste is defined as:

$$P_{Ln} \ x \ T \ \% \ P_{Ln} \ x \ (T\&1) \ \% \ P_{Ln} \ x \ (T\&2) \ \%... \ \% \ P_{Ln} \ x \ 1 \ ' \ P_{Ln} \ x \ 465 \ ton\&yr \qquad (D.2)$$

where P_{Ln} is the quantity of projected waste meeting Level *n,* in tons.

For RCC waste treatment alternatives, continued storage is necessary during the 5-year period when the backlog of stored waste is processed. The quantity of waste meeting the RCC which would be in storage would be 4/5 after the first year, 3/5 the second, 2/5 after the third, and 1/5 after the fourth. The integrated waste quantity in storage is defined by:

$$(4/5 \ \% \ 3/5 \ \% \ 2/5 \ \% \ 1/5) \ x \ S_{Ln} \ ' \ 2 \ x \ S_{Ln} \ \text{ton\&yr} \qquad \text{(D.3)}$$

For waste treatment alternatives that call for treatment of waste meeting only RCC Levels 1 or 2, some of the waste inventory (RCC Level 3 or Levels 2 and 3) would require long-term storage. The quantity of waste not meeting RCCs would be stored similar to the continued storage alternative. Wastes containing activity at a level greater than RCC Level 3 are excluded from the analysis. Table D.1 summarizes the integrated cumulative mass of waste (ton-yr) requiring storage for each RCC level.

D.1.2 Waste Treatment Alternatives

For the alternatives, the quantity of waste treated is a function of the RCC level, as shown in Table D.2. Waste not meeting the RCC criteria would be stored, as in the continued storage alternative. Waste that meets the chosen RCC level (units of tons) is counted only at the time it is processed.

Table D.1. Cumulative Stored Quantity of Waste, ton-yr

Waste Quantity	Continued Storage	Level 1	Level 2	Level 3
Stored	$30(S_{L1}+S_{L2}+S_{L3})$	$2S_{L1}+30(S_{L2}+S_{L3})$	$2(S_{L1}+S_{L2})+30S_{L3}$	$2(S_{L1}+S_{L2}+S_{L3})$
Projected	$465(P_{L1}+P_{L2}+P_{L3})$	$465(P_{L2}+P_{L3})$	$465(P_{L3})$	No Storage

Table D.2. Cumulative Quantity of Waste Requiring Treatment, tons

Waste Quantity	Level 1	Level 2	Level 3
Stored	S_{L1}	$S_{L1}+S_{L2}$	$S_{L1}+S_{L2}+S_{L3}$
Projected	$30\ P_{L1}$	$30(P_{L1}+P_{L2})$	$30(P_{L1}+P_{L2}+P_{L3})$

D.2 Cumulative Dose Estimates

It is assumed that regardless of the chosen RCC level, the backlog of stored waste meeting the RCC level for the alternative would be treated over a 5-year period, and projected waste would be treated in the year generated. It is assumed that the maximally exposed TSD worker would receive the RCC dose limit if all the waste treated by the facility met that RCC level (e.g., 1 mrem if all waste met RCC Level 2).

The bounding value of collective dose to the workers at a TSD facility is assumed to be the product of the throughput of RCC waste, the RCC dose limit, and the labor requirement of the facility, from Table D.3:

$$CDose_{Ln,k} \text{ ' } Labor_k \text{ x } (S_{Ln,k} \text{ \% } P_{Ln,}) \text{ x } Dose_{Ln} \quad \text{(D.4)}$$

where

$CDose_{Ln,k}$ = the collective dose for RCC Level *n*, facility *k*, person-rem
$Labor_k$ = the labor requirement for facility *k*, FTE/ton
$S_{ln,k}+P_{Ln,k}$ = quantity of stored plus projected waste meeting Level *n*, tons
$Dose_{Ln}$ = the RCC individual dose limit, rem/yr.

Table D.3. Labor Requirements for Waste Treatment Processes

Process or Activity	Capacity, ton/yr	Operating Labor, FTE/ton[(a)]
Incineration	30,000	3.0E-3
Shred/grout	15,000	3.0E-3
Stabilization	15,000	2.0E-3
Neutralization	50,000	1.0E-3
Landfill	150,000	1.0E-3
Transport	1,600 to 9,500	1E-4 to 6E-4[(b)]
Storage	5,500	2E-3[(c)]

(a) FTE, or full-time equivalent, represents a person-year of labor, at 2000 hours per year.
(b) FTE/ton transported; based on 0.5 to 3 d/load, 250 d/yr at 19.2 ton/load.
(c) FTE/ton/yr stored; 12 FTE/ 25,000 drums x drum/ 0.22 ton.

D.3 Radiation Worker Dose

The dose to workers at DOE mixed waste storage facilities was not addressed in Aaberg et al. (1995). It is included here to provide a full comparison of the collective cumulative dose from continued storage and commercial treatment of low-level mixed waste (LLMW) at various RCC levels.

The bounding collective dose for storage of RCC Level *n* waste, based on the maximum individual dose for Level *n* (without decay) applied to all storage workers, is calculated as follows:

$$CDose_{Max} = Q_{Ln} \times Labor_s \times Dose_{Ln} \quad (D.5)$$

where

$CDose_{Max}$ = the collective dose for storage workers, person-rem, (or FTE-rem) based on the maximum individual dose for each worker

Q_{Ln} = the cumulative quantity of Level *n* waste stored (functions of S_{Ln} and P_{Ln} from Table D.1), ton-yr

$Labor_s$ = the labor requirement for storage, 2 x 10^{-3} FTE/ton (from Table D.3)

$Dose_{Ln}$ = the RCC limiting dose at Level *n* (1E-5, 1E-3, 0.02 rem/yr).

The labor requirement for mixed waste storage used in this analysis is based on Westinghouse Hanford Company (WHC) mixed waste storage facility operating personnel (10 or 11 operators, plus 1 team leader) for storage of about 25,000 drums (equivalent) mixed waste.[(a)]

Modifications to Equation D.5 (the upper bound for dose to storage worker) are necessary to assess the impact of radioactive decay and differences in exposure scenarios for storage workers as opposed to TSD workers. Maximum or bounding doses are calculated, based on RCC limiting concentrations without radioactive decay. Reduction factors are used to adjust for decay during storage for both the backlog and annual accumulation of waste. For long-term storage of waste, the adjustment for decay of the source term is essential. The adjustment made for radioactive decay for stored waste is as follows:

$$DecayF_{S,j} = \frac{1 - e^{-\lambda_j T}}{\lambda_j T} \quad (D.6)$$

where

$DecayF_{S,j}$ = the integrated fraction of activity of radionuclide *j* present in the storage facility (dimensionless)

λ_j = the decay constant for radionuclide *j,* yr^{-1}T=the analysis period, 30 years.

T = the analysis period, 30 years.

The adjustment for radioactive decay for projected waste is calculated as follows, based on a constant receipt of projected waste:

(a) Conversation with Paul Crane, WHC (Organization PSS/SWD) on November 17, 1995 (509/373-4585).

$$\text{DecayF}_{P,j} = \frac{1/(\lambda_j t)\ (1-e^{-\lambda_j t})}{\sum_{t-1}^{t-T} t} \qquad \text{(D.7)}$$

where

$\text{DecayF}_{P,j}$ = the integrated fraction of activity of radionuclide *j* from projected wastes received annually by the storage facility, and other terms as defined above.

Projected waste that does not meet the chosen RCC is assumed to be stored from the time it is generated until the end of the study period (e.g., waste generated in year 10 will be stored for another 20 years).

External exposure is taken to be the only exposure pathway because waste is assumed to be packaged in non-leaking containers. The fraction of the RCC limiting dose received by a TSD worker which results from external dose is used in the calculation of dose to storage workers. This fraction was derived from the TSD scenario for landfill workers (Aaberg et al. 1995) and the RCC limiting concentration. The landfill scenario was used because it involved the greatest component of external dose of all the scenarios considered. The external dose fraction is calculated as follows:

$$\text{Fr}_{\text{ext(j)}} = \left(\text{DF}_j \times C_{L2(j)} \times \text{FT}\right) / \text{Dose}_{L2} \qquad \text{(D.8)}$$

where

$\text{Fr}_{\text{ext(j)}}$ = the fraction external dose from radionuclide *j*

Df_j = is the unit dose factor for radionuclide *j*, mrem/h per Ci/m^3 (from Aaberg et al. 1995)

$C_{L2(j)}$ = the concentration radionuclide *j* for waste at RCC Level 2, Ci/m^3

FT = full-time working hours, 2000 h/yr

Dose_{L2} = the RCC limiting dose for Level 2, 1 mrem/yr.

The concentration and dose limits used in Equation D.8 above are based on Level 2 for convenience (1-mrem basis); since the concentrations and doses are proportional, the resulting fraction is independent of the RCC level.

Table D.4 presents fractions of the RCC dose limit for TSD workers which are used to estimate the dose to storage workers (rad workers in DOE mixed waste storage facilities). The second column is the fraction of the RCC dose limit that is from the external component of the dose. The third column is the fraction external dose, modified for the decay during the study period (the integrated quantity present); the fourth column is the external component with decay, based on receipt of equal quantities of waste annually, throughout the study period.

Except for working off the backlog of stored waste, decay is not considered for TSD worker dose, because fresh waste at the RCC limit is assumed to be processed every year.

Table D.4. Fraction of RCC Limiting Dose Received by Storage Workers, Based on Externa Dose Only

Nuclide	Fraction External Dose for Current Storage,[a] $Fr_{ext(j)}$	Fraction External Dose for 30 years of Storage,[b] $Fr_{ext(j)} * DecayF_{S,j}$	Fraction External Dose for Projected Waste,[c] $Fr_{ext(j)} * DecayF_{p,j}$
^{3}H	0	0	0
^{60}Co	0.89	0.22	0.33
$^{90}Sr + D$	0.52	0.37	0.41
^{99}Tc	-	8E-5	8E-5
^{129}I	3E-9	2.5E-9	3E-9
^{137}Cs	0.88	0.64	0.71
$^{238}U+D$	0.55	0.55	0.55
^{237}Np	0.36	0.36	0.36
^{239}Pu	3E-5	3E-5	3E-5
^{241}Am	5E-6	5E-6	5E-6

(a) The storage scenario consists of 2,000 hours of exposure (external only) of an individual to waste at the RCC concentration limit. It is listed as a fraction of the limiting dose for the RCC limit, e.g., for ^{60}Co, 0.89 mrem at the RCC Level 2 (1 mrem) concentration limit of 0.45 pCi/g.

(b) Fraction of the RCC dose limit for stored waste is based on the integrated dose for a 30-year storage and decay period.

(c) Fraction of the RCC dose limit from accumulated waste is based on the integrated dose from waste in storage accumulated at a constant annual rate for a 30-year period.

Another modification to the bounding collective dose is the exposure time factor, or fraction of working time spent in proximity to waste. Storage workers are assumed to be in the proximity of the waste 25% of the work time, or 500 hours per year. The estimated collective dose based on the concentration of individual radionuclides present in waste over the storage period is as follows:

$$CDose_{Ln,j} \text{ ' } CDose_{Max} \times Fr_{ext(j)} \times T_{frac} \times DecayF_{W,j} \quad \text{(D.9)}$$

where

$CDose_{Ln,j}$ = the collective dose for storage workers, person-rem

T_{frac} = the fraction of work time in proximity of waste (taken to be 0.25)

$DecayF_{W,j}$ = the integrated fraction of activity present in waste *W* (stored or projected) for radionuclide *j*, over the time period of interest and other factors are defined above.

D.4 TSD Worker Dose

RCC limiting concentrations in Aaberg et al. (1995) are based on individual doses for TSD workers (or members of the public). The radionuclide concentration which would result in a given dose limit is calculated for the limiting scenario. These limiting concentrations are used here as a basis for the collective dose calculations.

Calculation of worker dose is based on the scenario analysis method for individual workers: assumptions regarding inhalation, incidental ingestion, and external exposure are used for each of nine worker scenarios based on incinerator, landfill, and transportation operations. These scenarios are documented in detail in Appendixes F and G of Aaberg et al. (1995).

The TSD worker collective dose is based on the individual TSD worker dose, weighted by the labor requirements and quantity of contaminated waste received by the facility. The bounding estimate of collective dose is based on the assumption that all hazardous waste workers at a facility would receive the dose estimated for the maximally exposed worker. The dose to TSD workers is assumed to be independent of the radionuclide contaminant because the limiting concentration is generally defined by the individual TSD worker dose. A fraction of the limiting dose is calculated for the exceptions (^{3}H, ^{35}S, ^{99}Tc, ^{125}I, and ^{129}I), for which the dose to an offsite individual is limiting. The collective dose for TSD workers is estimated from the number of waste workers required and the quantity of DOE waste (tons) at a given RCC limit:

$$CDose_{Ln} = \Sigma_k \left[Labor_k \times \left(S_{Ln,k} + P_{Ln,k}\right) \times Dose_{Ln} \right] \qquad (D.10)$$

where

$CDose_{Ln}$ = the collective dose for TSD workers, person-rem
$Labor_k$ = the labor requirement for facility *k*, FTE/ton
$S_{Ln,k} + P_{Ln,k}$ = the quantity of stored plus projected waste at RCC Level *n* processed by facility *k*, tons
$Dose_{Ln}$ = the RCC limiting dose at Level *n* (1E-5, 1E-3, or 0.02 rem/FTE)

The assumed labor requirements for incineration and disposal (landfill) given in Table D.5 are based on data from the incineration and disposal facilities noted in Table D.6. For other treatment operations (shred/grout, stabilization, and neutralization), the facility capacity, complexity, and operating characteristics are used to estimate the process labor requirements (Peters and Timmerhaus 1968, Figure 4-6). These assumptions concerning operating labor for are given in Table D.7.

Table D.5. Labor Requirement Assumptions for Incineration and Landfill Operations

Facility Type	Capacity, ton/yr	Waste Workers (Total)	FTE/ton
Incinerator	30,000	80 (150)	3E-3
Landfill	150,000	100 (180)	1E-3

Table D.6. Background Information Used to Estimate Labor Requirements for

Incineration and Landfill Operations

Facility Type (No. Units)	Facility Name	Facility Capacity, ton/yr	Total Staff	Waste-Handling Staff	Source of Information
Incinerator (1) fixed hearth	ThermalKem (Rock Hill)	24,000	195	100	Site visit 10/22/92
Incinerator (1) liquid injection	Laidlaw (Roebuck)	~24,000	63	43	Beck & Foltz[a]
Incinerator (1)	Aptus (Coffeyville)	25,000 - 30,000(capacity)	330		Chew [b] p. 7
Incinerator /Landfill	Rollins (Baton Rouge)	40,000(capacity) ~30,000 1991	150 200 max.	75 (50%)	Beck & Foltz[c] p.2
Incinerator (3)	Ensco (El Dorado)	54,000(estimated) 60,000(capacity)	~500	~100	Chew [d] p.8
Incinerator (1)	Rollins (Bridgeport)	54,000(estimated) 40,000(actual)[e]	165	100	Beck, phone contact [f]
Incinerator (3)	Rollins (Deer Park)	160,000[e] 250,000(estimated)	270	118	Chew [a] p.9
Landfill	Laidlaw (Pinewood)	135,000(Hazardous) 250,000 (Total)	135	85	Beck, Foltz & Adams [h]
Landfill	CWM (Emelle)	400,000 (800,000 maximum)	289 (375)	127	Site visit; Chew, p.8[i]
Landfill	CWM (Kettleman)	~400,000	230		EI Jan.92 p.34[j]

(a) Beck, W. L., and G. R. Foltz. 1993. *Exposure Pathway Assessment Report for Laidlaw Environmental Services, Roebuck, South Carolina*. ORISE 95/C-69. Prepared for U.S. Department of Energy by the Environmental Survey and Site Assessment Program, Oak Ridge Institute for Science and Education, Oak Ridge, Tennessee.

