EGG-WTD-9594 Vol. II
July 1991

INFORMAL REPORT

**Preliminary Systems Design Study
Assessment Report**

Volume II: Main Report

**J. L. Mayberry
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**Idaho
National
Engineering
Laboratory**

*Managed
by the U.S.
Department
of Energy*

*Work performed under
DOE Contract
No. DE-AC07-78ID01570*

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PRELIMINARY SYSTEMS DESIGN STUDY ASSESSMENT REPORT

Volume II
MAIN REPORT

J. L. Mayberry
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J. C. Del Signore

Published July 1991

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Prepared for the
U.S. Department of Energy
Idaho Field Office
Under DOE Contract No. DE-AC07-76ID01570

MASTER

PRELIMINARY SYSTEMS DESIGN STUDY
ASSESSMENT REPORT
EGG-WTD-9594
Volume II

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ABSTRACT

The System Design Study (SDS), part of the Waste Technology Development Department at the Idaho National Engineering Laboratory (INEL), examined techniques available for the remediation of hazardous and transuranic waste stored at the Radioactive Waste Management Complex's Subsurface Disposal Area at the INEL. Using specific technologies, system concepts for treating the buried waste and the surrounding contaminated soil were evaluated. Evaluation included implementability, effectiveness, and cost. SDS resulted in the development of technology requirements including demonstration, testing, and evaluation activities needed for implementing each concept.

The SDS results are published in eight volumes. Volume I contains an executive summary. The SDS summary and analysis of results are presented in Volume II. Volumes III through VII contain detailed descriptions of twelve system and four subsystem concepts. Volume VIII contains the appendixes.

ACKNOWLEDGMENTS

The authors would like to acknowledge the efforts of those that contributed to this report.

EG&G Idaho, Inc., Bechtel National, Inc., Ebasco Environmental, and IT Corp. for providing the assessments and functional and operational requirements for the 12 system and 4 subsystem concepts. Specifically, C. Klassy, K. Sherick and D. Haifner of EG&G Idaho, Inc., R. Schlueter, M. Pong, D. Harris, M. Beathard and P. Yen of Bechtel National, Inc., D. Prinzing, J. Bjorkstam, R. Vankateswar and S. Peck of Ebasco Environmental, J. Plum, J. Valdez, D. Vetter, M. Chavez, S. Djordevic, M. Swientoniewski, John McFee of IT Corp., and H. Kresny of Solmont Corporation.

Karen Grant and Janalee Nelson of EG&G Idaho, and Debra Iniquez of Bechtel National, Inc., for the extra effort required in editing this report.

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ACRONYMS

AEC	U.S. Atomic Energy Commission
ALARA	as low as reasonably achievable
ANL-W	Argonne National Laboratory-West
ARAR	applicable relevant and appropriate requirement
CAA	Clean Air Act
CEA	Atomic Energy Commission (France)
CEPOD	Catalytic Electrolytic Plutonium Oxide Dissolution
CEQ	Council of Environmental Quality
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CM	construction management
CWA	Clean Water Act
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOE-ID	Department of Energy-Field Office, Idaho
DOT	U. S. Department of Transportation
DSCF	dry standard cubic feet
DT&E	demonstration, testing, and evaluation
EM	electromagnetic
EPA	U.S. Environmental Protection Agency
ER	Environmental Restoration
ERDA	Energy Research and Development Administration
ERP	Environmental Restoration Program
F&OR	Functional and Operational Requirement
FFBD	functional flow block diagram

FOM	Figure of Merit
FS	feasibility study
FY	fiscal year
GPR	ground penetrating radar
HEPA	high-efficiency particulate air (filter)
HVAC	heating, ventilating, and air
IAG	Interagency Agreement
INEL	Idaho National Engineering Laboratory
I/O	input/output
ISV	in situ vitrification
LANL	Los Alamos National Laboratory
LDR	land disposal restriction
LLNL	Lawrence Livermore National Laboratory
LLW	low-level waste
MSA	Major System Acquisition
MSO	Molten Salt Oxidation
NEPA	National Environmental Policy Act of 1969
NPL	National Priorities List
NRC	U.S. Nuclear Regulatory Commission
NWCF	New Waste Calcining Facility
ORNL	Oak Ridge National Laboratory
PAN	passive neutron counting
PCB	polychlorinated biphenyl
PFD	process functional diagram
PREPP	Process Experimental Reduction Facility
PVC	polyvinyl chloride
RAM	reliability, availability and maintainability

RCRA	Resource Conservation and Recovery Act
R&D	research and development
RI	Rockwell International
RI/FS	Remedial Investigation and Feasibility Study
RO	reverse osmosis
ROD	Record of Decision
ROM	rough order of magnitude
ROV	remotely operated vehicles
RTR	real-time radiography
RTR	real-time radiography (device)
RWMC	Radioactive Waste Management Complex
scfm	standard ft ³ /min
SDA	Subsurface Disposal Area
SDS	System Design Study
SDWA	Safe Drinking Water Act
SEG	Scientific Ecology Group
SGS	gamma spectroscopy
SWEPP	Stored Waste Examination Pilot Plant
TCLP	toxicity characteristic leaching procedure
TEC	total estimated cost
T/O	tradeoff
TRAMPAC	transportation package
TRU	transuranic
TSA	Transuranic Storage Area
TSCA	Toxic Substances Control Act
TVR III	Transportable Volume Reduction and Solidification System
UCRL	University of California Research Laboratories

U/R	utilization of resources
WAC	Waste Acceptance Criteria
WAG	Waste Area Group
WERF	Waste Experimental Reduction Facility
WIPP	Waste Isolation Pilot Plant

VOLUME II

MAIN REPORT

1. INTRODUCTION AND SUMMARY

1.1 BACKGROUND

In 1954, the Idaho National Engineering Laboratory (INEL) began receiving low-level alpha emitting waste [referred to as alpha, or transuranic (TRU) wastes] such as plutonium-(Pu) contaminated waste produced in national defense programs. Most of this waste came from the Rocky Flats Plant near Golden, Colorado, and was placed in burial trenches and pits at the Subsurface Disposal Area (SDA) in the Radioactive Waste Management Complex (RWMC). The burial practice was stopped in the early 1970s because of safety issues. At that time, the Department of Energy (DOE) began placing TRU waste in retrievable surface storage at the Transuranic Storage Area (TSA).

TRU waste buried at the SDA includes both liquid and solid forms of varying TRU concentration and special-case wastes placed in drums and cardboard boxes in random and stacked configurations. Recent studies have shown some migration of contaminants from the SDA towards the Snake River Plain Aquifer. Although a number of options for the remediation of the TRU-buried waste at the SDA have been studied and evaluated in the past, no specific treatment strategy has been established to date.

On November 15, 1989, INEL was placed on the Environmental Protection Agency's (EPA's) list of priority sites for cleanup, known as the National Priorities List (NPL). Placement on this list mandates remediation of the SDA under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Accordingly, a remedial action option for the buried waste will be chosen via the CERCLA decision process. The selected option could be either no action, an in situ treatment and disposal (such as in situ vitrification, containment, etc.), or ex situ treatment and offsite disposal, such as retrieval followed by soil washing, melting, incineration, etc.

1.2 ORGANIZATION OF SYSTEM DESIGN STUDY (SDS) REPORT

The SDS results are published in eight volumes. Volume I contains an executive summary. The SDS summary and analysis of results are presented in Volume II. Volumes III through VII contain detailed descriptions of twelve system and four subsystem concepts. Volume VIII contains the appendices.

1.3 CONTENT AND ORGANIZATION OF THIS VOLUME

This volume contains an introduction in section 1, recommendation in Section 2, systems engineering approach in Section 3, and assumptions in Section 4. Sections 5 through 9 address each of the 12 systems and 4 subsystems studied, and are categorized according to the final waste form produced by the systems. These sections provide summary descriptions of each of the systems/subsystems as well as an assessment of the major considerations relevant to process risk and demonstration, testing, and evaluation (DT&E) needs. Section 10 summarizes the significant findings of the SDS.

1.4 SYSTEMS ENGINEERING

DOE Idaho Operations Office (DOE-ID) has established a Buried Waste Program to conduct remedial action in compliance with CERCLA. This program is a part of the INEL Environmental Restoration Program which is being executed according to the Major System Acquisition (MSA) requirements of DOE Order 4700.1. These requirements encourage application of systems engineering management tools in defining and implementing the most cost-effective solution to meeting the program's mission, need, and objectives.

The systems engineering process is a sequence of activities and decisions that transform an identified mission need into a description of system performance parameters and preferred system configuration. The process is applied to ensure that project activities are carried out so that the end result meets the defined need in a technically acceptable and cost-effective manner. Accordingly, the system configuration is derived through an iterative process which examines alternate approaches by synthesis, analysis, design,

and test, as applicable. Systems engineering integrates relevant technical parameters and ensures that all physical and functional interfaces are fulfilled. Systems engineering also provides assurance that all applicable special engineering requirements, such as safety, reliability, availability, operability, maintainability, and human factors have been appropriately factored into a cost-effective system configuration.

Although systems engineering covers all phases of a project life cycle, the SDS focuses only on the system requirements development and concept exploration phases. The requirement development phase involves developing requirements, derived from the project top-level requirements, which address all problems to be resolved by the system. Concept exploration identifies a set of system design concepts, provides a basis for their evaluation, and recommends a feasible design concept. These development phases are crucial stages in the project life cycle because decisions made during the first 10 percent of the system life cycle commit approximately 90 percent of the project resources. Furthermore, the cost of correcting system design errors increases exponentially as the time proceeds in the system life cycle.

Since the Buried Waste Program is governed by CERCLA requirements, the requirement development and concept exploration phases must be integrated with the CERCLA process. This process is defined in EPA Guidelines for Remedial Investigation and Feasibility Study (RI/FS).

1.5 SDS SCOPE

Remediation of buried waste at SDA will require a complex set of technologies for safe treatment and disposal of the waste. A key question for achieving the Buried Waste Program objectives is: what are the practical and cost-effective technologies that can satisfy the objectives of this program? Specific questions that need to be addressed include:

- What resources do we have available to build the system?
- Which is the availability of technology?

- Which technology can we use?
- Which technology promise significant cost reduction and high performance but require DT&E before they can be used?

Accordingly, the scope of the SDS was to examine the existing and emerging technologies for cost-effective remediation of the buried waste. Since no one technology can accommodate the complex remedial action process, the use of several technologies integrated as a system will have to be addressed. While examining the technology options, the SDS was to consider the above questions and focus on the technology requirements of the systems engineering process. The intent was to identify a set of cost-effective, practical, and acceptable treatment strategies; develop system concepts encompassing these strategies; and identify technologies within these concepts which will require DT&E.

In addition to their role in developing technology requirements, the SDS concepts can be used to establish detailed (derived) system requirements for future studies. Examples are:

- Input/Output (I/O) Requirements: Currently, only the top-level system I/O requirements are given for the Buried Waste Program. The top-level system input is the buried waste at the SDA, and the top-level output is the same waste but one that no longer threatens the environment. This top-level system output requirement could encompass a broad range of choices. A specific choice for the system output could be either no-action, or an acceptable waste form processed either by a system with in place remediation (in situ), or a system with removal and remediation (ex-situ) treatment method. The choice for output is a derived requirement, and will depend on a number of factors, including what the current technology can offer. Hence, the technology requirement studies are to identify the various output options and examine a wide range of technologies for each of these options. Furthermore, each of the system options are to be briefly assessed to provide a basis for derived requirements for the system output.

- Utilization of Resource (U/R) Requirements: With regard to the allowable costs and environmental, social, and economic impacts, the current top-level requirements are specified in terms of the most cost-effective approach and the approach with the least impact. However, the establishment of more specific cost objectives will be needed in the near future so that the DOE budget approval process for the Buried Waste Program can begin. The SDS was to develop a number of optional system concepts and to define a rough-order-of-magnitude (ROM) cost estimate for each of the concepts. These costs can be used as the starting point for establishing a more specific program cost objective. While the U/R limitations on the allowable environmental, social, and economic impacts will be decided through the National Environmental Policy Act (NEPA) and CERCLA process, the SDS results should provide guidance regarding technology limitations so that interim allowable environmental, social, and economic impacts for the system may be established.

In summary, the scope of the SDS was to examine the available and emerging technologies and treatment strategies for remediation of buried waste at the SDA. The results can assist DOE in its decision-making process regarding the funding of new technology development or demonstration, and allow for the definition of more detailed requirements for the system. The scope of the SDS did not include selecting an optimum waste form or an optimum strategy at this time.

1.6 SDS OBJECTIVES

The objective of the System Design Study was two-fold. The first objective was to provide a basis for making decisions on which waste processing concepts could be further developed to facilitate decisions concerning waste processing options. The following questions were addressed by this study.

- Should low-level waste (LLW) (reclassified TRU) be separated out before or after processing the TRU waste?

- Should Pu be recovered for TRU reduction?
- Is there a significant difference in costs between the various possible system output waste forms?
- For the most viable systems, which technologies need further development?
- What are the technical, safety, cost, and schedule risks associated with the most viable systems?
- For a given final waste form, how long will it take to start designing the processing systems?
- Are there energy requirements that make systems or final waste forms nonviable?
- Are there interim steps that can be taken in the near future to help remediate or reduce potential problems?
- What are the preliminary requirements for the most viable systems?
- Is extensive sorting before the process (to make the input controlled and more homogeneous) more desirable than mass processing?
- What are the cost differences between in situ and ex situ processing?

The second objective was to provide technical justification—from a system standpoint—for DT&E of technologies (i.e., for the most viable systems) required to remediate the plutonium-contaminated buried waste at the RWMC SDA.

1.7 SYSTEM BOUNDARIES

The Buried Waste Program system boundaries used in the SDS encompass the waste buried at the SDA and all facilities required to execute the remedial action. Acquisition of a space for disposal of residues from ex situ treatment options is not included in the system boundary.

1.8 SDS PARTICIPANTS

The SDS was performed by a project team consisting of personnel from Bechtel National, Inc.; Ebasco Environmental; EG&G Idaho, Inc.; and IT Corporation. EG&G Idaho provided the overall project management and technical guidance for the study and oversaw preparation of the final report. It should be pointed out that the technical assessments and other qualitative judgements given in this study are by the team members assigned to the SDS and not by their respective firms. During the final report preparation, technical input provided by the SDS team members was revised, as needed, to provide for consistency particularly in areas of cost estimating and program implementation risk assessments.

1.9 STUDY SUMMARY

Characteristics of the TRU waste buried at SDA were established based on the historical record and the latest characterization efforts (see Volume VIII). This data, in conjunction with the INEL Environmental Restoration Program top-level requirements, was used to select treatment strategies.

To develop technology requirements, a survey was conducted to identify the existing as well as emerging technologies for treatment of the SDA TRU buried waste. Based on the survey, and taking into account the decisions to be made regarding waste treatment strategies, a logic diagram for selecting system concepts was developed (see Figure II-1-1). Using this logic diagram,

Figure II-1-1. Concept selection logic diagram.

an initial set of 73 optional system concepts was developed. Similar concepts were then combined into 27 concepts with 4 subsystems. From the 27 systems, 12 systems and 4 subsystems were selected for further evaluation. Process functional diagrams for the 15 systems, not subjected to detailed analysis, are presented in Volume VIII. The 12 selected system concepts were divided into two possible treatment options: in situ treatment and ex situ treatment.

Two in situ concepts were selected for detailed development and assessment. These concepts, which are referred to as "process in-place, leave in-place" systems, are:

- Barrier (1-BE-1)
- In Situ Vittrification (1-EB-2).

Details about these systems are discussed in Volume III, and a summary description is presented in Section 5 of this volume.

Systems considered for the ex situ treatment were divided between three categories according to system output: (a) those producing a leach resistant, high integrity (i.e., glass or rock) waste form, (b) those producing waste forms that meet land disposal restriction (LDR) requirements and limit the hydrogen generation potential from metals, and (c) those producing waste forms that meet the current Waste Isolation Pilot Plant (WIPP) and TRAMPAC (transportation package) requirements for TRU wastes. The following three systems were considered for the leach resistant final waste form:

- Melting/Incineration System with LLW Presort (2-EG-1)
- Melting/Incineration System with LLW Postsort (2-EG-4)
- In Situ Vittrification (ISV) and Retrieval Processing System (2-EB-3).

Systems 2-EG-1 and 2-EG-4 were chosen to determine the effects of separating LLW before or after the main processing of TRU waste. In this

case, LLW had to meet only the LDR requirements, while the TRU waste had to meet the requirement of a high waste form of glass or rock. Details of these systems are discussed in Volume IV, while a summary is presented in Section 6 of this volume.

For the LDR compliance required, hydrogen generation restricted waste form, the following five systems were considered and included:

- Thermal Treatment/Solidification with LLW Presort (3-IT-1)
- Thermal Treatment/Solidification with LLW Postsort (3-IT-3)
- Pyrolysis/Acid Leach with Plutonium Extraction (3-EB-6)
- Molten Salt Oxidation (3-BE-7)
- Chemical Oxidation/Solidification (3-IT-8).

Systems 3-IT-1 and 3-IT-3 were chosen to determine the effects of separating LLW before or after the main processing of TRU waste. In each case, LLW had to meet the LDR requirements, whereas the TRU waste had to meet the LDR requirement and the hydrogen generation minimization requirement. System 3-EB-6 was chosen to determine the effects of separating out plutonium in order to minimize the disposal of TRU waste and, hence, maximize the disposal of LLW. Systems 3-BE-7 and 3-IT-8 were chosen to determine if alternative thermal treatment and biotreatment options may be viable. Details of these systems are discussed in Volume V, while a summary is presented in Section 7 of this volume.

For the final waste form, meeting WIPP and TRAMPAC requirements, two systems were considered:

- Sort, Treat, and Repackage (4-BE-2)
- Volume Reduction and Repackage (4-BE-4).

System 4-BE-2 was chosen as the conventional system meeting the minimum requirements of WIPP and TRAMPAC. System 4-BE-4 was chosen to provide a basis for volume reduction in order to minimize the eventual cost of storage in a facility such as WIPP. Details of these systems are discussed in Volume VI, while a summary is presented in Section 8 of this volume.

In addition, four subsystems were chosen to be used as options within the systems. The subsystems examined were:

- Metals Decontamination/Sizing (S-BE-1)
- Soils Processing (S-EB-2)
- Low-Level Waste (S-IT-3)
- Retrieval (S-BE-4).

Details of these subsystems are discussed in Volume VII, while a summary is presented in Section 9 of this volume.

Summary findings and conclusions are given in Section 10, and recommendations are presented in Section 2 of this assessment report.

2. SYSTEMS ENGINEERING APPROACH

2.1 BACKGROUND

DOE-ID has established a Buried Waste Program to conduct remedial action in compliance with CERCLA. This Program is a part of the INEL Environmental Restoration Program which is being executed in accordance with the MSA requirements of DOE Order 4700.1. The application of systems engineering management tools in defining and implementing the most cost-effective solution to meeting the program "mission need and objectives" is encouraged by DOE Order 4700.1.

Systems engineering covers the entire life cycle of a project, which is categorized as follows:

1. Advanced Development (including requirement development and concept exploration)
2. Engineering Development
3. System Construction
4. System Test
5. System Operation
6. Retirement.

Although systems engineering covers all phases of a project, significant emphasis is placed on Advanced Development which includes requirements development and concept exploration. These phases are crucial stages in the project life cycle because decisions made during the first 10 percent of the system life cycle commit approximately 90 percent of the project resources. Furthermore, the cost of correcting system design errors increases exponentially as the time proceeds in the system life cycle.

Advanced Development involves stating the problem as comprehensively as possible.

System requirements could be put into the following categories:

- Input/Output (I/O) Requirements: What is the system supposed to do in terms of I/O and system function?
- Performance Requirements: How well must the system perform the function specified in the I/O and functional requirements? (how fast, how accurately, and how reliably?)
- Technology Requirements: What technology is available to build the system? Availability of components?
- Utilization of Resources (U/R) Requirements: What are the system life cycle cost limitations (how much money can be spent)? What are the allowable environmental, social, and economic impacts?
- Tradeoff (T/O) Requirements: What are the tradeoffs among performance criteria, among cost criteria, and between performance and cost?
- System Test Requirements: How well can the system test be specified for observance, conformance, compliance, and acceptance? What are requirements and procedures in terms of observed data and conformance, compliance, and acceptance of the real system as compared to the model which was built?

Concept exploration identifies a set of system design concepts and describes a concept for each design concept. It records a value for each I/O, U/R, and T/O Figure of Merit (FOM) for each design concept. During the concept exploration stage, a recommendation is made for the best set of attractive system design concepts. Concept exploration for the system also includes functional analysis and allocation. This involves decomposition and

allocation of the requirements associated with each "top-level" system function to several new, lower category functions.

Since the Buried Waste Program is governed by CERCLA requirements, the requirement development and concept exploration stage must be integrated with the CERCLA process. This process is defined in EPA Guidelines for Remedial Investigation and Feasibility Study (RI/FS). The relationship between the SDS and CERCLA process is shown in Figure II-2-1.

2.2 SYSTEMS ENGINEERING APPROACH FOR SDS

In order to focus on the technology requirement aspect of the Buried Waste Program, first the project mission need and objectives (top-level requirements) are identified (see Figure II-2-2). Available and emerging technologies are identified and used in identifying a set of treatment strategies and in developing system concepts encompassing these strategies. The development of concepts puts to use the system engineering principal of functional analysis and allocation. System concepts are assessed in terms of their current status and DT&E needs, lead time, and ROM cost estimate. The system concept development and assessment results are used to develop preliminary system requirements for the Buried Waste program.

2.2.1 Requirement Development

Mission need and objectives for the Buried Waste Program, as defined in the Preliminary Program Plan for the INEL Environmental Restoration (ER) Program, are given in Section 3. These top-level requirements are the only firm requirements at this time. For developing the system concepts and conducting an assessment, several assumptions were made. These assumptions are given in Section 4 of this report.

2.2.2 System Concept Exploration

Given the top level requirements (defined need, objectives, and constraints) provided by the DOE, three interrelated activities are used in developing buried waste remedial action concepts. These include functional

Figure II-2-1. The relationship of the system design study to the CERCLA process.

identification, functional performance requirements analysis, and functional allocation.

Functions are identified in a Functional and Operational Requirement (F&OR) document to carry out the activities to meet the defined need. Identification of functions is accomplished through the use of process functional diagrams (PFDs), which depict the relationships among functions. Each function is displayed by a block in the PFDs. Taken together, the blocks show the sequential relationship of all functions of a system, which meets the defined need.

A rough estimate of performance requirements is identified for the concept and given in the system description sections. These are qualitative values assigned to each function. In addition, the inputs into and outputs from each function are identified to better understand the interrelationships of all system functions.

Requirement allocations are performed to decompose the requirements until a level is reached at which a specific technology can fulfill the needed functional/performance requirements.

2.2.3 System Concept Assessment

After selection of unit operations (system components that accomplish a given function) of the system concept, two different evaluations were performed to determine the degree to which the system functional requirements are satisfied. A third evaluation process, CERCLA process, is described below but was not used at this stage of study. It is anticipated that the CERCLA process evaluation will be used in the future studies.

Performance Measurables Assessment. Tables II-2-1 and II-2-2 are matrices that identify the performance measurables and their applicability to the major unit operations of the in situ and ex situ system concepts. These tables show a grading process on a qualitative basis. This process was used to determine the degree to which a unit operation achieves a performance measurable. In the SDS performance, measurables were scored from one to ten

with ten indicating a very high compliance or concurrence with the measurable performance criteria.

Table II-2-3 provides definitions for the performance measurables applied in the SDS.

Program Implementation Risk Assessment. Areas of uncertainty and weaknesses of each concept were identified by performing a qualitative program implementation risk assessment. For each of the system concepts, the programmatic risks associated with implementing the concept were assessed. This assessment identified major uncertainties requiring focused work and attention, and provided a degree of confidence that the Program can be executed to meet the mission need objectives stated in this volume. The assessment is performed according to the guidelines given in DOE 4700.1 for risk assessment during the initial project phase.

