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Integrated Thermal Treatment System Study— Phase 1 Results

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ABSTRACT

An integrated systems engineering approach is used for uniform comparison of widely varying thermal treatment technologies proposed for management of contact-handled mixed low-level waste (MLLW) currently stored in the U.S. Department of Energy complex. Ten different systems encompassing several incineration design options are studied. All subsystems, including facilities, equipment, and methods needed for integration of each of the ten systems are identified. Typical subsystems needed for complete treatment of MLLW are incoming waste receiving and preparation (characterization, sorting, sizing, and separation), thermal treatment, air pollution control, primary and secondary stabilization, metal decontamination, metal melting, mercury recovery, lead recovery, and special waste and aqueous waste treatment. The evaluation is performed by developing a preconceptual design package and planning life-cycle cost (PLCC) estimates for each system. As part of the preconceptual design process, functional and operational requirements, flow sheets and mass balances, and conceptual equipment layouts are developed for each system. The PLCC components estimated are technology development, production facility construction, pre-operation, operation and maintenance, and decontamination and decommissioning. Preconceptual design data and other technology information gathered during the study are examined and areas requiring further development, testing, and evaluation are identified and recommended. Using a qualitative method, each of the ten systems are ranked.

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ABBREVIATIONS AND ACRONYMS

APC	Air pollution control
BDAT	Best demonstrated available technology
CAA	Clean Air Act
CEM	Continuous emissions monitoring
CFR	Code of Federal Regulations
D&D	Decontamination and decommissioning
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
DRE	Destruction removal efficiency
EPA	U.S. Environmental Protection Agency
ES&H	Environmental, safety, and health
FAD	Functional allocation diagrams
F&ORs	Functional and operational requirements
FTE	Full-time equivalent
HEPA	High-efficiency particulate air
HVAC	Heating, ventilation, and air conditioning
INEL	Idaho National Engineering Laboratory
ITTS	Integrated thermal treatment system
LLNL	Lawrence Livermore National Laboratory
LLW	Low-level (radioactive) waste
MLLW	Mixed low-level (radioactive) waste
NEPA	National Environmental Policy Act
ORNL	Oak Ridge National Laboratory
PAN	Passive/active neutron
PCB	Polychlorinated biphenyls
PIC	Product of incomplete combustion
PFD	Process functional diagram
PLCC	Planning level life-cycle cost
POHC	Principal organic hazardous constituent
ppmv	Parts per million (by) volume
ppmw	Parts per million by weight

ABBREVIATIONS AND ACRONYMS (Continued)

RCRA	Resource Conservation and Recovery Act
RTR	Real-time radiography
RWMC	Radioactive Waste Management Complex
SAIC	Science Applications International Corporation
SCC	Secondary combustion chamber
SEG	Scientific Ecology Group
SGS	Segmented gamma scanning
SNR	Sorting not required
SR	Sorting required
SSL	Scoping study layout
SRS	Savannah River Site
TCLP	Toxicity characteristic leaching procedure
TDS	Total dissolved solids
TOC	Total organic carbon
TRU	Transuranic
TSCA	Toxic Substances Control Act
VOCs	Volatile organic compounds
WIPP	Waste Isolation Pilot Plant

Integrated Thermal Treatment System Study— Phase 1 Results

1. INTRODUCTION

1.1 Background

The U.S. Department of Energy's (DOE) Environmental Management Office of Technology Development has commissioned an integrated thermal treatment system (ITTS) study to assess alternative systems for treating contact-handled mixed low-level radioactive waste (MLLW) and alpha-MLLW.^a The MLLW in the DOE complex consists of organic and inorganic solids and liquids comprising a wide variety of materials contaminated with radioactive substances. Treatment is needed that will destroy the organic material. Other operations are needed to stabilize the treatment residues, inorganic materials, and radionuclides prior to disposal in a MLLW disposal facility. Regulations promulgated by both DOE and the U.S. Environmental Protection Agency (EPA) govern the storage, treatment, and disposal of these wastes.