(b) Chew, M. H, and Associates. 1992. *Radiological Dose Assessment of the Treatment, Storage, and Disposal of Department of Energy Waste by Aptus Environmental Services, Inc., Coffeyville, Kansas*. Compiled for Department of Energy, Office of Environmental Restoration and Waste Management by M. H. Chew & Associates, Inc., under contract to BDM International, Inc.

(c) Beck, W. L., and G. R. Foltz. 1993. *Exposure Pathway Assessment Report for Rollins Environmental Services Site, Baton Rouge, Louisiana*. ORISE 93/J-175. Prepared for U.S. Department of Energy by the Environmental Survey and Site Assessment Program, Oak Ridge Institute for Science and Education, Oak Ridge, Tennessee.

(d) Chew, M. H., and Associates. 1993. *Radiological Dose Assessment of the Treatment, Storage, and Disposal of Department of Energy Waste by Environmental Systems Company, El Dorado, Arkansas*. Compiled for Department of Energy, Office of Environmental Restoration and Waste Management by M. H. Chew & Associates, Inc., under contract to BDM International, Inc.

(e) Gruber, W. 1992. *EI Digest*, May 1992. "Hazardous Waste Incineration 1992," pp. 23-30. Environmental Information, Ltd., Minneapolis, Minnesota.

(f) Beck, W. L., communication with Rollins Environmental Services, Bridgeport, New Jersey.

(g) Chew, M. H., and Associates. 1994. *Radiological Dose Assessment of the Treatment, Storage, and Disposal of Department of Energy Waste by Rollins Environmental Services Site, Deer Park, Texas*. Compiled for Department of Energy, Office of Environmental Restoration and Waste Management by M. H. Chew & Associates, Inc., under contract to BDM International, Inc.

(h) Beck, W. L., G. R. Foltz, and W. C. Adams. 1995. *Exposure Pathway Assessment Report for Laidlaw Environmental Services, Pinewood, South Carolina*. Prepared for U.S. Department of Energy by the Environmental Survey and Site Assessment Program, Oak Ridge Institute for Science and Education, Oak Ridge, Tennessee.

(i) Chew, M. H and Associates. 1993. *Radiological Dose Assessment of the Treatment, Storage, and Disposal of Department of Energy Waste by Chemical Waste Management, Inc., Emelle, Alabama*. Compiled for Department of Energy, Office of Environmental Restoration and Waste Management by M. H. Chew & Associates, Inc., under contract to BDM International, Inc.

(j) Stamps, David. 1992. *EI Digest*, January 1992. "Chem Waste's Kettleman Hills Landfill" p. 32-39. Environmental Information, Ltd. Minneapolis, Minnesota.

Table D.7. Assumptions Used to Estimate Labor Requirements for Waste Processing Facilities

Facility Type	Conditions	Capacity, ton/yr (T/D)	Man-hr/day/step	No. of steps	Labor, FTE/ton
Shred/grout	Batch operation	15,000 (50)	40-65	6[(a)]	3×10^{-3}
Stabilize	Batch operation	15,000 (50)	40-65	5[(b)]	2×10^{-3}
Neutralize	Fluid processing	50,000 (170)	40-50	4[(c)]	4×10^{-4} [(d)]

(a) Processing steps: receiving, preparation, shredding, mixing, packaging, effluent treatment.
(b) Processing steps: receiving, preparation, mixing, packaging, effluent treatment.
(c) Processing steps: receiving, neutralization, precipitation, stabilization.
(d) A conservative estimate of 1×10^{-3} FTE/ton was used in spreadsheet calculations.

D.5 Population Dose

The population dose factors used in this study (in person-rem per Ci/yr released) are taken from Aaberg et al. (1995, Table E.4) and generated with CAP88-PC. Population dose factors are based on generic meteorology (Class D, windspeed 4 m/s), a 30-m stack, and uniform population density of 80 persons/km^2.

The assumed base case population density of 80 persons/km^2 corresponds to the average found for 14 hazardous waste incinerators. The population density in the vicinity of hazardous waste incinerators considered is estimated to range from a low of 13/km^2 for a facility in rural Arkansas to 290/km^2 for a facility in New Jersey (U.S. Bureau of the Census 1991).

Emissions from the facility are based on the activity of the waste processed (RCC limiting concentration, multiplied by the mass of waste) and the emission factor. Release factors and incineration and other processes, and resulting dose factors based on RCC Level 2 are given in Table D.8. The dose factors, in terms of person-rem per ton processed, scale directly with the RCC level. RCC Level 2 waste, with a limiting dose of 1 mrem to an individual, is used as an example. The collective dose is based on processing the limiting quantity of waste, with the process release factor applied. Emission factors for incineration for this analysis are taken from Aaberg et al. (1995, Table C.2).

For the stabilization treatment, it is assumed that it is necessary to use size reduction to make some debris-type waste more uniform. Offsite dose from shredding or stabilizing operations would be a result of fugitive dust from the facility during these operations. The release is assumed to be ground-level, with an emission factor of 1×10^{-7}. This factor is based on various processes in cement batching, which

Table D.8. Population Dose Factors Used in This Analysis, Based on Processing of Waste at RCC Level 2

	Dose Factor, person-rem per ton processed [(a)]					
	TSD Facility Type					Release Factor[(b)]
Nuclide	Incinerate	Shred/Grout	Stabilize	Neutralize	Land-fill	
^{3}H	7.8E-05	8.6E-11	8.6E-11	8.6E-12	8.6E-12	0.9
^{60}Co	8.3E-08	8.3E-12	8.3E-12	8.3E-13	8.3E-13	0.01
$^{90}Sr+D$	4.9E-07	4.9E-09	4.9E-09	4.9E-10	4.9E-10	0.0001
^{99}Tc	1E-04	1E-09	1E-09	1E-10	1E-10	0.1
^{129}I	2.9E-05	9.6E-11	9.6E-11	9.6E-12	9.6E-12	0.3
^{137}Cs	1.8E-07	9.0E-11	9.0E-11	9.0E-12	9.0E-12	0.002
^{238}U	4.4E-06	8.8E-09	8.8E-09	8.7E-10	8.7E-10	0.0005
^{237}Np	2E-06	4E-09	4E-09	4E-10	4E-10	0.0005
^{239}Pu	6.7E-06	1.3E-08	1.3E-08	1.3E-09	1.3E-09	0.0005
^{241}Am	3.4E-06	6.7E-09	6.7E-09	6.7E-10	6.7E-10	0.0005
Release Factor	(see last column)	1E-06	1E-06	1E-07	1E-07	Incineration

(a) Units: $Ci/ton_{(@\ L2)}$ x Release Factor x Dose Factor, person-rem/Ci [=] person-rem/ton processed at RCC Level 2.
(b) Release factors for incineration, taken from Aaberg et al. (1995).

involve transfer and mixing of materials in the form of small particles. Mixer and truck loading have emissions of about 0.01 to 0.02 kg/ton (Masser 1984) or a fraction on the order of about 10^{-5}. A range of 10 to 20% by weight consists of particles less than 5 μm, which is typical for cement. It is assumed that the waste undergoing processing has a larger particle size than cement and that emissions would be controlled by filtration, lowering the emission factor by another two orders of magnitude. All radionuclides are assumed to have the same emission factor because there is no driving force (such as high temperature) which would result in differences in emissions between radionuclides.

D.6 Sensitivity

Table D.9 compares the results of the sensitivity cases with the base case for the composite source term (see Table 4.4), listing the dose calculated for each receptor group by alternative (continued storage and the three treatment alternatives).

The source terms listed in Table 4.4 have a ceiling concentration of 2000 pCi/g, and a total sum of RCC fractions of 1.0. For RCC Levels 2 and 3, the source term is brought up to 2000 pCi/g by adding tritium (which is still at a low fraction of its RCC value). The fraction of RCC is consistent for RCC Levels 1 through 3, except for tritium concentration, and ^{60}Co and ^{238}U are modified slightly to achieve the desired sum-of-fractions and activity.

The dose from waste containing tritium, based on RCC limiting concentrations, is also presented as a hypothetical case. If the higher values for tritium were used, the alternative of treating RCC Level 3 waste would result in a higher overall dose than the continued storage alternative, due to population dose. Even if this were a credible case, the resulting collective dose is negligible. The maximum collective dose, presented in Table D.9, is less than 30 person-rem over a 30-year analysis period, equates to a dose to an average individual of thousandths of a millirem per year. The annual risk of causing a radiogenic cancer would be less than 0.05, essentially zero cancers. An International Atomic Energy Agency (IAEA) study of recycling materials from nuclear facilities used a collective dose of 1 man-Sv per year (100 person-rem per year), as a cut off value exempt practices from regulatory control without more detailed examination of other options, based on low risk to the public (IAEA 1992).

For all alternatives, the quantity of waste and distribution into categories (or which RCC level that a given waste stream would meet) are important factors for both the economics and the dose consequences of implementing a RCC for DOE waste. The type of waste and, thus, the type of treatment appropriate determine the release fraction, which in turn controls the population dose. For example, the impact of the treatment method for soils is considered as a variant. If soils were stabilized instead of incinerated, as in the base case, the resulting population dose is decreased by about 50%. This results in a minor change to the total dose with the composite source term (see Table D.9).

The next modification of the source term is in the increase of the projected mass of waste in the form of soil. This variation is considered since it was indicated that the soil quantity given in the CMWIR (from which the inventory assumptions were made) could be understated. If the quantity of soils in the projected waste is increased ten-fold, the resulting changes are mostly from the increased mass of waste material to be stored or treated. The cumulative dose would nearly double the base case value. The dose for treating RCC Level 3 is slightly higher than the continued storage case.

Scenario-related variables which were investigated include worker scenarios, release factors, and population density. The activities of interest resulting in dose to radiation workers at DOE facilities involve hands-on operations with waste containers. These operations have a large potential impact on collective dose not only for the continued storage alternative but also for the alternative treatment to Levels 1 and 2. The balance between waste-handling and paperwork in an office environment is the variable of interest. It is assumed that, for the base case, the workers are in close proximity to waste containers only 25% of the time. The maximum time that a worker is assumed to be in proximity to wastes is 75% of the time, or 1,500 hours per year.

Table D.9. Cumulative Dose (over 30 years) to All Receptors for Sensitivity Study, Composite Source Term (see also Table 4.4)

	Dose by Receptor Category, person-rem			
Case and Receptor	**Continued Storage**	**Treat RCC Level 1**	**Treat RCC Level 2**	**Treat RCC Level 3**
Base Case				
Radiation Workers	12.3	12.3	12.0	0.65
TSD Workers	—	0.0005	0.16	8.1
General Population	—	0.001	0.22	2.2
Total	**12.3**	**12.3**	**12.35**	**10.9**
Stabilize Soils				
Radiation Workers	12.3	12.3	12.0	0.65
TSD Workers	—	0.0005	0.14	7.7
General Population	—	0.0003	0.05	1.2
Total	**12.3**	**12.3**	**12.2**	**9.6**
Projected Soils x 10				
Radiation Workers	22.4	22.4	22.1	0.65
TSD Workers	—	0.0006	0.18	18.4
General Population	—	0.001	0.26	8.4
Total	**22.4**	**22.4**	**22.6**	**27.4**
Radiation Worker Time: 75%				
Radiation Workers	37	37	36	2
TSD Workers	—	0.0005	0.16	8.1
General Population	—	0.001	0.22	2.2
Total	**37**	**37**	**36**	**12**
Collective TSD				
Radiation Workers	12.3	12.3	12.0	0.065
TSD Workers	—	9E-5	0.02	1.0
General Population	—	0.001	0.22	2.2
Total	**12.3**	**12.3**	**12.2**	**3.3**

Table D.9. (contd)

Case and Receptor	Dose by Receptor Category, person-rem			
	Continued Storage	**Treat RCC Level 1**	**Treat RCC Level 2**	**Treat RCC Level 3**
Release Factors x 10				
Radiation Workers	12.3	12.3	12.0	0.65
TSD Workers	—	0.0005	0.16	8.1
General Population	—	0.005	1.2	19.2
Total	**12.3**	**12.3**	**13.4**	**28**
General Population Density: 320/km^2				
Radiation Workers	12.3	12.3	12.0	0.65
TSD Workers	—	0.0005	0.16	8.1
General Population	—	0.006	0.87	8.7
Total	**12.3**	**12.3**	**13**	**17.5**

Shading indicates the alternative resulting in the lowest dose.
Collective worker dose based on Aaberg et al. (1995), Table I.2.

Other factors relating dose to workers are not presented in detail. Among these are labor requirements (FTE/tons) at various facility types. Labor requirements over the 30-year study period range from a maximum of 8,800 FTE-years for continued storage to 1,270 FTE-years for treatment at Level 3. Storage of mixed waste is the dominant factor not only for the continued storage alternative but also for treatment at Levels 1 and 2, where it accounts for 99% and 95% of the labor requirement, respectively. Storage during work-off of the inventory accounts for 37% of the labor requirement for treatment to Level 3. If one-tenth of the labor is required for running a mixed waste storage facility, treatment would not be the alternative yielding the minimum dose.

Transportation, although an important cost factor, has no discernable effect on the overall collective dose and is, therefore, not presented as a sensitivity case.

A calculation of collective dose for TSD workers was performed using less conservative assumptions than the base case (all workers receiving a dose equal to that of the maximally exposed worker MEW proportional to the fraction of DOE waste handled). Differing levels of exposure were assumed, based on collective dose for incineration and landfill workers presented in Aaberg et al. (1995). The resulting doses are nearly an order of magnitude lower than the initial assessment, making the treatment alternative for Level 3 waste more attractive from a collective dose standpoint.

Release factors for all treatment options were increased by a factor of 10 (or to a maximum of 100%) to determine the effect on population dose. Uranium and technicium are the major contributors to population dose for treatment of wastes at Level 3, accounting for about 72% of the population dose.

For dose calculations using generic meteorology, population dose is a function of population density and other parameters related to agricultural production. For the base case, the population density was assumed to be 80 persons/km^2, or a total of 1.6-million persons within an 80-km radius. The base case corresponds to the average for 14 hazardous waste incinerators considered. The population density in the vicinity of the hazardous waste incinerators considered is estimated to range from a low of 13 per km^2 for a facility in rural Arkansas to 290 per km^2 for a facility in New Jersey. If the population density were increased by a factor of 4 to 320 per km^2, the cumulative population dose for treating Level 3 would be less than 10 person-rem based on the composite source term.