CERCLA Evaluation. Ultimate selection of a remedy for the buried waste at SDA will be by evaluation and ranking against the CERCLA criteria (see Table II-2-4). This formal evaluation and ranking will be done during the CERCLA Feasibility Study (FS) stage. The selected remedial action alternative will be implemented only after joint approval by DOE, EPA, and the state via the CERCLA ROD process. The SDS data should be helpful in the remedial actions assessment during the FS and ROD stages of the Buried Waste Program.

Table II-2-1. Systems with in-place remediation

<u>Function</u>	<u>Waste Site Description</u>	<u>Preparation</u>	<u>Remediation</u>	<u>Monitoring</u>
<u>Segment</u>	<u>Description (Provided in Site Description)</u>	<u>Placement of apparatus Forming, Drilling Utilities</u>	<u>Solidify Vitrification Capping Grouting Soilwash Bioremediation</u>	<u>Instrumentation Drilling Samples Techniques</u>
<u>Measurable</u>	<u>Input</u>			
Timeliness		X	X	X
Availability		X	X	X
Completeness		X	X	X
Risk		X	X	X
Flexibility		X	X	X
Cost		X	X	X
Safety		X	X	X

Table II-2-2. Systems with removal and remediation

Function	Waste Site Description	Retrieval	Separation Sorting	Package for Transport on INEL	Transport on INEL	Facility Process	Package for Disposal	Storage/Disposal or Transportation to Disposal
						Interim Storage Open Container Manipular Sort Incinerator On-Line Assay Trommel Bioremediation TRU Clean Steam Decon Acid Wash		
	Description (Provided in Site)	Excavate	Sort	On-Line Assay Package	Metal Sizing Recover PU Transport	Package Container Solidify	Store Dispose Assay	Transport
<u>Measurable</u>	<u>Input</u>							
Timeliness		X	X	X	X	X	X	X
Availability		X	X	X	X	X	X	X
Completeness		X	X	X		X	X	
Risk		X	X	X	X	X	X	X
Flexibility		X	X	X	X	X	X	X
Cost		X	X	X	X	X	X	X
Safety		X	X	X	X	X	X	X
Waste Reduction						X	X	
Complexity		X	X	X			X	X

Table II-2-3. Definition of system performance measurables

Measurable	Definition	Example
Timeliness	The ability of the system to complete the remediation within the 10-year period. Here the system processing time is assessed and a system that has the ability to be scaled up to handle a large throughput with acceptable results and within the time frame would rate a higher score than a system with a smaller output not completing the processing within the time frame.	The system relies on bioremediation techniques which will extend process requirements 5 years beyond the 10-year period expected for remediation.
Availability	This measurable assesses the maturity and the degree to which the system can be applied now. The systems that are fully developed, operational, time-proven, and commercially available would rate a higher score than emerging, unproven technologies.	The system includes elements which have only reduced scale and lab test histories which are highly promising. However, further technology development is required.
Completeness	The ability of the system to process anything requiring remediation. The physical and chemical characteristics of the stored and buried wastes at the RUMC vary widely in a very heterogeneous mixture. The mix includes solid combustibles, organic liquids, inert solids including soils, and solidified sludges. Therefore, a system that is versatile enough to accept practically any type of waste would rate a higher score than one that has limitations.	Once the system has been applied to a specific location and input waste stream, the ability of the system to process another site with significantly different waste inputs is better than other systems.
Risk	The technical risk associated with the system and its ability to perform as intended.	The process appears to be technically sound, but process complexity may require readaptation if the emerging technology is not complete.
Flexibility	The capability of the system to respond or to conform to changing requirements.	The requirements for acceptable release limits changed significantly, and the system is capable, through minor adjustments at the subsystem/component level, of meeting the new requirements.
Cost	An assessment of how well the costs of the system can be defined.	The system costs are well known or can be developed because the technology is known, whereas another system has technology unknowns, and costs are more in doubt.

Table II-2-3. (continued)

Measurable	Definition	Example
Safety	The ability of the system to operate within the range of acceptable exposure to the operators and general public.	The safety analysis and risk assessment of the system shows reasonable operating parameters for exposure to the operators and general public.
Waste Reduction	The ability of the system to reduce or minimize the quality of processed or stored waste.	One system has a significant advantage over other systems in achieving a volume reduction of a factor of three in the processed product.
Complexity	The degree of complexity of the system and assessing process complexity, ease of operation, and maintenance requirements. System complexity is important because the simpler the system the less likely the occurrence of an event that leads to a release. This aspect is important because of the very hazardous nature of the RWMC wastes.	A system with fewer subsystems would rate a higher score than that of a highly complex system requiring many process steps.

Table II-2-4. CERCLA evaluation criteria

NINE EVALUATION CRITERIA	or relevant and appropriate requirements of other Federal and State environmental laws or whether a waiver can be justified.	5. Cost includes estimated capital and operation and maintenance costs, and net present worth costs.
EPA has developed nine criteria to be used to evaluate remedial alternatives to ensure all important considerations are factored into remedy selection decisions. These criteria are derived from the statutory requirements of Section 121, particularly the long-term effectiveness and related considerations specified in Section 121(b)(1), as well as other additional technical and policy considerations that have proven to be important for selecting among remedial alternatives.	Primary Balancing Criteria Five primary balancing criteria are used to identify major trade-offs between remedial alternatives. These trade-offs are ultimately balanced to identify the preferred alternative and to select the final remedy.	Modifying Criteria These criteria may not be considered fully until after the formal public comment period on the Proposed Plan and RI/FS report is complete, although EPA works with the State and community throughout the project.
Threshold Criteria	1. <i>Long-term effectiveness and permanence</i> refers to the ability of a remedy to maintain reliable protection of human health and the environment overtime, once cleanup goals have been met. 2. <i>Reduction of toxicity, mobility, or volume through treatment</i> is the anticipated performance of the treatment technologies a remedy may employ. 3. <i>Short-term effectiveness</i> addresses the period of time needed to achieve protection and any adverse impacts on human health and the environment that may be posed during the construction and implementation period, until cleanup goals are achieved. 4. <i>Implementability</i> is the technical and administrative feasibility of a remedy, including the availability of materials and services needed to implement a particular option.	1. <i>State acceptance</i> addresses the support agency's comments. Where the State or other Federal agency is the lead agency, EPA's acceptance of the selected remedy should be addressed under this criterion. State views on compliance with State ARARs are especially important. 2. <i>Community acceptance</i> refers to the public's general response to the alternatives described in the Proposed Plan and the RI/FS report. The 1990 NCP at 55 FR 8719-23 describes how the detailed analysis of alternatives is to be performed using these criteria. The detailed analysis is the information base upon which the remedy selection decision is made. Chapter 7 of the "Interim Final Guidance for Conducting Remedial Investigations and Feasibility studies Under CERCLA" (October 1988) provides further detail on the process.
1. <i>Overall protection of human health and the environment</i> addresses whether or not a remedy provides adequate protection and describes how risks posed through each exposure pathway (assuming a reasonable maximum exposure) are eliminated, reduced, or controlled through treatment, engineering controls, or institutional controls. 2. <i>Compliance with applicable or relevant and appropriate requirements (ARARs)</i> addresses whether a remedy will meet all of the applicable		

3. MISSION NEED AND OBJECTIVES

The buried waste remedial system concepts were developed and assessed per the INEL Environmental Restoration Program's preliminary mission need and objective statements. These statements, presented below, will be finalized as the INEL site Federal Facility Agreement Consent Order (IAG) is signed by the DOE, EPA and the State of Idaho in the near future.

3.1 MISSION NEED

DOE-ID is responsible for ER activities at the INEL. The INEL ER Program activities include remedial actions to eliminate the source of potential releases from several inactive sites, including the buried waste pits and trenches at the RWMC. In order to resolve the potential conflict of many laws with overlapping jurisdictions by various agencies, a Federal Facility Agreement Consent Order [hereinafter referred to as the Interagency Agreement (IAG)] is being signed between DOE-ID, EPA Region 10, and the State of Idaho. The IAG and its Action Plan outline the process for assessment and cleanup activities at INEL. In addition, they integrate CERCLA response obligations with RCRA, and Idaho's Hazardous Waste Management Act corrective action obligations. The mission of the Remedial Action tasks of the INEL ER Program is explicitly stated in the legal section of the IAG. Accordingly, the mission is to ensure that (a) the environmental impacts associated with past and present activities at the INEL site are thoroughly investigated, and (b) appropriate remedial action be taken, as necessary, to protect the public health and welfare and the environment.

3.2 OBJECTIVES

3.2.1 Technical Objectives

Technical Objectives are as follows:

- Cleanup Standards: Baseline cleanup standards for buried waste sites at the RWMC (Remedial Actions Tasks) cannot be established

until a ROD pursuant to the CERCLA process is reached for the Remedial Action. These standards will be derived as described below:

- CERCLA Cleanup Standards: The provisions of CERCLA Section 121, "Cleanup Standards," will be the primary source. Codified by the EPA in 40 CFR 300, Subpart F, such provisions establish criteria for selecting remedial actions and require compliance with standards from other environmental statutes such as the Toxic Substances Control Act (TSCA), Safe Drinking Water Act (SDWA), Clean Air Act (CAA), and Clean Water Act (CWA) to the extent that the standards prescribed under such other statutes are applicable or relevant and appropriate (Applicable or Relevant and Appropriate Requirements or ARARs under the CERCLA process). With respect to releases of hazardous waste, DOE-ID has agreed that RCRA shall be considered an ARAR pursuant to Section 121 of CERCLA.
- Risk Assessment: Risk assessment techniques will be used in establishing standards as a means of ensuring safe cleanup levels. Criteria for risk assessment, including land-use and point-of-compliance requirements, will have significant impact on cleanup level requirements. Under IAG requirements, agreed-upon criteria for risk assessment will be established.
- State and Local Statutes: Requirements of state authorized programs may be substituted for Federal standards [according to CERCLA Section 121(d)] if the State imposes requirements that are more stringent than Federal standards.

3.3 HEALTH AND SAFETY OBJECTIVES

Health and safety objectives for the INEL ER Program are to ensure that all remedial actions will be performed in a manner that will protect the health and welfare of the workers and the general public. Remedial actions include (a) identifying hazards of the remedial action operation and (b) providing measures to eliminate, control, or mitigate identified hazards.

3.4 INSTITUTIONAL OBJECTIVES

- Public involvement: Public involvement objectives are to carry out a public participation plan that encourages public input into the Program decision-making process to meet CERCLA, NEPA, and DOE requirements.
- NEPA Compliance: NEPA compliance objectives are to ensure that environmental concerns are adequately addressed in the selection and implementation of RCRA/CERCLA remedial actions and that provisions of the NEPA, as implemented by Council of Environmental Quality (CEQ) regulations and DOE-ID Guidelines (draft 2/21/1991), are satisfied.

3.5 SCHEDULE OBJECTIVES

The objective of the Buried Waste schedule, as identified in the IAG, is to complete (a) the Assessment Phase of the Remedial Actions and reach all RODs as early as possible but no later than the end of FY 2001 and (b) the post-RI/FS Cleanup Phase as early as possible but no later than FY 2019. The SDS risk analyses is based on assuming that ROD will be concurrent with the DOE key decision 2, (as defined in DOE 4700.1, key decision 2 is approval of the start of Title II, or final/detailed design activities) which is approval to start Title II and detailed design. If an 18-month period is assumed for the ROD process, then the advanced development DT&E program must be completed and remedial action options selected for the ROD process by mid-1999.

3.6 COST OBJECTIVES

A baseline total estimated cost (TEC) for the post-RI/FS Cleanup Phase of the Buried Waste Program has not been established at this time. TEC for the post-RI/FS Cleanup Phase related to remedial actions will be optimized after defining cost-effective solutions in the future.

4. ASSUMPTIONS

The System Design Study made the following assumptions that apply to all systems developed under this study.

4.1 FINAL WASTE FORM

The assumptions made for the final waste form requirement, output of the system, can be classified by in situ and ex situ processing of TRU waste and LLW. For in situ treatment options, waste form requirements will depend on the ARARs definitions and risk assessment results, as a part of the CERCLA decision making process. For the ex situ processing options, the waste removed from the SDA must be processed in a constructed facility to meet the disposal site requirements. Such requirements cannot be established until a disposal site is identified. As of now, the plutonium-contaminated buried waste does not have a designated disposal site.

Since specific requirements for waste form cannot be defined at this stage of the Buried Waste Program, technology requirements must be established to the Program's future flexibility selecting the most suitable treatment strategy. To maintain this flexibility, SDS examined all of the possible disposal options. Based on this examination, waste forms for four generic disposal options were identified. System concepts examined by the SDS are based on producing an output that meets one or more of the established waste forms. The four disposal options and their corresponding waste form requirements are given below. For all LLW waste it is assumed that the LDR, NRC, and DOE waste form requirements for shallow-land disposal will be applicable.

- Waste Form 1 - Process In-Place, Leave In-Place: This waste form is the result of in situ (process in-place, leave in-place) treatment. The waste form requirements will depend on the ARARs definition and risk assessment as a part of the CERCLA decision making process.

- Waste Form 2, Leach Resistance, High Integrity: This waste form is leach resistant and high integrity glass or rock, and meets the general requirements established for a high-level nuclear waste to be disposed of in a deep geologic repository. The waste form also complies with the transportation (TRAMPAC) requirements. Because of its high quality, this waste form meets the less stringent requirements for waste forms 3 and 4, discussed below.
- Waste Form 3 - LDR Compliance Required, Hydrogen Generation Restricted: This final waste form complies with the LDR requirements (i.e., destroy organics and fix inorganics), restricts the hydrogen generated from metals, and complies with TRAMPAC requirements. It is assumed that this waste form will be suitable for a disposal facility similar to WIPP, except that LDR compliance is assumed to be required. Waste Form 3 will not meet the requirements of the Waste Form 2 (i.e., it is not a glass or rock) but will meet Waste Form 4 requirements discussed below.
- Waste Form 4 - WIPP WAC/TRAMPAC Compliance Required: The final waste form complies with the current WIPP Waste Acceptance Criteria (WAC) and the TRAMPAC requirements. It is assumed that this waste form will be suitable for a disposal facility similar to WIPP. Waste Form 4 will not meet any of the above waste form requirements.

4.2 GENERAL CONSIDERATIONS AND ASSUMPTIONS USED IN SYSTEM CONCEPTS DEVELOPMENT

4.2.1 Waste Property Assumptions

The waste input considered in this study is described in a document titled, "A Brief Analysis and Description of TRU Wastes in the SDA of the Radioactive Waste Management Complex at INEL" (see Appendix A, Volume VIII). The following are additional assumptions concerning the input waste criteria:

- The total volume of waste is 2,325,000 ft³; the total volume of contaminated soil is 9,734,000 ft³. The average density of the waste is 37.23 lb/ft³. The average density of the soil is 116 lb/ft³.
- Forty percent of the actual waste is LLW (i.e., less than 100 nanocuries/g).
- Ninety percent of the soil is LLW or clean. Soils contain both organic and inorganic hazardous components.
- All lead wastes are, or can be made into, LLW. Lead is one percent by weight of the waste.
- Waste containing materials that can jeopardize the safety of retrieval and processing operations either exists in small quantities and can be safely handled, or can be segregated out for handling and processing as special material (see below). Waste material in this category may include high radiation objects, containers having free liquids, compressed gas cylinders, etc.
- The removal and treatment of the rock sub-layer are not included in this system analysis.
- Terms used to characterize certain waste types are as follows:
  - Special material includes waste which is not suitable for normal processing (i.e., processing capability of the system concept described in this report) including large objects, high radiation materials, large construction material, and any object requiring special handling and processing not included in the system design. Processing and handling features for special material are not included in the system models. Special material handling, processing, and disposal methods will be decided on a case by case basis.

- Large objects include discarded vehicles, reactor shielding, tanks, etc.
- Large construction material includes discarded construction material such as concrete slabs, steel beams, sections of brick walls, timber, etc.
- High radiation objects include reactor vessels, piping, pumps, fuel components, etc.

4.2.2 General Assumptions

- Plutonium recovery is strictly for TRU reduction, not recycling.
- All TRU waste metals will be decontaminated where possible for volume reduction.
- The bulk of the soil will be excavated without waste entrained. A small amount of soil contains the waste.
- The retrieval will be done inside a building that is classified as a low hazard facility per UCRL 15910.
- The processing buildings for LLW and TRU are classified as a Solid Radioactive Facility per DOE Order 6430.1A, and a moderate hazard facility per UCRL 15910.
- The operational time span for the processing of the plutonium-contaminated waste is 10 years.
- Operational assumptions: 24 hours/day, 5 days/week, and 70 percent plant availability during operation, operational 240 days/year.

4.3 CRITERIA AND ASSUMPTIONS FOR PROGRAM IMPLEMENTATION RISK ASSESSMENT

For each of the system concepts, the programmatic risks associated with implementing the model are assessed. It is expected that this assessment will identify major uncertainties requiring focused work and attention, and will provide a degree of confidence that the Program can be executed to meet the objectives stated in Section 2, Volume II. The assessment is performed according to the guidelines given in DOE Order 4700.1 for risk assessment during the initial project planning phase. Program implementation risk assessments in this report are qualitative and are based on the judgement of the study team members. Because the Buried Waste Remedial Actions Program is still early in the initial phase of the acquisition process, detailed information for a full analysis does not yet exist. Hence, The qualitative judgements are based on several assumptions which are presented below.

Each of the unit operations were considered during an initial risk assessment of the system concepts. This was done by applying the knowledge of experienced personnel and using this knowledge to rank each of the program objectives as low, moderate, or high. Then, a composite risk level for the overall system concept was assigned based on the risk associated with the unit operations. In most cases, only the overall system risks are presented in this report. In general, a low ranking implies that the system could be implemented at the present time with virtually no risk. Assignment of moderate rank means that although the implementation of the system concept is feasible, certain aspects of implementation still need to be resolved. If a system concept has considerable amount of uncertainty regarding achievement of the given objective, then a high risk ranking is assigned.

4.3.1 Project Mission Need and Objectives

The project mission need and objectives are given in Section 2, Volume II.

4.3.2 Technical and Performance Risk Considerations

The following considerations were used in characterizing the technical performance risks:

- Contamination Type and Size: The TRU waste buried at the RWMC has been preliminarily characterized for this study (see Volume VIII). Characterization of the risks relative to the ability to comply with the performance objectives is based on these waste characteristics. However, it should be noted that detailed and accurate information on the materials buried at each of the trenches and pits, or the extent of the site contaminants, does not exist at this time. If found, pyrophoric materials and compressed gas cylinders containing volatile and toxic gases can have a significant impact on the performance compliance risk characterization.
- Major ARARs for In-Situ Treatment Options: Major ARARs applicable to in-situ options are RCRA and DOE regulations and guidelines for disposal of waste in shallow land burial sites (10 CFR 61).
- ARARs for Thermal Processes: Major ARARs applicable to Thermal Processes are the Clean-Air Act, and RCRA and DOE regulations for radiation protection.

4.3.3 Health and Safety Risk Considerations

The following considerations were used in characterizing the health and safety risks:

- General Construction-Related Concerns: As with any construction-related activity, there will be general health and safety concerns associated with the buried waste cleanup operations. Risk associated with the ability of the Program to define and mitigate general construction-related health and safety concerns is believed to be low.

- Radioactive and Hazardous Material Handling Concerns: Due to radioactive (including TRU), hazardous, mixed waste contamination of the material that will be encountered during operations, the Program will be subject to health and safety concerns with respect to low-level radiation, alpha particles, and hazardous material exposures. The risk associated with the ability of the Program to define and mitigate these health and safety concerns is believed to be moderate for all system options involving retrieval and processing, and low for the two options involving in situ treatment.
- Criticality: Due to the measurable quantity of plutonium in the buried waste, the Program will be subject to health and safety concerns with respect to criticality. The risk associated with the ability of the Program to define and mitigate these health and safety concerns is largely dependent on the availability of techniques to detect Pu contamination of the waste before it is handled. In this study it is assumed that for all system models, except those using ISV process, such techniques are available and therefore the risk is low. For the ISV, some have expressed a concern that the melting of the material may result in potential concentration of Pu compounds in the bottom of the melt. A preliminary review of criticality in ISV process, however, suggests that due to the high chemical reactivity of molten Pu metal and the high melting point and moderate specific gravity of compounds (PuO₂, PuCl₃, PuH₄, etc.) that would most likely form, the risk of Pu collecting in a quantity and geometry that would allow a critical mass to form is very low. It is believed that the oxides of plutonium are soluble in the magma and are expected to be uniformly dispersed in the melt. Verification of this behavior is recommended. Due to the consequences of such an occurrence, however, the subject should be examined in more depth during the site characterization effort. For this study, the risk to identify and mitigate criticality concerns for the ISV options is considered to be low.

- Pyrophoric and Volatile and Toxic Gas: Since the SDS waste characteristics document (see Appendix A, Volume VIII) does not identify pyrophoric material or compressed gas cylinders containing volatile and toxic gases, the ability of the Program to define and mitigate health and safety concerns related to these wastes is not addressed at this time.

4.3.4 Institutional Risk Considerations

The following considerations were used in characterizing the risks:

- Disposal of Residues after Retrieval: Options involving ex situ treatments (i.e., excavation, removal, and disposal) will involve disposal of TRU-contaminated mixed waste. Currently, DOE has no disposal space for these wastes. Therefore, the question of institutional risk of ex situ techniques will require addressing ultimate disposal of the residues. However, since the system boundary for the SDS does not include the ultimate disposal of the residues, characterization of the institutional risk did not address the disposal question.
- State and Public Acceptance of Leave-In Place Options: System options involving leave-in-place are characterized as high risk with regard to institutional acceptance. This is due to anticipated opposition by the state and the public. Over the last several years, the State of Idaho and the Federal Government have communicated several times concerning the retrieval and removal of TRU waste buried at the INEL. The DOE (and its predecessors, AEC and ERDA) have made commitments to the State of Idaho to remove the TRU waste.
- Thermal Process Public Acceptability: Due to past experience with public opposition at other DOE sites (e.g., Rocky Flats), system options involving the incineration process are characterized as a high risk with regard to acceptance.

4.3.5 Schedule Risk Considerations

The following considerations were used in characterizing the risks:

- Time Available for DT&E: As indicated above, schedule objectives are to reach Title II design by FY 1999. To achieve this objective, it is assumed that detailed information to evaluate the remedial action options is needed by 1996. Therefore, any system technology requiring DT&E leadtime longer than five years is believed to be high risk.
- Thermal System Burn Test Requirements: Due to past experience in lengthy burn tests and EPA approval process at other DOE sites (e.g., Rocky Flats, Oak Ridge National Laboratories), system options involving the incineration process are characterized as a moderate risk with regard to compliance with the schedule objectives.

4.3.6 Cost Risk Considerations

Since a baseline cost estimate has not been established at this time, the assessment of cost risk is based on how well the program will be able to define the cost of the given system in the future if the system is selected as the preferred option. As indicated in Section 1.6.2, if found, materials and contaminants that can have a significant impact on the technical performance risk characterization include pyrophorics and compressed gas cylinders containing volatile and toxic gases. This will also impact cost risk characterization.

4.4 COST ESTIMATING ASSUMPTIONS

4.4.1 Cost Estimating Guidelines

Cost estimating guidelines were developed to support development of a ROM cost for each system concept. The guidelines included building/space cost per square foot, design, inspection, and project administration percentages for

the various types of building/space. Also included are operating costs to be considered for development of life cycle costs. All costs are presented in FY-91 dollars, including operating and maintenance costs.

Building Space costs. The building unit rate costs listed below are based on similar facilities at the INEL. The costs are representative of the building and its support systems, including utilities and site development costs. The Alpha Cell Space building costs include the high-efficiency particulate air (HEPA) filter systems. Special equipment and any additional mechanical or electrical systems needed for the operation of the equipment have not been included in these costs. The unit rates include construction direct and indirect costs. Indirect costs associated with the additional building costs and equipment costs are established to be 20.5% of the direct costs.