The purpose of the ITTS study is to conduct a systematic engineering evaluation of a variety of MLLW treatment system alternatives. Preconceptual designs (process functional diagrams, facility layouts, equipment lists, and material mass balances) have been developed, and the relative merits and life-cycle costs for each treatment alternative identified. The study also identified the research and development, demonstrations, and testing and evaluation needed to assure performance of the unit operations in the most promising alternative systems.

a. Alpha-MLLW has ≥ 10 but ≤ 100 nCi/g of TRU.

Thermal treatment^b is the most effective technique for destruction of toxic organic materials. Incineration,^c a form of thermal treatment, has been designated by the EPA as the best demonstrated available technology (BDAT) for destroying a number of these organic waste constituents. Worldwide, dozens of incinerators have been put into service for destruction of hazardous waste. Over the past 30 years, various incineration systems have also been designed, constructed, and operated for processing radioactive waste in the United States by the DOE and its predecessor agencies, as well as in Europe and Asia.

Because incineration is a mature and proven technology, it has generally been the primary choice of industry for destroying hazardous wastes. The technical risks are low and the costs are well established. Proven effectiveness is a critical issue in the commercial sector where investments are provided by stockholders and the investors expect a profit. However, in spite of many years of successful experience with incineration, public opposition to incineration has been growing in recent years. At the same time, a number of corporations and research organizations, including the DOE, have developed or proposed thermal treatment concepts that can be considered as alternatives to incineration. This study assesses incineration and its alternatives for treating the DOE MLLW.

The ITTS study was divided into two phases. Phase 1 focuses on establishing a baseline understanding of well-developed thermal treatment technologies, namely a rotary kiln incinerator with six variations, a fixed hearth controlled-air incinerator, an indirectly heated pyrolyzer, a thermal desorber for inorganic residue with a rotary kiln for the combustible waste fraction, and a plasma hearth melter system. The variations were used to examine the effects of combustion gas, air pollution control system design, and stabilization technology for the treatment residues on system performance and costs. Phase 2 addresses innovative technologies such as one-step processing, degasification, low-temperature oxidation, molten salt oxidation, and molten metal destruction of wastes. This report describes the results of the Phase 1 studies.

b. As defined by EPA in 40 CFR 260.10, p. 10, "Thermal treatment means the treatment of hazardous waste in a device which uses elevated temperature as the primary means to change the chemical, physical, or biological character or composition of the hazardous waste. Examples of thermal treatment processes are incineration, molten salt, pyrolysis, calcination, wet air oxidation, and microwave discharge."

c. As defined by EPA in 40 CFR 260.10, p. 10, "Incinerator means any enclosed device that (1) uses controlled flame combustion and neither meets the criteria for classification as a boiler, sludge dryer, or carbon regeneration unit, nor is listed as an industrial furnace, or (2) meets the definition of an infrared incinerator or plasma arc incinerator."

The various wastes identified for treatment are described in the DOE Mixed Waste Inventory Report^{1,d}. The systems evaluated were required to treat all waste stored in the DOE complex. This requirement established the need for several treatment lines to accommodate the range of MLLW encountered. Section 3 provides additional information on the specific composition of the wastes used for this study.

1.2 Technical Approach

A key to accurate evaluation of the thermal treatment systems is using an integrated system engineering approach that provides a uniform basis for comparing the merits of widely varying treatment alternatives. The systems discussed in this report consist of all facilities, equipment, and methods needed for treating and disposing MLLW currently stored in the DOE complex, including waste receiving, characterization, sizing, incineration, air pollution control, and secondary waste residue processing for eventual disposal. This approach more accurately evaluates systems such as plasma melters or electric arc furnaces that have a higher initial cost but produce less residue for disposal.

The focus of the ITTS study is on innovative and cost effective treatment systems that minimize the short- and long-term adverse impacts on the worker and public environment, health, and safety. Examples of such treatments are the use of contaminated soil for vitrification of process residues and use of CO₂ absorbent materials for volume-reduction of process offgas discharged to the atmosphere.