D.7 References

Aaberg, R. L., D. A. Baker, M. F. Jarvis, K. Rhoads, and W. E. Kennedy, Jr. 1995. *Radiation Dose Assessment Methodology and Preliminary Dose Estimates to Support U.S. Department of Energy Radiation Control Criteria for Regulated Treatment and Disposal of Hazardous Wastes and Materials*. PNL-9405, Pacific Northwest National Laboratory, Richland, Washington. Prepared for the U.S. Department of Energy, Office of Environmental Safety and Health, Washington, D.C.

International Atomic Energy Agency (IAEA). 1992. *Application of Exemption Principles to the Recycle and Reuse of Materials from Nuclear Facilities*. Safety Series No. 111-P-1.1, International Atomic Energy Agency, Vienna, Austria.

Masser, C. 1984. "Concrete Batching." Computation of Air Pollution Emission Facts. AP-42, 3rd ed., plus supplements 1-15, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Peters, M. S., and K. D. Timmerhaus. 1968. *Plant Design and Economics for Chemical Engineers*. 2nd ed. McGraw-Hill, New York.

U.S. Bureau of Census. 1991. *State and Metropolitan Area Data Book 1991*. U.S. Government Printing Office, Washington, D.C.

Appendix E

Worker and Transportation Safety

Appendix E

Worker and Transportation Safety

Impacts of RCC alternatives on worker and transportation safety are evaluated to assess potential differences between alternatives.

E.1 Worker Safety

Cumulative labor requirements were calculated from facility labor requirements in terms of FTE/ton (see Table D.3), and the quantity of waste that would be treated or stored at each RCC level, in tons (see Table 4.2). For waste remaining in storage, the quantity stored must be integrated over the storage period to account for the number of years that it is maintained in a storage facility. One ton of waste currently in storage would thus equal 30 ton-years of waste stored for the continued storage alternative, based on the 30-year study period. One ton per year of projected waste equals 465 ton-years in storage, accounting for accumulation [1 ton x (30 y + 29 y + 28 y ... +1 y) = 465 ton-years]; see Table D.1 for a definition of cumulated stored quantity.

Table E.1 lists the estimated labor requirements for Continued Storage and the three RCC Levels. The labor requirements for the continued storage alternative are greater than those for the RCC treatment options because the waste must be maintained for multiple years. Cumulative labor requirements for waste treatment depend only on the quantity treated, which is a function of the RCC level.

Table E.2 gives the estimated cumulative number of safety incidents expected over the 30-year study period for both storage and treatment operations, based on the labor and vehicle distances in Table E.1. The greatest number of safety incidents would be expected for the continued storage option because the greatest number of worker-years are required.

Table E.1. Cumulative Labor Requirements for Storage and Treatment

	Labor Requirements, FTE-yr			
Facility Type	**Continued Storage**	**RCC Level 1**	**RCC Level 2**	**RCC Level 3**
Storage Facility	8,800	7,960	5,410	470
TSD	-	70	228	690
Total[(a)]	**8,800**	**8,030**	**5,690**	**1,160**
(a) Rounding may cause the sum to differ from the subtotals presented				

Table E.2. Cumulative Projected Safety Incidents for Storage and Alternatives

	Projected Safety Incidents, cumulative[(a)]			
Facility Type	**Continued Storage**	**RCC Level 1**	**RCC Level 2**	**RCC Level 3**
Storage Facility	379	342	233	20
TSD	-	3	12	30
Total[(b)]	**379**	**345**	**245**	**50**
(a) Based on 0.043 injuries or illnesses per worker-year (NSC 1995). (b) Rounding may cause the sum to differ from the subtotals presented.				

Table E.3 gives the cumulative fatalities from storage and treatment over the 30-year study period. One fatality would be expected, based on labor statistics for the number of worker-years required. RCC Level 3 option would have a reduced probability of a fatal accident, due to the lower labor requirements.

E.2 Transportation Safety

Transportation labor requirements are listed in Table E.4. No transport of waste offsite is necessary for continued storage; the personnel and vehicle-miles increase as the RCC acceptance criteria are less restrictive. The bounding estimate for transportation requirements is based on a one-way shipping distance of about 2,000 km (1,230 miles) for each 19.2-ton (42,320-lb) load of waste.

Table E.5 shows shipping requirements in terms of cumulative trips and FTEs. The number of projected transportation accidents and injuries is given in Table E.5. Cumulative fatalities, presented in Table E.6, are based on National Safety Council data (NSC 1995) for transportation and public utilities.

Table E.3. Cumulative Fatalities for Storage and Alternatives

	Fatalities, cumulative[a]			
Facility Type	**Continued Storage**	**RCC Level 1**	**RCC Level 2**	**RCC Level 3**
Storage Facility	1.1	1.0	0.6	0.06
TSD	-	9E-3	0.04	0.09
Total Fatalities[b]	**1**	**1**	**1**	**0.1**

(a) Based on 1.2E-4 fatalities per worker-year (NSC 1995).
(b) Rounding may cause the sum to differ from the subtotals presented.

Table E.4. Cumulative Transportation Requirements for Treatment Alternatives

	Transport Parameter		
Parameter	**RCC Level 1**	**RCC Level 2**	**RCC Level 3**
Labor, FTE-yr			
Truck Drivers, FTE-y[a]	11	44	108
Distance Driven, million km			
Truck-km (maximum)[b]	1.9	7.7	19.

(a) Based on 176,000 km (110,000 mi) per FTE-year (250 d x 8 h x 55 mi/h x 1.6 km/mi).
(b) Based on 19.2 MT/load and 2,000 km/trip.

Table E.5. Cumulative Projected Accidents from Waste Transport

	Safety Incidents[a]		
Individual Type	**RCC Level 1**	**RCC Level 2**	**RCC Level 3**
Crew	0.1	0.4	1.1
Public	3.1	12.4	30.
Total Accidents/Injuries	**3**	**13**	**31**

(a) Based on 2.28E-8 accidents/injuries per km for crew and 8.0E-7 accidents/injuries per km for the public (Cashwell et al. 1986).

Table E.6. Cumulative Projected Fatalities Resulting from Transport

	Fatalities		
Individual Type	**RCC Level 1**	**RCC Level 2**	**RCC Level 3**
Crew[(a)]	0.006	0.2	0.6
Public[(b)]	0.2	0.8	2
Total Fatalities	**0.3**	**1**	**3**
(a) Based on 1.5E-8 fatalities per km for crew (Cashwell et al. 1986). (b) Based on 5.3E-8 fatalities per km for public (Cashwell et al. 1986) round trip.			

E.3 References

Cashwell, J. W., K. S. Neuhause, P. C. Reardon, and G. W. McNair. 1986. *Transportation Impacts of the Commercial Radioactive Waste Management Program*. SAND85-2715, Sandia National Laboratories, Albuquerque, New Mexico.

National Safety Council (NSC). 1995. *Accident Facts, 1995 Edition*. National Safety Council, Itasca, Illinois.

Appendix F

RCRA Cell Failure Scenarios

Appendix F

RCRA Cell Failure Scenarios

The purpose of this appendix is to address the issue of potential Resource Conservation and Recovery Act (RCRA) cell failure scenarios. Radiological Control Criteria (RCC) waste is hazardous waste, which contains by definition only low levels of radioactive contaminants. The concentrations of activity are limited by the potential to result in a dose to an individual worker or member of the public. RCC levels 1, 2, and 3 addressed in this study correspond to maximally exposed individual (MEI) doses of 0.01 mrem, 1 mrem, and 20 mrem (worker) or 10 mrem (public), respectively.

Disposal of RCC waste in a RCRA cell would offer a level of protection to individuals and the environment equal to that of disposal in a low-level waste burial ground. During the active phase, RCRA landfills require (40 CFR 264) certain features, such as liners and a leachate collection system, which are not required by low-level waste burial grounds (10 CFR 61). In the long term, RCRA cells and low-level waste disposal units are similarly designed for long-term containment with minimal maintenance. Site characteristics for both types of facilities are directed toward long-term isolation, minimal erosion, and minimal infiltration of water.

RCRA hazardous waste landfills are designed for zero release. If either during operations or following closure, the facility fails and constituents in the waste begin to migrate, it is presumed that remedial measures will be taken by the responsible parties to correct that condition.

The first part of this appendix describes the potential worker dose from RCRA cell-remediation efforts and the responsibility for the remediation effort. The second part describes the radiological dose impacts to the public from potential groundwater contamination due to failed RCRA cells at three sites. The potential dose was evaluated using the RESRAD model and computer code (Yu et al. 1993b) and a three-dimensional enhancement, RESRAD-OFFSITE.[(a)] A third part considers the potential dose impacts from existing and projected U.S. Department of Energy (DOE) waste streams that may qualify as RCC waste.

F.1 Remediation of a Failed RCRA Cell

The purpose of this section is to quantify the potential dose to workers from future remediation of a RCRA cell. Remediation of a leaking RCRA cell may entail excavation of waste and repair or replacement of a section of the cell liner material. A limited excavation scenario was addressed in Aaberg

(a) Under development by C. Yu and others at Argonne National Laboratory.

et al. (1995). In this scenario, an individual worker was assumed to work in the proximity of excavated waste for 20 hours while wearing full protective gear (full-face respirator, protective clothing). This exposure scenario represents excavation of a specific item or area within a landfill.

F.1.1 Remediation Scenario

A remediation project in which a leaking liner is repaired or replaced would likely be more extensive than a simple excavation. The bounding scenario for work in a large contaminated zone was also presented in the RCC document as the full-time landfill worker scenario. In that scenario, a worker is exposed full-time (2000 h/yr) to an essentially infinite plane of contaminated material 1 m thick, shielded by 15 cm of clean soil. Inhalation exposure was based on a (contaminated) dust loading of 100 mg/m^3, with breathing protection provided by a full-face respirator. The fraction of inhaled material getting through the respirator was 1×10^{-5}. Ingestion exposure (inadvertent ingestion of 10 mg/event) was assumed to occur daily.

F.1.2 Dose from Remediation Efforts

The scenario description above suggests that the limiting exposure for an individual performing remediation work will be equal to or less than the RCC limit for a given RCC level. A dose to a treatment, storage, and disposal (TSD) worker of 1 mrem would be an upper bound for waste at RCC Level 2. Conservative assumptions in the application of the landfill worker scenario to remediation work include the following:

- The landfill worker is assumed to be exposed to the contaminated zone for a full 2000 h/yr. The duration of a remediation project could be a fraction of a year.

- The scenario is conservative for a full-time landfill worker because less than 100% of the work day is spent in the contaminated zone. All the waste in the cell is assumed to contain the RCC limiting concentration. In fact, the DOE waste would probably be a small fraction of the waste in a cell.

- No decay time is assumed for landfill workers. Significant decay of short-lived radionuclides may take place prior to remediation work, which may not be necessary for 30 years or more in the future.

F.1.3 Responsibility for Remediation

Federal standards for management of hazardous waste treatment, storage, and disposal facilities are established in 40 CFR 264 and 265. These standards regulate essentially all aspects of hazardous waste management at TSD facilities. RCRA legislation and regulations thus provide a variety of mechanisms for managing waste disposal units and addressing releases of hazardous constituents into the environment.

The exact regulatory mechanism for responding to a release would depend on the type of waste management unit and the nature of the release. RCRA addresses releases largely through prevention and

through minimum technical standards for the types of waste management units (e.g., tanks, containers, landfills, etc.). There are extensive standards for detecting, assessing, monitoring, and remediating releases should they occur. For active hazardous waste land-disposal units, RCRA requires a groundwater protection program that includes detection monitoring, assessment of any detected releases, and corrective action. For active TSD facilities, response actions may be voluntary, or they may be conducted as a requirement of a permit or compliance order.

For RCRA land disposal and other units that will continue to contain wastes after closure, there are extensive RCRA standards for closure plans, post-closure care, maintenance, and monitoring. RCRA provides for a post-closure period of 30 years, although the U.S. Environmental Protection Agency (EPA) can extend this period indefinitely or as needed. As with active TSD facilities, response actions may be voluntary, or they may be a requirement of a permit, a closure plan, or a compliance order.

RCRA and its sister legislation, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), provide a range of provisions to ensure an ability to respond to releases from hazardous and solid waste management units. Initially, responsibilities for response to releases and corrective action will reside with the RCRA facility owner or operator. With the exception of United States government facilities, all TSD facility owners and operators are required to carry performance bonds, insurance, and other financial instruments to provide for releases. For situations where a TSD facility owner or operator is unable to respond for financial or other reasons, the EPA may take action to address releases under its CERCLA authorities. In such cases, the TSD owner or operator, or any waste generator who may have sent waste to the TSD facility, may be held liable for cleanup costs. While exempt from RCRA financial assurance requirements, the United States government retains the same liabilities as other potentially responsible parties (PRPs).

F.2 Groundwater Breakthrough Scenario Calculations

The purpose of this section is to determine the impact to groundwater from a RCRA landfill with a leaking liner, which is either not repaired at all or is not repaired until contaminants have leached into the groundwater.

F.2.1 Groundwater Calculations

Calculations were made using three different existing sites: a dry western site (Beatty, Nevada) and two wet southeastern sites (Emelle, Alabama, where the groundwater is more than 180 m deep, and Deer Park, Texas, where groundwater is less than 5 m deep). Parameter values used to describe the aquifer and cell at the three sites are given in Table F.1 (tables and figures are gathered at the end of this appendix). Site-specific parameters were used when available (Chau et al. 1992). RESRAD default parameters were used when site-specific information was not available. Figure F.1 is a schematic diagram of a landfill and well as modeled by RESRAD. The conceptual model is a rectangular waste site with infiltration through a clay cover, with contaminants driven from the waste zone through a clay liner and vadose zone to the aquifer. A well adjacent to the site is located such that it intercepts groundwater down-gradient from the source of contamination. The well is assumed to be used as a source of drinking water, from which the MEI is assumed to ingest 2 L/d.

RESRAD is a user-friendly, publicly available screening model developed by DOE, containing a one-dimensional, plug-flow vadose-zone model. RESRAD-OFFSITE, a three-dimensional version of RESRAD currently under development at ANL,[(a)] was used to assess groundwater impacts with consideration of dispersion, to make the calculations more realistic. The RESRAD-OFFSITE code to model the transport in the aquifer, accounting for longitudinal, lateral, and vertical dispersion in addition to advection. Additional parameters required by the RESRAD-OFFSITE code are given in Table F.2.

The groundwater analyses presumed that a cover, which reduces the infiltration rate, is installed as part of site-closure activities. A clay liner, which is more effective than soil in retaining most contaminants, was used as a barrier to migration. The synthetic impermeable liner system (man-made materials) was presumed to fail and not retard migration of the constituents from the cell. The infiltration rate was estimated using literature data and simulation results from the UNSAT-H model[(b)]; thus, surface runoff and evapotranspiration were not addressed specifically.