- High hazard building space is \$650/ft²
- Moderate hazard building space is \$350/ft²
- Alpha cell space with one confinement barrier is \$1,000/ft²
- Alpha cell space with two confinement barriers is \$1,200/ft²
- Retrieval building space is \$100/ft².

Design Inspection and Project Administration Costs. To determine the design, inspection, and project administration costs for each option, the percentages listed below were applied. These percentages are historical averages for types of activities covered by SDS concepts.

- Contingency on all costs is 25%
- Design costs applied to construction costs (both demonstration and production) total 30%

- Inspection costs applied to construction costs (both demonstration and production) total 7%
- Project administration costs applied to construction costs (both demonstration and production) total 10%
- Indirects applied to total construction costs (both demonstration and production) is 20.9%
- Construction management (CM) and CM reserve (combined percent) applied only to production construction costs total 28.7%.

Operating Costs. The utility rates and operating rates listed below were established by EG&G Idaho for use in the development of life cycle costs. Present day costs were used for the preparation of these estimates. A contingency factor of 25% was applied to the project subtotal.

- Electricity is \$0.035/kWh
- Propane is \$0.60/gal
- Operating staff is \$60/hr.

4.4.2 System Concept Cost Estimate Normalization and Modification

ROM cost estimates were prepared by the team members for the twelve systems and four subsystems based on the above guidelines. These initial cost estimates were examined by an independent estimating team to determine if the estimates were comparable in estimating approach and techniques, and, if not, the estimate approach and techniques were modified so that the estimates could be compared to one another. The independent estimating team corrected the initial estimate inconsistencies concerning the application of multipliers, estimating approach, summary sheets, backup sheets, years of operation, and cost per square foot. The following steps were used in modifying the estimates.

- Normalized Cost: The initial ROM estimates for the twelve systems and four subsystems were first "normalized" by a consistent application of the multipliers for indirect, design, inspection, project administration, construction management, and contingency. These revised ROM cost estimates were referred to as "Normalized ROM Costs."
- Modified Costs: A second review of the ROM cost estimates for the twelve system and four subsystem models was conducted for comparable square footage in allocating the building space, consistent cost per square foot, consistent time basis used in operating and maintenance costs, omissions and errors, and comparable equipment costs with other similar equipment used within the sixteen estimates. The ROM cost estimates of the twelve system models were revised to correct any of the above inconsistencies. This second revision of the estimates was titled "Modified Costs." Major areas requiring modification were the following:
  - Due to inconsistent use of criteria, the system models facility sizes were corrected to remove front-end receiving, unloading and storage areas, and back-end drum storage areas. Space requirements for these functions were assumed to be 200,000 square feet for all ex situ system models. The ROM cost for this space was estimated to be approximately \$30 million.
  - An average square footage for similar operations was developed and used in cases where assignment of alpha cell square footage varied widely for similar operations.

4.5 DT&E ASSESSMENT ASSUMPTIONS

Major unit operations in each of the system and subsystem models were evaluated to estimate DT&E needs, lead time, and resource requirements. Following are some of the criteria and assumptions used as the basis for these estimates.

- Project Execution: It is assumed that the Buried Waste Program will be executed according to the project management system advocated by DOE Order 4700.1. Figure II-4-1 shows the various categories of work and the various phases of research and development in a typical project executed under the DOE Order 4700.1 requirements.
- Research and Development (R&D) Categories of Technologies: It is intended that the twelve system and four subsystem options considered in the SDS not use technologies that fall in the categories of "basic research," "applied research," or "technology or exploration development" as defined in DOE Order 4700.1 (page I-5). Only technologies that have passed the "technology or exploration development" stage are assessed. Under the EG&G RDDT&E Program definitions, technologies considered are assumed (a) to have completed R&D activities comprised of application of knowledge from research toward proof of technology including development of non-specific application prototype and processes, and (b) require only DT&E activities to compare the effectiveness of alternative processes; to determine the applicability of a particular technology to a site-specific use; to establish a level of confidence in a treatment process; to yield such information as process results, design criteria, and operational sensitivities; and to obtain regulatory agency concurrence or approvals, as needed. The EG&G DT&E activities are considered to be comparable to the "advanced development" activities defined in DOE Order 4700.1.
- DT&E Output Assumptions: When a DT&E program is proposed for a given unit operation, the intent is to identify a series of activities to develop the unit operation to a point where the results will support DOE "key decision 2" for the Buried Waste Program. In addition, it is intended that the program output will be in accordance with EPA "Guide for Conducting Treatability Studies Under CERCLA," EPA/540/2-89/058, December, 1989.

Figure II-4-1. Categories of work effort and research and development and acquisition phases.

- DT&E Steps: In order to allow a consistent assessment of DT&E needs, the activities are divided into the following logical steps (Figure II-4-2). These steps are consistent with the EPA "Guide for Conducting Treatability Studies Under CERCLA," EPA/540/2-89/058, December, 1989.
  - Primary Paper Evaluation: The objective of the primary paper evaluation is to study the various options using existing information. This evaluation will result in defining scope and conceptual design for the next steps of the DT&E phase. It will eliminate from further consideration those options that are not likely to be cost effective.
  - Bench-scale studies: Bench-scale studies are the next logical step, but in some cases it is assumed that the DT&E efforts can move directly from initial paper evaluation to the pilot-plant/prototype test studies. For example, evaluating a robotics operation in waste segregation would not be conducive to bench-scale studies.
  - Secondary paper evaluation: When further pilot-scale studies are shown to be necessary, a secondary paper including more detailed concept development may be needed. This will help to eliminate options that are not cost-effective, and focus the pilot or prototype test study on essential issues, normally using a single technology option.
  - Pilot-Plant/Prototype Test Studies: The objective of pilot-plant/prototype test studies is to provide reliable information for developing design criteria including scale-up limitations and cost estimates for processes and ancillary equipment. Full scale prototype tests are assumed to be necessary for non-process equipment such as robotics development. Generally, pilot-plant/prototype studies are assumed to cover only the critical portions of the equipment requiring advanced development.

Figure II-4-2. Assumed phases of demonstration, testing, and evaluation during advanced development.

- Number of Technology Options Studied in Typical DT&E Program: It is assumed that primary paper evaluation, bench scale studies, and secondary paper evaluation steps will result in narrowing the alternatives to a single option. Pilot-plant/prototype studies are assumed to be applied only to the selected option, and are proposed only if it is deemed to be necessary.

- DT&E Lead Times: In order to provide a consistent estimate of the DT&E lead times, the timespans listed below are assumed for the DT&E steps. Based on the complexity of the technologies being considered, the timespan is narrowed down to a specific duration in the assessment sections of the system models. The timespans include allowances for a one-month procurement process and one-month report preparation for bench scale and paper studies. For pilot-plant/mock-up studies, a 2-month procurement process, 2-12 month design, 4-12 month fabrication, and 6-24 month test and report preparation are assumed to be necessary.
  - Primary paper evaluation: 5-6 months
  - Bench-scale studies: 5-18 months
  - Secondary paper evaluation: 5-6 months
  - Pilot-plant/mock-up test studies: 14-60 months

5. PROCESS IN-PLACE AND LEAVE IN-PLACE SYSTEMS

This section provides a summary description, assessment of required DT&E and risks, for the Process In-Place and Leave In-Place System concepts. These systems result in waste forms referred to as waste form 1 and are described in more detail in Volume III of the SDS report.

5.1 BARRIER SYSTEM (1-BE-1)

5.1.1 Summary System Description

The Barrier System results in situ isolation of the TRU and mixed waste buried at the INEL RWMC. This system isolates the waste in situ by means of manmade barriers over, under, and around the waste pits and trenches. The barriers will be designed to have low permeabilities, such that the flow of any leachate through the barriers will be less than or equal to the design criteria (10^{-7} cm/sec per RCRA). The Barrier System will include a leachate collection and monitoring unit installed inside the barrier and groundwater monitoring wells installed in the outside perimeter. Once the system is constructed, there are no other activities required except for monitoring.

The unit operations of this system consist of barriers, water diversion, and monitoring as depicted in Figure II-5-1. The vertical barrier provides a water-impermeable vertical barrier around the pit, trench, multiple pits, or multiple trenches, and will be composed of a soil/bentonite or a cement/bentonite slurry. The subsurface horizontal barrier will extend underneath the waste pits and trenches and will be designed to meet the design criteria requirements for permeability to minimize further flow of leachate through the waste pit bottom. The surface barrier is a cap designed to exclude surface water from infiltrating into the waste pit or trench and will be either a composite cap consisting of soil, sand, and a flexible membrane; a structural concrete cap; or a maintenance-free composite cap. Surface water diversions will direct runoff and flood water away from the facility,

Figure II-5-1. Barrier system (1-BE-1) process functional diagram.

adding conservatism to the barriers against water infiltration. Finally, a system of leachate collection and monitoring wells will allow for periodic and regular sampling of the groundwater and vadose zone. The leachate collection and monitoring units confirm effectiveness of the Barrier System.

The Barrier System is a passive system. After construction, the only activities will be occasional handling or processing of any potential leachate. Minor attendant facilities or equipment to support site monitoring will be needed. This will involve not only institutional control but also measuring, sampling, and monitoring a system of wells in and around the isolated waste pits and trenches.

5.1.2 Assessment Summary

The purpose of this section is to provide an overall evaluation on a system basis and to identify the major considerations (both advantages and disadvantages) resulting from the detailed assessments provided in Volume III. Barrier systems are in current use and provide a recognized means of site remediation. At this point, several technologies for a vertical barrier installation exist and may be chosen. The horizontal subsurface barrier and placement of a leachate collection system under the existing trenches and pits will be a first-of-a-kind technology and will require DT&E. Surface water diversion is required to ensure a hydraulic gradient will not develop. The water diversion system may require a redesign of the existing flood control system.

Several program implementation risks have been identified for the Barrier System. The program implementation risks associated with this system concept, including major areas of concern, are summarized in Table II-5-1. The subsurface barrier and leachate collection and monitoring units have the greatest risk of failing to meet technical objectives because the techniques for installation are still under DT&E. Furthermore, the subsurface barrier and leachate collection system may be difficult or impossible to emplace for two reasons: (a) the waste pits and trenches have contaminated waste sitting on top of bedrock and waste containers may prevent placement of the barrier

Table II-5-1. 1-BE-1 Summary of program implementation risks and major areas of concern

Technical	Health and Safety	Institutional	Schedule	Cost
Inability to place a subsurface barrier and leachate collection unit under the pits and trenches.	Inability to define and mitigate radioactive, hazardous, toxic, and volatile gases during barrier placement.	Low State and public support of leave in place options.	Prolonged DT&E on leachate collection and subsurface barriers placement techniques. collection unit DT&E.	Cost overruns due to uncertainties in the scope of horizontal barrier and leachate design and construction.
Potential need for a double barrier system under the disposal units to meet RCRA requirements.				Potential need for a double barrier under the pits and trenches.
Moderate	Low	High	Moderate	Moderate

and leachate piping, and (b) the basalt bedrock surface is irregular. The result is that there is probably insufficient room between the waste and the bedrock for safe and effective placement of the barrier with leachate collection. The demonstration of the longevity of the barrier system represents significant risk. Also, there is a possibility that the regulating agency may require a double liner system. Furthermore, compliance with institutional objectives represents a high risk because of low public support for an in-place treatment strategy.

The significant advantage for the barrier concept is that it provides an interim remediation solution that may be acceptable for the long term. Alternate technologies could be developed during this interim period that could provide better long-term solutions.

The evaluations conducted under this study conclude that DT&E is required on surface barrier, leachate collection and monitoring and subsurface barrier. Qualitative judgments were used in developing the extent of DT&E required. A more detailed assessment is needed to draw a definitive conclusion on DT&E programs and technology selection.

5.2 IN SITU VITRIFICATION (1-EB-2)

5.2.1 Summary System Description

Vitrification is a thermal treatment process that converts mixed waste into a chemically inert, stable glass and crystalline product. The in situ vitrification (ISV) process is employed in place (the buried waste is undisturbed) and for this system the product remains in the ground where it is formed. Figure II-5-2 provides a process functional diagram for the In Situ Vitrification System.

The unit operations of this system consist of site characterization, ISV site preparation, in situ vitrification, off-gas treatment, immobilization verification, cap and mark, and site monitoring. Geophysical techniques such as ground penetrating radar (GPR) and magnetics and electromagnetics (EM)

Figure II-5-2. In situ vitrification system (1-EB-2) process functional diagram.

offer relatively simple, nonintrusive methods of characterizing the RWMC site. ISV site preparation will include depositing uncontaminated dry soil on top of the trenches and pits to adjust elevations, compensate for void collapse, improve capture of contaminants, and reduce the chance of losing electrical continuity when molten glass fills a void. In situ vitrification will be accomplished through the use of movable electrodes to sustain an electrical current capable of heating the waste material to 3600°F and producing a molten material that will eventually harden at substantially reduced volume. Off-gas treatment utilizing HEPA filters will be used for the primary hood over the electrodes of the ISV process as well as to maintain a negative pressure inside the secondary enclosure of the ISV process train. Verification of immobilization will be achieved through leach testing to quantify that contaminants in the final hardened glass waste form are immobile, remain immobile, and present an acceptably low source term. The vitrified mass will be covered with a vegetative cap, sized to accommodate runoff considerations. Finally, methods used to monitor the migration of contaminants at hazardous waste sites will be used and may involve perimeter wells, monitors, or core sampling.

5.2.2 Assessment Summary

The purpose of this section is to provide an overall evaluation on a system basis and to identify the major considerations (both advantages and disadvantages) resulting from the detailed assessments provided in Volume III. ISV has been under development since 1980 as a promising technology for remediating hazardous and radioactive waste. Although it has yet to be used for full-scale remediation, it has been selected as the preferred process at 11 Superfund sites. A substantial amount of research and development has been invested in the process and it is now commercially available. Demonstrations of up to 1000 tons of vitrified material have been performed. The process has been scaled up to provide adequate throughput rates to meet the remediation criteria of complete processing within 10 years.

In a single process, ISV destroys and/or permanently immobilizes both organic and inorganic hazardous and radioactive contaminants, producing a leach-resistant, high integrity final waste form. A key advantage of this

process is that it is performed in place without removing or disturbing the waste. This significantly reduces both personnel exposure and facility/equipment costs. The process is relatively energy efficient, because the electrical energy is converted directly to heat in the vitrifying material. The process requires relatively large off-gas flow to remove the heat generated during the melting process. Also, the off-gas treatment system must be designed to withstand accidental eruption of the melt due to trapped gasses. The off-gas treatment process is well-established and is commercially available.

ISV achieves substantial volume reduction (from 20 percent to 60 percent, depending on the waste material) because there are no additives and the final waste form is relatively dense and free of voids. Substantial amounts of back-fill material would be required to retain the current ground level. Also, some waste materials could present processing problems. For example, large metal objects could cause a short between the electrodes, and compressed gas cylinders and barrels of organic liquids could overwhelm the off-gas treatment system.

The program implementation risks associated with this system concept, including major areas of concern are summarized, in Table II-5-2. Cost estimates for ISV are reasonably well-defined because of the amount of research and development that has already taken place. However, there is an uncertainty regarding the hazards classification of the ISV enclosure. If it is determined that an alpha certified enclosure is needed, then there could be a significant increase in the life-cycle costs including a prolonged schedule for processing the SDA buried waste.

DT&E needs for ISV are handling metals and large volumes of combustibles, site specific demonstration, and modeling (gas transport, fluid flow, heat exchange, process chemistry, etc.).

Table II-5-2. ISV concept (1-EB-2) summary of program implementation risks and major areas of concern

Technical	Health and Safety	Institutional	Schedule	Cost
- Downward Migration of contaminants. - Sudden expansion and eruption of trapped gases during ISV. - Could result in diffusion of contaminants to adjacent soil. - Heat could result in release of gases in adjacent soil. - Presence of metals could short circuit and result in incomplete vitrification.	- Inability to mitigate criticality concerns during ISV. - Inability to mitigate fire in the disposal unit. - Ability to define and mitigate Pu contaminated material safety concerns. - Inability to define and mitigate radioactive, hazardous, toxic, and volatile gases during normal and postulated accident events.	Lack of public support for leave in place options.	- Demonstrating RCRA compliance of thermal process. - Demonstrating compliance with the DOE & NRC emissions criteria.	Cost overruns due to uncertainties in the scope of ISV DT&E.
Moderate	Moderate	High	Moderate	Moderate

6. LEACH RESISTANT HIGH INTEGRITY STRUCTURE SYSTEMS

This section provides a summary description, assessment of required DT&E and risks, for the Leach Resistant High Integrity Structure Systems concepts. These systems result in waste forms referred to as waste form 2, and are described in more detail in Volume IV of this assessment report.

6.1 MELTING AND INCINERATION WITH LLW PRESORT (2-EG-1)

6.1.1 Summary System Description

This waste processing system is shown in Figure II-6-1. At the waste facility, LLW is presorted and transported to a LLW subsystem for treatment. Metal objects are sorted out for decontamination in a metal decontamination subsystem. The remaining waste is sorted into combustible and noncombustible waste and is processed through an incinerator and a melting furnace, respectively. The incinerator ash is then processed through the melting furnace with the noncombustible waste. Most of the process byproducts including TRU contaminated metal and residue resulting from the metal decontamination subsystem, TRU soil from the soils processing subsystem, and incinerator ash are fed to the melting furnace. The melter output is a leach resistant slag.

The unit operations of this system consist of on-line assay, opening containers and bags, metal sorting, combustible sort, sizing, melting, incineration, off-gas, and package/assay. Subsequent to site characterization and collection via the Retrieval Subsystem (S-BE-4), an on-line assay is performed to distinguish the LLW from the TRU and the two are sent through separate processes. Waste containers are opened by conventional means including the use of shredding, trommels, knives, and puncturing equipment. Metal sorting is performed by magnetic equipment and manipulators to direct waste to the Metals Decontamination and Sizing Subsystem (S-BE-1). Any metal that remains TRU contaminated is returned to the melter with any TRU sludge from the metal decontamination processes. Combustible and noncombustible waste is sorted out for incineration and melting, respectively, utilizing a

Figure II-6-1. Melting and incineration with LLW presort (2-EG-1) process functional diagram.

combination of visual inspection and aerodynamic and density measuring equipment. Next, sizing is performed to facilitate melting or incineration, and may be performed with shredders or alternatively, cryofracture.

Melting technologies will treat the waste at high temperatures (e.g., 3600°F) to destroy the toxic organic material and to vitrify and stabilize the inorganic materials and heavy metals into a molten glassy, leach resistant slag. Incineration will be used to thermally treat combustible waste in the form of solids, sludges, or liquids and will occur at temperatures in the range of 1800 to 2200°F. Off-gas from both the incinerator and the melting furnace will be treated in the same off-gas treatment system and the off-gas treatment residue can either be processed back through the melting furnace, encapsulated or dissolved in the melt from the melting furnace, or stabilized in some other media such as grout. Finally, the melt is poured into cooling containers, assayed, and packaged in containers suited for the destination of the waste.

The principal operations of this system after sorting and sizing the waste involve melting and incineration. The plasma and Joule melter systems are generally favored for melting purposes because of the low off-gas levels involved with heating. However, several melting technologies could be utilized including those involving fuel combustion. Similarly, several technologies exist for the incineration process.

6.1.2 Assessment Summary

The purpose of this section is to provide an overall evaluation on a system basis and to identify the major considerations (both advantages and disadvantages) resulting from the detailed assessments provided in Volume IV. Currently, a wide variety of melting and incineration technologies exist and are in various stages of DT&E. Incineration is used in fossil power plants as well as in sanitary waste facilities; both have to address stringent emission requirements. In addition, melting techniques are employed in the mining and metals industry much of which is applicable to processing hazardous waste; however, thermally treating melting of mixed hazardous waste in a melter has only been performed on a limited scale.

The program implementation risks associated with this system concept including major areas of concern are summarized in Table II-6-1. The unknown characteristics of the waste stream feed stock in the melter present potential problems with the operation of the melter, such as corrosion of the liner of the furnace. Certain types of input wastes may react with the furnace liner, requiring repair, significant down time, and exposure to maintenance personnel. In addition, the treatment of gaseous effluents resulting from melting or incinerating unknown materials may result in medium risk in designing the off-gas unit operation for a wide range of effluents. There is also a risk that the melter, incinerator, and off-gas unit operations could become a choke point for processing the waste. This risk is controllable by installing more than one unit if capacity factor limitations are a concern.

The significant advantages for melting and incineration are the waste reduction and conversion of the waste to a benign form. However, the significant disadvantages of melting and incineration are the potential for large volumes of off-gas and the need for secondary burners to further treat off-gas. The system requires significant leadtime for DT&E and the cost estimates for this system are sensitive to the input waste stream composition and conversion energy requirements.

6.2 IN SITU VITRIFICATION AND RETRIEVAL PROCESSING SYSTEM (2-EB-3)

6.2.1 Summary System Description

Vitrification is a thermal treatment process that converts mixed waste into a chemically inert, stable glass and crystalline product. The ISV process is employed as discussed in Section 5.2 followed by retrieval. The final destination for the remediated waste of this system is offsite; therefore, the vitrified mass is excavated from the site and sized for packaging and disposal. The fines created from the fracturing can become mobile in a final disposal site; therefore, they are transported from the site to a thermal process facility within the INEL Site boundaries and vitrified

Table II-6-1. Melter/incinerator system with LLW presort concept (2-EG-1) summary of program implementation risks and major areas of concern

Technical	Health and Safety	Institutional	Schedule	Cost
- Alpha cell confinement of radioactive, hazardous, toxic, and volatile gases during normal and postulated accident events. - Potential jamming and malfunction of complex mechanical devices and becoming a choking point. - Dust control during operations in the alpha cells. - Dust control and equipment decon & maintenance requirements could become a limitation on application of commercially available equipment. - Extensive DT&E to demonstrate versatility and compliance with rules and regulations. - High-temperature operation with limited experience on feeds similar to buried waste. - Critical material life is unknown.	- Ability to define and mitigate Pu contaminated material safety concerns. - Ability to define and mitigate radioactive, hazardous, toxic, and volatile gases during normal and postulated accident events. - Ability to define postulated accident events for the melter and incinerator (high-temperature) processes.	Institutional acceptance of thermal process.	Buried waste streams application verification and compliance with RCRA & DOE may require prolonged DT&E.	- Alpha cells in this environment is a first-of-a-kind design. - MSO is a first-of-a-kind application. - Use of remotely operated mechanical equipment on TRU waste is a first-of-a-kind application.

Table II-6-1. (continued)

Technical	Health and Safety	Institutional	Schedule	Cost
- Characteristic requirements for the incoming waste stream waste effluent are unknown. - DI&E will be needed to demonstrate versatility needed for buried waste streams application, and compliance with RCRA and DOE requirements. - Defining composition and amount of additives to obtain an a leach resistant glass or rock waste form could require extensive DI&E.	Moderate	High	Moderate	Moderate

again into a molten magma. The magma is quenched to form a larger size of vitrified waste that is not mobile, packaged in containers, and assayed for disposal.

The unit operations of this system, as depicted in Figure II-6-2, consist of site characterization, ISV site preparation, in situ vitrification, off-gas treatment, fracturing and excavating, screen, melters, and package/ containers and assay. Similar to the In Situ Vitrification System (1-EB-2), site characterization will be performed through the use of GPR and EM techniques. ISV site preparation will include depositing uncontaminated dry soil on top of the trenches and pits to adjust elevation, compensate for void collapse, improve capture of contaminants, and reduce the chance of losing electrical continuity when molten glass fills a void. In situ vitrification will be accomplished through the use of movable electrodes to sustain an electrical current capable of heating the waste material to 3600°F and producing a molten material that will eventually harden at substantially reduced volume. Off-gas treatment utilizes a primary hood over the electrodes of the ISV process, to maintain a negative pressure over the melt. Fracturing the vitrified waste may be accomplished either by cryogenic fracture or by mechanically breaking the material. Screening technologies to sort radioactive materials by size include disc screens, sliding screens, bar screens, and trommels. A large Joule heater unit will be used to melt the fines resulting from the fracture and excavation of the vitrified waste. The gases from this system will also be routed through the offgas treatment.