Initially, twelve thermal treatment systems were considered. These twelve systems were various combinations of the incinerator subsystem, the air pollution control subsystem, and the waste stabilization subsystem. Incinerator subsystems considered were rotary kiln, plasma arc furnace, fixed hearth furnace, and fluidized bed incinerator. Air pollution control subsystem designs included both wet and dry technologies. Waste stabilization subsystem options included concrete, polymer, and glass- or vitrified soil-based final waste forms. While many more than twelve systems could be

d. The quantities and physical and chemical compositions of the input waste used in Phase 1 systems are based on a preliminary waste input database developed at the onset of the Integrated Thermal Treatment System study. Since that time, the inventory database has been modified to incorporate the latest U.S. Department of Energy information. The modified database will be used for developing Phase 2 systems. To allow a uniform comparison of all systems, mass balance data shown in this report will be revised to incorporate the latest waste inventory data. The revised mass balance information will be published with the Phase 2 report.

configured from this list, even twelve alternative systems could not be evaluated in detail within the time and resources available. Consequently, a panel of engineers with diverse experience and technical backgrounds in incineration and stabilization was convened to reduce the number of possible choices. Ten systems were retained (designated in this report as A-1 through A-6, and B through E), which are listed in Table 1-1 and shown schematically in Figure 1-1. This selection process preserved the ability to evaluate the costs and benefits of parameters such as incinerator type, oxygen for combustion gas versus air, CO₂ retention, and wet versus dry/wet air pollution control.

Since the public is often concerned with stack emissions, specific attention was focused on alternative air pollution control unit designs. The intent was to specify a configuration that would provide better emission performance (by an order of magnitude) than required to meet current EPA standards. Where research, development, demonstration, testing, and evaluation activities were expected to be necessary to verify component performance for this application, those costs were included.

A second major concern of the public is disposal of hazardous solid residues, especially when radioactive. Thermal treatment alone will not render the wastes nonhazardous; the residues will contain hazardous materials as defined by the Resource Conservation and Recovery Act (RCRA), as well as radionuclides. Under EPA regulations, residues might have to be stabilized before disposal if

Table 1-1. Systems included in the Integrated Thermal Treatment System Study in Phase I.

System description	Designation
Rotary kiln with air for combustion and dry/wet APC – baseline system	A-1
Rotary kiln with oxygen for combustion and dry/wet APC	A-2
Rotary kiln with air for combustion and wet APC	A-3
Rotary kiln with oxygen for combustion and CO ₂ retention	A-4
Rotary kiln with air for combustion and polymer stabilization	A-5
Rotary kiln with air for combustion and maximum recycling	A-6
Indirectly heated pyrolyzer with oxygen and dry/wet APC	B-1
Plasma hearth furnace with air and dry/wet APC	C-1
Fixed hearth furnace with oxygen and CO ₂ retention	D-1
Debris desorption and grouting with rotary kiln for oxidation of combustibles	E-1

Figure 1-1. Ten integrated thermal treatment systems evaluated in the ITTS study.