Sorption coefficients for 12 radionuclides, representing both mobile radionuclides and others found in DOE wastes, are listed in Table F.3. Values used to represent the clay liner, soil (at Beatty and Deer Park), and chalk (at Emelle) in the calculations are compared with literature values in Table F.3. The sources cited as literature values are from a data collection handbook (Yu et al. 1993a) and a performance assessment study performed for grouted tank wastes (Kincaid et al. 1995). The grout waste form is used as a surrogate for stabilized RCRA waste. The K_d values for grout indicate that it is possible to contain carbon, neptunium, and uranium more effectively than was assumed in the RESRAD calculations.

Migration was assumed to start at the time of cell closure. Institutional controls would add an additional time lag of at least 30 years (the minimum RCRA monitoring period).

F.2.2 Results of Groundwater Breakthrough Scenario Calculations

The RESRAD code was used to calculate the concentration of individual radionuclides in groundwater as a function of time after an assumed liner breach. The time-dependent concentration of an individual contaminant can be described simply by three values: breakthrough time, time of maximum concentration (or dose), and dose-to-source ratio at the time of maximum dose.

- Breakthrough occurs when a radionuclide is first present at the location of the well, indicated as years after liner failure.

- Time of maximum concentration in the groundwater (T_{MAX}, or time of maximum dose via the drinking water pathway) is a function of the leach rate, velocity through the various layers in the vadose zone and the saturated zone, and the rate of decay of the radionuclide. Some short-lived or slow-moving radionuclides may not reach groundwater.

(a) Methodology documented in Appendix K of RESRAD manual (Yu et al. 1993b).
(b) Personal communication from M. N. Fayer, June 15, 2000.

- The dose-to-source ratio (DSR) is a measure of the potential dose consequences of disposing of a given quantity of a radionuclide in a site. It is specific to the particular geometry of the disposal unit, site characteristics, exposure scenario, radionuclide, and time. The exposure scenario in this case consists of ingestion of contaminated groundwater at a rate of 2 L/d.

Breakthrough time, time of maximum concentration, and dose-to-source ratio at the time of maximum dose are presented in the following sections for the Beatty, Emelle, and Deer Park sites. In addition, the results of a sensitivity analysis performed with RESRAD are given to show the effects of various parameters at each site. Both DSR and T_{MAX} were determined as each of three parameters of interest (depth to groundwater, waste-layer thickness, and aquifer velocity) was varied, generally from about half the base-case value to two times the base-case value.

Cover performance was demonstrated by evaluation of some reasonable bounding scenarios. Figure F. 2 shows the base case and bounding infiltration rates. For the Beatty site, the bounding case, no vegetation on the cover, would increase the infiltration rate from less than 0.1 cm/yr to 0.5 cm/yr. An additional case of 1.0 cm/yr was also run with RESRAD. For the two wetter sites, two bounding scenarios were identified to demonstrate cover performance. These were removal of the top 15 cm of topsoil by erosion, which decreases infiltration, and deeper root penetration, which increases infiltration (by increasing saturated conductivity). The results of the sensitivity analysis are included in a table and plots for each site.

The time of appearance of contaminants in groundwater varies significantly for these sites, as shown in Figure F. 3. The time of maximum concentration varies from on the order of hundreds of years for Deer Park to tens of thousands of years for the Beatty site.

At all sites, for less mobile species, such as ^{60}Co, ^{90}Sr, and ^{137}Cs, decay prevents offsite migration; the source would be completely attenuated by radioactive decay before reaching groundwater (i.e., the DSR is zero). This is a consequence of a short half-life and high distribution coefficient (K_d). Long-lived, relatively immobile species (e.g., plutonium) are confined to the disposal area for more than 1000 years.

Beatty, Nevada, Site

The Beatty site is in an arid region of the southwestern U.S., which receives about 11 cm of precipitation annually. An infiltration rate of 0.1 cm/yr was used in simulations; the estimated infiltration rate is actually less than 0.1 cm/yr. Because of the low infiltration rate and approximately 75 m depth to groundwater, none of the 12 radionuclides considered in migration calculations have the potential for offsite groundwater contamination in a 1000-year time period in the event of immediate cell failure without repair. As shown in Table F.4, the most mobile contaminants, ^{14}C, and ^{99}Tc, would not appear in groundwater at the edge of the contaminated area for about 10,000 years after a liner/cap breach. Iodine (^{129}I) would appear nearly 30,000 years later. Less mobile radionuclides would not be expected to reach groundwater within 100,000 years.

- Table F.5 shows the effect of varying depth to groundwater, thickness of the waste layer, aquifer velocity, and infiltration rate. Several observations can be made from these results: neither T_{MAX}

nor DSRs vary significantly with waste layer thickness for this site. Waste thickness is a measure of the quantity of waste in a given area. For the volume of a waste disposal cell at the Beatty site, 1 pCi/g corresponds to 2.2 Ci of a contaminant.

- T_{MAX}, and thus breakthrough time, increases with the thickness of the unsaturated zone.

- Aquifer velocity does not affect T_{MAX} for the onsite calculations because the source of groundwater is taken to be at the edge of landfill, rather than some distance from it.

- DSR decreases with increased aquifer velocity because increased velocity (with other parameters held constant) corresponds to increased dilution in the saturated zone.

- DSR increases with water infiltration, which transports contaminants through the vadose zone to groundwater. In the estimated bounding case, infiltration of 0.5 cm/yr, is five times greater than the base case. A value of 1.0 cm/yr was also run for comparison. Figures F.4a and F.4b show how T_{MAX} and DSR vary with infiltration rate at the Beatty site.

- Figure F.4a shows that T_{MAX} decreases as infiltration rate increases. At an infiltration rate greater than the bounding case (0.5 cm/yr), the time of maximum concentration is less affected by infiltration rate.

- Figure F.4b shows that DSR increases proportionally with infiltration rate for technetium and iodine. When ^{14}C to reaches the aquifer (9800 years for the base case), only about 30% remains. For the 0.5 cm/yr infiltration rate (breakthrough at 2000 years), 79% remains. Decay results in a greater difference between high and low DSR values for ^{14}C.

Emelle, Alabama, Site

Emelle, Alabama, has a relatively high precipitation rate of about 120 cm/yr. While the infiltration rate of 2.9 cm/yr (about 30 times than that of the Beatty site) enhances migration of contaminants, the thicker unsaturated layer at Emelle (180 m, more than twice that at Beatty) helps to delay migration of contaminants to groundwater. The most mobile contaminant at Emelle, ^{99}Tc, is estimated to reach groundwater in about 1400 years, compared with about 10,000 years at the Beatty site..

Comments and observations can be made from RESRAD results shown in Table F.6.

- Although tritium is estimated to break through to groundwater in less than 1000 years, a very small amount (<1/1020) would remain after more than 60 half-lives.

- Only the very mobile radionuclides, e.g., ^{99}Tc and ^{129}I, have the potential to affect dose from drinking water within a 10,000-year time frame.

- Selenium could potentially reach groundwater, but not for nearly 100,000 years.

- The K_d for carbon is taken to be large for the chalk (calcium carbonate) geological unit at Emelle. It represents three removal processes acting on ^{14}C (adsorption, volatilization to CO_2, and precipitation into the chalk structure). For any ^{14}C disposed at Emelle, leaching from the cell would be contained within the geologic structure surrounding the cell.

In addition to the base case, waste-layer thickness, unsaturated zone thickness, aquifer velocity, and infiltration rate were varied to determine the effect of each on results of RESRAD runs. Table F.7 shows parameters varied and the resulting values of DSR and T_{MAX} for radionuclides ^{14}C, ^{99}Tc, and ^{129}I. Values for the base case are presented in bold type, and the parameters are varied from about half to two times the base case value. At this site, the length of time for contaminants to reach the aquifer would prevent the appearance of ^{14}C and tritium in groundwater.

Figures F.5a and F.5b show how T_{MAX} and DSR vary with infiltration rate at the Emelle site.

Figures F.5a shows that T_{MAX} decreases as the infiltration rate increases for the bounding values considered. Figure F.5b shows that DSR remains constant while the infiltration rate is changed to bounding values. The bounding values vary by only 0.7 cm/yr, and differ from the base case by 10% to 14%.

Deer Park, Texas, Site

The Deer Park site is in a high-rainfall area near the Gulf Coast of Texas. The drinking water pathway is only hypothetical because the groundwater is saline and non-potable. The Deer Park site has an infiltration rate of 1.2 cm/yr, and rainfall that exceeds 120 cm/yr. Results of the RESRAD simulation for base case conditions are given in Table F.8.

Thickness of the unsaturated layer, 3.2 m, is much less than that of the two sites previously described. Waste layer thickness is also less than at the other sites (8 m versus 30.5 m), resulting in a more rapid leach rate calculated by the code.[(a)] This results in the appearance of contaminants in groundwater much earlier than at the other sites described. Tritium is projected to break through to the aquifer, rather than decay completely before reaching groundwater. Both ^{3}H and ^{14}C are expected to appear in groundwater less than 100 years after liner breach, ^{99}Tc by about 200 years, ^{129}I within 300 years. Other constituents such as ^{79}Se would not appear for more than 100,000 years. Table F.9 is a tabulation of the parameters varied and the resulting values of DSR and T_{MAX} for radionuclides ^{3}H, ^{14}C, ^{99}Tc, and ^{129}I. Figures F.6a and F.6b show T_{MAX} and DSR for different values of infiltration rate.

RESRAD Offsite Dose Calculations

(a) The first-order leach rate constant used in RESRAD is estimated on the basis of residence time for the initial thickness of the contaminated zone (Yu et al. 1993b, p. 198). The leach rate is proportional to the infiltration rate, and inversely proportional to the water content of the contaminated zone, initial thickness of the contaminated zone, and retardation factor in the contaminated zone for a given radionuclide.

A compilation of RESRAD-OFFSITE results for Beatty, Emelle, and Deer Park is shown in Table F.10. In general, the peak concentration appears later (T_{MAX} is greater) and is lower (DSR is lower) than that calculated with the simpler ONSITE version of RESRAD. Figure F.7 compares the time of maximum concentration calculated by the ONSITE vs. OFFSITE codes. The OFFSITE values (symbols outlined) are in all cases greater than those for ONSITE (symbols filled).

For environmentally mobile radionuclides, it is the total inventory (curies of activity) of the radionuclides in the disposal unit, rather than their concentration, that is most important in assessing the consequences of a potential RCRA cell failure. The source term used in RESRAD is a concentration averaged over the extent of the contaminated zone, which contains the total amount of activity in the cell. A source of 1 pCi/g at Deer Park corresponds to 0.86 Ci disposed; 1 pCi/g at Beatty corresponds to 2.2 Ci, and at Emelle, 3.3 Ci. The dose-to-source ratio is the relationship between a potential inventory of contaminated materials and the maximum dose level based on the drinking water pathway with no corrective action after the cell failure groundwater (^{14}C).

F.2.3 Estimated Effect of Remediation on Groundwater

In a monitored RCRA cell, any breach in the liner system will be detected in a leachate collection system. If a breach occurred, it could be repaired before any groundwater was affected. If the leachate collection were not functioning, detection of a breach in the liner or cover would be delayed. As a hypothetical breakthrough scenario, it is assumed that a well near the site (potentially an existing monitoring well) could be used for drinking water. This well is assumed to be located 100 m downgradient from the RCRA cell.

It is possible to perform remediation after contaminants are detected in groundwater. Assuming that this remediation involves removing waste from the cell, the portion of contaminants that had already reached the vadose zone would still be available for leaching into the groundwater. The effectiveness of such a remediation program would depend on (a) the ratio of interval between the breach and detection and (b) the time between detection and the maximum concentration in groundwater at the receptor location.

The model of remediation that can be used with RESRAD involves the removal of contaminants from the cell. The result of this action cannot be detected at the well until a period of time equal to the breakthrough time has passed after remediation. If the breakthrough occurs before the maximum concentration in groundwater has been reached, the maximum concentration of contaminants at the well would be reduced.

The relative concentration of ^{99}Tc in groundwater following a hypothetical release from a RCRA cell is illustrated for Beatty, Emelle, and Deer Park in Figures F.8 through F.10, respectively. In each figure, the line represents RESRAD-OFFSITE results, and the discrete points marked by "x" are based on RESRAD-ONSITE results, for comparison.

Beatty, Figure F.8, has the longest delay before contaminants could reach groundwater (nearly 20,000 years), making remediation of only minor interest.

Contaminants at Emelle, Figure F.9, could be detected less than 3000 years following a release of ^{99}Tc. Remediation after detection of contaminants would reduce concentrations only after 5000 years.

At the Deer Park Site, Figure F.10, has the least delay (about 200 years) before contaminants appear in well water. Remedial action could reduce water concentrations from a significant fraction of the peak value.

F.3 Application of Potential Source Term for Disposal in a RCRA Cell

The purpose of this section is to present hypothetical long-term groundwater impacts from disposal of actual RCC waste streams in the three RCRA landfills presented in the previous section.

F.3.1 Stored Waste

The DOE has possession of a large quantity of mixed waste that is currently stored at DOE sites around the country. High-volume waste streams listed in the 1995 Mixed Waste Inventory Report (MWIR), accessed with the Material Inventory and Tracking Information (MITI) software system (DOE 1995), were reviewed to determine which could potentially meet RCC levels.

The mixed waste inventory data were examined to determine the major waste streams for each of the DOE sites with large quantities of waste (see Appendix B, "Development of Generic Waste Inventory"). A list of contact-handled mixed waste streams, sorted by stored inventory, was developed for each of these sites. The detailed report on waste-stream characteristics (Section 3 of the waste stream report from MITI) was reviewed for each of the largest waste streams. It was determined from the listed radiological characteristics whether a waste met the RCC Level 2 or Level 3 criteria. The quantity of waste and inventory of mobile radionuclides were determined for each waste stream meeting an RCC level. For many waste streams, the radiological characterization had not been compiled for the database, limiting the number of waste streams for which RCC levels could be determined.

A summary of currently stored waste streams identified, which apparently meet RCC Level 3 concentrations, is given in Table F.11. The summary is a sample from the available information, rather than a complete waste stream inventory. Sites represented include the K-25 and Y-12 plants at Oak Ridge, the Portsmouth Gaseous Diffusion facility, and the Savannah River Site. Several other DOE sites were examined, but many major waste streams were not included for one of three reasons: (a) inadequate characterization, (b) characterization data not compiled for the database, or (c) the sum of fractions of the radionuclide concentrations exceeding RCC Level 3. Sites that were not represented for these reasons include Hanford, Los Alamos, the Idaho National Engineering and Environmental Laboratory, Rocky Flats, and Lawrence Berkeley Laboratory.

No waste streams containing ^{129}I were identified as RCC waste because those waste streams were too radioactive to qualify as RCC waste. Much less ^{129}I than ^{99}Tc was generated at DOE sites, and it is assumed that most of the ^{129}I went into high-level waste. It is known that ^{3}H and ^{14}C are present at many DOE sites, but they seemed to be under-represented in the selected major waste streams.