The system output, a molten magma, cools and hardens to a high integrity material with very low leachability (reportedly less than glass or granite), is very resistant to weather degradation, and is compared to the naturally occurring volcanic glass, obsidian. The ISV mass cools by heat transfer into the surrounding soils and to the surface, while the Joule melter process uses a quench tank to cool the magma. Process off-gas in both cases is collected and treated by off-gas hoods and treatment systems.

Figure II-6-2. In sit vitrification and retrieval processing system (2-EB-3) process functional diagram.

6.2.2 Assessment Summary

The purpose of this section is to provide an overall evaluation on a system basis and to identify the major considerations (both advantages and disadvantages) resulting from the detailed assessments provided in Volume IV. ISV has been under development since 1980 as a promising technology for remediating hazardous and radioactive waste. Although it has yet to be used for full-scale remediation, it has been selected as the preferred process at 11 Superfund sites. A substantial amount of research and development has been invested in the process, and it is now commercially available. Demonstrations of up to 1000 tons of vitrified material have been performed. The process has been scaled up to provide adequate throughput rates to meet the remediation criteria of complete processing within 10 years.

Joule heated melters have been used by the glass making industry for over 30 years and are a well-established, commercially available technology. A commercial facility would have to be adapted with the appropriate radiological control requirements for use with plutonium-contaminated vitrified waste, and a moderate hazard facility would have to be constructed, but the process parameters are well-established.

In a single process, ISV destroys and/or permanently immobilizes both organic and inorganic hazardous and radioactive contaminants, producing a leach-resistant, high integrity final waste form. A key advantage of this process is that it is performed in place, without removing or disturbing the raw waste. This significantly reduces both personnel exposure and facility/equipment costs. The process is relatively energy efficient, because the electrical energy is converted directly to heat in the vitrifying material. Also, the process requires relatively little off-gas treatment compared to processes that use combustion gases to heat the material. The off-gas treatment process is well-established and commercially available.

ISV achieves substantial volume reduction (from 20 to 60%, depending on the waste material) because there are no additives, and the final waste form is relatively dense and free of voids. Substantial amounts of back-fill material would be required to retain the current ground level. Also, some waste

materials could present processing problems. For example, large metal objects could cause an electrical short between the electrodes, and compressed gas cylinders and barrels of organic liquids could overwhelm the off-gas treatment system. The program implementation risks associated with this system concept including major areas of concern are summarized in Table II-6-2.

Removing the vitrified waste would be safer and much less complicated than removing untreated waste. However, care will need to be taken to control Pu-contaminated dust while fracturing and excavating the monolith.

Cost estimates for ISV are reasonably well defined because of the amount of research and development that has already taken place. However, there is an uncertainty regarding the hazards classification of the ISV enclosure. If it is determined that an alpha certified enclosure is needed, then there could be a significant increase in the life-cycle costs including a prolonged schedule for processing the SDA buried waste. The melter and its associated moderate hazard facility, though processing only a fraction of the total waste, contributes significantly to the overall cost of remediation.

Major DT&E needs for this system include handling metals and large volumes of combustibles, site specific demonstration, modeling (gas transport, fluid flow, heat exchange, and process chemistry), fracture and retrieval dust control, Joule heated melter concept and investigation of additives to ensure proper melting and product quality.

Table II-6-2. ISV, Retrieval and Processing Concept (2-EB-3) Summary of program implementation risks and major areas of concern

Technical	Health and Safety	Institutional	Schedule	Cost
• Downward Migration of contaminants. • Sudden expansion and eruption of trapped gases during ISV. • Could result in diffusion of contaminants to adjacent soil. • Heat could result in release of gases in adjacent soil. • Presence of metals could short circuit and result in incomplete vitrification.	• Ability to mitigate criticality concerns during ISV. • Ability to mitigate fire in the disposal unit. • Ability to define and mitigate Pu contaminated material safety concerns. • Ability to define and mitigate radioactive, hazardous, toxic, and volatile gases during normal and postulated accident events. • Ability to define postulated accident events for the melter (high-temperature) process.	• Institutional acceptance of thermal process	• Demonstrating RCRA compliance of thermal process. • Demonstrating compliance with the DOE & NRC emissions criteria. • Fracturing and retrieval of vitrified soil may require prolonged DT&E • Buried waste streams application verification and compliance with RCRA & NRC may require prolonged DT&E.	• Cost overruns due to uncertainties in the scope of ISV DT&E. • Cost overruns due to uncertainties in the facility hazardous classification, and method for alpha confinement. • Cost associated with fracturing and retrieval of vitrified soil is undefined. • Alpha cells in this environment is a first-of-a-kind design. • Melter process application to TRU waste are first-of-a-kind applications. • Use of remotely operated mechanical equipment on TRU waste is a first-of-a-kind application.

Table II-6-2. (continued)

Technical	Health and Safety	Institutional	Schedule	Cost
Alpha cell confinement of radioactive, hazardous, toxic, and volatile gases during normal and postulated accident events.				
Potential jamming and malfunction of complex mechanical devices.				
Dust control during operations in the alpha cells.				
DT&E to demonstrate vitrification and emissions compliance with rules and regulations.				
Moderate	Moderate	High	Moderate	Moderate

6.3 MELTING AND INCINERATION WITH LLW POSTSORTING SYSTEM (2-EG-4)

6.3.1 Summary System Description

This waste processing system is shown in Figure II-6-3. At the waste facility the waste containers are opened and the metal is sorted out for decontamination in the Metal Decontamination/Sizing Subsystem. The remaining waste is sorted into noncombustible and combustible waste. The noncombustible waste is shredded and processed through a melting furnace, and the combustible waste is shredded and incinerated. Other input streams to the melting furnace are TRU metal and residue resulting from the metal decontamination subsystem and TRU soil from a soils processing subsystem.

The unit operations of this system consist of: open containers and bags, metal sorting, combustible sort, sizing, melting, incineration, off-gas, and package/assay. The principal unit operations of this system after sorting and sizing the waste involve melting and incineration. The plasma and Joule melter systems are generally favored for melting purposes because of the low off-gas levels involved with heating; however, several melting technologies could be utilized including those involving fuel combustion. Similarly, several technologies exist for the incineration process.

Melting technologies will treat the waste at high temperatures (e.g., 3600°F) to destroy the toxic organic material and to vitrify and stabilize the inorganic materials and heavy metals into a molten glassy, leach resistant slag. Incineration will be used to thermally treat combustible waste in the form of solids, sludges, or liquids and will occur at temperatures in the range of 1800 to 2200°F. Off-gas from both the incinerator and the melting furnace will be treated in the same off-gas treatment system and the off-gas treatment residue can either be processed back through the melting furnace, encapsulated in the melt from the melting furnace, or stabilized in some other media such as grout. Finally, the melt is poured into cooling containers, assayed, and packaged in containers suited for the destination of the waste.

Figure II-6-3. Melting and incineration system with LLW postsort (2-EG-4) process functional diagram.

6.3.2 Assessment Summary

The purpose of this section is to provide an overall evaluation on a system basis and to identify the major considerations (both advantages and disadvantages) resulting from the detailed assessments provided in Volume IV. A wide variety of melting and incineration technologies exist and are in various stages of development and test. Incineration is currently used in fossil power plants as well as in sanitary waste facilities and both have to address stringent emission requirements. Melting techniques are employed in the mining and metals industry, much of which is applicable to processing hazardous waste. Melting of mixed hazardous waste has been performed only on a limited scale.

The unknown characteristics of the waste stream feed stock in to the melter presents potential problems with the operation of the melter such as corrosion of the liner of the furnace. Certain types of input wastes may react with the furnace liner, requiring repair, causing significant down time and exposure to maintenance personnel. The treatment of gaseous effluents resulting from melting or incinerating unknown materials may result in medium risk in designing the off-gas unit operation for a wide range of effluents. There is a risk that the melter, incinerator, and off-gas unit operations could become a choke point for processing the waste. The program implementation risks associated with this system concept, including major areas of concerns, are summarized in Table II-6-3.

The significant advantages for melting and incineration are the waste reduction and conversion of the waste to a benign form. The significant disadvantages of melting and incineration are the potential for large volumes of off-gas and the need for secondary burners to further treat off-gas.

Table II-6-3. Melter/incinerator system with LLW postsort concept (2-EG-4) summary of program implementation risks and major areas of concern

Technical	Health and Safety	Institutional	Schedule	Cost
- Alpha cell confinement radioactive, hazardous, application verification toxic, and volatile gases during normal and postulated accident events. - Potential jamming and malfunction of complex mechanical devices and becoming a choking point. - Dust control during operations in the alpha cells. - Dust control and equipment decon & maintenance requirements could become a limitation on application of commercially available equipment. - DT&E to demonstrate vitrification and emissions compliance with rules and regulations. - Defining composition and amount of additives to obtain an a leach resistant glass or rock waste form could require extensive DT&E.	- Ability to define and mitigate Pu contaminated material safety concerns. - Ability to define and hazardous, toxic, and mitigate radioactive, volatile gases during normal and postulated accident events. - Ability to define postulated accident events for the incinerator & melter (high-temperature) processes.	Institutional acceptance of thermal process.	Buried waste streams and compliance with RCRA & NRC may require prolonged DT&E.	- Alpha cells in this of environment is a first-of-a-kind design. - Melter and incinerator process application to TRU waste are first-of-a-kind applications. - Use of remotely operated mechanical equipment on TRU waste is a first-of-a-kind application.
Moderate	Moderate	High	Moderate	Moderate

7. LAND DISPOSAL RESTRICTION REQUIRED/HYDROGEN GENERATION RESTRICTIVE SYSTEMS

This section provides a summary description, assessment of required DT&E and risks, and recommendations resulting from the system assessment of the Land Disposal Restriction Required/Hydrogen Generation Restrictive Systems. These systems result in waste forms referred to as Waste Form III, and are described in more detail in Sections 1 through 5 of Volume V of this assessment report.

7.1 THERMAL TREATMENT/SOLIDIFICATION SYSTEM WITH LLW PRESORT(3-IT-1)

7.1.1 Summary System Description

This waste processing system, depicted in Figure II-7-1, is one in which the buried waste is treated to meet the requirements of RCRA LDR using the technologies of incineration and solidification. More specifically, TRU sludges are solidified in one of several solidification agents: combustibles and inerts are processed through a thermal treatment system, and the resultant ash is similarly immobilized. Metals are processed in the metals decontamination and sizing subsystem to convert most of the metal to LLW. LLW is presorted from TRU so that it can be processed in a subsystem.

The unit operations of the system consist of: assay, open packages/sort, dump drums and sort, grinder for cemented inorganic sludges, organics treatment for sludges, shredder, thermal treatment, off-gas treatment, concentrator and liquid waste treatment system, dryer, solidification of salts, solidification of sludges and combustible ash, and metal melting.

Subsequent to site characterization and receipt from the Retrieval Subsystem (S-BE-4), all packages will be passed through an assay system to determine if the packages are LLW or TRU. The system will be patterned after the existing TRU waste handling facilities at the RWMC and allow

Figure II-7-1. Thermal treatment/solidification system with LLW presort process (3-IT-1) functional diagram.

identification of fissionable material inventory as well as beta/gamma scanning. After assaying, the LLW will be sent to the LLW Processing Subsystem and the TRU waste will proceed through the TRU treatment system. TRU waste packages will be examined visually and using real-time radiography, opened, sorted according to waste type, and directed to one of the treatment systems: sludge treatment, combustibles and inerts incineration, or the Metals Decontamination and Sizing Subsystem (S-BE-1).

Sludge drums will be sorted (if the drums are still intact), and a determination will be made whether the sludges contain organics or are inorganic. Visual examination will determine whether the sludges have been cemented. The drum contents will be dumped into appropriate hoppers for further treatment, and the drums will be sent to the Processing system. Those inorganic sludges that have previously been cemented in a "parfait" fashion will probably not meet the TCLP criteria and will be directed through a grinder to be processed in the same manner as the uncemented sludges. Organic sludges will be thermally treated to meet LDR. Thermal treatment by several direct or indirect heating methods will be acceptable. The off-gases from the thermal treatment will contain organic constituents and will be further treated in a secondary combustion chamber associated with the combustibles thermal treatment. The final step for sludge treatment will be solidification to immobilize the sludges and meet LDR requirements. TRU sludge from soils treatment, LLW treatment, and metal decontamination will be immobilized with the mainstream sludges.

Combustibles and inerts will be shredded prior to thermal treatment. A shredder system, consisting of remote package handling, oversize item retrieval, and sticky material handling equipment will be used to ensure proper thermal treatment operation. The thermal treatment unit will be capable of processing large volumes of combustibles and noncombustibles. In addition, a very high carbon burnout will be necessary to make the resultant product compatible with the subsequent solidification agents. Gases resulting from thermal treatment will be removed from the effluent stream to meet TCTA and Clean Air Act criteria. Ash from the thermal treatment will be solidified using a formulation compatible with the resultant ash. Because the thermal off-gas cleanup equipment will produce a liquid waste consisting of an aqueous

salt solution, a concentrator and dryer will be used to separate liquid from the salt, and the latter will be solidified. TRU metals from the Metals Decontamination and Sizing Subsystem (S-BE-1) will be melted into ingots.

7.1.2 Assessment Summary

The purpose of this section is to provide an overall evaluation on a system basis and to identify the major considerations (both advantages and disadvantages) resulting from the detailed assessments provided in Volume V.

For the most part, the major unit operations within this system are either developed and demonstrated or can probably be fully demonstrated within two to four years. Some DT&E will be required for organics treatment of sludges, thermal treatment of combustibles, and for solidification of the various treated waste products. The integration of the unit operations into a viable waste treatment facility seems to be well within the capability of the architect/engineering and chemical plants industries to perform. Presorting LLW before processing the TRU waste has advantages, because the confinement requirements for TRU processing are more stringent than those for LLW.

By presorting the LLW, a smaller TRU processing line can be built, with commensurate safety advantages. In addition, the volume of waste disposed of in a TRU geologic repository is minimized. Two disadvantages were identified during the course of the study. The first pertains to the effect of changing regulatory climates on the thermal treatment, off-gas, and solidification operations. The tendency toward more stringent requirements may produce regulatory uncertainties that must be recognized during the facility planning stage. The second disadvantage concerns the presorting of LLW and the need for an additional LLW process line in addition to the TRU waste processing line. The program implementation risks associated with this system concept including major areas of concern are summarized in Table II-7-1.

Table II-7-1. Thermal treatment/solidification system with LLW presort concept (3-II-1) summary of program implementation risks and major areas of concern

TECHNICAL	HEALTH AND SAFETY	INSTITUTIONAL	SCHEDULE	COST
- Ability to characterize waste and implement the proper LDR treatment techniques. - Alpha cell confinement of radioactive, hazardous, toxic, and volatile gases during normal and postulated accident events. - Potential jamming and malfunction of complex mechanical devices and becoming a choking point. - Dust control during operations in the alpha cells. - Dust control and equipment decon & maintenance requirements could become a limitation on application of commercially available equipment. - Thermal desorber DT&E to demonstrate versatility and compliance with rules and regulations. - Solidification process DT&E to demonstrate compliance with rules and regulations.	- Ability to define and mitigate Pu-contaminated material safety concerns. - Ability to define and mitigate radioactive, hazardous, toxic, and volatile gases during normal and postulated accident events. - Ability to define postulated accident events for thermal desorber process.	Lack of public support for thermal processes.	- Solidification Process application, verification, and compliance with RCRA & NRC may require prolonged DT&E. - Thermal desorber application, verification, and compliance with RCRA & NRC may require prolonged DT&E.	- Thermal desorber application to large scale plants. - Alpha cells in this environment is a first-of-a-kind design. - Use of remotely operated mechanical equipment on TRU waste is a first-of-a-kind application.
Moderate	Low	High	Low	Moderate

7.2 THERMAL TREATMENT/SOLIDIFICATION SYSTEM WITH LLW POSTSORT (3-IT-3)

7.2.1 Summary System Description

The Thermal Treatment/Solidification System with LLW Postsort (3-IT-3), a system in which the buried waste is treated to meet the requirements of RCRA Land Disposal Restrictions using the technologies of incineration and solidification, is depicted in Figure II-7-2. More specifically, TRU sludges are solidified in one of several solidification agents; combustibles and inerts are processed through a thermal treatment system and the resultant ash is similarly immobilized. Metals are processed in the metals decontamination and sizing subsystem to convert most of the metal to LLW. LLW is processed with TRU waste and separated in the final assay.

The unit operations of this system consist of assay, open packages/sort, dump drums and sort, grinder for cemented inorganic sludges, organics treatment (sludges), shredder, thermal treatment, off-gas treatment, concentrator and liquid waste treatment system, dryer, solidification of salts, solidification of sludges and combustible ash, lead decontamination, and melting metal.

This system will treat wastes that will be sorted into TRU and LLW categories after treatment. The waste to be treated consists of combustibles and inerts, sludges, lead, soils, and other metals.

After receipt of waste from the Retrieval Subsystem (S-BE-4), all packages will be passed through an assay system to determine their fissionable content. The system will be patterned after SWEPP and allow identification of fissionable material inventory as well as beta/gamma scanning. After assaying, the waste will proceed through the treatment system. Waste packages will be examined visually and using real-time radiography, opened, sorted according to waste type, and directed to one of the treatment systems: sludge treatment, combustibles and inerts incineration, or the Metals Decontamination and Sizing Subsystem (S-BE-1).

Figure II-7-2. Thermal treatment/solidification system with LLW postsort (3-IT-3) process functional diagram process functional diagram.

Sludge drums will be sorted (if the drums are still intact), and a determination will be made as to whether the sludges contain organics or are inorganic. Visual examination will determine whether the sludges have been cemented. The drum contents will be dumped into appropriate hoppers for further treatment, and the drums will be sent to the Metals Processing System. Those inorganic sludges that have previously been cemented in a "parfait" fashion will probably not meet the TCLP criteria and will be directed through a grinder to be processed in the same manner as the uncemented sludges. Organic sludges will be thermally treated to meet LDR requirements. Thermal treatment by several direct or indirect heating methods will be acceptable. The off-gases from the thermal treatment will contain organic constituents and will be further treated in a secondary combustion chamber associated with the combustibles thermal treatment. The final step for sludge treatment will be solidification to immobilize the sludges and meet LDR requirements. TRU sludge from soils treatment and metals decontamination will be immobilized with the mainstream sludges.

Combustibles and inerts will be shredded prior to thermal treatment. A shredder system, consisting of remote package handling, oversize item retrieval, and sticky material handling equipment, will be used to ensure proper thermal treatment operation. The thermal treatment unit will be capable of processing large volumes of combustibles and noncombustibles. In addition, a very high carbon burnout will be necessary to make the resultant product compatible with the subsequent solidification agents. Gases resulting from thermal treatment will be removed from the effluent stream to meet RCRA and Clean Air Act criteria. Ash from thermal treatment will be solidified using a formulation compatible with the resultant ash. Because the thermal off-gas cleanup equipment will produce a liquid waste consisting of an aqueous salt solution, a concentrator and dryer will be used to separate liquid from the salt, and the latter will be solidified. Lead will be decontaminated by melting and partitioning radionuclides into the resultant slag. The slag will be immobilized to meet TCLP criteria. TRU metals from the Metals Decontamination/Sizing Subsystem will be melted into ingots.

All treated waste packages will be assayed to determine TRU content. Other analytical and physical testing dictated by regulations or WIPP waste

acceptance criteria will be performed. These final measurements will complete certification for packages destined for disposal at WIPP. LLW will be separated for disposal.

7.2.2 Assessment Summary

The purpose of this section is to provide an overall evaluation on a system basis and to identify the major considerations (both advantages and disadvantages) resulting from the detailed assessments provided in Volume V.

For the most part, the major unit operations within this system are either developed and demonstrated, or can probably be fully demonstrated within two to four years. It appears that DT&E will only be required for decontamination of lead. This will entail investigation of radionuclide partitioning into the lead slag and evaluation of slag solidification/immobilization formulations and techniques. Some development will be required for organics treatment of sludges, thermal treatment of combustibles, and for solidification of the various treated waste products. The integration of the unit operations into a viable waste treatment facility seems to be well within the capability of the architect/engineering and chemical plant industries.

By not presorting LLW, the higher volume of waste processed by the common system will require a larger waste processing line designed to meet the more stringent requirements of a TRU waste processing facility. The larger TRU facility also has some safety disadvantages over a smaller TRU line. The volume of waste that will be disposed of in a TRU geologic repository is likely to be higher than if LLW was presorted before processing. This disadvantage might be minimized by using a campaign approach to processing TRU and LLW through the facility. However, campaigning may require a large receiving and storage area. Another disadvantage identified during the course of the study pertains to the effect of changing regulatory climates on the thermal treatment, off-gas, and solidification operations. The tendency toward more stringent requirements may produce regulatory uncertainties that must be recognized during the facility planning stage. The program implementation risks associated with this system concept, including major areas of concern, are summarized in Table II-7-2.

Table II-7-2. Thermal treatment/solidification system with LLW presort concept (3-IT-3) summary of program implementation risks and major areas of concern

TECHNICAL	HEALTH AND SAFETY	INSTITUTIONAL	SCHEDULE	COST
- Ability to characterize waste and implement the proper LDR treatment techniques. - Alpha cell confinement of radioactive, hazardous, toxic, and volatile gases during normal and postulated accident events. - Potential jamming and malfunction of complex mechanical devices and becoming a choking point. - Dust control during operations in the alpha cells. - Dust control and equipment decon & maintenance requirements could become a limitation on application of commercially available equipment. - Thermal desorber DT&E to demonstrate versatility and compliance with rules and regulations. - Solidification process DT&E to demonstrate compliance with rules and regulations.	- Ability to define and mitigate Pu. contaminated material safety concerns. - Ability to define and mitigate radioactive, hazardous, toxic, and volatile gases during normal and postulated accident events. - Ability to define postulated accident events for thermal desorber process.	Lack of public support for thermal processes.	- Solidification Process application, and compliance with RCRA & NRC may require prolonged DT&E. - Thermal desorber application, and compliance with RCRA & NRC may require prolonged DT&E.	- Thermal desorber application to large scale plants. - Alpha cells in this environment is a first-of-a-kind design. - Use of remotely operated mechanical equipment on TRU waste is a first-of-a-kind application.
Moderate	Low	High	Low	Moderate

7.3 PYROLYSIS AND ACID LEACH WITH PLUTONIUM EXTRACTION SYSTEM (3-EB-6)

7.3.1 Summary System Description

This system, as depicted in Figure II-7-3, is designed to treat containerized TRU wastes, TRU soils from the soil processing subsystem, TRU sludge, and TRU metals from the Metal Decontamination Sizing Decontamination Subsystem. The purpose of the system is to separate plutonium and other TRU constituents from the waste, and process them in a manner that produces a final waste form that meets LDR requirements and restricts hydrogen generation. This is accomplished by pyrolyzing combustible material to reduce volume and destroy organic contaminants. Plutonium is extracted from the pyrolysis char by acid leaching to minimize the volume of TRU waste. Noncombustible waste, solids from the acid leach process, and wastes from the pyrolysis off-gas treatment are solidified to fix inorganic contaminants. Containers are assayed and TRU waste is separated from LLW following waste processing.

The unit operations of this system consist of: sort, pyrolysis, acid leach, solvent extraction, fume incinerator, off-gas treatment, shredder, and solidification. Containerized waste is sorted into combustible and noncombustible materials. Subsequent to site characterization and receipt from the Retrieval Subsystem (S-BE-4), sorting will be performed with manipulators or air classification techniques. Pyrolysis, the process of thermally decomposing materials in the absence of oxygen, will achieve volume reduction without producing SO_x, NO_x, or other objectionable compounds (dioxins and furans). Acid leaching utilizing a mixture of nitric and hydrofluoric acid will then be employed to dissolve plutonium. Alternatively, the Catalytic Electrolytic Plutonium Oxide Dissolution (CEPOD) process may be used. The solvent extraction step is needed to separate the plutonium, americium, and other TRU metals from the waste. Fume incineration will be utilized to destroy the organics present in the gases that leave the pyrolysis unit. The flue gas from the fume incinerator must be treated to remove contaminants prior to discharge. Shredding equipment will be used to process noncombustible wastes onto a form amenable for subsequent solidification.