	4. PRIMARY STABILIZATION SUBSYSTEM	5. SECONDARY STABILIZATION SUBSYSTEM	OTHER SUBSYSTEMS	LEGEND
ACK ALT	 VITRIFICATION	 POLYMER	6. METAL DECONTAMINATION 7. METAL MELTING 8. LEAD RECOVERY 9. AQUEOUS WASTE TREATMENT 10. MERCURY AMALGAMATION 11. SPECIAL WASTE TREATMENT 12. CERTIFY AND SHIP	UNIT SIZE RELATIVE TO BASELINE BASELINE LARGER THAN BASELINE SMALLER THAN BASELINE NOT COMPARABLE
ACK ALT	 VITRIFICATION	 POLYMER	6. METAL DECONTAMINATION 7. METAL MELTING 8. LEAD RECOVERY 9. AQUEOUS WASTE TREATMENT 10. MERCURY AMALGAMATION 11. SPECIAL WASTE TREATMENT 12. CERTIFY AND SHIP	
ACK ALT	 VITRIFICATION	 POLYMER	6. METAL DECONTAMINATION 7. METAL MELTING 8. LEAD RECOVERY 9. AQUEOUS WASTE TREATMENT 10. MERCURY AMALGAMATION 11. SPECIAL WASTE TREATMENT 12. CERTIFY AND SHIP	
CLE E L	 VITRIFICATION	 POLYMER	6. METAL DECONTAMINATION 7. METAL MELTING 8. LEAD RECOVERY 9. AQUEOUS WASTE TREATMENT 10. MERCURY AMALGAMATION 11. SPECIAL WASTE TREATMENT 12. CERTIFY AND SHIP	ABBREVIATIONS A ASH E EXHAUST AIR W UNPROCESSED WASTE S SLAG P POLYMER STABILIZED G GROUT STABILIZED T SALTS L SPENT LIME M METALS D DEBRIS
ACK ALT	 POLYMER	—	6. METAL DECONTAMINATION 7. METAL MELTING 8. LEAD RECOVERY 9. AQUEOUS WASTE TREATMENT 10. MERCURY AMALGAMATION 11. SPECIAL WASTE TREATMENT 12. CERTIFY AND SHIP	
ACK ALT SALT RECYCLE	 VITRIFICATION	 POLYMER	6. METAL DECONTAMINATION 7. METAL MELTING 8. LEAD RECOVERY 9. AQUEOUS WASTE TREATMENT 10. MERCURY AMALGAMATION 11. SPECIAL WASTE TREATMENT 12. CERTIFY AND SHIP 13. SALT RECOVERY	
ACK SALT	—	 POLYMER	6. METAL DECONTAMINATION 7. METAL MELTING 8. LEAD RECOVERY 9. AQUEOUS WASTE TREATMENT 10. MERCURY AMALGAMATION 11. SPECIAL WASTE TREATMENT 12. CERTIFY AND SHIP	
ACK SALT	—	 POLYMER	6. METAL DECONTAMINATION 7. LEAD RECOVERY 8. AQUEOUS WASTE TREATMENT 9. MERCURY AMALGAMATION 10. SPECIAL WASTE TREATMENT 11. CERTIFY AND SHIP	
CYCLE E L	 DRYER VITRIFICATION GROUT	 POLYMER	6. METAL DECONTAMINATION 7. METAL MELTING 8. LEAD RECOVERY 9. AQUEOUS WASTE TREATMENT 10. MERCURY AMALGAMATION 11. SPECIAL WASTE TREATMENT 12. CERTIFY AND SHIP	
ACK SALT	 VITRIFICATION	 POLYMER	6. METAL DECONTAMINATION 7. METAL MELTING 8. LEAD RECOVERY 9. AQUEOUS WASTE TREATMENT 10. MERCURY AMALGAMATION 11. SPECIAL WASTE TREATMENT 12. CERTIFY AND SHIP	

leachability standards^e are not met. To ensure RCRA compliance and to provide long-term isolation of residues, the baseline process chosen for primary residue stabilization was molten glass or soil-based stabilization, referred to as vitrification. If done correctly, vitrification provides the greatest protection against future environmental releases following disposal and also provides a margin against more stringent future release standards. Vitrification binds the hazardous inorganic residues (glass or metal oxides) and the radioactive contaminants (also metal oxides) into a solid solution of rock-like material. DOE is currently supporting considerable research in the field of waste vitrification to improve the process engineering and understand the physical, chemical, and thermal treatment requirements to assure high performance. It is also expected that vitrification of residues may result in disposal cost savings and reduced public apprehension.

Variations in the stabilization process included polymers and cement. Some waste residues, such as salts resulting from the neutralization of acidic combustion gases and volatile incinerator fly ash, were stabilized in a second process using a polymer (at vitrification temperatures [up to 1,600°C] salts will volatilize). Mercury is another material that cannot be vitrified. In this study, amalgamation was presumed to be the best stabilization process for mercury since it is listed by the EPA as the BDAT for radioactive mercury.

As part of the design process, functional and operational requirements, flow sheets and mass balances, and conceptual equipment layouts were developed for each system. Mass balances were performed to account for all materials treated or used in the processes. All secondary residues were processed in accordance with regulatory requirements, and the final volumes for disposal were estimated. Transportation and disposal cost estimates were applied to the disposal volume of each system as part of the planning level life-cycle cost (PLCC) estimate. Simplified system energy balances were conducted to assure that no system was excessively energy intensive. Costs have been estimated assuming the system is government owned and contractor operated (GOCO).