Table F.12 presents potential MEI doses from contaminant transport to groundwater from a breached RCRA cell. Values are based on the Level 2 inventory presented in Table F.11 and dose-to-source ratios from RESRAD-OFFSITE runs. The inventory listed is a sample of potential RCC Level 2 waste streams; there may be additional waste streams that meet the Level 2 criteria. The highest dose to the MEI is based on ^{99}Tc, and would be less than 0.1 mrem/yr.

Table F.13 presents potential MEI doses based on Level 2 plus Level 3 inventories. This represents an estimate of the maximum potential future impacts of disposal of the hazardous waste, based on the previously described scenario for each of the three RCRA landfill sites.

The most important contributor to dose based on RCC Level 3 waste is the inventory of ^{99}Tc (about 42 Ci) from K-25, which represents currently stabilized and unstabilized B/C pond sludge. Although radiological characteristics for stabilized waste are not given in the MITI database, they are assumed to be similar to the unstabilized sludge, but with dilution for addition of cement stabilizer. The absence of drinking-quality water at the Deer Park site would preclude the drinking water pathway.

The highest potential dose, based on the groundwater pathway, therefore, would be at the Emelle site and would occur for a nearby well over 3000 years after cover or liner failure. The 13-mrem potential dose presented in Table F.13 represents less than one-seventh of the 100-mrem DOE primary dose limit for all sources.

F.3.2 Projected Waste

The MITI database includes a 5-year projection for wastes to be generated at DOE sites. These projected quantities and radiological characteristics are less certain than for stored wastes. The radiological characteristics are projected for only a few waste streams in the MITI database. In some cases, radionuclide contaminants are known from process knowledge, but concentrations are not included, making it difficult to develop a set of wastes which will meet the various RCC levels. It is expected that many yet uncharacterized wastes from remediation efforts will be suitable for disposal as RCC waste.

The projected quantity and inventory of ^{3}H, ^{99}Tc, and U of the identified waste streams are listed in Table F.14. These RCC Level 3 waste streams include residue from a rotary kiln incinerator at K-25, WETF/CP treatment sludge at Y-12, and SRTC low-activity waste at Savannah River. Wastes identified as meeting RCC Level 2 include two streams from the Portsmouth Gaseous Diffusion Plant, including personal protective equipment and hazardous waste unit closure waste. Four waste streams identified at Savannah River include waste oil, tritiated waste oil, soils, and sludges.

Table F.15 gives potential dose consequences based on disposal of 5-year inventory of RCC Level 2 plus Level 3 waste in single RCRA cell. The dose to the MEI would be less than 0.01 mrem/yr in all cases, based on the drinking water pathway.

F.4 Discussion of RCRA Cell Failure Scenario Results

This section discusses the long-term impacts of disposing RCC waste in a RCRA landfill, primarily potential dose from ingestion of groundwater, but also potential dose to a worker repairing a failed cell liner. The dose to a remediation worker is bounded by the limiting or basis dose for RCC. Concentrations of radionuclides in RCC waste are defined by the dose which would be received by a worker, assuming all waste at the RCRA landfill were at the RCC limit. Therefore, a hazardous waste worker on a remediation project would receive a dose no greater than the fraction of a working year spent on the project, times the RCC basis dose.

The RESRAD and RESRAD-OFFSITE computer models were used to calculate the potential dose from ingestion of groundwater, after failure of a landfill cell liner with and without repair of the cell. If a water well adjacent to the site were a community water system, analyses for gross alpha and gross beta would be required on an annual basis. Thus, radionuclide contaminants could be detected before much time had elapsed. The detection-level requirement for tritium is 1000 pCi/L (1/20 of the maximum concentration limit). The detection limit requirement for gross beta is 4 pCi/L (see 40 CFR 141.25), which would limit potential exposure to the public to beta-emitting nuclides such as ^{99}Tc, if a well near a closed RCRA site were a public drinking water source.

The results of this study indicate that for only a few mobile radionuclides, including ^{99}Tc, ^{14}C, and ^{129}I, disposed in permitted sites could potentially reach groundwater. For shorter-lived and less mobile radionuclides, radioactive decay would prevent contamination of groundwater. Only the Deer Park site, where the depth of groundwater is only 3.2 m, had the potential to contaminate groundwater within 1000 years. The migration of ^{14}C could be stopped effectively by a vadose zone composed of limestone, as in the case of the Emelle, Alabama, site.

For each mobile radionuclide, results of breakthrough time, T_{MAX} and DSR were determined. High DSR values for ^{129}I indicate that the quantity to be disposed in a landfill is more limiting than the RCC based on worker exposures. Limits for an individual landfill could be determined based on calculations using site-specific parameters. Although site-specific parameters are used (if available), the values of some very important parameters are not well known for some of the sites. In particular, soil types, pH, and other geologic and hydrologic parameters have a large impact on migration of radionuclides.

RESRAD, a screening model which is more conservative than the RESRAD-OFFSITE version, was used to study the sensitivity of DSR and T_{MAX} to waste-layer thickness, precipitation (or infiltration), unsaturated zone thickness, and aquifer velocity. These parameters were varied from about one-half to twice the base case value.

In the most extreme and bounding case, remediation of a RCRA cell after groundwater was contaminated was shown to be only marginally effective in reducing the maximum dose from drinking water. The results show that early intervention, prompted by the early warning of a leak detection system, would be necessary to prevent migration of contaminants into a groundwater system. Remediating the cell alone may be of use if done before half the time to reach maximum concentration (T_{MAX}). After a contaminant has reached a water supply, the vadose zone would remain a source of contamination until it has been flushed out by the passage of more water.

Potential doses from some actual waste streams that may meet RCC levels were estimated using RESRAD-OFFSITE. The radionuclide that was most limiting in these streams was ^{99}Tc, which is present in wastes from recycled uranium. The greatest potential MEI doses from the drinking water pathway, based on 16 currently stored waste streams meeting RCC Level 3, was 13 mrem/yr. This is based on disposal of 42 Ci of ^{99}Tc from K-25 at Emelle. The maximum dose would be expected to occur more than 3000 years in the future.

There was less inventory information for projected inventory, and the uncertainty is greater. From the limited information available in the mixed waste inventory report, there are nine projected waste streams that would meet RCC Levels 2 and 3 criteria. Potential maximum dose from the drinking water pathway was estimated to be less than 0.1 mrem/yr and would not occur for more than 3000 years.

F.5 References

Aaberg, R. L., D. A. Baker, M. F. Jarvis, K. Rhoads, and W. E. Kennedy, Jr. 1995. *Radiation Dose Assessment Methodology and Preliminary Dose Estimates to Support U.S. Department of Energy Radiation Control Criteria for Regulated Treatment and Disposal of Hazardous Wastes and Materials*. PNL-9405, Pacific Northwest National Laboratory, Richland, Washington.

Chau, T. K., R. Shuman, R. D. Baird, and E. A. Jennrich. 1992. *Draft Release Limits for Contaminated Sludges and Solids*. RAE-9005/7-2, Rogers and Associates Engineering Corporation, Salt Lake City, Utah.

Ikenbery, T. I., and B. A. Napier. 1992. *Scoping Calculation for Components for the Cow-Milk Dose Pathway for Evaluating the Dose Contribution From Iodine-131*. BN-SA-3361 HEDR, Pacific Northwest Laboratory, Richland Washington.

Kincaid, C. T., J. W. Shade, G. A. Whyatt, M. G. Piepho, K. Rhoads, J. A. Voogd, J. H. Westsik, Jr, M. D. Freshley, K. A. Blanchard, and B. G. Lauzon. 1995. *Performance Assessment of Grouted Double-Shell Tank Waste Disposal at Hanford*. WHC-SD-WM-EE04, rev. 1, vol. 1, Westinghouse Hanford Company, Richland, Washington.

U.S. Department of Energy (DOE). 1995. Mixed Waste Inventory Report, MITI software system. Downloaded via the Internet at http://www.em.doe.gov/ffcabb/bbcaftp/index.html. Includes MWIRUSER.EXE, a self-extracting executable containing the 1995 MWIR program user manual, and MWIR1995.EXE, a self-extracting executable containing the 1995 MWIR program. (Posted 1/11/1996)

Yu, C., C. Loureiro, J. J Cheng, L. G. Jones, Y. P. Chia, and E. Faillace. 1993a. *Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil*. ANL/EAIS-8, Environmental Assessment and Information Sciences Division, Argonne National Laboratory, Argonne, Illinois.

Yu, C., A. J. Zielen, J. J. Cheng, Y. C. Yuan, L. G. Jones, D. J. DePoire, Y. Y. Wang, C. O. Loureiro, E. Gnanapragasam, E. Faillace, A. Wallo III, W. A. Williams, and H. Peterson. 1993b. *Manual for*

Implementing Residual Radioactive Material Guidelines Using RESRAD, Version 5.0. ANL/EAD/LD-2, Argonne National Laboratory, Argonne, Illinois.