Figure II-7-3. Pyrolysis and acid leach with plutonium extraction system process functional diagram.

7.3.2 Assessment Summary

The purpose of this section is to provide an overall evaluation on a system basis and to identify the major considerations (both advantages and disadvantages) resulting from the detailed assessments provided in Volume III. In general, all of the eight major unit operations in the proposed system utilize state-of-the-art technology. The acid leach step using the CEPOD dissolver appears to be the only exception where some innovative technology is involved. Each of these unit operations is currently available and individually demonstrated. These operations are not conceptual, and considerable performance data is available from operations on other materials. The weakest link in the entire system design is the lack of specific performance data on the type of waste materials that will actually be processed through the system. The success of the design to meet specific performance objectives will depend largely on the availability of such data. The lack of such data is not an unusual or insurmountable problem. The necessary data can be generated through DT&E.

Throughout the analysis of the system, it was assumed that the concentration of Pu in the wastes will be so small that criticality will not be achieved at the proposed processing rates. The validity of this assumption is fundamental to the safe operation of the system. The program implementation risks associated with this system concept, including major areas of concern, are summarized in Table II-7-3.

The DT&E program must be designed to answer the following questions:

Pyrolysis Unit.

- Can the necessary heat be supplied to the waste through indirect heating? Will the heat transfer rates be adequate or will some form of direct contact heating be necessary?
- Can pyrolysis temperatures be controlled in the 1,000 to 1,200°F range?

Table II-7-3. Pyrolysis and acid leach with Pu extraction system concept (3-EB-6) summary of program implementation risks and major areas of concern

TECHNICAL	HEALTH AND SAFETY	INSTITUTIONAL	SCHEDULE	COST
- Effectiveness of pyrolysis process in temperature control, removal of fixed carbon prior to acid leach, and heat transfer rates. - Ability to define characteristics of char. - Ability to control pyrolysis temperature. - Fume incinerator trial burn for operability & environmental compliance. - Design maturity of the acid leach process. - Availability of commercial scale CEPD dissolver. - Alpha cell confinement of radioactive, hazardous, toxic, and volatile gases during normal and postulated accident events. - Potential jamming and maloperation of complex mechanical devices and becoming a choking point. - Dust control during operations in the alpha cells.	- Ability to define and mitigate Pu contaminated material safety concerns. - Ability to define and mitigate radioactive, hazardous, toxic, and volatile gases during normal and postulated accident events. - Ability to define postulated accident events for thermal desorber process.	Low public support of thermal processes.	- Prolonged pyrolysis and fume incinerator DT&E to confirm process applicability and regulatory compliance. - Prolonged pyrolysis DT&E. - Prolonged DT&E in definition of char characteristics. - Prolonged DT&E to develop a commercial scale CEPD process. - Prolonged, DT&E of the solidification unit regulatory compliance. - Prolonged DT&E, design, and construction of alpha cells. - Prolonged DT&E, design, and construction of remotely operated mechanical equipment.	- Cost of pyrolysis, acid leach, and solvent extraction unit operations cannot be defined until DT&E is complete. - Uncertainties in defining cost of the solidification unit operations. - Alpha cells in TRU waste environment is a first-of-a-kind design. - Use of remotely operated mechanical equipment on TRU waste is a first-of-a-kind application.

Table II-7-3. (continued)

TECHNICAL	HEALTH AND SAFETY	INSTITUTIONAL	SCHEDULE	COST
- Dust control and equipment decon & maintenance. requirements could preclude application of commercially available equipment. - Solidification process demo. compliance with rules and regulations.	Moderate	High	Moderate	High
High				

- Can the fixed carbon in the char be adequately removed by controlled combustion in the pyrolysis unit?
- Will the geometry of the pyrolysis unit present a criticality problem during waste processing.

CEPOD Dissolver.

- What design data is needed to construct a commercial scale CEPOD dissolver?
- Which characteristics are desirable in the char from the pyrolysis unit to ensure efficient plutonium extraction? Will the char require pretreatment before extraction?
- How will changes in process conditions in the pyrolysis unit affect the operation of the CEPOD dissolver?

Solvent Extraction.

- Can the efficiency of the solvent extraction technology be improved to extract plutonium from the CEPOD product?
- Is ion exchange a better alternative to solvent extraction for removing plutonium?

Fume Incinerator.

- What type of heat recovery system should be incorporated to improve overall operating efficiency?
- Will there be a significant amount of NO_x or SO_x generated, and will it require treatment?

Off-gas Treatment System.

- How effective is the off-gas treatment system in controlling gaseous and particulate emissions?
- Is the operation of the off-gas treatment system susceptible to changes in waste characteristics fed to the pyrolysis unit?

Solidification.

- What are the reagents to be added to accomplish immobilization of hazardous constituents?
- What is the optimum mix ratio to use for solidification?
- What analytical procedures will be used to ensure that the required treatment standards are met?

7.4 MOLTEN SALT OXIDATION AND PACKAGING SYSTEM (3-BE-7)

7.4.1 Summary System Description

The Molten Salt Oxidation (MSO) and Packaging System (3-BE-7) is depicted in Figure II-7-4. This system includes unique unit operations that interface with three subsystems: the Retrieval Subsystem (S-BE-4), the Soils Processing Subsystem (S-EB-2), and the Metal Decontamination/Sizing Subsystem (S-BE-1).

The unit operations of this system consist of: incoming (unprocessed) waste receiving and opening, sorting (nonmetal/metal), size reduction, molten salt oxidizer, off-gas treatment, liquid waste treatment, solidification, assay/certification, interim storage, and shipping. Prepackaged waste is first received from the Waste Retrieval Subsystem (S-BE-4) and will then be processed by opening the prepackaged containers (reusable); sorting and segregating waste for input to appropriate unit operations; completing inventory storage and accountability of waste; and uncapping, opening, and

Figure II-7-4. Molten salt oxidation and packaging system (3-BE-7) process functional diagram.

dumping waste. The sorting unit operation is designed to segregate metals from nonmetals and, where applicable, to further sort by waste type (TRU, LLW, soil, etc.). Shredding, or crushing, and fine sorting to minimize the amount of soils fed to the oxidizer prepares the incoming waste stream for the molten salt oxidizer. A molten salt oxidizer will be utilized to thermally reduce and destroy the wastes. Off-gas treatment examines, quantifies, and treats the process stream to permit release to the environment and secondary waste stream process subsystems. Liquid waste treatment processes will include filtrate, neutralization, demineralization, reverse osmosis, evaporation, and/or precipitation.

The solidification unit operation receives fines, liquids, and organic waste by-products, and combines these utilizing physical or chemical processes to solidify the materials. Assay/certification will examine and quantify the radioactive physical properties of the filled containers to determine proper classification and adherence to appropriate regulations. Finally, storage and eventual shipment will complete the unit operations of this system.

7.4.2 Assessment Summary

The purpose of this section is to provide an overall evaluation on a system basis and to identify the major considerations (both advantages and disadvantages) resulting from the detailed assessments provided in Volume V.

The Molten Salt Oxidation unit operation is presently undergoing significant DT&E. This program is funded by DOE, and is being executed by Lawrence Livermore National Laboratory (LLNL) and Rockwell International (RI). The RI system consists of a 1-t/day baseline design that has been mass balanced for LLNL waste streams. The pilot-scale unit for LLNL is scheduled to be completed and operated in FY-91. The process developed by RI is patented. It is an air breathing (open loop exhaust), isothermal 1,652°F process. The prototype 1-t/day unit has demonstrated the destruction of Pu-containing wastes, where the Pu is retained by the melt, and a high level of destruction of hazardous wastes (PCBs, chemical warfare agents, halogenated organics, solids, and aqueous slurries) occurs. In most cases, the destruction was quantified to be in the 99.99 percent efficiency range. The

RI process is a single vessel system that favors low-ash, low-moisture feed stock. High aluminum/silicon ash combined with an excessive oxygen level dynamically increases viscosity to the point of solidification, thereby rendering the melt useless. High moisture requires a large increase in fuel use. It is anticipated that the MSO process will have difficulty with the SDA waste streams because of the high soil content.

The program implementation risks associated with this system concept, including major areas of concern, are summarized in Table II-7-4. The Molten Salt Oxidation unit operation and its impacts on supporting unit operations represent the greatest risk for this system. The other unit operations are well-known and present a minimal risk. The ability to process waste streams of unknown characteristics presents a significant risk. A significant advantage of this system is its ability to convert organic halogens to water, carbon dioxide, and salt. Processing efficiencies are high for known waste stream compositions. A significant disadvantage of this system is its inability to process unknown waste stream compositions. Problems have occurred with sand/clay mixtures at high temperatures. This system requires significant lead time for DT&E. The cost estimate for this system is highly dependent on the final configuration of the MSO process.

7.5 CHEMICAL OXIDATION/SOLIDIFICATION SYSTEM WITH LLW POSTSORT (3-IT-8)

7.5.1 Summary System Description

This is a system that uses chemical oxidation and solidification as its main processing units. More specifically, combustibles, inerts, and sludges are processed through an oxidation system. All treated products and residues are solidified. Metals are processed in the Metals Decontamination and Sizing Subsystem for conversion to LLW or clean metal. LLW is separated from TRU after processing.

Table II-7-4. Molten salt oxidation system concept (3-BE-7) summary of program implementation risks and major areas of concern

TECHNICAL	HEALTH AND SAFETY	INSTITUTIONAL	SCHEDULE	COST
- Alpha cell confinement of radioactive, hazardous, toxic, and volatile gases during normal and postulated accident events. - Potential jamming and malfunction of complex mechanical devices and becoming a choking point. - Dust control during operations in the alpha cells. - Dust control and equipment decon & maintenance. requirements could become a limitation on application of commercially available equipment. - Extensive DT&E to demonstrate versatility and compliance with rules and regulations - High-temperature operation with limited experience on feeds similar to buried waste.	- Ability to define and mitigate Pu contaminated material safety concerns. - Ability to define and mitigate radioactive, hazardous, toxic, and volatile gases during normal and postulated accident events. - Ability to define postulated accident events for the MSO (high-temperature) process.	Institutional acceptance of thermal process.	Buried waste streams application and verification with RCRA & NRC may require prolonged DT&E.	- Alpha cells in this environment is a first-of-a-kind design. - MSO is a first-of-a-kind application. - Use of remotely operated mechanical equipment on TRU waste is a first-of-a-kind application.

Table II-7-4. (continued)

TECHNICAL	HEALTH AND SAFETY	INSTITUTIONAL	SCHEDULE	COST
• Critical material life is unknown. • Characteristic requirements for the incoming waste stream waste effluent are unknown. • DT&E will be needed to demonstrate versatility needed for buried waste streams application, and compliance with RCRA, NRC and DOE requirements. • Technologies for solidification(stabilization) of the MSO waste output has not been tested. There is a concern that the waste output may not be compatible with the existing technologies. • Defining the composition of the waste and testing properties of solidified waste could require prolonged DT&E.	Moderate	High	Moderate	Moderate
High				

The unit operations of this system, as depicted in Figure II-7-5, include open packages and sort, screens, inerts treatment, shredder, chemical oxidation, biotreatment/adsorption, off-gas treatment, dewatering of sludges, liquid waste treatment, solidification of sludges, lead decontamination, and melting metal.

After receipt of waste from the Retrieval Subsystem, all packages will be examined visually. Using real-time radiography, These packages will be opened, sorted according to waste type, and directed to one of the treatment systems: inerts treatment, combustibles and sludges chemical oxidation, lead treatment, or the Metals Decontamination/Sizing Subsystem. Inert materials will be screened to separate large inerts from sludges and smaller particulates. Large inerts will proceed to the inerts treatment system, and the remainder will be conveyed to the chemical oxidation system. The large inerts will be treated to remove organic and oxidizable inorganic constituents using a chemical oxidation process such as super-critical water, wet oxidation, or acid digestion. Residual organic constituents from the oxidation process will be further treated by biological processes or carbon adsorption.

Sludge from dewatering following the oxidation, biotreatment, and adsorption process will be removed from the treated waste stream and forwarded to the solidification system. Effluent will be treated in the liquid waste treatment system to remove radioactive contamination. Residues will be sent to the solidification system. Gases that result from oxidation and biotreatment/adsorption processes will contain light organics and will be treated by scrubbing, adsorption, or fume incineration. Liquid solutions will be treated in the liquid waste treatment system.

Lead will be decontaminated by melting and partitioning radionuclides into the resultant slag. The slag will be immobilized to meet TCLP criteria. TRU metals from the Metal Decontamination/Sizing Subsystem will be melted into ingots.

All treated waste packages will be assayed to determine TRU content. Other analytical and physical testing dictated by regulations or WIPP waste

Figure II-7-5. Chemical oxidation/solidification system with LLW postsort (3-IT-8) process functional diagram.

acceptance criteria will be performed. These final measurements will complete certification for packages destined for geologic disposal. LLW will be separated for disposal.

7.5.2 Assessment Summary

The purpose of this section is to provide an overall evaluation on a system basis, and to identify the major considerations (both advantages and disadvantages) resulting from the detailed assessments provided in Volume V.

Approximately one-third of the major unit operations within this system will require DT&E. As a result, it will probably require about five to six years before these unit operations have been demonstrated for use in the facility. It appears that DT&E will be required for the inerts treatment, chemical oxidation, biotreatment/adsorption, liquid waste treatment, and lead decontamination unit operations. Some additional DT&E will be required for solidification of sludges. In general, the integration of the unit operations into a viable waste treatment facility seems to be well within the capability of the architect/engineering and chemical plant industries. However, the application of chemical oxidation and biotreatment techniques may complicate the integration of unit operations from the standpoint of waste and product flow through the system. Oxidation and biotreatment are typically slower processes than, for example, incineration.

The program implementation risks associated with this system concept, including major areas of concern, are summarized in Table II-7-5.

If presorting of LLW does not occur, the higher volume of waste processed by the common system will require a larger waste processing line designed to meet the more stringent requirements of a TRU waste processing facility. The larger TRU facility also poses safety disadvantages that a smaller TRU line does not. The volume of waste that will be disposed of in a TRU geologic repository is likely to be higher than the volume produced if LLW is presorted before processing. This disadvantage might be minimized by using a campaign approach to processing TRU and LLW through the facility. However, campaigning may require a large receiving and storage area. Another

disadvantage identified during the course of the study pertains to the effect of changing regulatory climates on the off-gas and solidification operations. The tendency toward more stringent requirements may produce regulatory uncertainties that must be recognized during the facility planning stage.

Table II-7-5. Chemical oxidation solidification system concept (3-IT-8) summary of program implementation risks and major areas of concern

Technical	Health and Safety	Institutional	Schedule	Cost
• The three major processes, inert treatment, chemical oxidation, and biotreatment are immature. • Ability to define waste characteristics for LDR and provide the EPA specified treatment. • Alpha cell confinement of radioactive, hazardous, toxic, and volatile gases during normal and postulated accident events. • Potential jamming and maloperation of complex mechanical devices and becoming a choking point. • Dust control during operations in the alpha cells. • Dust control and equipment decon & maintenance requirements could preclude application of commercially available equipment. • Solidification process demo. compliance with rules and regulations.	• Ability to define and mitigate Pu contaminated material safety concerns. • Ability to define and mitigate radioactive, hazardous, toxic, and volatile gases during normal and postulated accident events.	• None	• Prolonged DT&E of treatment, chemical oxidation, and biotreatment processes. • Prolonged DT&E of the solidification unit operations, due primarily to regulatory compliance. • Prolonged DT&E, design and construction of alpha cells. • Prolonged DT&E, design and construction of remotely operated mechanical equipment.	• Cost of inert treatment, chemical oxidation, and biotreatment processes cannot be defined until DT&E is complete. • Uncertainties in defining cost of the solidification unit operations. • Alpha cells in TRU waste environment is a first-of-a-kind design. • Use of remotely operated mechanical equipment on TRU waste is a first-of-a-kind application.
High	Moderate	Low	Moderate	High

8. WIPP AND TRAMPAC ACCEPTABLE SYSTEMS

This section provides a summary description, an assessment of the required DT&E and related risks, and recommendations resulting from the system assessment of the WIPP and TRAMPAC Acceptable Systems. These systems result in waste forms referred to as Waste Form 4, and are described in more detail in Volume VI of this assessment report.

8.1 SORT, TREAT, AND REPACKAGE SYSTEM (4-BE-2)

8.1.1 Summary System Description

The Sort, Treat, and Repackage System (4-BE-2) includes unique unit operations that interface with three subsystems: Retrieval Subsystem (S-BE-4), Soils Processing Subsystem (S-EB-2), and Metal Decontamination and Sizing Subsystem (S-BE-1). The integration of the unique unit operations of the Sort, Treat, and Repackage System (4-BE-2) with the above subsystems may require additional developmental efforts.

The unit operations of this system, as depicted in Figure II-8-1, consist of incoming (unprocessed) waste receiving and opening, sorting (nonmetal/metal), size reduction, sludge drum unloading, solidification, vent bags, decompression, assay/certification, interim storage, and shipping.

The Retrieval Subsystem provides all of the necessary processes and unit operations to retrieve and gross sort the buried waste. There are four major output streams from the Retrieval Subsystem: peripheral soil, bulk metal, loose material, and intact containers.

The peripheral soil output is transported via reusable containers to the Soils Processing Subsystem (S-EB-2). This subsystem has all of the facilities and equipment necessary to treat and dispose of the contaminated soil.

Figure II-8-1. Sort, treat, and repackage system (4-BE-2) process functional diagram.

The bulk metal output is containerized and transported to the Metal Decontamination and Sizing Subsystem (S-BE-1). This subsystem has all of the facilities and equipment necessary to treat the metal for LDR, and to reduce hydrogen generation potential.

Loose material and intact containers (including gas cylinders) are transported to the Waste Receiving, Processing, and Packaging Facility. At this facility the containers are opened, and the waste is removed and processed through a sorting unit. The sorting unit segregates the waste into metal and nonmetal (including gas cylinders) streams. The metal waste stream is sent to the Metal Decontamination and Sizing Subsystem. The nonmetal stream is further sorted into combustibles and noncombustibles, organic and inorganic sludge, fines and liquid waste, plastic bags, and compressed gas cylinders.

Each of the five waste streams are treated by various unit operations according to the specific WIPP-WAC and TRAMPAC-II waste form compliance requirements.

Combustible and noncombustible wastes are reduced, and stored in WIPP containers. The fines and liquid waste stream are stabilized by mixing with a solidification agent. The solidified waste is also packaged in WIPP containers. The plastic bags and compressed gas cylinders are punctured or shredded, and filled into WIPP containers without extensive processing for volume reduction.

Each packaged waste container is processed through a radio-assay and a final certification process. At this point, the containers are certified either as TRU or LLW. Certified containers are sent to an interim storage facility. When they are shipped, containers are transferred out of the interim storage area and loaded into transportation over-packs. Over-packs, mounted on shipping vehicles, are used for offsite shipment and disposal.

8.1.2 Assessment Summary

The purpose of this section is to provide an overall evaluation on a system basis and to identify the major considerations (both advantages and disadvantages) resulting from the detailed assessments provided in Volume VI.

Excluding cryofracture, techniques employed in this system are well-known, commercially available, and currently in use by the industry. The cryofracture process is presently being utilized, but on a more limited scale than any other technology in the system.

There is a risk associated with the alpha cell enclosure and accessibility to repair or maintain the equipment. It is likely that cryofracture will not perform well with some types of stainless steel. There may be some incompatibility with the waste stream composition and the solidification system. The decompression unit operation may pose safety hazards. The program implementation risks associated with this system concept, including major areas of concern, are summarized in Table II-8-1.

A significant advantage of this system is that the processes employed by the system are all in use and well-known.

The technologies, except for solidification and cryofracture, do not require significant DT&E. Development/demonstration time is required for integration of all unit operations.

8.2 VOLUME REDUCTION AND PACKAGING SYSTEM (4-BE-4)

8.2.1 Summary System Description

The Volume Reduction and Packaging System (4-BE-4) includes unique unit operations that interface with four subsystems: Retrieval Subsystem (S-BE-4), Soils Processing Subsystem (S-EB-2), Metal Decontamination/Sizing Subsystem (S-BE-1), and Low-Level Waste Processing Subsystem (S-IT-3). The integration

Table II-8-1. Sort, treat, and repackaged system concept (4-BE-2) summary of program implementation risks and major areas of concern

Technical	Health and Safety	Institutional	Schedule	Cost
- Alpha cell confinement of radioactive, hazardous, toxic, and volatile gases during normal and postulated accident events. - Potential jamming and malfunction of complex mechanical devices and becoming a choking point. - Dust control during operations in the alpha cells. - Dust control and equipment decon & maintenance requirements could become a limitation on application of commercially available equipment.	- Ability to define and mitigate Pu contaminated material safety concerns. - Ability to define and mitigate radioactive, hazardous, toxic, and volatile gases during normal and postulated accident events.	None	- Prolonged DT&E, design and construction of remote equipment for alpha cells. - Prolonged design and construction of alpha cells.	- Alpha cell in TRU waste handling environment is a first-of-a-kind design. - Use of remotely operated mechanical equipment on TRU waste is a first-of-a-kind application.
Moderate	Low	Low	Low	Moderate

of the unique unit operations of the Volume Reduction and Packaging System (4-BE-4) with the above subsystems may require additional development.

As depicted in Figure II-8-2, the unit operations of this system consist of: incoming (unprocessed) waste receiving and opening, sorting (nonmetal/metal), volume reduction, sludge drum unloading, decompression, thermal decomposition, off-gas treatment, solidification, assay/certification, interim storage, and shipping.

The system is comprised of the four previously mentioned subsystems and dedicated unit operations. The Retrieval Subsystem is located over the hazardous waste site. The other subsystems and unit operations are housed within the Receiving, Processing, and Packaging Facility. The Retrieval Subsystem provides all of the necessary processes and unit operations to retrieve and gross sort the buried waste. There are four major output streams from the Waste Retrieval Subsystem: peripheral soil, bulk metal, loose material, and intact containers.

The peripheral soil output is transported in reusable containers to the Soils Processing Subsystem (S-EB-2). This subsystem has all of the facilities and equipment necessary to treat and dispose of the contaminated soil.

The bulk metal output is containerized and transported to the Metal Decontamination/Sizing Subsystem (S-BE-1). This subsystem has all of the facilities and equipment needed to treat the metal for LDR and to reduce hydrogen generation potential.

Loose material and intact containers (including gas cylinders) are transported to the Waste Receiving, Processing, and Packaging Facility. At this facility the containers are opened, and the waste is removed and processed through a sorting unit. The sorting unit segregates the waste into metal and nonmetal (including gas cylinders) streams. The metal waste stream is sent to the Metal Decontamination and Sizing Subsystem. The nonmetal stream is further sorted into LLW and TRU.

Figure II-8-2. Volume Reduction and Package System (4-BE-4) process functional diagram.

LLW stream is fed to the Low-Level Waste Subsystem. This subsystem has all of the facilities and equipment needed to treat and dispose of LLW.

The TRU waste stream from the second sorting unit is sent to a third sorting unit. This unit segregates the incoming stream into combustibles and noncombustibles, compressed gas cylinders, inorganic sludge, organic sludge, plastic bags, and liquid waste.

Each of the four waste streams is treated by various unit operations according to the specific WIPP-WAC and TRAMPAC-II waste form compliance requirements.

Combustibles and noncombustibles are volume reduced and filled into containers. Compressed gas cylinders are decompressed, size reduced, processed for volume reduction, and filled into containers. Inorganic sludge is filled directly into containers.