1.3 Summary of Main Assumptions, Bases, and Requirements

This section summarizes the main assumptions, bases, and requirements used for developing the preconceptual design and PLCC estimates of the systems studied in this report. Appendix A contains detailed descriptions of these assumptions.

e. Toxicity characteristic leaching procedure, TCLP.

1.3.1 Regulations and Permitting

It is assumed that a full environmental impact statement will be needed for the integrated thermal treatment facility. The main thermal unit in the integrated thermal treatment facility must conform to the Toxic Substances Control Act (TSCA). It is assumed that a TSCA permit will be required (which is supplementary to the permits required under RCRA and the Clean Air Act). It is assumed the integrated thermal treatment facility will process only limited quantities of waste covered by the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (which is buried but will be disinterred), but will process all of the RCRA waste, which is stored at DOE installations. It is assumed that listed waste will be treated by the thermal treatment facility. Characteristic waste should be pretreated, if necessary, and then treated by an appropriate subsystem. Regardless of whether the waste is listed or not, the generator will determine whether it exhibits any of the four characteristics of hazardous waste by either (1) testing the waste or (2) applying process engineering knowledge. Management of secondary wastes will be according to the EPA "derived from" rule. In this study, it is assumed that residue from treatment of all waste is stabilized to meet the concentration-based extraction test (TCLP). Some of the secondary waste streams in this study are investigated for potential delisting.

Thermal units will be permitted for RCRA regulations as described in 40 CFR 270.62. This regulation requires three things: (1) a description of conditions necessary to operate in compliance with performance standards of 40 CFR 264 343 during the permit period; (2) a description of restrictions on waste constituents, waste feed rates, and operating parameters as described in 40 CFR 264-345; and (3) a proposal for a trial burn plan. RCRA monitoring requirements will be met while thermally treating hazardous wastes.

The Clean Air Act requires that all source categories, including thermal treatment units, be identified and that technology-based emission standards be promulgated for each category. Tables 1-2 and 1-3 provide emission limits for nonmetals and metals, respectively, for ITTS design. Details regarding the basis for selecting these limits are discussed in Appendix A.

Table 1-2. Proposed emission limits for nonmetals.

Pollutant	Regulatory limit	Averaging period of emission limit	Proposed level to be used by ITTS working group
CO	100 ppmv from thermal treatment unit		100 ppmv from thermal treatment unit
	35 ppmv from stack	1 hour	35 ppmv from stack (1 hr period)
	9 ppmv from stack	8 hour	9 ppmv from stack (8 hr period)
Total hydrocarbons	20 ppmv		20 ppmv
Sulfur dioxide	100 $\mu\text{g}/\text{m}^3$	1 year	100 $\mu\text{g}/\text{m}^3$
Ozone	235 $\mu\text{g}/\text{m}^3$	1 hour	235 $\mu\text{g}/\text{m}^3$
Particles smaller than 10 microns	34 mg/m^3		34 mg/m^3
Sulfur dioxide	80 $\mu\text{g}/\text{m}^3$	1 year	365 ng/m^3 (24 hr period)
	365 $\mu\text{g}/\text{m}^3$	24 hours	
	1,300 $\mu\text{g}/\text{m}^3$	3 hours	
PCB	DRE of 99.9999%		DRE of 99.9999%
Radionuclides	10 mrem/yr	1 year	10 mrem/yr
POHCs	DRE of 99.99%		DRE of 99.999%
Dioxins	30 ng/m^3		0.1 ng/m^3
HCl	1.8 kg/hr	1 hour	1.8 kg/hr
Chlorine (Cl_2)	0.001 g/s		0.001 g/s
Radon 222	3×10^{-9} $\mu\text{Ci}/\text{mL}$	1 year	3×10^{-9} $\mu\text{Ci}/\text{mL}$

Table 1-3. Proposed emission limits for metals.