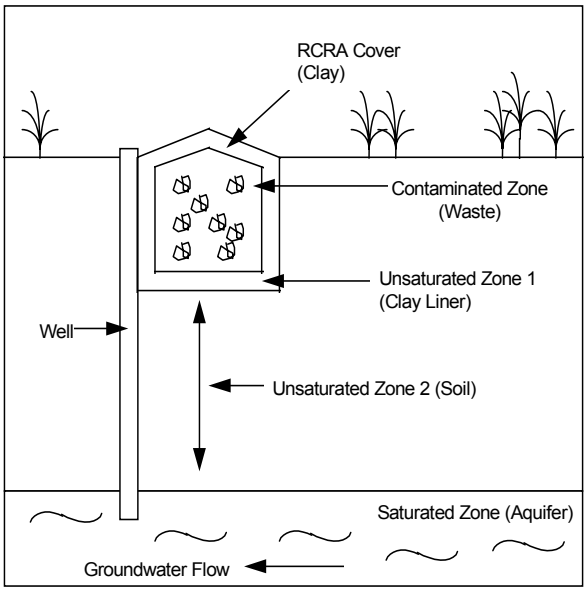

Figure F.1. Schematic Diagram of Landfill for RESRAD Model

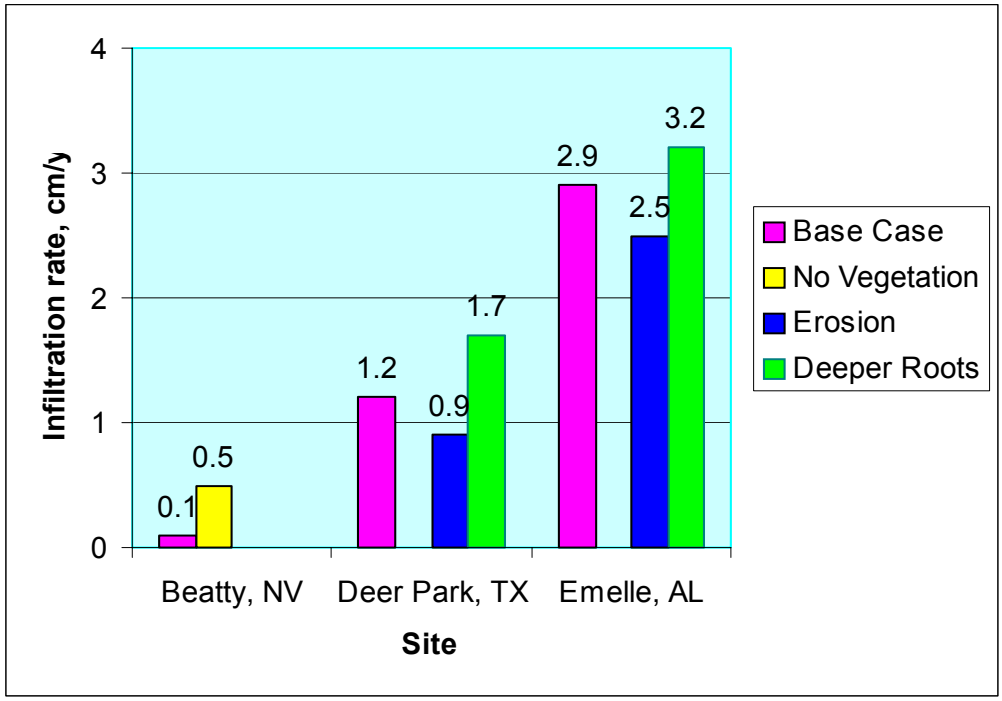

Figure F.2. Base Case and Bounding Infiltration Rates

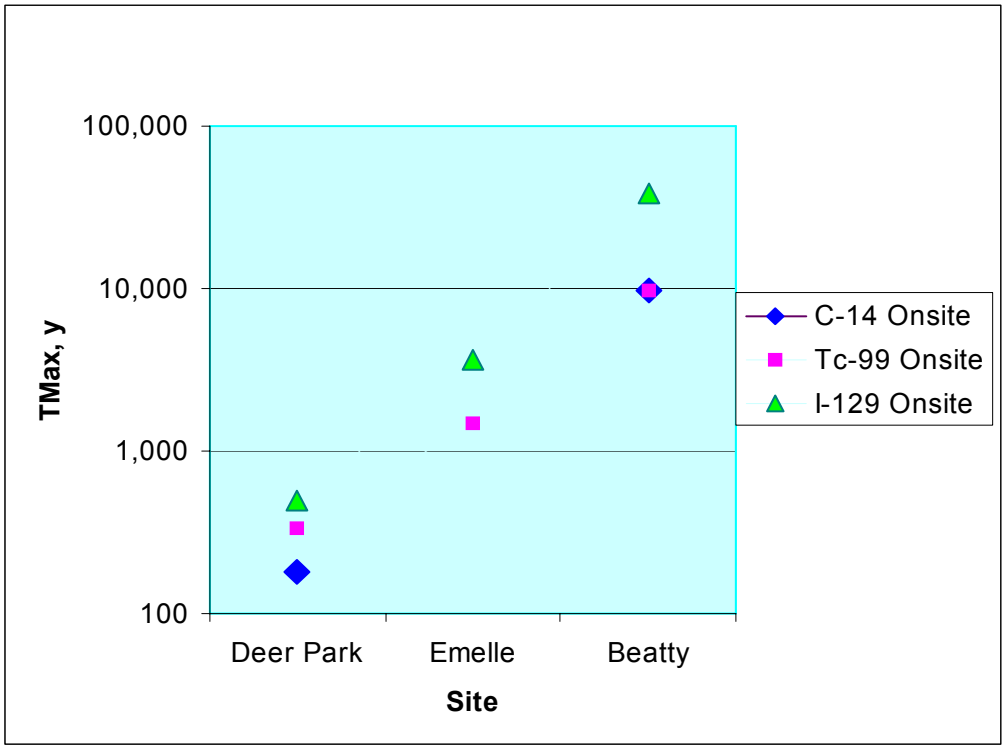

Figure F.3. Time of Maximum Concentration

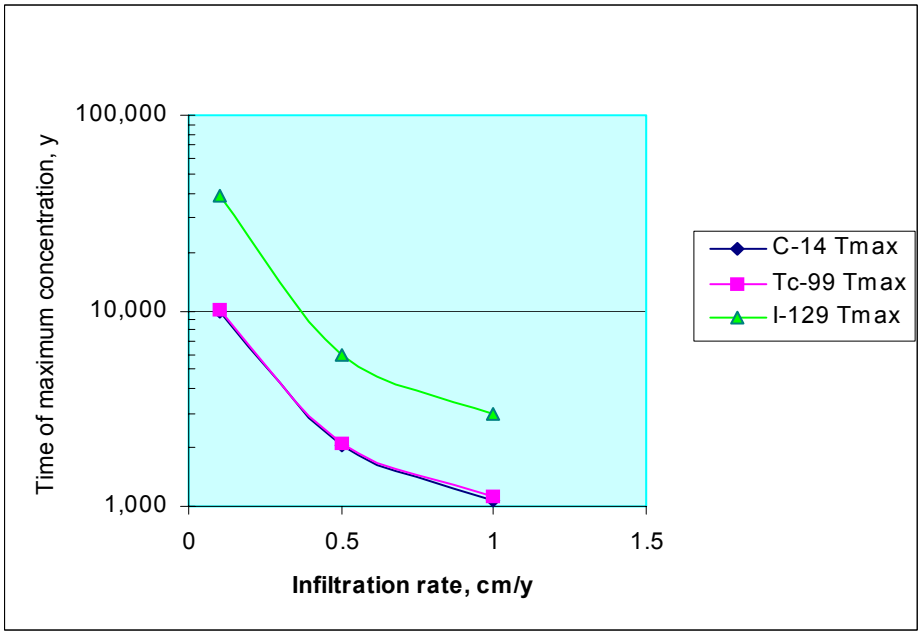

Figure 4a. T_{MAX} for Beatty as a Function of Infiltration Rate

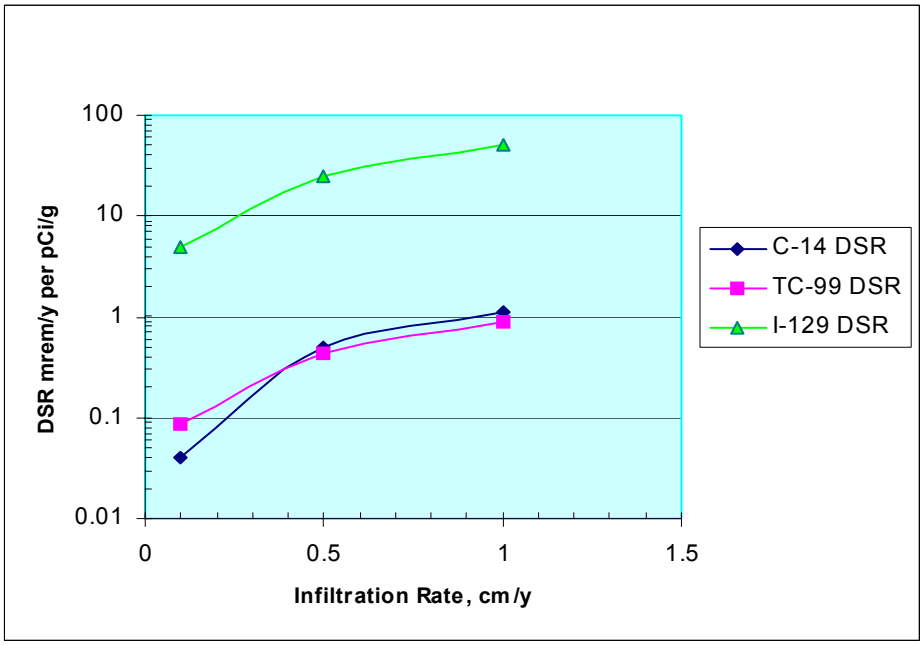

Figure F.4b. DSR for Beatty as a Function of Infiltration Rate

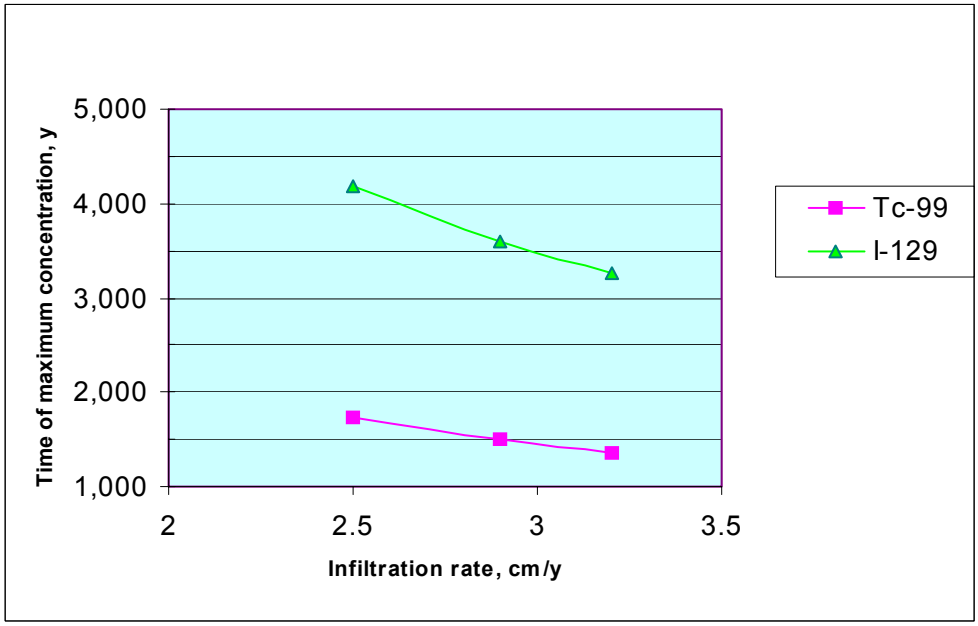

Figure F.5a. T_{MAX} at Emelle as a Function of Infiltration Rate

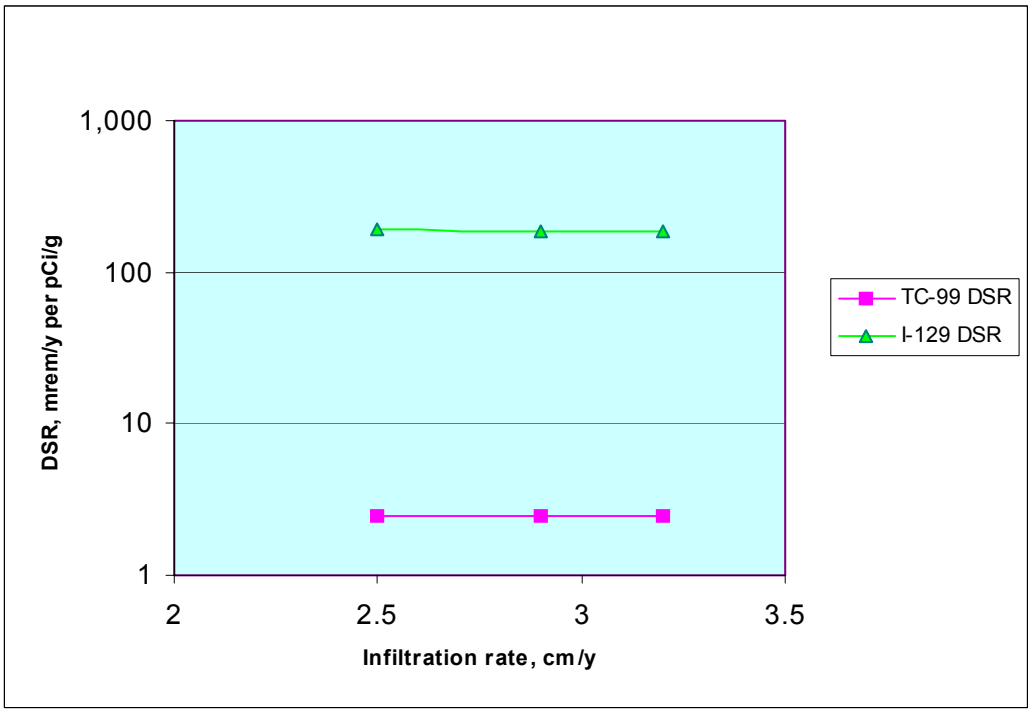

Figure F.5b. DSR for Emelle as a Function of Infiltration Rate

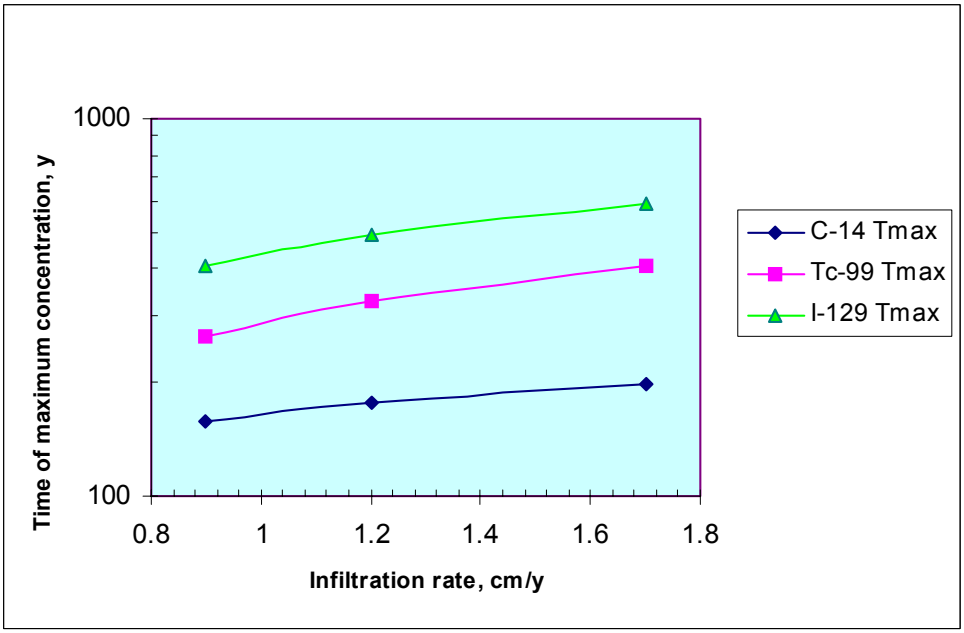

Figure F.6a. T_{MAX} for Deer Park as a Function of Infiltration Rate

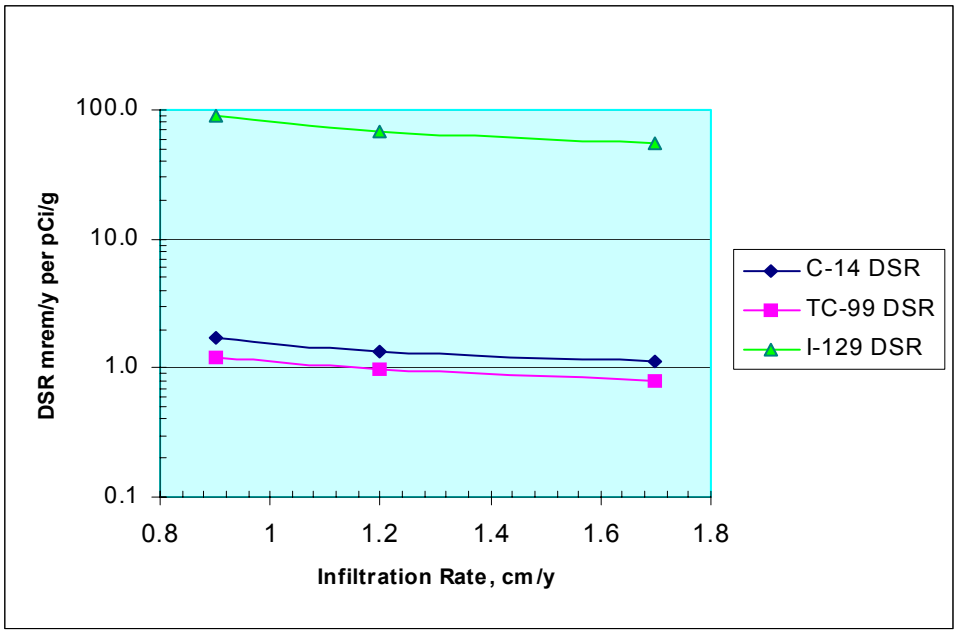

Figure F.6b. DSR for Deer Park as a Function of Infiltration Rate

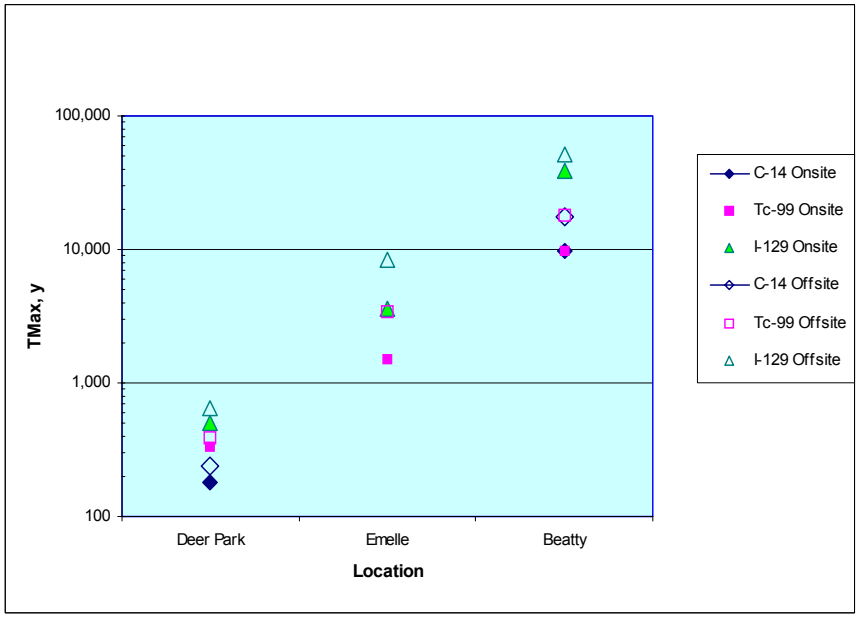

Figure F.7. T_{MAX} Onsite vs Offsite

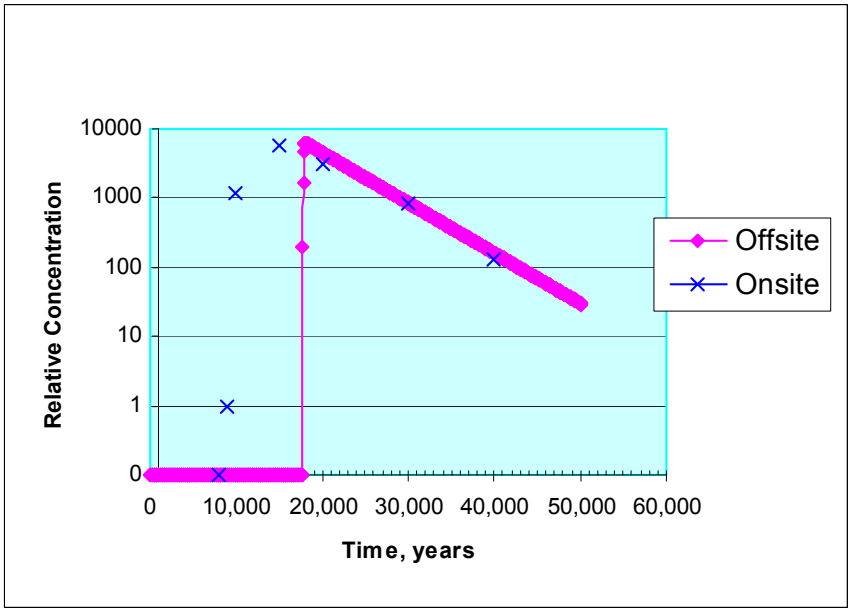

Figure F.8. Groundwater Concentration Based on a Hypothetical ^{99}Tc Release at the Beatty, NV, Site