The organic sludge, plastic bags, and liquid waste stream are incinerated. The incineration product is discharged to a solidification unit. The incineration secondary combustion waste stream includes gaseous and liquid waste streams. The gaseous waste stream is treated in an off-gas unit operation and discharged to the atmosphere. The liquid stream is sent to the solidification unit operation.

The incineration products and the liquid waste are solidified in containers. Each packaged waste container is processed through a radio-assay and a final certification process. Certified containers are sent to an interim storage facility. The containers are shipped by removing the containers from the interim storage area and loading the containers into transportation over-packs. Over-packs, mounted on shipping vehicles, are used for offsite shipment and disposal.

A description of the unit operations in the Waste Receiving, Processing, and Packaging Facility is presented below.

8.2.2 Assessment Summary

The purpose of this section is to provide an overall evaluation on a system basis and to identify the major considerations (both advantages and disadvantages) resulting from the detailed assessments provided in Volume VI.

The program implementation risks associated with this system concept, including major areas of concern, are summarized in Table II-8-2.

The techniques employed in this system, except for cryofracture, are well-known, commercially available, and currently in use by the industry. The cryofracture process is currently utilized but on a more limited scale than any other technology in the system. The thermal decomposition unit operation, while having been employed previously, will require detailed information regarding the composition of the input waste stream to achieve desired efficiencies of removal and to permit integration with other unit operations.

There is a risk associated with the alpha cell enclosure and accessibility to repair or maintain the equipment. It is likely cryofracture will not perform well with some types of stainless steel. There may be some incompatibility with the waste stream composition and the solidification system. The decompression unit operation may pose safety hazards.

Table II-8-2. Volume reduction and packaging system concept (4-BE-4) summary of program implementation risks and major areas of concern

Technical	Health and Safety	Institutional	Schedule	Cost
- Alpha cell confinement of radioactive, hazardous, toxic, and volatile gases during normal and postulated accident events. - Potential jamming and malfunction of complex mechanical devices and becoming a choking point. - Dust control during operations in the alpha cells. - Dust control and equipment decon & maintenance. requirements could become a limitation on application of commercially available equipment. - Thermal decomposition DT&E to demonstrate versatility and compliance with rules and regulations.	- Ability to define and mitigate Pu contaminated material safety concerns. - Ability to define and mitigate radioactive, hazardous, toxic, and volatile gases during normal and postulated accident events. - Ability to define postulated accident events for thermal decomposition process.	Potential lack of support for thermal desorber process	- Thermal decomposition application verification and compliance with RCRA & NRC may require prolonged DT&E. - Prolonged DT&E, design and construction of remote equipment for alpha cells. - Prolonged design and construction of alpha cells	- Thermal decomposition application to large scale plants. - Alpha cell in TRU waste handling environment is a first-of-a-kind design. - Use of remotely operated mechanical equipment on TRU waste is a first-of-a-kind application
Moderate	Moderate	Low	Low	Moderate

9. SUBSYSTEM OPTIONS

This section provides a summary description, an assessment of the required DT&E and program implementation risks, and recommendations resulting from the system assessment of the Subsystem Options. These subsystems are described in more detail in Volume VII of this assessment report.

9.1 METAL DECONTAMINATION AND SIZING SUBSYSTEM (S-BE-1)

9.1.1 Summary System Description

The Metal Decontamination/Sizing Subsystem, (S-BE-1), shown in Figure II-9-1, is comprised of several unit operations. These include metal pretreatment, size reduction, metal decontamination, liquid waste treatment, and assay.

The subsystem is housed within the Waste Receiving, Processing, and Packaging Facility, and receives bulk metallic waste from the Retrieval Subsystem and loose metallic waste from unit operations within the Waste Receiving, Processing, and Packaging Facility.

The Retrieval Subsystem provides all of the necessary processes and unit operations to retrieve and gross sort the buried waste.

There are four major output streams from the Metal Decontamination and Sizing Subsystem: LLW metal, TRU metal, TRU residue, and treated clean liquid.

The subsystem includes equipment to pretreat and size-reduce the contaminated bulk metal as well as loose metal that requires size reduction. The size-reduced metal and remaining loose metal are decontaminated to remove or reduce TRU contamination and hazardous materials from the surface of the metallic waste. The decontaminated metal is assayed to segregate the TRU metal from the LLW metal. The LLW metal and TRU metal are transferred via

Figure II-9-1. Metal decontamination and sizing subsystem process (S-BE-1) functional diagram.

reusable containers to other unit operations within the Waste Receiving, Processing, and Packaging Facility for treatment and disposal. The liquid waste stream, produced from the metal decontamination and bulk metal pretreatment, is treated in a liquid waste treatment unit operation. The concentrated TRU residue waste is transferred via reusable containers to other unit operations within the Waste Receiving, Processing, and Packaging Facility for treatment and disposal. The treated liquid is discharged to the environment.

The Metal Decontamination and Sizing Subsystem includes an alpha certified enclosure with appropriate ventilation equipment to maintain control and prevent release of TRU and other hazardous waste. Spent filters from this ventilation unit are transferred to other unit operations in the Waste Receiving, Processing, and Packaging Facility for treatment and disposal.

9.1.2 Assessment Summary

The purpose of this section is to provide an overall evaluation on a subsystem and to identify the major considerations (both advantages and disadvantages) resulting from the detailed assessments provided in Volume VII.

The techniques employed in this subsystem are well-known, commercially available, and currently in use by the industry. There is a risk associated with the alpha cell enclosure and accessibility to repair or maintain the equipment. There is an operational risk associated with processing the size and volume of the anticipated waste stream. This may require added redundancy and/or larger capacity to avoid processing delays.

The significant advantage of this subsystem is that the processes it employs are all well-known and in use. The significant disadvantage of this subsystem is the generation of additional liquid waste without the benefit of free release of metal. Another disadvantage of the subsystem is that many metallic materials absorb radioactive contamination within the grain boundaries of the metal, and decontamination of the metal for controlled

release is extremely difficult. Decontamination to LLW should be easily achievable for most metals.

The technologies do not require significant DT&E. Development/demonstration time is required for integration of all unit operations for this subsystem. The costs for this subsystem should be well-known because the technologies are currently in use.

9.2 SOILS PROCESSING SUBSYSTEM (S-EB-2)

9.2.1 Summary System Description

The Soils Processing Subsystem interfaces with the other systems within the System Design Study to process the large quantities of soil retrieved from the INEL RWMC. The final products are TRU soil (which is returned to the parent system for further processing), solidified LLW soil (which meets the LDR requirements), and clean soil.

The unit operations of this subsystem, shown in Figure II-9-2, consist of thermal desorption, TRU soil washing/separation, liquid waste TRU removal, solidification, and LLW Assay Conveyor. To homogenize the soil prior to thermal desorption treatment, soil entering the Soils Processing Subsystem is initially emptied from its container into a crusher. A thermal desorber heats the soil to approximately 450°F. At or below this temperature, most volatile and semivolatile organic compounds are thermally stripped from the soil. The organic vapors are captured in a treatment system consisting of either granular activated carbon or an afterburner and/or scrubber.

The organic-free soil is cooled and conveyed to the soil washing/separation operation, which is a physical treatment process that gravimetrically separates the TRU-contaminated soil fines from the larger volume of soil. The final product, a small portion of soil contaminated with concentrated TRUs and heavy metals, is dewatered and packaged for further processing by the parent system.

Figure II-9-2. Soils Processing Subsystem (S-EB-2) process functional diagram.

The liquid waste TRU removal operation requires water to generate a slurry for its separation process. This water can be recycled if the TRUs are removed from it. The liquid waste TRU removal process will polish this recycle water and use potassium ferrate to precipitate out ferric hydroxide complexes containing TRU. The sludge that is formed in the liquid waste TRU removal process is dewatered and combined with the TRU soil exiting the soil washing/separation operation.

The non-TRU soil separated in the liquid waste TRU removal operation is assayed for LLW on a conveyor. Batches of soil that are identified as containing LLW are segregated from the clean soil. The clean soil is packaged for delivery to its proper disposal/refill site. Prior to packaging, each batch of clean soil will be tested for RCRA controlled metal contamination. Those soils contaminated with metals will be combined with the LLW soil for solidification/stabilization.

The LLW soil is solidified by mixing the soil with a binder (such as Portland cement) and water, and pouring the mixture into drums. The dried product is leach resistant and will meet LDR standards. The solidification operation will be automated to the extent feasible.

9.2.2 Assessment Summary

The purpose of this section is to provide an overall evaluation on a subsystem basis and to identify the major considerations (both advantages and disadvantages) resulting from the detailed assessments provided in Volume VII.

A soils processing subsystem based on thermal desorption (to remove volatile organics), treatment (to capture the organics), soil washing/ separation (to separate TRU soil, LLW soil, and clean soil), liquid waste TRU removal (to polish the soil washing/separation recycle water), and solidification (to stabilize LLW and metal contaminated soils) is both conceivable and implementable. With the exception of the thermal desorber, most of the unit operations have been demonstrated in a TRU environment. Soil washing techniques are very-soil and contaminate specific and thus require

demonstration on the SDA soils. Thermal desorption has been demonstrated in hazardous and LLW environments.

A DT&E program on soil washing is proposed for Pit 9 at SDA. This program, if completed, will provide ample data on soil cleaning feasibility.

Prior to further assessment of the subsystem, a greater characterization of the INEL soils will have to be made. Samples that represent the extreme conditions of contamination should be taken. From this information, a profile of variations in the concentration of individual contaminant in the soil can be drawn.

It is recommended that the Soils Processing Subsystem be divided into two parallel operating trains of the same size. Although the cost of two trains would be larger than the cost of one, there are several advantages to operating two trains. Principle advantages include a 50 percent reduction in downtime (assuming that one train, capable of handling half the process rate, will always be on-line) and equipment sizing on a scale that vendors have used and can guarantee.

The Soils Processing Subsystem is designed to treat soils, and cannot be used for other matrices. In particular, the thermal desorber is designed to remove organics from soil that will volatilize at or below 450° F. If the soils contain heavy hydrocarbons, this technology may have to be replaced with another technology such as soil washing or incineration. The remaining operations of the subsystem are unlikely to be eliminated because of such limitations. The INEL soil consists of basalt and clay and, therefore, is more difficult to process in a soil washing or separation process.

Interfaces between the unit operations will require a continuous exchange of information between the vendors. The soil washing/separation operation is the heart of the subsystems, and will interface with the other operations. It is expected that all interfaces can be made compatible.

The production rate and performance of the subsystem will be limited by two operations: the accuracy of the TRU contaminate detectors in the TRU

clean system and the reliability of the LLW solidification system. A better sense of these indicators may come from the demonstration runs. The production rate requires a substantial amount of LLW soil to be solidified and packaged, and clean soil to be packaged. Careful consideration of the materials handling and storage of the processed soils is required. To understand the immensity of the volume, it is necessary to picture the soil being packaged in 55-gal drums. There would be 528 drums of LLW packaged and manifested per day (or 14,800 drums per month) and 384 drums of clean soil packaged per day (or 10,800 drums per month). Many operators have not experienced this quantity of handling and paperwork.

Safety concerns lie with those processes (thermal desorption, soil washing/separation) where plutonium dust could escape from the vessel. A demonstration should help to clarify the acceptability of the risks. Another area of concern is the initial unloading of soils and final packaging of TRU soil and LLW soil. These tasks require the constant presence of operators. These operations should be automated to the greatest extent possible and designed to minimize radioactive emissions. Easy and quick repairs should be kept in mind when designing the placement of the materials handling equipment.

The largest cost component of the system is the thermal desorber followed by the soil washing/separation process. The cost components that will require further research in order to pin down a more precise figure are the thermal desorber and the solidification/materials handling. The thermal desorber may require alterations in the current design and materials in order to operate in a TRU environment. The cost of the solidification/material handling system will be tied significantly to the architectural design of the building. The bulk of the operating costs are attributed to the packaging required for the soils and, to a lesser extent, the TCLP and metals testing. Material costs for the liquid waste TRU removal system will vary directly with fluctuations in contaminant concentration power requirements for the subsystem. Thermal desorption, treatment, and TRU Clean require most of the power needs.

Demonstration, testing and evaluation of the subsystem could be performed in 18 months at best. Because the technologies have been developed for the most part, efforts would be directed towards the specific application of these

technologies to the INEL soil. This includes testing each unit operation in meeting its performance requirements. A pilot-scale demonstration could be scheduled so that the unit operations are demonstrated at or close to the same time and, thus, use real influent streams. Ideally, one production-scale train (of the proposed two train system) would be built for demonstration and, if successful, the second train would be added for full-scale operation. This takes advantage of the fact that one train alone is on the same scale as most of the vendors' pilot-scale equipment. A liquid waste TRU removal technology, TRU/clear, has been demonstrated for several DOE facilities and is a DOE patented process.

Most of the subsystem can be fabricated and skid-mounted offsite with the exception of the solidification system. The thermal desorber would require the longest fabrication time, and the solidification and packaging systems would take the longest time to install. Startup of the subsystem depends on the operation of the more complex equipment: the thermal desorber and the soil washing/separation system.

9.3 LOW-LEVEL WASTE SUBSYSTEM (S-IT-3)

9.3.1 Summary System Description

This is a subsystem in which the LLW is treated to meet the requirements of RCRA LDR using the technologies of thermal processing and solidification. More specifically, LLW sludges are solidified in one of several solidification agents: combustibles and inerts are processed through a thermal treatment system and the resultant ash is similarly immobilized. Ferrous metals are sized prior to packaging. Lead is decontaminated in a melting process.

This processing system is schematically presented in Figure II-9-3. The system will treat LLW consisting of combustibles, loose materials, soil, sludges, and lead, and consists of the following unit operations: open packages and sort, LDR treatment of lead, LDR treatment of sludges, LDR treatment of combustibles, secondary waste treatment, solidification of sludges and ash, and assay.

Figure II-9-3. Low-level waste subsystem process (S-II-3) functional diagram.

After receipt from waste assay, waste packages will be examined visually and, using real-time radiography, opened, sorted according to waste type, and then directed to one of the treatment systems: LDR organics treatment for sludges or combustibles and inerts and LDR treatment for lead. Organic sludges will be thermally treated to meet LDR requirements. Thermal treatment by several direct or indirect heating methods would be acceptable. The off-gases will contain the organic constituents, which will be further treated in a secondary combustion chamber associated with the combustibles thermal treatment. Combustibles and inerts will be treated to remove or eliminate organic constituents by thermal means or biotreatment. Biotreatment is not expected to be a viable process, and, therefore, thermal equipment capable of treating large volumes of combustibles, noncombustibles, and large objects will be required. In addition, a very high carbon burnout will be necessary to make the resultant product compatible with the subsequent solidification process. Several candidate incinerators as well as thermal desorption devices may be considered.

An off-gas cleanup process will be required to treat gases from the thermal processes to meet RCRA and Clean Air Act requirements. Because of the chlorinated material in the waste, a wet process is the likely choice, but a dry scrubbing system may be an alternative. Sludges from the process will be solidified, and clean gases will be vented to the atmosphere. Based on test results, a solidification agent will be selected to immobilize the treated solids to meet LDR requirements. Several materials are candidates for this process.

LDR treatment of lead can consist of macroencapsulation or decontamination. Because macroencapsulation will probably not meet LDR requirements lead will be decontaminated by melting and partitioning radionuclides into the resultant slag. The slag will be immobilized to meet LDR criteria.

All treated wastes will be sampled and analyzed to determine if they meet the LDR requirements.

9.3.2 Assessment Summary

The purpose of this section is to provide an overall evaluation on a subsystem basis and to identify the major considerations (both advantages and disadvantages) resulting from the detailed assessments provided on Volume VII.

For the most part, the major unit operations within this subsystem are either developed and demonstrated or can probably be fully demonstrated within two to four years. It appears that basic research will only be required for LDR treatment of lead, assuming that this also entails elimination of radionuclides. This will entail investigation of the elimination of hazardous constituents as well as radionuclide partitioning into the lead slag, and evaluation of slag solidification/immobilization formulations and techniques. Some development will be required for LDR treatment of sludges and combustibles and for solidification of the various treated waste products. The integration of the unit operations into a viable waste treatment facility seems to be well within the capability of the architect/engineering and chemical plant industries to perform.

By presorting LLW before processing, the lower volume of waste processed by the TRU waste processing systems minimizes the amount of waste being shipped to the TRU waste geologic repository. The facility can also be designed on the basis of the LLW, rather than alpha confinement criteria. A disadvantage identified during the course of the study pertains to the effect of changing regulatory climates on the thermal treatment, and solidification operations. The tendency toward more stringent requirements may produce regulatory uncertainties that must be recognized during the facility planning stage. An inherent disadvantage of a separate LLW subsystem is the need for additional equipment and building space, apart from that needed for other waste processing needs.

9.4 RETRIEVAL SUBSYSTEM (S-BE-4)

9.4.1 Summary System Description

The Retrieval Subsystem (S-BE-4), as shown in Figure II-9-4, is comprised of several unit operations: characterization, alpha enclosure, object location identifier, visual inspection, radiation surveyor, peripheral soil, high radiation objects, large objects, large construction material, loose material, intact container, and bulk metal. The subsystem characterizes, retrieves, gross sorts, and packages the material for transportation to one of the following: the Waste Receiving, Processing, and Packaging Facility; the Soils Processing Subsystem; or the Metal Decontamination and Sizing Subsystem. The retrieval operation is accomplished in an airtight alpha environmental enclosure.

There are four major output streams from the Retrieval Subsystem: peripheral soil, bulk metal, loose material, and intact containers. The subsystem includes excavation equipment that removes the top soil cover placed on the buried waste trenches or pits. The excavated cover (peripheral soil), which may contain low concentrations of TRU material, is placed in reusable transportation containers and shipped to the Soils Processing Subsystem (S-EB-2) for treatment and disposal.

After removing the cover soil, the Retrieval Subsystem scans the area of the trench under consideration. The scanning operation identifies and prepares a location map of buried large objects and other wastes requiring special handling. The information obtained from the scanning operation is issued to plan the retrieval operation.

Remotely operated excavation tools are provided to extract special waste such as high radiation objects, large discarded components, and structural pieces. After retrieval, special waste is packaged and placed in an enclosed interim storage area near the trench. Final disposal option of special wastes will be decided on a case-by-case basis.

Figure II-9-4. Retrieval subsystem (S-BE-4) process functional diagram.

Also included are remotely operated tools, equipment, and instruments for excavation of loose material, removing intact waste containers, and bulk metal objects.

The excavated waste is grouped into bulk metal objects and loose material and intact containers. Each type of waste is placed in a separate reusable transportation container. The bulk metal waste containers are transported to the Metal Decontamination and Sizing Subsystem (S-BE-1) for treatment and disposal.

The loose material and intact containers are sent to the Waste Receiving, Processing, and Packaging Facility for treatment and disposal. The Waste Receiving, Processing, and Packaging Facility may be represented by any of the 12 candidate F&OR sections.

Ventilation equipment is provided to maintain barriers needed for an alpha certified environmental enclosure. Spent filters from this ventilation unit are placed in loose material containers and shipped to the Waste Receiving, Processing, and Packaging Facility for treatment and disposal.

9.4.2 Assessment Summary

The purpose of this section is to provide an overall evaluation on a subsystem and to identify the major considerations (both advantages and disadvantages) resulting from the assessments in the previous sections. This includes an evaluation of the ability to integrate the various unit operations into a smooth, well-functioning subsystem.

The techniques employed in this system are well-known, commercially available, and currently in use by the industry. This subsystem is depicted in the process flow diagram as unique unit operations. There is equipment currently available that combines many of the functions into a single unit. The excavation, extraction, and retrieval of buried waste may be made more efficient through the application of robotics currently under development.

There is a risk associated with the alpha cell enclosure and accessibility to repair or maintain the equipment. There is risk in achieving an adequate seal between the ground and the alpha cell enclosure. There are also risks associated with the design of the overall size and mobility of the alpha cell enclosure.

Excluding the alpha cell enclosure size, the significant advantage of this system is that the processes employed are all well-known and in use. The significant disadvantage associated with the Retrieval Subsystem involves generating the dust and contamination during the excavation and extraction process.

The technologies employed in this subsystem do not require significant DT&E. DT&E is required for integration of all unit operations. The costs for this system should be well-known because the technologies are currently in use.

10. SUMMARY OF STUDY RESULTS

10.1 ANALYSIS OF SYSTEM CONCEPTS

10.1.1 In Situ Concepts

The in situ systems considered for analysis and evaluation were the Barrier System and the ISV System. Each system provides different levels of isolation for the waste and can be used as an interim action solution or a final solution, depending on the CERCLA selection process.

The Barrier System (1-BE-1) provides a means for minimizing the migration of Pu and hazardous material into the basalt levels below the waste piles. At a minimum, a vertical barrier and a cap over the top of the waste pile will be needed. Depending on the results of the performance assessment on the waste piles, an additional horizontal subsurface barrier (single or double) and a leachate collection unit, below the waste, may be required. The majority of the costs, DT&E efforts, and risks are associated with this horizontal subsurface barrier(s). The costs for just the cap and vertical barrier are 75% less than the costs than result when horizontal subsurface barriers are included. The main concern with the horizontal barrier is the possible variation in the levels of rock at the bottom of the waste piles. In addition, because some of the pits and trenches are close together, distances may be too long for the horizontal drilling and grouting, considering there is rock formation a short depth below the waste piles.

The ISV System (1-EB-2) also provides a way to minimize the migration of Pu and hazardous material into the basalt below the waste piles. Because the waste form from ISV is a glass-like structure, the long-term stability of the waste is much greater than the Barrier concept, with less likelihood of intrusion and further migration of the hazardous material. There is a probability that sometime during the ISV operation, the primary confinement (an environmental enclosure) may be breached. For this reason, the concept of eight simultaneous operation under one environmental enclosure may need to be changed to individual environmental enclosures. Individual environmental

enclosures presented in this study may cost more, but they will allow for independent operations and less contamination spread in the event of a breach of the primary confinement. Also, the schedule for performing the ISV campaigns needs further evaluation. At this point it is not clear how long the ISV enclosure must be kept on top of the melt before it can be moved to the next location. DT&E will be needed to characterize the molten rock cooling time, and the composition and quantity of gases released during the cooling period. In addition, a more detailed analysis of the offgas system and the environmental enclosure designs will be needed to ensure that the removal of the heat generated during the ISV is adequately addressed. Also, the ISV concept in the SDS is based on low hazards confinement of the ISV operations. A more detailed analysis may show that a higher classification of the hazards may be required. This higher classification could result in the need for an alpha enclosure. It is quite possible that instead of vitrifying SDA waste in 5 years, 10 years will be needed, and the overall cost would be higher than the ROM estimate given in the SDS.

10.1.2 Ex Situ

The SDS examined 10 different system concepts that produced one of the three final waste forms (i.e., those that are a leach-resistant, high integrity structure; those that meet LDR requirements and those that meet current WIPP and TRAMPAC requirements). These three waste forms give a wide selection of the quality of the waste form where the leach-resistant, high integrity structure is the best form, and the WIPP/TRAMPAC has the least quality.

At this stage of the Buried Waste Program, the only considerations that can be used in narrowing the number of ex situ systems selected for further development are (a) program implementation (technical, health and safety, institutional, schedule, and cost) risks, (b) the quality of the three final waste forms, and (c) the Program flexibility requirements that must accommodate the CERCLA remedial selection process. To comply with the latter consideration, it is prudent that future ex situ concept development efforts involve both thermal and non-thermal processes. Ex situ concepts best meeting the above criteria are Melter/Incinerator, (2-EG-2 and 2-EG-4), ISV and

Retrieval (2-EB-3), and Oxidation/Solidification (3-IT-8) systems. A more detailed discussion of the selected system concepts is presented in Section 11 of this Volume.

The ISV and Retrieval System has an added advantage in that it can be selected for an interim action solution, while keeping open the option for future removal of the vitrified waste. This option will be discussed later in Interim Solutions, Section 10.4. A main issue associated with retrieval of an ISV waste matrix, other than those associated with the actual ISV process, is the excavation of the ISV waste matrix. While not analyzed in this study, there are health and safety advantages of retrieval of vitrified waste versus the retrieval of unprocessed waste. The concept of processing the fines in a processing facility, contained in the ISV and Retrieval concept developed in the SDS, needs to be further evaluated. It may be better and more cost-effective to ISV any fines generated during the retrieval operation in a separate pit in a field operation using existing equipment.