Pollutant	EPA Limit	Averaging Period of Emission Limit	Proposed Level to be Used by ITTS Working Group (g/s averaged over 1 hour)
Antimony	0.061 g/s	1 hour	0.0061
Barium	10.0 g/s	1 hour	1.0
Nickel	0.0084 g/s	1 hour	0.00084
Mercury	0.016 g/s	1 hour	0.0016
Selenium	0.80 g/s	1 hour	0.080
Silver	0.61 g/s	1 hour	0.061
Arsenic	0.00047 g/s	1 hour	0.0000471
Thalium chlorides	0.061 g/s	1 hour	0.0061
Cadmium	0.00111 g/s	1 hour	0.000111
Lead	0.0177 g/s 1.5 µg/m ³	1 hour annual	0.00177
Beryllium	0.000833 g/s	1 hour	0.00008333
	0.0001155 g/s	24 hours	
Chromium	0.0001666 g/s	1 hour	0.0000166

1.3.2 Input Waste Characteristics

The ITTS will treat MLLW and alpha-MLLW of the types listed in Table 1-4. By definition, this waste contains EPA listed^f and characteristic^g waste. All waste considered in the ITTS study is contact-handled; if high-activity waste inside shielded containers is found, it will be rejected and returned to its point of origin. Consequently, the system will be designed with minimum shielding. Some shielding could be necessary in areas of the facility with concentrated TRU waste or fission-

f. Listed wastes are wastes included on a specific list of hazardous wastes prepared by EPA. Under RCRA, EPA has listed three separate categories of chemicals: hazardous wastes from nonspecific sources ("F wastes"), hazardous wastes from specific sources ("K wastes"), and discarded commercial chemical products, off-specification species, container residues, and spill residues ("P wastes" and "U wastes").

g. Characteristic wastes are wastes that demonstrate hazardous characteristics, both physical hazards and adverse health effects. Under RCRA, EPA has defined four such categories: corrosivity, ignitability, reactivity, and toxicity. Individual states have added additional characteristics. For example, California has added "persistent or bioaccumulative" as the fifth characteristic.

Table 1-4. System input MLLW.^a

Type of waste	Total quantity (lbs)	Feed rate ^b (lbs/hr)	Nominal capacity ^c
Metal with surface contamination	7,110,700	88	200 lbs/hr
Metal with fixed contamination	218,800	3	100 lbs/hr
Combustible solids and debris	36,601,300	468	468 lbs/hr
Noncombustible solids and debris	119,914,000	1,532	1,532 lbs/hr
Lead with surface contamination	413,600	5	20 lbs/hr
Lead with entrained contamination	1,654,500	21	80 lbs/hr
Aqueous waste ^d	6,490,000	80	20 gpm
Mercury contaminated waste	4,063,800	50	100 lbs/hr
Special waste	<u>12,314,600</u>	<u>153</u>	200 lbs/hr
Total	188,781,300	2,400	

Notes:

- Based on data shown in Table A-4 in Appendix A.
- Feed rates are calculated based on one integrated thermal treatment facility operating 4,032 hours per year for twenty years.
- Nominal capacities are based on smallest available equipment and also account for secondary waste.
- Solar pond waste at Rocky Flats Plant (approximately 101,752,000 lbs) has been deleted as a feed to an integrated treatment facility. It is assumed that the pond waste will be treated at Rocky Flats Plant by a system specially designed for this waste stream.

product radionuclides (e.g., thermal treatment ash). However, shielding is not considered to be a factor in the relative performance of the different systems.

The treatment system receives solid and sludge waste in drums, metal bins, and wooden or fiberglass boxes, which are delivered to the treatment facility by wheeled vehicles. Liquid waste is shipped to the system either by a pipeline, in tank trucks, or in containers placed on wheeled vehicles. The nominal capacity of the treatment system for each type of waste is assumed to be as shown in Table 1-4.

1.3.3 Waste Characterization

Each step of the thermal treatment process will require waste characterization, starting with the individual waste containers and ending with the final waste form, offgas, and scrubber liquor and

solids. It is assumed that throughout normal operation, the owner/operator of a thermal treatment unit must conduct sufficient waste analysis to verify that waste fed to the unit is within the physical and chemical limits specified in the permit.

Current drum assay procedures for radionuclides can have errors of $\pm 100\%$ at 100 nanocuries per gram (nCi/g); this accuracy should be adequate for characterizing input fed to a thermal treatment unit. Real-time x-ray radiography will be used for physical characterization of the waste. Physical characteristics will be useful in presorting waste before processing.