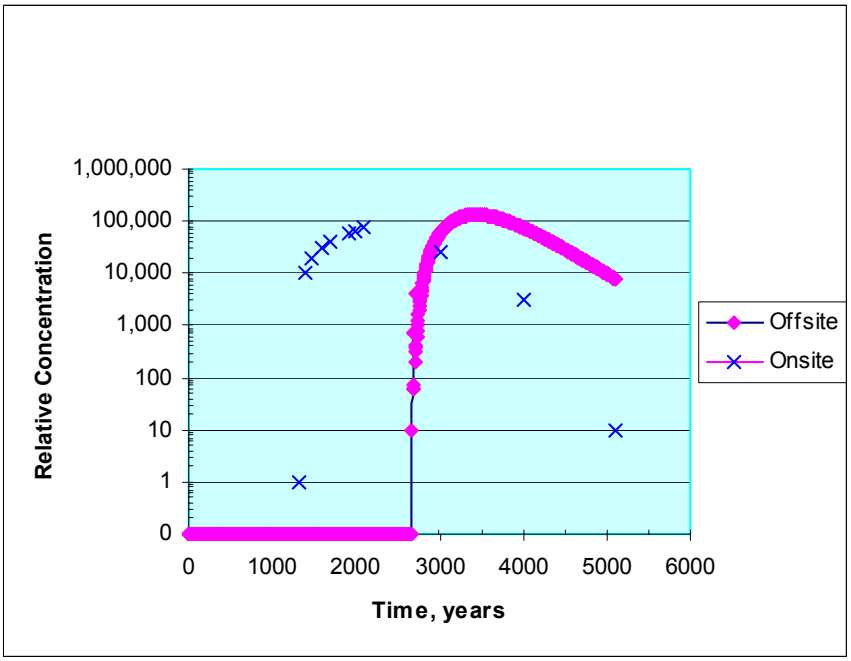

Figure F.9. Groundwater Concentration Based on a Hypothetical ^{99}Tc Release at the Emelle, AL, Site

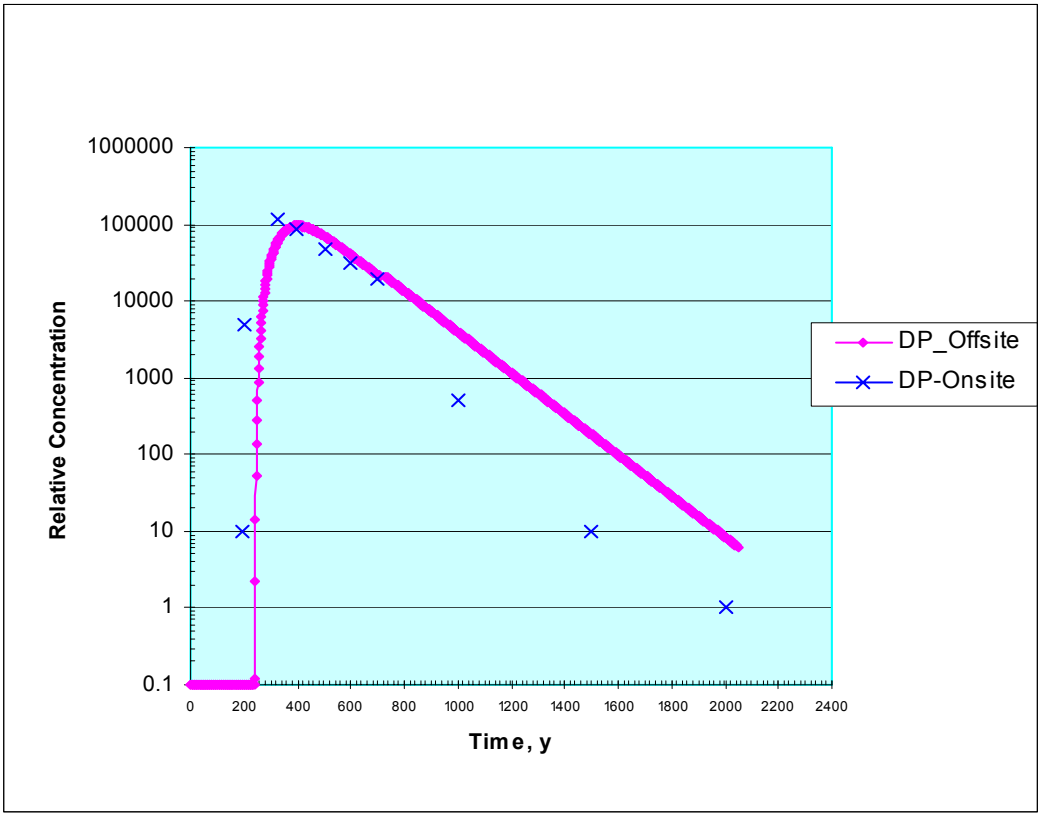

Figure F.10. Groundwater Concentration Based on a Hypothetical ^{99}Tc Release at the Deer Park, TX Site

Table F.1. Input Parameters for RESRAD Calculations

Parameter	Dry Site Beatty, NV	Wet Sites	
		Emelle, AL	Deer Park, TX
Landfill and Aquifer Parameters			
Area of contaminated zone (m^2); dimensions (m)	4.54 E+04 305 * 149	6.68 E+04 274 * 244	6.68 E+04 274 * 244
Thickness of contaminated zone (m)	30.5	8	30.5
Length parallel to aquifer (m)	305	274	274
Cover depth (m)	2.4	1.2	1.7
Density of cover material (g/cm)	1.5	1.5	1.5
Cover depth erosion rate ($m*yr^{-1}$)	-- [a]	--[a]	--[a]
Infiltration rate following liner failure (cm/yr)[b]	<0.1[b]	2.9[c]	1.2[c]
Runoff coefficient	-- [d]	-- [d]	-- [d]
Evapotranspiration coefficient	-- [e]	-- [e]	-- [e]
Density of contaminated material (g/cm^3)	1.6	1.6	1.6
Aquifer velocity (m/yr)	2[f]	0.15	1.2
Aquifer porosity	0.4	0.33	0.48
Distance to aquifer (m)	76.2	183	3.2
Liner Parameters			
Thickness of clay liner (m) Density (g/cm^3)	0.2 1.5	1.2 1.5	1.2 1.5
Total porosity[f]	0.448[g]	0.448[g]	0.448[g]
Effective porosity[f]	0.448[g]	0.448[g]	0.448[g]
Soil-specific exponential parameter[f]	10[g]	10[g]	10[g]
Hydraulic conductivity (m/yr)	4.1E-2	3.3E-2	3.15E-2

(a) Cover erosion rate and water table drop rate were not considered.
(b) Infiltration rate for Beatty is based on field data using chloride mass balance method (personal communication from M.J. Fayer, June 15, 2000).
(c) Infiltration estimated using the UNSAT-H model; low reliability due to lack of soil or vegetation data.
(d) Runoff coefficient not used; infiltration is estimated separately.
(e) Evapotranspiration coefficient is not used; infiltration is estimated separately.
(f) A value of 90 in Chau et al. (1992) was questioned. The authors contacted Bill Andrews and Todd Johnson, both at the University of Nevada, Las Vegas, and Randy Laczniak and Dave Prudic at USGS Project Office and Water Resources in Carson City, Nevada, to validate data used in earlier RESRAD runs. It was found that the aquifer flow rate is dependent on the aquifer; the rate was modified for this assessment.
(g) Parameter values adapted from Kincaid et al. 1995.

Table F.2. Input Parameters for RESRAD-OFFSITE Calculations

Parameter	Dry Site Beatty, NV	Wet Sites	
		Emelle, AL	Deer Park, TX
Distance from down-gradient edge of source to well (m)	100	100	100
C/C distance from source to well (m)	252.5	237.0	237.0
Longitudinal dispersivity (m)	25.25	23.7	23.7
Horizontal lateral dispersivity (m)	8.3325	7.821	7.821
Vertical lateral dispersivity (m)	0.2525	0.237	0.237
Depth of aquifer (m)	23	120	10
Note: In the absence of information about the aquifer thickness at Deer Park, the well depth is used. If aquifer thickness is greater, the predicted concentration will be lower.			

Table F.3. Sorption Coefficient (K_d) Used in Calculations and Literature Values

Element	K_d Values Used in Calculations, cm^3/g			Literature K_d Values, cm^3/g or mL/g				
				Handbook[(a)]			Grout PA[(b)]	
	Clay Liner[(c)]	Soil[(c)]	Chalk[(d)]	Sand	Loam	Clay	Grout	Soil
^3H	0	0	0	--	--	--	0	0
C	0	0	100	5	20	1	2625	0
Co	1000	200	NA[(e)]	60	1300	550	125	3
Se	1000	3	NA[(e)]	150	500	740	125	3
Sr	100	30	NA[(e)]	15	20	110	125	3
Tc	1	0	0.1	0.1	0.1	1	2	0
I	1	0.3	0.5	1	5	1	0	0
Cs	1000	400	NA[(e)]	280	4600	1900	125	3
U	100	15	4	35	15	1600	2625	0
Np	40	10	10	5	25	55	125	3
Pu	2000	200	NA[(e)]	550	1200	5100	2625	21
Am	1000	100	40	1900	9600	8400	2625	21

(a) Yu et al. 1993a.
(b) Kincaid et al. 1995. Grout K_d values could be a surrogate for waste treated with Portland cement and pozzolanic materials.
(c) Personal communication with DI Kaplan, PNNL, March 27, 1997.
(d) Informal letter report, *Selection of K_d Values Used for the Emelle, AL Landfill Site*, DI Kaplan, PNNL, May 13, 1997.
(e) NA - Sorption coefficient estimate in chalk is not available for this element.

Table F.4. RESRAD Results from Beatty, Nevada, Site, at Infiltration of 0.1 cm/yr

Nuclide	Breakthrough Time, yr	T_{MAX} for Radionuclide, yr	DSR at T_{MAX}, (mrem/yr) /(pCi/g)
^{3}H	NA [(a)]	—	—
^{14}C	**9,740**	**9,780**	**0.04**
^{60}Co	NA[(a)]	—	—
^{79}Se	NA	—	—
^{90}Sr	NA[(a)]	—	—
^{99}Tc	**10,080**	**10,120**	**0.09**
^{129}I	**38,800**	**38,900**	**5.00**
^{137}Cs	NA[(a)]	—	—
^{238}U	NA[(b)]	—	—
^{237}Np	NA[(b)]	—	—
^{239}Pu	NA[(b)]	—	—
^{241}Am	NA	—	NA

(a) Time at maximum dose is not applicable; nuclide decays before reaching well.
(b) No release of these long-lived nuclides until more than 100,000 years in the future.

Table F.5. Tabulation of Sensitivity Case Results for Beatty Site (Base case values in **bold**)

Parameter	T_{MAX} and DSR by Radionuclide							
	^{3}H[(a)]		^{14}C		^{99}Tc		^{129}I	
	T_{MAX}	DSR	T_{MAX}	DSR	T_{MAX}	DSR	T_{MAX}	DSR
Waste Thickness, m								
8.0	--	--	9,800	0.04	10,100	0.09	39,000	**5.0**
15.0	--	--	9,800	0.04	10,100	0.09	39,000	**5.0**
30.5	--	--	9,800	0.04	10,100	0.09	39,000	**5.0**
45.0	--	--	9,800	0.04	10,100	0.09	39,000	**5.0**
Unsaturated Zone Thickness, m								
38.0	--	--	**4,900**[(b)]	**0.07**	**5,300**	0.09	**20,000**	**5.0**
76.2	--	--	**9,800**	**0.04**	**10,100**	0.09	**39,000**	**5.0**
152.0	--	--	**19,000**	**0.01**	**20,000**	0.08	**77,000**	**5.0**
Aquifer Velocity, m/yr								
1.0	--	--	9,800	**0.08**	10,100	**0.17**	39,000	**10.0**
2.0	--	--	9,800	**0.04**	10,100	**0.09**	39,000	**5.0**
5.0	--	--	9,800	**0.016**	10,100	**0.035**	39,000	**2.0**
10.0	--	--	9,800	**0.008**	10,100	**0.018**	39,000	**1.0**
90.0	--	--	9,700	**0.0009**	10,100	**0.002**	39,000	**0.1**
Infiltration Rate, cm/yr								
0.1	--	--	**9,800**	**0.04**	**10,000**	**0.09**	**39,000**	**5.0**
0.5	--	--	**2,000**	**0.5**	**2,100**	**0.4**	**5,900**	**25.0**
1.0	--	--	**1,100**	**1.1**	**1,100**	**0.9**	**2,900**	**50.0**

(a) The simulation indicates that tritium (^{3}H) decays completely before reaching groundwater at the Beatty site.
(b) **Shaded areas** indicate that T_{MAX} or DSR vales changed by a factor of 2 or more.

Table F.6. RESRAD Results for Emelle, Alabama, Site at Infiltration Rate of 2.9 cm/yr

Nuclide	Breakthrough Time, yr	T_{MAX} for Radionuclide, yr	DSR at T_{MAX}, (mrem/yr) /(pCi/g)
^{3}H	840	—	—
^{14}C	>>100,000	—[a]	—
^{60}Co	--[b]	—	—
^{79}Se	92,000	>100,000	—
^{90}Sr	--[b]	—	—
^{99}Tc	1400	1500	2.5
^{129}I	3300	3600	190
^{137}Cs	--[b]	—	—
^{238}U	>100,000	—	—
^{237}Np	>100,000	—	—
^{239}Pu	--[c]	—	—
^{241}Am	—	—	—

(a) No release would occur until long after 100,000 years.
(b) Nuclide source decays before reaching well.
(c) K_d values for Pu in chalk were not available.