10.2 SUMMARY COST ANALYSIS

The cost estimates for the 12 system and 4 subsystems were developed by the SDS team, and reviewed and analyzed by an independent team to facilitate an accurate cost comparison between the systems. The basis for the cost estimates and the role of the independent cost estimating team are discussed in Section 4 of this volume.

Table II-10-1 lists the costs for each of the systems and subsystems. The cost estimates for DT&E, production construction costs, annual operational costs, and total life cycle costs are included. Costs that were not included are the offsite utility cost of power, water, and sewer and laboratory facilities. The power requirements of the ISV and melting technologies are not included, but should be added to the life cycle costs. Though power costs will be significant, on a per pound basis, it requires less power to treat material in situ versus ex situ. The cost for program support, including the environmental documentation, was not included. However, it should be about the same for all systems. For ex situ options, disposal costs for the waste have not been included.

Table II-10-1. System concept cost summary (includes all costs for the appropriate subsystems)

System Concept	Number	DT&E (\$ x 10 ⁶)	Prod. Construction (\$ x 10 ⁶)	Annual Operating (\$ x 10 ⁶)	Total Life Cycle (\$ x 10 ⁶)	Life Cycle ^a (\$/Cubic Yard)
Barrier	1-BE-1	76	162	0.1	239	538
In situ vitrification	1-EB-2	37	124	26	288	648
Melting/incineration with LLW presort	2-EG-1	293	777	103	2096 ^b	4716 ^b
ISV and retrieval processing	2-EB-3	59	210	36	447 ^b	1005 ^b
Melting/incineration with LLW postsort	2-EG-4	258	667	90	1821 ^b	4097 ^b
Thermal treatment/solidification with LLW presort	3-IT-1	299	1043	131	2651 ^b	5965 ^b
Thermal treatment/solidification with LLW postsort	3-IT-3	276	833	108	2190 ^b	4928 ^b
Pyrolysis/acid leach with plutonium extraction	3-EB-6	229	545	102	1796 ^b	4041 ^b
Molten salt oxidation	3-BE-7	268	691	175	2708 ^b	6093 ^b
Chemical oxidation/solidification	3-IT-8	330	705	105	2090 ^b	4703 ^b
Sort, treat, and repackaging	4-BE-2	249	597	159	2432 ^b	5472 ^b
Volume reduction and repackaging system	4-BE-4	284	817	183	2932 ^b	6597 ^b

a. Based on 444,444 cubic yards of untreated waste.

b. Excludes disposal cost of the excavated waste.

10.3 RDDT&E SUMMARY SCHEDULE

Summary DE&E schedules of all systems and subsystems are presented in Figure II-10-1. Further evaluation of these schedules is required before conclusions can be drawn as to which final waste form or system will take longer to develop before design and construction can take place.

10.4 INTERIM SOLUTIONS

The results of this study can be used to draw conclusions on whether or not there are technologies or systems that can be used as interim solutions, while keeping open the options for future retrieval of the waste. Accordingly, both the Barrier Systems, and In Situ Vitrification System can be used as an interim solution. While providing an interim confinement, both options allow for future retrieval, processing, and disposal of the residues. Another interim solution could be the immediate removal of the waste using the Retrieval Subsystem (S-BE-4), followed by retention in large above-ground storage facilities. Storage facilities for unprocessed waste were not addressed in the SDS.

For the Barrier System, the interim solution consists of placing barriers and a cap around the pits and trenches. At a minimum, the vertical barrier and cap could be used, and perhaps the horizontal barrier under the waste could be used. After the performance assessment is completed, if it is decided that the waste must be removed, the waste can then be removed and processed.

For the ISV System option, the pits and trenches could be vitrified to minimize the migration. If it is decided that the vitrified block would not be the permanent solution, the vitrified waste could then be excavated, packaged, processed, if necessary, and sent to disposal as high-quality waste form.

Figure II-10-1. DT&E lead time summary.

The third interim option would be to retrieve the waste immediately, package it, and store it in RCRA storage modules until a process is developed and constructed. Of the three options, the barrier system can be implemented the quickest and at the lowest expense, particularly if the horizontal barrier was not required.

10.5 PROCESSING OF RECLASSIFIED TRU WASTE

A major concept addressed in this study was whether LLW should be presorted (i.e., TRU waste reclassified to LLW and separated at the beginning of the process) and processed in a dedicated LLW facility, or postsorted (i.e., TRU waste and LLW processed together in a single facility and then the product assayed to separate out the less than 100 nanocuries/g waste from the TRU waste). In order to determine the best method, 2-EG-1 and 2-EG-4 were compared for the leach resistant high integrity waste form, and 3-II-1 and 3-II-3 were compared for the LDR requirement waste form. The results of the comparison indicated that more data will be needed to draw a definitive conclusion. For example, the cost of disposing either TRU or LLW is not available at this time. Furthermore, a reasonable accurate estimate of the volume of the LLW, either in the presort or postsort concepts, will require more detailed waste characteristics data than is currently available. The only conclusions that can be reached at this time are that LLW presorting will increase the number of unit operations, and may increase the facility capital and operating costs. LLW presorting is generally viable if increased in operation and capital costs are offset by the savings from (a) disposing the LLW in existing INEL disposal sites and (b) a LLW facility design that is less costly than a comparable TRU processing facility. To assess the LLW presorting economy, a detailed conceptual design of the facilities and an accurate estimate of the disposal costs will be needed.

11. RECOMMENDATIONS

This section contains recommendations on technology requirement development strategy, system concepts ranking strategy, viable concepts and major unit operations employed in the concepts, and future activities for the systems engineering task. Also included in this section are key recommendations on the DT&E activities necessary for the implementation of viable concepts and technologies for treatment of buried waste at SDA.

11.1 TECHNICAL REQUIREMENTS DEVELOPMENT STRATEGY

Figure II-11-1 is the SDS functional decomposition diagram of the Buried Waste Program top-level requirements. Also depicted in this diagram are key waste treatment decisions which must be made in order to support the final selections of a treatment strategy. These decisions are dependent on several factors such as: (a) technical uncertainties requiring detailed analysis, (b) institutional issues requiring EPA, State, DOE, and public consensus, and (c) funding allocations requiring Congressional approval. The availability and cost-effectiveness of remedial technologies will also affect these decisions.

A primary recommendation of the SDS is that selected system concepts should allow for flexibility in decision making. See Figure II-11-1. At this point in the Buried Waste Program, it is imperative that work on viable system concepts, covering both in situ and ex situ treatment options, continue in parallel.

11.2 SYSTEM CONCEPTS RANKING STRATEGY

To narrow the number of acceptable systems, at this stage of the program a preliminary ranking system using three different set of criteria (cases) has been performed. Cases 1 and 2 are based on the program implementation qualitative risk characterization of the various concepts. In these cases, the following weighting factors were used for each of the five program

Figure II-11-1. Decomposition of buried waste top-level requirements.

implementation risk areas (i.e., technical, health and safety, institutional, schedule, and cost risks).

The weighting factors are:

<u>Program Implementation Risk Category</u>	<u>Weighting Factor</u>		
	<u>Case 1</u>	<u>Case 2</u>	<u>Case 3</u>
Performance objectives compliance	50%	20%	100%
Health and safety objectives compliance	20%	15%	0
Institutional objectives compliance	15%	50%	0
Schedule objectives compliance	10%	10%	0
Cost objective compliance	<u>5%</u>	<u>5%</u>	<u>0</u>
	100%	100%	100%

The distribution of the weighting factors in Case 1 is based on giving the highest emphasis to technical performance objectives compliance. In Case 2, compliance with institutional objectives is given the highest emphasis. A third ranking case based on the quality of waste form produced by the ex situ concepts is also suggested. In Case 3, waste form 1 concepts are not addressed because their waste form is not comparable with the ex situ concepts.

The ranking and selection of systems for further studies take into account a combination of the three cases. A summary of such ranking is presented in Table II-11-1. In Cases 1 and 2, systems in the top 25 percent are given a high ranking, systems in the middle 50 percent are ranked as moderate, and those in the bottom 25 percent are given a low ranking. In Case 3, system concepts producing waste form 2 are given high ranking, those producing waste form 3 are given moderate ranking, and systems concepts resulting in waste form 4 are given low ranking.

Table II-11-1. System concepts ranking

System Concept	Number	Ranking		
		Case 1	Case 2	Case 3
Barrier	1-BE-1	M	M	—
In situ vitrification	1-EB-2	M	M	—
Melting/incineration with LLW presort	2-EG-1	M	M	H
ISV and retrieval processing	2-EB-3	M	H	H
Melting/incineration with LLW postsort	2-EG-4	H	M	H
Thermal treatment/solidification with LLW presort	3-IT-1	M	L	M
Thermal treatment/solidification with LLW postsort	3-IT-3	M	M	M
Pyrolysis/acid leach with plutonium extraction	3-EB-6	L	L	M
Molten salt oxidation	3-BE-7	L	L	M
Chemical oxidation/solidification	3-IT-8	L	H	M
Sort, treat, and repackage	4-BE-2	H	H	L
Volume reduction and repackage system	4-BE-4	H	M	L

11.3 ACCEPTABLE CONCEPTS

For ex situ treatment concepts, the melting/incineration system concepts produce a superior waste form that could be acceptable for the LDR compliance and WIPP disposal scenarios. Therefore, one advantage of selecting a melter/incineration concept is that the need for a decision on ex situ waste forms would be eliminated. However, a major disadvantage of this strategy is that thermal processes have a high risk compliance with institutional objectives. In the past, many waste treatment facilities based on thermal processes have failed to materialize, or their commissioning has been prolonged due to lack of institutional and public support. Hence, it is prudent that development of non-thermal system concepts continue in parallel until a broad institutional consensus on a waste treatment strategy is reached, or until a remedial action is approved through the CERCLA Record of Decision (ROD) process.

Another decision to be made regarding waste treatment strategy is the presorting of LLW (see Figure II-11-1). The presorting of LLW has a seemingly economic advantage because once it is segregated, LLW can be treated in a low-cost facility with a lower hazard classification than a TRU waste treatment facility. Furthermore, there is a disposal cost advantage because the treated LLW can be disposed of in existing shallow land disposal facilities (in compliance with the current regulations and rules). These shallow land disposal facilities are anticipated to be less costly than a TRU waste disposal facility. Presorting of LLW can also reduce the disposal space needed for TRU waste and make it easier for future acquisition of facilities for the disposal of TRU waste. The disadvantage of presorting LLW is that it increases the number of waste handling and treatment unit operations and will require development of a reliable assay technique for segregating the waste stream.

In the SDS, the complicated LLW presorting issues were not addressed in enough detail to justify a decision on a LLW treatment strategy. For example, the study could not accurately determine what percentage of the incoming waste volume would be classified as LLW in a presort concept as compared to a postsort concept. In addition, the disposal cost savings could not be

determined because the cost of disposing TRU waste as compared to LLW was not available. Since these analyses were not performed, it is suggested that development of a LLW subsystem continue into the next phases of the study until additional data to support a decision is developed.

In conclusion, it is believed that the system concept development and assessments in the SDS can support the following recommendations on screening of the system concepts (see Table II-11-2):

- Continuation of studies on the two in situ concepts (1-BE-1 and 1-EB-2)
- Continuation of studies on the three waste ex situ concepts (2-EG-1, 2-EB-3, and 2-EG-4) producing waste form 2
- Continuation of studies on the four subsystems (S-BE-1, S-EB-2, S-IT-3, and S-BE-4).

In addition, the following is also recommended:

- Among systems producing waste form 3, the two Thermal Treatment/Solidification system concepts (3-IT-1 and 3-IT-3) are not recommended because they use thermal processes that duplicate the processes contained in the Incinerator/Melter concepts. The Molten Salt Oxidation and the Pyrolysis, and Acid Leach with Pu Extraction concepts (3-EB-6 and 3-BE-7) are not recommended because they received low ranking. The remaining concept, the Chemical/Oxidation/Solidification (3-IT-8) system, uses nonthermal processes. Therefore, it is recommended that this concept be further developed. The concept should use feasible nonthermal treatment techniques.
- The two options producing waste form 4 (4-BE-2 and 4-BE-4) use unit operations that are similar to the melter/incinerator or thermal treatment/solidification concepts recommended above. As a result, it is recommended that system concepts producing waste form 4 be

Table II-11-2. Summary of SDS concepts and recommendations for further development

<u>System Concept</u>	<u>Concept Number</u>	<u>Recommended for Further Development</u>	<u>Comments</u>
Barrier	1-BE-1	Yes	Offers potentially less than health and safety risk and less cost than ex situ concepts. New disposal site will not be needed. Also can be used as interim action. High institutional objectives compliance risk if used as a permanent solution.
In situ vitrification	1-EB-2	Yes	Offers potentially less health and safety risk and less cost than retrieval. New disposal site will not be needed. Also can be used as interim action. High institutional objectives compliance risk if used as a permanent solution.
Melting/incineration system with low-level waste (LLW) presort	2-EG-1	Yes	Offers volume reduction and a benign waste form. Thermal processes are well known. Thermal processes have high institutional objectives compliance risk. Reduces TRU waste disposal space.
In situ vitrification (ISV) and retrieval processing system	2-EB-3	Yes	Offers volume reduction/conversion to a benign waste form. Can be used as interim action followed by retrieval in the future. ISV and melter processes are well known. Thermal processes have high institutional objectives compliance risk.
Melting/incineration system with LLW postsort	2-EG-4	Yes	Offers volume reduction/conversion to a benign waste form. Thermal processes have high institutional objectives compliance risk.

Table II-11-2. (continued)

System Concept	Concept Number	Recommended for Further Development	Comments
Thermal treatment/solidification system with LLW presort	3-IT-1	No	Offers waste form compliance with LDR requirements. Processes are well known except thermal desorption (low temperature). Potentially acceptable as a nonthermal option/moderate institutional risk. Reduces TRU waste disposal space.
Thermal treatment/solidification system with LLW postsort	3-IT-3	No	Offers waste form compliance with LDR requirements. Processes are well known except thermal desorption (low temperature). Potentially acceptable as a nonthermal option/moderate institutional risk.
Pyrolysis/acid leach with plutonium extraction system	3-EB-6	No	First-of-a-kind concept. Key technologies including ,DJD,did,KD and CEPD dissolver require significant DT&E. High technical risk.
Molten salt oxidation system	3-BE-7	No	First-of-a-kind concept. Key process, molten salt oxidation, require significant DT&E. High technical risk.
Chemical oxidation/solidification system	3-IT-8	Yes	First-of-a-kind concept. Key technologies including chemical oxidation and biotreatment require DT&E. High technical risk.
Sort, treat, and repack system	4-BE-2	No	Key technologies are commercially available. Low waste volume reduction efficiency. However, waste form is poor and is acceptable only if WIPP WAC is found suitable.
Volume reduction and repack system	4-BE-4	No	Key technologies are commercially available. Reduces waste volume. However, waste form is poor and is acceptable only if WIPP WAC is found suitable.

Table II-11-2. (continued)

<u>System Concept</u>	<u>Concept Number</u>	<u>Recommended for Further Development</u>	<u>Comments</u>
Metal decontamination/sizing subsystem	S-BE-1	Yes	Needed for all ex situ concepts. Available technology. Resolves hydrogen generation problem. Reduces TRU waste disposal space needs.
Soils processing subsystem	S-EB-2	Yes	Needs for all ex situ concepts. Available technology except thermal desorber, TRU Clean, and TRU/Clear. Reduces TRU waste disposal space needs.
Low-level waste subsystem	S-IT-3	Yes	Can be used in ex situ concepts to reduce the TRU disposal space needs. Available technology. Reduces the size of TRU processing equipment and alpha cells. Potential increase in the facility cost. Increases the number of unit operations.
Retrieval subsystem	S-BE-4	Yes	Needed for all ex situ concepts. Significant cost risks associated with alpha enclosure and unit operations. Characterization and excavation unit operations require DT&E.

dropped from further consideration. These concepts can easily be revived in the future, if needed.

11.4 TECHNICAL REQUIREMENTS FOR BURIED WASTE PROGRAM

The above recommendations lead to the following technical requirements for the Buried Waste Program.

11.4.1 Process In Place, Leave In Place Requirements

Acceptable Concepts. A physical barrier concept and ISV concept have been addressed in this study. A preliminary assessment of the two concepts indicates that both require DT&E before all questions regarding their feasibility can be answered. For the Barrier concept (1-BE-1), the main areas of uncertainty are the availability of a suitable and cost-effective technology to place a subsurface horizontal barrier and a leachate collection unit under the existing SDA trenches and pits. For the ISV concept, the main uncertainties are potential diffusion and accelerated release of some of the contaminants out of the disposal cells, potential for existence of an incomplete melt, and the inability to mitigate accidents. These two options could potentially offer significant cost savings and less negative health and safety effects than a retrieval option. Hence, it is recommended that at this time both concepts be considered acceptable. DT&E should be done to resolve uncertainties.

Recommended DT&E. A summary of key DT&E needs is presented below. A more detailed discussion of other less important DT&E areas is given in other volumes containing assessment of the systems concepts.

- Barriers Below the Waste Piles: The function of the subsurface horizontal barrier is to provide a water impermeable zone between the hazardous waste and the fractured basalt zone below the waste. The proposed approach is based on horizontal columns emplaced by jet grouting. Jet grouting is a state-of-the-art technology that requires additional DT&E efforts. The initial activities of a horizontal barrier DT&E program must include performance assessment

studies of the overall barrier concept to define permeability factors and other requirements that must be imposed on a subsurface horizontal barrier.

Other unknown factors to be investigated during the DT&E program include the following:

- The ability of the current drilling technologies to reliably drill several horizontal holes from the surface to below the waste, taking into consideration the hazardous nature of the TRU waste and the unique geology of the basalt beneath the TRU buried waste trenches and pits (e.g., the underlying rock zone).
- The ability to guarantee that all of the horizontal columns overlap as designed and do not separate or deviate over distance.
- The ability to guarantee a given permeability factor for the horizontal barrier.
- The ability of the current construction techniques to place a leachate collection unit under the existing trenches and pits.
- Surface Barriers: One of the most critical elements in the barrier concept is the surface barrier. This barrier must ensure the waste underneath is protected from erosion, failure due to natural events, and intrusion by animals and humans. The cap must be maintenance-free and must not fail over its design life. As with the horizontal barrier, the DT&T program must start by first conducting performance assessment studies to define longevity, intrusion protection, and other requirements imposed on a surface horizontal barrier. Then various cap composites and materials (e.g., concrete, rock, etc.) must be evaluated and tested to ensure compliance with the established requirements.

- In Situ Vitrification: ISV is a thermal process that uses electrical current supplied by electrodes inserted into the soil to convert contaminated soil into a chemically inert and stable glass and crystalline product. High temperatures created by the electrical current pyrolyzes organic contaminants, and melts or dissolves inorganic constituents into a obsidian like or vitrified product. Additional DT&E is recommended for the ISV technology to advance the current understanding of the technology to the point of reliable use in the remediation of buried waste. The following will also be required:
  - Methods to accurately detect the depth of the vitrified melt during processing, as well as methods to reach greater ISV depths. The RWMC requires treatment to a depth of 25 to 30 feet in some areas.
  - Additional testing to determine the fate of volatile organics during ISV to resolve the question over whether the organics are forced away from the molten mass (laterally or downward), or drawn into the melt.
  - DT&E of the off-gas collection and treatment system to improve pollutant capture and to provide a more reliable combustion environment under the hood for the destruction of organic gas emissions.
  - DT&E to improve on waste form homogeneity and leach resistant encapsulation, as well as a better definition of the acceptable metal and combustibles content for successful ISV treatment.
  - A better understanding of cooling rates of large ISV sites and the length of time that hazardous gases, vapors will be emitted.

11.4.2 Retrieval Subsystem

Acceptable Concepts. A retrieval subsystem (S-BE-4) will be needed if ex situ treatment strategies are pursued. A retrieval enclosure along with several unit operations mounted in the enclosure were investigated in the SDS. The retrieval enclosure included an alpha-certified environment for the digging area. The subsystem concept used two large traction wheel-mounted structures. A preliminary assessment indicated that the cost of this approach could be high. Therefore, it is suggested that engineering studies be conducted to investigate cost-effective options for other alternative environmental enclosure designs. At this point, the recommended technology requirements for a retrieval system include digging operations be required inside an alpha-certified enclosure designed to provide safety provisions for accidental release of radioactive, toxic, and volatile gases. Studies on the type of enclosure design to be used are inconclusive. Further design studies, based on a more detailed knowledge of waste characteristics, should be conducted to narrow the design options.

Key unit operations used in the retrieval subsystem include waste object location identifiers, soil and material excavators, characterization, sorting, and assay equipment. Available technologies for these unit operations are:

- Object Location Identifiers: Ground penetrating radar, induced current, magnetic anomaly detection, acoustic refraction, and cone penetrometer.
- Soil and Material Excavators: Crane, wall or floor mounted robots, remotely operated vehicles (ROVs), and vacuum excavators.

Recommended DT&E. A summary of key DT&E needs is presented below. A more detailed discussion of other less important DT&E areas is given in other volumes containing assessment of the systems concepts.

- Characterization of Waste by Nonintrusive Technique: Nonintrusive identification of the objects is needed to determine the location

of buried material prior to exhuming the waste. The identification should provide size, depth, and information on the chemical and radioactive properties of the buried objects. This information is needed to facilitate remote tool application planning for the retrieval operation. Also, nonintrusive identification will help to ensure the operation is conducted with adequate planning for safety. DT&E of the existing technologies (e.g., ground penetration radar, induced current, magnetic anomaly detection, acoustic refraction, and cone penetrometer) and other emerging techniques should be pursued. DT&E should focus on integration of sensing units with robotic or ROV devices.

- Robotics for Retrieval and Sorting: Although the bulk of the buried waste is contact-handled, the issues of possible high-level waste, high radioactive waste, unknown levels of hazardous material, physical limitations of human intervention, and costs associated with regulatory compliance issues act as drivers for the development and use of remote technology solutions through the application of automation and robotics. Large-scale use of land-based mobile robots in an unstructured environment is still not commonplace and is often misunderstood (or full of false expectations). Some areas that need further investigation and DT&E include the following:
  - Scaling-up of automation and firmware control architecture to large, traditional construction equipment capable of reasonable work capacity.
  - Continued development of graphic-based user interface and controls, including integration of CAD/DATABASE and control architecture in full-duplex or closed-loop control schemes.
  - Integration of passive and active sensor package output to more user friendly data display. This data would pertain to system status as well as to environmental information. The

output needs to be understood not only by the operator but also by the automated equipment so that real-time control can be exercised (automatically) by an intelligent (knowledge-based or artificial intelligent) control architecture. An example would be current DT&E efforts by the Department of Defense in advanced weapons and aircraft control systems and displays. The correlation of this example to the Buried Waste Program would be using modular, automated, unmanned systems (remotely operated systems) that could characterize and remediate a hazardous area.

- Graphical information system development of the meaningful display of sensor data. This would provide multi-dimensional or intelligent attributes to a solid (3-D) model of the environment and/or automated equipment. An example would be a 3-D model of a site that is tied to a database providing additional attributes of the environmental and physical characteristics of the site [e.g., gamma levels, isotope profiles, chemical hazard identification and quantity, and ground penetrating radar (buried object locations) information, etc.]. Graphics codes, sensor packages, and control algorithms need to be developed.

11.4.3 Assay and Sorting

Concepts applicable to assay and sorting unit operations are common to all ex situ concepts evaluated in the SDS. These unit operations are currently a part of the main system. However, in the future studies, it is recommended that assay and sorting unit operations be considered as a common subsystem.