Existing EPA SW-846 analytical methods are assumed for analyzing scrubber solutions. Radioassay of the transuranic (TRU) waste content of bottom ash and fly ash will be performed by routine methods. It is assumed that the scrubber liquor and solids will be analyzed for salt content to adjust the chemistry before conversion to the final waste form. Analysis for RCRA metals will not be needed since it can be assumed that the waste will have levels of regulatory concern. Analysis of the scrubber liquor and solids for total carbon is required to show the absence of organics. If carbon is present in significant quantities, further analyses could be required (e.g., thermal desorption/GC-MS).

1.3.4 Waste Treatment

Waste pretreatment will be compatible with requirements of the primary waste treatment technology. For example, bulk metals (e.g., ferrous metals and lead larger than about 10 cm) will be removed from the waste stream and sent to the appropriate treatment subsystem. Potentially temperature-sensitive materials, such as pressurized gas cylinders, will be set aside and safely depressurized, emptied, or otherwise made safe for the next step of treatment.

It is assumed that the primary treatment system will have a high likelihood of public acceptance and regulatory approval. Acceptable technologies are those having successfully completed the proof-of-principal phase or those that have successful operating experience in other industrial applications. Technologies selected for the Phase 1 studies were limited to those believed to be ready for pilot-scale demonstration in 2 years, incorporation into a final design in 3 years, and construction in 5 years.

During primary treatment, combustible materials will be oxidized to achieve volume reduction and destruction of RCRA-controlled organic materials. Noncombustible materials, such as inorganic

sludge contaminated with solvent, will be treated to destroy RCRA- and TSCA-controlled organic contaminants, if present, and to remove moisture prior to stabilization. Aqueous waste will be treated to evaporate the water and immobilize the contaminants in the final waste form. (No liquid effluent will be generated; however, some moisture will be discharged to building exhaust or the process stack.) Highly acidic or alkaline aqueous waste will be pretreated to return the pH to near neutral. Organic liquid waste will be treated by oxidation. If chloride salts are formed, these will be treated in a similar manner to salt residues from offgas treatment. The waste treatment temperatures and times will be sufficient to ensure that the product meets RCRA and TSCA destruction efficiency requirements, while keeping waste stream characterization to a minimum.

The offgas from primary treatment will meet or exceed requirements set forth in RCRA, TSCA, and other regulations controlling air pollution. Performance specifications will be set to exceed current regulations by one order of magnitude (10 times). Parts of the system that process alpha-contaminated MLLW will operate at slightly negative pressure to avoid releasing contamination. Tolerable in-leakage will be included in the design. For systems using air for combustion, the air will be taken from the innermost containment.

Bulk ferrous metals will be treated either by decontamination to free-release standards of DOE Order 5400.5 or by metal melting to assure destruction of any RCRA-controlled contaminants and removal of surface contamination by slagging. Metal treated by melting will be removed from the disposal stream and be considered recyclable for DOE purposes with zero economic value.

Bulk lead, such as lead brick, will be treated by surface decontamination if it is reasonably determined to have no activation products. Other lead, such as blankets, wool, and activated lead, will be treated by melting to remove combustible nonlead products and will be cast into blocks for reuse by DOE. The alternative to reuse will be treatment to EPA microencapsulation standards.

Elemental mercury, if found to have radioactive contamination, will be treated by amalgamation. If not radioactive, elemental mercury will be recovered, by distillation and capture, and released for recycle.

The primary and secondary treatment waste outputs will meet current and anticipated disposal regulations, such as 40 CFR 268 for substances regulated by RCRA and DOE Order 5820.2A. The waste form will be a stable, leach resistant, high-integrity solid produced by either vitrification or

solidification. The final waste form will be delistable to reduce the cost of disposal (RCRA Subtitle D versus Subtitle C). The final waste form will also meet the requirements of DOE 5820.2A for low-level waste. The alpha-MLLW final waste form will be able to satisfy performance assessment requirements for a typical DOE disposal site, while TRU waste will meet the Waste Isolation Pilot Plant (WIPP) waste acceptance criteria and TRUPACT II TRU packaging and shipping criteria. The potential for gas generation will be minimized; however, if this requirement results in a significant increase in the final waste volume it will be reconsidered.