Table F.7. Tabulation of Sensitivity Case Results for Emelle Site (Base case values in **bold**)

Parameter	T_{MAX} and DSR by Radionuclide							
	^{3}H		^{14}C[(a)]		^{99}Tc		^{129}I	
	T_{MAX}	DSR	T_{MAX}	DSR	T_{MAX}	DSR	T_{MAX}	DSR
Waste Thickness, m								
8.0	--	--	--	--	1500	1.8	3600	140
15.0	--	--	--	--	1500	2.2	3600	170
30.5	**--**	**--**	**--**	**--**	**1500**	**2.5**	**3600**	**190**
45.0	--	--	--	--	1500	2.6	3600	200
Unsaturated Zone Thickness, m								
90.0	--	--	--	--	830	2.5	1900	190
140.0	--	--	--	--	1200	2.5	2800	190
183.0	**--**	**--**	**--**	**--**	**1500**	**2.5**	**3600**	**190**
230.0	--	--	--	--	1800	2.5	4400	190
Aquifer Velocity, m/yr								
0.1	--	--	--	--	1500	2.4	3600	180
0.15	**--**	**--**	**--**	**--**	**1500**	**2.5**	**3600**	**190**
0.3	--	--	--	--	1500	2.5	3600	190
Infiltration Rate, cm/yr								
2.5	--	--	--	--	1700	2.5	4200	190
2.9	**--**	**--**	**--**	**--**	**1500**	**2.5**	**3600**	**190**
3.2	--	--	--	--	1400	2.5	3300	190

(a) Transport of ^{14}C from the site is limited by exchange with the carbonate-based geologic formation; ^{14}C does not migrate appreciably from the waste disposal site.

Table F.8. RESRAD for Deer Park, Texas, Site at Infiltration Rate of 1.2 cm/yr

Nuclide	Breakthrough Time, yr	T_{MAX} for Radionuclide, yr	DSR at T_{MAX}, (mrem/y) /(pCi/g)
^{3}H	70	80	8.E-5
^{14}C	70	180	1.4
^{60}Co	--	--	--
^{79}Se	<100,000	>100,000	--
^{90}Sr	--	--	--
^{99}Tc	220	330	0.97
^{129}I	270	500	70.0
^{137}Cs	--	--	--
^{238}U	--	--	--
^{237}Np	--	--	--
^{239}Pu	--[(a)]	--	--
^{241}Am	--	--	--

(a) Indicates time at maximum dose is not applicable; nuclide decays before reaching well.

Table F.9. Tabulation of Sensitivity Case Results for Deer Park Site (Base case values in **bold**)

Parameter	T_{MAX} and DSR by Radionuclide							
	^{3}H		^{14}C		^{99}Tc		^{129}I	
	T_{MAX}	DSR	T_{MAX}	DSR	T_{MAX}	DSR	T_{MAX}	DSR
Waste Layer Thickness, m								
4	81	7.8E-5	177	1.0	330	0.73	495	57
8	**82**	**8.2E-5**	**177**	**1.4**	**330**	**0.97**	**495**	**69**
15	82	8.4E-5	177	1.6	331	1.1	495	76
30.5	83	8.5E-5	177	1.7	331	1.2	495	80
Unsaturated Zone Thickness, m								
1	60	**2.8E-4**	155	1.4	309	1.0	430	69
1.6	64	**2.2E-4**	159	1.4	313	1.0	443	69
3.35	**82**	**8.2E-5**	**177**	**1.4**	**330**	**1.0**	**495**	**69**
5	100	**3.0.E-5**	195	1.4	348	1.0	545	69
Aquifer Velocity, m/yr								
0.6	82	**8.1E-5**	289	**2.0**	443	**1.5**	721	**113**
1.2	**82**	**8.2E-5**	**177**	**1.4**	**330**	**0.97**	**495**	**69**
2.4	82	**8.2E-5**	121	**0.80**	274	**0.57**	382	**38**
5	82	**8.2E-5**	92	**0.42**	245	**0.30**	323	**19**
Infiltration Rate, cm/yr								
0.9	63	**3.2E-4**	158	1.7	265	1.2	409	89
1.2	**82**	**8.2E-5**	**177**	**1.4**	**330**	**1.0**	**495**	**69**
1.7	104	**1.9E-5**	299	1.1	405	0.8	596	55

Table F.10. RESRAD OFFSITE Results for Beatty, NV, Emelle, AL, and Deer Park, TX, Sites

Nuclide	T_{MAX} for Radionuclide, yr	T_{MAX} for Onsite Calculations, yr	DSR at T_{MAX}, (mrem/y) /(pCi/g)	DSR for Onsite Calculations
Beatty, NV				
^{3}H	—	9,700	—	—
^{14}C	17,600	9,700	0.0085	0.04
^{99}Tc	17,900	10,100	0.047	0.09
^{129}I	52,000	39,000	2.8	5.0
Emelle, AL				
^{3}H	—	840	—	—
^{14}C	—	>100,000	—	—
^{99}Tc	3400	1400	1.0	2.7
^{129}I	8300	3300	78	190.
Deer Park, TX				
^{3}H	150	70	6.E-6	8.E-5
^{14}C	240	70	1.1	1.4
^{99}Tc	390	220	0.79	1.0
^{129}I	640	270	54	70.0

(a) Time at maximum dose is not applicable; nuclide decays before reaching well.

Table F.11. Summary of Stored RCC Potential Waste Streams Identified from MITI Database (DOE 1995)

DOE Site	Number of Waste Streams	Treated Volume, m^3	Radionuclide Inventory, Ci		
			^{3}H	^{99}Tc	U[(a)]
Stored Inventory, RCC Level 3[(b)]					
K-25	3[(c)]	30,510	--	42	0.50
Y-12	2[(d)]	11,540	--	0.0004	0.22
Portsmouth	4[(e)]	430	--	0.08	0.07
Savannah River	1[(f)]	60	0.07	--	0.002
Total, Stored Level 3	10	42,540	0.07	42	0.79
Stored Inventory, RCC Level 2					
Y-12	1[(g)]	400	--	--	0.014
Portsmouth	2[(h)]	600	--	0.02	0.009
Savannah River	3[(i)]	1,200	0.0001	--	0.015
Total, Projected Level 2	6	2,200	0.0001	0.02	0.038

(a) U is not generally considered a mobile contaminant, but is an important part of many waste streams; all isotopes are included.
(b) Waste streams > RCC Level 2 are listed separately. The waste streams listed below as meeting RCC Level 2 would also meet the Level 3 criteria.
(c) Waste streams from K-25 include B/C pond sludge, both currently stabilized and to be stabilized, residue from rotary kiln (TSCA ash), and Th, Pu, Np, and Cs.
(d) Waste streams from Y-12 include WETF/CPCF treatment sludges and soils, and soils contaminated with solvents. Waste streams also include Th, Pu, and Cs.
(e) Waste streams from Portsmouth include clean-up and spill response residue, chromic acid tank closure waste (includes ^{226}Ra), paints and thinners, and metal shavings and scrap.
(f) Waste stream from Savannah River is SRTC low-activity waste (also contains ^{137}Cs and ^{239}Pu).
(g) Level 2 waste stream from Y-12 consists of solvent-contaminated soils.
(h) Level 2 material from Portsmouth includes waste from hazardous waste unit closure and personal protective equipment and miscellaneous debris.
(i) Level 2 waste streams from Savannah River include M area plating line sludge, mixed waste oil, and tritiated oil.

Table F.12. Potential MEI Dose Based on **Stored** RCC Levels 2 and 3 Inventory

RCC Levels 2 and 3 Inventory, Ci		Potential Dose to MEI,[a] mrem/yr		
		Beatty	Emelle	Deer Park[b]
^{3}H	0.070[c]	--	--	5.E-07
^{14}C	0[d]	--	0 [e]	--
^{99}Tc	41.8	1	13	38
^{129}I	0[d]	--	--	--
U	0.828	0	0	0
Time of Maximum Dose, yr		>10,000	3400	400
Contributing Nuclide(s)		Tc	Tc	Tc
Maximum Dose, mrem		1	13	—

(a) Potential dose based on DSR from RESRAD-OFFSITE.
(b) Drinking water pathway not credible for Deer Park. Nonpotable saline aquifer underlies site; therefore, maximum dose is not applicable (NA).
(c) There was a limited inventory of tritium in the identified waste streams.
(d) No RCC waste streams containing ^{14}C or ^{129}I were identified.
(e) The geology at Emelle would preclude the migration of ^{14}C if it were present.

Table F.13. Potential MEI Dose Based on **Stored** RCC Level 2 Inventory

RCC Level 2 Inventory, Ci		Potential Dose to MEI, mrem/yr		
		Beatty	Emelle	Deer Park[a]
^{3}H	0.0001	--	--	7.0E-10
^{14}C	0[b]	--	0[c]	--
^{99}Tc	0.02	4.E-4	6.E-3	2.E-2
^{129}I	0[b]	--	--	--
U	0.038	0	0	0
Time of Maximum Dose, yr		>10,000	3400	400
Contributing Nuclide(s)		^{99}Tc	^{99}Tc	^{99}Tc
Maximum Dose, mrem		4.E-4	6.E-3	—

(a) Drinking water pathway not credible for Deer Park. Nonpotable saline aquifer underlies site; therefore, maximum dose is not applicable (NA).
(b) No RCC waste streams containing ^{14}C or ^{129}I were identified.
(c) The geology at Emelle would preclude the migration of ^{14}C if it were present.

Table F.14. Summary of **Projected** RCC Waste Streams Identified from MITI Database (DOE 1995)

DOE Site	Number of Waste Streams	Treated Volume, m^3	Radionuclide Inventory, Ci		
			^{3}H	^{99}Tc	^{238}U[(a)]
Projected Inventory, RCC Level 3					
K-25	1[(b)]	700	--	3.5E-4	0.365
Y-12	1[(c)]	1600	--	7.E-5	0.031
Savannah River	1[(d)]	525	0.05	--	--
Total, Level 3	**3**	**2800**	**0.05**	**4.2E-4**	**0.396**
Projected Inventory, RCC Level 2					
Portsmouth	2[(e)]	1500	--	0.09	0.042
Savannah River	4[(f)]	1800	1.1E-2	--	2.7E-4
Total, Level 2	**6**	**3300**	**1.1E-2**	**0.09**	**0.042**

(a) U is not generally consider a mobile contaminant, but is an important part of many waste streams; all isotopes are included.
(b) The projected RCC Level 3 waste from K-25 consists of residue from the rotary kiln (TSCA ash) as well as Th, Pu, Np, and Cs.
(c) The projected RCC Level 3 waste from Y-12 is WETF/CPCF treatment sludges and soils.
(d) The projected RCC Level 3 waste is from Savannah River SRTC low-activity waste (also contains ^{137}Cs and ^{239}Pu).
(e) The projected RCC Level 2 material from Portsmouth includes waste from hazardous waste unit closure and from personal protective equipment and miscellaneous debris.
(f) Projected Level 2 waste streams from Savannah River include M area plating line sludge, IDW soils, sludge, and slurry, mixed waste oil, and tritiated oil.

Table F.15. Potential MEI Dose Based on **Projected** RCC Levels 2 and 3 Inventory

RCC Levels 2 and 3 Inventory, Ci		Potential Dose to MEI, mrem/yr		
		Beatty	**Emelle**	**Deer Park[a]**
^{3}H	0.05	--	--	3.E-7
^{14}C	0[b]	--	0[c]	--
^{99}Tc	0.09	0.002	0.03	0.08
^{129}I	0[b]	--	--	--
U	0.44	0	0	0
Time of Maximum Dose, yr		>10,000	3400	400
Contributing Nuclide(s)		^{99}Tc	^{99}Tc	^{99}Tc
Maximum Dose, mrem		0.002	0.03	—

(a) Drinking water pathway not credible for Deer Park. Nonpotable saline aquifer underlies site; therefore, maximum dose is not applicable (NA).
(b) No RCC waste streams containing ^{14}C or ^{129}I were identified.
(c) The geology at Emelle would preclude the migration of ^{14}C if it were present.

Distribution

No. of
Copies

OFFSITE (51)

Gary Robertson
Waste Management Section
Division of Radiation Protection
Airdustrial Center Bldg. # 5
P.O. Box 47827
Olympia, Wa 98504-7827

William Sinclair
Division of Radiation Control
Department of Environmental Quality
P.O. Box 144850
Salt Lake City, UT 84114-4850

Ken Weaver
Radiation Services
Colorado Department of Public Health and Environment
Laboratory and Radiation Services Division
8100 Lowry Blvd.
Denver, CO 80230-6928

Mikel Elsen
Division of Radiation Protection
Airdustrial Center Bldg. # 5
P.O. Box 47827
Olympia, Wa 98504-7827

Denny Gallow
Department of Environmental Protection
Bureau of Air Management
Division of Radiation
79 Elm Street
Hartford, CT 06106-5127

Thor Strong
MI Department of Environmental Quality
LLRW Authority
P.O. Box 3063
Lansing, MI 48909-8130

Nancy Stanley
New Jersey Department of Environmental Protection
Radiation Protection Programs
Bureau of Environmental Radiation
P.O. Box 415
Trenton, NJ 08625-0415

John Volpe
Radiation Health and Toxic Agents Branch
Cabinet of Health Services
275 Main Street
Mailstop HS 2E-D
Frankfort, KY 40621-0001

Mark Yeager
Department of Health and Environmental Control
Bureau of Land and Waste Management
2600 Bull Street
Columbia, SC 29201

Jeff Deckler
Remedial Programs Manager
Colorado Department of Public Health and Environment
4300 Cherry Creek Drive South
Denver, CO 80246-1530

Larry Erickson
Environmental Engineer IV
Missouri Department of Natural Resources
1738 E. Elm, Lower Level
Jefferson City, MO 65101

Joan M. Jones
Environmental Specialist III
Maine Department of Environmental Protection
BRWM 17 State House Station
Augusta, ME 04533

Robert C. Maiers, P.E.
Chief, Decommissioning Section
Bureau of Radiation Protection
Rachel Carson State Office Bldg.
P.O. Box 8469
Harrisburg, PA 17105-8469

Graham E. Mitchell
Chief, Office of Federal Facility Oversight
Ohio EPA
401 East Fifth Street
Dayton, OH 45402-2911

Dale Rector
Assistant Director
TN DEC
DOE Oversight Division
761 Emory Valley Rd
Oak Ridge, TN 37830

Dania E. Rodriguez
Federal Facilities Staff Associate
ASTSWMO
444 North Capitol Street, NW
Suite 315
Washington, DC 20001

Ronald Wascom
Administrator
LS DEQ
Division of Environmental Assistance
P.O. Box 821235
Baton Rouge, LA 70884-2135

Mike Wilson
Program Manager, Nuclear Waste Program
Washington Department of Ecology
300 Desmond Dr, SE
P.O. Box 47600
Olympia, WA 98504-7600

Barbara Youngberg
Chief, Radiation Section
Division of Solid and Hazardous Materials
New York State Department of Environmental Conservation
625 Broadway
Albany, NY 12233-7255

Margaret MacDonell, EAD/900
Argonne National Laboratory
9700 S. Cass Ave.
Argonne, IL 60439

Terry Ross
P.O. Box 2212
Ames, Iowa 50010

Charley Yu, Ph.D, CHP
Argonne National Laboratory
EAD-900
9700 S. Cass Avenue
Argonne, IL 60439

G. A. Vazquez (30)
U.S. Department of Energy, Headquarters
Forrestal Building, EH-412
1000 Independence Avenue, S.W.
Washington, DC 20585

		No. of Copies
ONSITE	**(10)**	
R. Aaberg	K3-54	(3)
B. Killand	K3-75	(2)
T. Moon	P8-45	
R. Hill	L1-08	
P. Miller	K6-04	
HTL	P8-55	(2)