Acceptable Concepts. Subsequent to retrieval, an on-line assay is performed on the waste when it arrives at the waste facility. The methods used are typical of on-line assay systems used throughout the nuclear industry. The waste containers are opened by technologies typically used in

the municipal and nuclear waste industry. These technologies use shearers, shredders, knives, and puncturing devices. After waste containers are opened, the waste is segregated at various stages into metal, non-metal, combustible, non-combustible, TRU, LLW, and soil streams. This sorting is done with various commercially available technologies, including magnetic separation, manipulators, visual inspection, density equipment, trommels, and aerodynamic equipment. Radioactivity assay may be performed by passive neutron detection devices, gamma spectroscopy/multi-channel analysis equipment, and gross gamma detectors. Real-time radiography may be used to characterize the waste material and detect any free liquid in the incoming containers. Organics and VOC assay may be performed by sniffers and container headspace sampling techniques.

Recommended DT&E. A summary of key DT&E needs is presented below. A more detailed discussion of other less important DT&E areas is given in other volumes containing assessment of the systems concepts.

- Sorting of Large Quantities of Waste: The sorting of waste (forms) prior to treatment would reduce the cost, time, and resource expenditures associated with mixed waste steam processing. There is significant potential for actually reducing the total amount of waste processed (by one method or another). Some items that need further investigation include:
  - Weight/density, pneumatic/air classifiers, magnetic, and screen type technologies. Identification of an optimum sorting approach and confirmation of the application of currently available commercial techniques in an alpha cell environment.

In addition, exploration of the following is recommended:

- Development of remote equipment for (a) handling and removal of objects from sorting tables and (b) conveying of the sorted objects to the various processing stations.
- Work cell development with integrated assay and automated equipment development.

- Development of adequate material handling and cross contamination controls.
- On-line Assay and Organic Volatiles: Recent advances have been reported for remote monitoring of organic constituents in the air. Remote Fourier transform infrared spectroscopy has been demonstrated to have good sensitivity at levels as low as one ppm for a one meter path length. This technology should be tested to determine applicability to an on-line waste assay on retrieved buried waste.

11.4.4 Soils Treatment

Acceptable Concepts. A soils processing subsystem will be needed for all ex situ concepts. A subsystem based on thermal desorption (to remove volatile organics), off-gas treatment (to capture the organics), soils washing (to separate TRU soil, LLW soil, and clean soil), liquid waste treatment (to polish the soils washing recycle waste), and solidification (to stabilize LLW and metal contaminated soils) is both conceivable and implementable. Most of the unit operations have been demonstrated in a TRU environment, the exception being the thermal desorber. Thermal desorption has been demonstrated in hazardous and LLW environments and is expected to perform adequately when TRU compounds are present.

Recommended DT&E. A summary of key DT&E needs is presented below. A more detailed discussion of other less important DT&E areas is given in other volumes containing assessment of the systems concepts.

- Thermal Desorption of Organic Materials from Soils: Thermal desorption can remove most of the organics, yet it is necessary to determine the concentration and character of Texas Regal Oil in the soil. If the soil is saturated with heavy hydrocarbons, low temperature thermal desorption may not be effective in treating

the soil. In addition, the extent of PCB contamination in the soil must be characterized. The effectiveness of thermally desorbing PCBs is questionable. Extensive bench-scale demonstrations of thermal desorption operations should reveal the limitations and efficiency of the operation. If successful, thermal desorption would be a much more economical process than incineration. If not, incineration or vitrification should be evaluated as an alternate technology. Pilot-scale testing of the thermal desorber will be required to evaluate the containment of plutonium compound dust. Previous studies with rotary kiln incineration have shown this containment to be a problem. It may be necessary to test different thermal desorption technologies to determine which type of equipment is most qualified. A screw-type processor should be tested first. During the pilot-scale test, the extent of radionuclide contamination in the off-gas should also be characterized.

- Removal/Reduction of Pu from Large Quantities of Soils: Soils washing operations have previously been tested on coral soils at Johnson Island. The soils at INEL, however, are nonhomogeneous soils containing clay and basalt. Both the physical characteristics and the chemical content (oils, eutectics) of the soils will need to be evaluated. Numerous mixing industry techniques are potentially applicable to the cleanup of INEL soils. These will require evaluation and testing. These evaluations more than likely can be determined during bench-scale testing. A pilot study will have to be made to determine the effects of scale-up on the extent of volume reduction of TRU contaminated soil. During this study, the percentage of soil leaving the process as TRU soil will have to be determined in order to provide the other unit operation vendors with the appropriate mass balances.
- Removal/Reduction of TRU in Liquids: If liquid waste streams are generated during soil cleaning activities, a demonstration close to full-scale will be required of TRU removal from liquids.

Previous studies have indicated it is difficult to judge the scale-up of chemistry from the bench to the field. In most cases, the results were much more efficient (i.e., less ferrate used per 1,000 gallons) than originally expected. Conventional wastewater treatment tanks can be used for this demonstration. During this test, the requirement for the addition of caustic can also be determined.

11.4.5 Metal Sizing and Decontamination Subsystem

Acceptable Techniques. This subsystem includes equipment to pretreat and size-reduce the contaminated bulk metal that requires size reduction. This equipment is needed for all ex situ concepts. The size-reduced metal and remaining loose metal are decontaminated to remove or reduce TRU contamination and hazardous materials from the surface of the metallic waste. The decontaminated metal is assayed to segregate the TRU metal from the LLW metal. The LLW metal and TRU metal are transferred via reusable containers to other unit operations within the main system for treatment and disposal.

The techniques that may be employed in the subsystem include abrasive blasting, high pressure blast, grit blast, vibratory cleaners, chemical cleaning, electropolishing, and steam cleaning. A majority of these techniques are well-known, commercially available, and in current use by the industry. Areas requiring further investigation include alpha cell enclosure and accessibility to repair or maintain the equipment, disposal of mixed liquid waste generated during decontamination operations, and development of techniques for decontamination of different metals (e.g., lead, copper aluminum, etc.).

Recommended DT&E. A summary of key DT&E needs is presented below. A more detailed discussion of other less important DT&E areas is given in other volumes containing assessment of the systems concepts.

- Effectiveness of Decontamination Methods: A small scale DT&E program may be needed to investigate and select optimum decontamination techniques. The selected techniques must have the

capability to decontaminate various types of metals such as lead, steel, copper, aluminum, etc., while producing a minimal amount of secondary wastes. In addition, the selected techniques need to be demonstrated for application in an alpha environment.

- Decontamination Liquid/Sludge Waste Treatment: The second area where DT&E is required for metal decontamination and sizing is the development of techniques for detoxification of low-level liquid waste produced during the decontamination operation. It is anticipated that a large portion of the liquid waste produced during the decontamination operations will be non-TRU and will have chemical contaminants subject to Resource Conservation and Recovery Act (RCRA) requirements. The detoxification processes will help remove the waste requiring disposal from the RCRA controls. This will allow burial in the DOE LLW disposal sites.

11.4.6 LLW Processing Subsystem

Acceptable Techniques. This subsystem will be needed for ex situ concepts only if LLW presorting is economically viable. For the most part, the major unit operations within this subsystem are either developed and demonstrated, or will be fully demonstrated within two to four years.

Recommended DT&E. DT&E will be required for LDR treatment of sludges and combustibles and for solidification of the various treated waste products; LDR treatment of lead, assuming that this also entails elimination of radionuclides; assay systems for presorting LLW; and investigation of the elimination of hazardous constituents as well as radionuclide partitioning into the lead slag and evaluation of slag solidification/immobilization techniques. A more detailed discussion of other less important DT&E areas is given in other volumes containing assessment of the systems concepts.

11.4.7 System Concepts for High Integrity Waste Forms

Acceptable Concepts. Melting and incineration with LLW pre- and postsort as well as ISV and retrieval processing concepts have been addressed

in the SDS. A preliminary assessment of the three concepts indicates that all three require DT&E before questions regarding their acceptability can be answered. For the Melting and Incineration with LLW Presort (2-EG-1) and Melting and Incineration with LLW Postsorting (2-EG-4), the main area of uncertainty is the wide variety of melting and incineration technologies in existence and their various stages of DT&E. Additionally, the melting of mixed hazardous waste has only been performed on a limited scale. For the ISV and Retrieval Processing System (2-EB-3), there are uncertainties regarding the potential diffusion and accelerated release of some of the contaminants out of the disposal cells, potential for existence of an incomplete melt, and the inability to mitigate accidents due to the release of trapped gases. The melting and incineration and ISV concepts offer the advantages of waste reduction and conversion of the waste to a benign rock-like form.

Recommended DT&E. A summary of key DT&E needs is presented below. A more detailed discussion of other less important DT&E areas is given in other volumes containing assessment of the systems concepts.

- Excavation of ISV Waste Sites: If removal of an ISV waste form appears to be viable or necessary, there will need to be DT&E activity associated with this excavation process. Issues that need addressing include the type of excavation equipment required.
- Melting Concepts: Significant DT&E efforts are needed to select an optimum, reliable melting process for remediation of RWMC buried waste. Several melter technology options were identified in the study, and all of the options require research in areas of processing simulated and TRU waste of various constituents in an alpha environment. The DT&E primary objectives will be to resolve problems associated with the waste feed, slag removal, and secondary waste handling subsystems. A significant portion of the DT&E program must be devoted to the development and demonstration of the incinerator off-gas unit operation. This unit operation must be capable of handling the various hazardous emissions while minimizing release to the atmosphere. Other areas that need further DT&E investigation include:

- A testing program to determine the effects of a broad scope of input materials and the combination of input materials for the formation of glass or slag. This type of research can determine which mixtures of materials can be melted successfully, and identify fluxes facilitating the melting of material and mixtures that have not been investigated or are currently understood to be difficult to melt into a homogeneous waste form.
- Improved technology to control the cold cap of continuous, high volume melting processes with variable feed constituents. The cold cap is the slag that constantly forms on the top of the melt and dissolves in the moving mass of the metal or glass. Current technology is limited in its capability to reduce the large off-gas volume fluctuations and to produce a homogeneous, leach resistant waste form from a continuous process with a varying waste feed stream.
- Technology for visually observing the cold cap in radiological and high temperature environments, and improvements in operations including feed control and optimum residence times.
- Air quality control of off-gas from melting furnaces to improve capture of gaseous (low vapor pressure) metal and other pollutants, and modeling techniques for estimating emission volumes and pollutant concentrations.
- Because there are several potential technologies for the melter unit operation, the initial part of the melter DT&E program must be the selection of melter concept(s). The melter concept preselection process may include a short DT&E period where unknown factors of each concept are investigated to a level that allows a more thorough evaluation of the options. In addition to the general

unknown areas listed above, each of the melter options considered in the study will require investigation of the specific unknown areas listed below.

- Plasma Pyrolysis, Plasma Arc Furnace, and Plasma Centrifugal Reactor: These techniques will require research in areas of feasibility of reintroduction of condensed volatile metals into a slag phase, optimization studies of slag chemistry, electrode life studies, destruction efficiency of hazardous organics, and the leach characteristics of the resulting melt.
- Joule Melter: This technique will require optimization studies of the effect of metals on the melter performance and long-term life and maintenance requirements.
- Gas Cyclonic: This technique will require DT&E to optimize the air input angle and the velocity to reduce the production of carbon particles.
- Slagging Pyrolysis: This technique will require optimization studies of slag chemistry, the types of coal and bark needed for supplementary heat, and the need for additives to create a molten form.
- Incineration Technologies: As with the melter, significant DT&E efforts are needed to select an incineration process. Several incineration technology options were identified in the study. All of the techniques will require research in areas of processing simulated and TRU waste of various constituents in an alpha environment for the wide diversity of waste to be incinerated. The primary objective will be to resolve problems associated with the waste feed, ash removal, and secondary waste handling subsystems. A significant portion of the DT&E program must be devoted to the development and demonstration of the incinerator off-gas unit operation. This unit operation must be capable of

handling the various hazardous emissions while minimizing their release to the atmosphere. Because there are several potential technologies for the incineration unit operation, the initial part of the incinerator DT&E program must be the selection of incineration concept(s). The incineration concept preselection process may include a short DT&E period where the unknown factors of each concept are investigated to a level that allows a more thorough evaluation of the options. In addition to the unknown areas listed above, each of the melter options considered in the study will require investigation of the specific unknown areas listed below.

- Rotary Kiln: This technique will require research to optimize the seals to reduce the spread of contamination. New seals were developed for the INEL PREP incinerator prior to its shutdown but these were never tested in a production environment. In addition, a rotating system capable of containing TRU contaminants must be developed. Demonstration efforts must include evaluation of the maintenance requirements.
- Controlled Air: The controlled air incinerator DT&E efforts must consider the experience of the existing controlled air incineration program at LANL.
- Fluidized Bed: The fluidized bed incinerator DT&E efforts must utilize the experience gained during the design, testing, and pre-operation of the existing fluidized bed incinerator at the Rocky Flats Plant.
- Infrared: This technique will require research and demonstration in areas of flow-rate capacities, optimization of chloride concentration allowable in the waste, and the ability to handle liquids.

- Pyrolysis: This technique will require research and demonstration to identify optimum furnace design (rotary kiln, rotary hearth, etc.) to carry out the pyrolysis reaction and to evaluate the ability of the furnace to handle corrosive waste under reducing pyrolysis conditions.

11.4.8 System Concepts for LDR Compliance and H₂ Generation Reduction

Acceptable Concepts. For the LDR compliance and restriction on hydrogen generation waste form, five systems were considered: Thermal Treatment/Solidification System with LLW Presort (3-IT-1), Thermal Treatment/Solidification System with LLW Postsort (3-IT-3), Pyrolysis/Acid Leach with Plutonium Extraction System (3-EB-6), Molten Salt Oxidation System (3-BE-7), and Chemical Oxidation/Solidification System (3-IT-8).

The Thermal/Solidification System with LLW Pre- and Postsorting concepts utilize a thermal process as their main unit operation. This unit operation will use technologies that are basically the same as the Melter/Incinerator System concept. A majority of the other unit operations, such as sorting, assay, are also the same as the Melter/Incinerator system concepts. In addition, the Thermal/Solidification System concepts use high temperature thermal processes that are considered high risk with respect to the institutional objectives.

The acceptability of the Pyrolysis and Acid Leach with Plutonium Extraction System (3-EB-6) is indeterminate at the conclusion of this assessment. In general, all eight of the major unit operations of this concept utilize state-of-the-art technology. The acid leach step using the CEPOD dissolver appears to be the only exception where development of innovative technologies will be involved.

The Molten Salt Oxidation and Packaging System (3-BE-7) is found to have a number of uncertainties and requires significant DT&E for the molten salt oxidation unit operation. The basic technical uncertainty is the difficulty the process has in dealing with waste streams of high soil content.

The Oxidation/Solidification System concept uses an oxidation unit operation to remove organic and oxidizable inorganic constituents. Typical chemical oxidation process such as super-critical water, wet oxidation, or acid digestion may be utilized. Biological treatment or carbon adsorption processes are used to remove residual organic constituents. The Oxidation/Solidification system concept is recommended for further exploration because it employs potentially viable non-thermal processes for the treatment of the incoming waste. Approximately one-third of the major unit operations in the Oxidation/Solidification System concept will require DT&E. These include inerts treatment, chemical oxidation, biotreatment/adsorption, liquid waste treatment, and lead decontamination unit operations. Some additional DT&E will be required for solidification of sludges. The application of chemical oxidation and biotreatment techniques may complicate the integration of unit operations from the standpoint of system waste throughput. Oxidation and biotreatment are typically slower processes than, for example, incineration.

Recommended DT&E. DT&E is recommended for the Oxidation/Solidification System concept. A more detailed discussion of DT&E is presented in other volumes containing assessment of the system concept.

Chemical Oxidation and Biotreatment and Adsorption. DT&E on chemical oxidation, biotreatment and adsorption is recommended for the Oxidation/Solidification System concept. The throughput and applicability of chemical oxidation processes such as super-critical water, wet oxidation, or acid digestion should be investigated. Biological treatment or carbon adsorption processes should be assessed to determine their application to the Oxidation/Solidification System concept.

Waste characterizations. DT&E is recommended on techniques for characterization of the incoming waste in order to allow for determination of the applicable LDR treatment requirements. Some of the emerging technologies to be addressed are described in the DT&E activities previously recommended for the sorting and assay unit operations.

Waste Treatment and Solidifications. DT&E is recommended for establishing treatment techniques for the sludges, volume reduction of combustibles, solidification of the various treated waste products, and decontamination, treatment, and stabilization of lead.

11.4.9 System Concepts For WIPP and TRAMPAC Waste Form

Concepts assessed for this waste form include: Sort, Treat, and Repackage System (4-BE-2) and Volume Reduction and Packaging System (4-BE-4). These system concepts employ unit operations and techniques which are well-known, commercially available, and in current use by the industry, with the exception of cryofracture. In addition, most of the unit operations have been used by other system concepts previously assessed in the SDS. Therefore, these two systems are considered redundant, and hence, are not recommended for the next phase of the design studies. If needed, these two system concepts can be revived using DT&E information from those activities which have previously been recommended in this section.

11.5 RECOMMENDATIONS FOR FUTURE ACTIVITIES

11.5.1 DT&E Activities

Summary recommendations on DT&E were presented in the previous subsection. Preliminary ROM cost estimates and lead time schedules are presented for the DT&E activities. Before they can be used, this data requires more detailed development, specifically by those organizations performing these DT&E activities. Hence, it is recommended that before any planning of DT&E activities, a detailed assessment of the cost and schedules should be prepared.

11.5.2 Systems Engineering Tasks

The next phase of the systems engineering should proceed first by developing a systems requirements document. This document should be based on the results of this study and should contain the following sections:

- I/O requirements: What are the system and the various unit operations supposed to do in terms of input/output and system function?
- Performance Requirements: How well must the system and its unit operations perform the function specified in the I/O and functional requirements? (how fast, how accurately, and how reliably?)
- Technology Requirements: What technology is available to build the system? Availability of components?
- U/R Requirements: What are the system life cycle cost limitations (how much money can be spent)? What are the allowable environmental, social, and economic impacts?
- Tradeoff (T/O) Requirements: What are the tradeoffs among performance criteria, among cost criteria, and between performance and cost?
- System Test Requirement: How well has the system test been examined for observance, conformance, compliance, and acceptance? What are the requirements and procedures in terms of observed data and conformance, compliance, and acceptance of the real system as compared to the model which was built.

Some of the activities needed to accomplish the above tasks are:

- Characteristics of the Incoming Waste: There needs to be a better understanding of the waste characteristics to be excavated and processed. It is important to understand the safety hazards associated with the waste such as pyrophoric material, gas cylinders, and perhaps other hazardous material. The estimated composition of the waste is important for understanding the risks and for selecting the technologies required to retrieve and process the waste. For processing waste, the compositional extremes, as well as the averages, are important. Field characterization data supported by process analysis should be used to determine the range of acceptable physical chemical and radiological parameters for the various processes. This information will be needed as design criteria.

- Concept Development: System engineering tools should be employed to perform design synthesis of the candidate system and subsystem concepts. This effort should include development of the process flow diagrams, facility arrangements, major equipment outline specifications and equipment lists. The Soils Processing Subsystem, Metal Decontamination/Sizing Subsystem, and Retrieval Subsystem need to be expanded for investigation of other options and technologies.
- Cost Estimates: A set of ROM life-cycle-cost estimates were developed for system concepts and subsystems. These costs must be further refined based on a more detailed development of the system flow diagrams, facility general arrangement drawings, major unit operation components, and detailed equipment lists. Characteristics of the incoming waste form must be better defined to allow for a more reliable cost estimate. All utilities required for operation of a system need to be included in the cost of that system.
- Figure of Merit Analysis Criteria: T/O requirements including criteria for ranking and selection of the preferred options must be developed based on further analysis, CERCLA process integration, and DOE and national laboratory input and acceptance.

BIBLIOGRAPHY

- Arrenholz, D. A., 1990, *In Situ Vitrification Program Treatability Investigation Program Report*, EGG-WTD-9383, December.
- Arrenholz D. A., and J. L. Knight, 1991, *A Brief Analysis and Description of Transuranic Wastes in the Subsurface Disposal Area of the Radioactive Waste Management Complex and INEL*, EGG-WTD-9438, February.
- Boehmer, A. M. et al., 1986, "Solidification of Hazardous and Mixed Radioactive Waste at the Idaho National Engineering Laboratory," *Proceedings of the 1986 Symposium on Waste Management, Tucson, Arizona, March*.
- Borham, B. M. et al., 1986, "Handling of Transuranic Waste for Volume Reduction by Incineration," *Proceedings of the 1986 Symposium on Waste Management, Tucson, Arizona, March*.
- Bowen, M. D. et al., 1978, "A Vertical-Bed Pyrolysis System, Solid Waste and Residues Conversion by Advanced Thermal Processes," *175th Meeting of the American Chemical Society, Anaheim, California, March 13-17*.
- Bramlitt, E. T., 1988, "Plutonium Mining for Cleanup," *Health Physics*, Vol. 55, No. 2, August pp 451-453.
- Cleveland, J. M., 1970, *The Chemistry of Plutonium*, Garden and Breech Publications: New York, pp 48-61.
- Cwynar, J. C. et al., 1986, "Retrofit and Operation of Low-level Radwaste Solidification System," *Proceedings of the 1986 Symposium on Waste Management, Tucson, Arizona, March*.
- Deininger, J. Paul, 1990, "Developments in Transuranic Element Polishing from Radioactive Wastewaters Using Ferrate Chemical Technology," *Waste Management '90 Conference, Tucson, Arizona, March*.
- Francis, C. J., and T. M. Starr, 1990, "The ANF LLW Incinerator Design & Start-Up," *Fourth Annual Symposium on Incineration of Industrial Wastes, Knoxville, Tennessee*.
- Freeman, H. M., 1989, *Standard Handbook of Hazardous Waste Treatment and Disposal*, McGraw Hill: New York.
- Geosafe Corporation, 1989, *Application and Evaluation Considerations for In Situ Vitrification Technology: A Treatment Process for Destruction and/or Permanent Immobilization of Hazardous Materials*, GSC 1901, April.
- Jessop Dale et al., 1986, "Design, Installation, Testing and Start-up of a Material Handling System at the West Valley Demonstration Project," *Proceedings of the 1986 Symposium on Waste Management, Tucson, Arizona, March*.

- Koegler, S. S., R. K. Farnsworth, R. K. Nakaoka, S. O. Bates, 1989, *Vitrification Technologies for Weldon Spring Raffinate Sludges and Contaminated Soils Phase 2 Report: Screening of Alternatives*, Battelle PNL-7125, November.
- Nielson, Roger K. et al., 1989, "Low Temperature Thermal Treatment of Volatile Organic Compounds," *1989 Incineration Conference*, Knoxville, Tennessee, May.
- Palmer, Carlet A1, 1989, "X-TRAX Y-12 Sludge Detoxification Demonstration," *1989 Incineration Conference for Chemical Waste Management*, Knoxville, Tennessee, May.
- Perry and Chilton, Perry's Chemical Engineer's Handbook, Fifth Edition, Table 25-50.
- Peters, M. S., and K. Timmerhous, 1990, *Plant Design and Economics, for Chemical Engineers*, 4th edition, New York: McGraw-Hill.
- Stewart, J. A., and D. L. Charlesworth, 1986, "Design and Operation of a Remotely Operated Plutonium Waste Size Reduction and Material Handling Process," *Waste Management-'86, Proceedings of the Symposium on Waste Management at Tucson, Arizona, March 2-6*.
- Theodore, L., and T. Reynolds, 1987, *Introduction to Hazardous Waste Incineration*, Wiley-Interscience:.
- TRU Clean: A Process for Decontaminating Radioactive and Hazardous Soils, AWC Inc., 1989.
- Vietzke, H., *Minimizing of Organic Waste by Pyrohydrolysis*.
- Wheelwright, E. J., L. A. Bray, J. L. Ryan, 1980, 1987, *Development of the CEPOD Process for Dissolving Plutonium Oxide and Leaching Plutonium from Scrap or Wastes*, PN-6483, Prepared for the U.S. Department of Energy under Contract DE-AC06-76RLD.

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