The assumed disposal methods are shallow land burial for LLW and treated MLLW, engineered shallow land disposal for alpha-LLW and alpha-MLLW, and disposal at WIPP for TRU waste, if generated in the process of treating the wastes. For calculating transportation costs, it is assumed that the LLW, MLLW, alpha LLW, and alpha MLLW final waste forms will be disposed at the Nevada Test Site. However, for purposes of selecting a waste form, it is assumed that the Nevada Test Site might not be available; therefore, the final waste form will be stable so that it can be accepted at surface disposal facilities at other major DOE installations, such as the Hanford Site, Washington; Idaho National Engineering Laboratory, Idaho; Oak Ridge Reservation, Tennessee; Los Alamos National Laboratory, New Mexico; and Savannah River Site, South Carolina. An average cost of disposal will be used for calculations.

The final waste form will be packaged in 55-gallon drums meeting U.S. Department of Transportation (DOT) requirements. For vitrified waste, thick-walled steel containers will be required if the casting process involves pouring molten materials directly into the waste container. It is assumed that these containers can be qualified to meet DOT and TRUPACT II criteria or equivalent if required. Final waste forms will meet contact handling requirements with no other shielding than the shipping container.

Facilities handling MLLW are placed in Seismic Category 1 and are classified as moderate-hazard facilities.² The facilities will be designed in accordance with applicable local, state, and federal regulations, including general design criteria for DOE facilities contained in DOE Order 6430.1A. The subsystems will be designed to handle at least 125% of the expected mass flow rate, shown on process functional diagram (PFDs) for each subsystem.

For personnel safety, the system for treating alpha-LLW and alpha-MLLW is assumed to be able to safely handle input waste with radioactivity levels exceeding 100 nCi/g. The primary design

requirement stemming from this assumption is triple containment for control of alpha contamination. Since the treatment system is used for both alpha and non-alpha waste, all process steps with potential of generating airborne contamination will have a tertiary containment system. Only two levels of containment are required for other processes involving materials with a limited potential for becoming airborne.

The preconceptual designs are based on the assumption that MLLW will be treated during a 20-year operating period. During this time, the treatment facility will operate 24 hours per day, 5 days per week, 240 days per year, at 70% availability during operation. This is equivalent to operating 168 days, or 4,032 hours, per year of operation. In subsystems with small capacities, where a three-shift operation is not justified, a single shift per day or part-time shifts are assumed.

1.4 ITTS Study Team

This project was initiated and directed by Carl Cooley of the U.S. DOE, EM-50 Office. A team of employees of EG&G Idaho, Inc. and Morrison Knudsen Corporation, Engineering, Construction & Environmental Group performed the engineering and analysis for the ITTS study. In addition to the authors, the following individuals and organizations furnished their expertise and services for parts of the Phase 1 study.

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2. SYSTEMS TECHNOLOGIES

This section describes the ten thermal treatment systems examined. Each system consists of all structures, buildings, and equipment needed to accomplish the functional and operational requirements (F&ORs). Systems A-1 through A-6 are based on conventional rotary kiln technology. System B-1 uses an indirectly heated, starved-air incinerator that operates in a pyrolysis mode. System C-1 uses a plasma-arc furnace. System D-1 is a fixed-hearth, controlled-air incinerator distinguished by the addition of a CO₂ retention system. System E-1 uses a rotary kiln for treatment of combustibles combined with an indirectly-heated rotary calciner used for the thermal desorption of debris.

System A-1 is the baseline system. For the sake of brevity, only System A-1 is described in full. The discussions of the other systems focus on their differences from the baseline system. Systems described in this section were developed based on the requirements and assumptions given in Appendix A. Detailed process functional diagrams (PFD), functional allocation diagrams (FAD), and plan views and perspective views for the systems and subsystems are included in Appendix B; the FADs and perspective views for System A-1 are also included in this chapter. (For convenience in reading the text, the figures for this chapter are located at the end of the chapter, beginning on page 31.)

2.1 System A: Conventional Rotary Kiln

2.1.1 System A-1: Rotary Kiln, Air Combustion Gas, Dry-Wet APC (Baseline System)

The majority of the technologies in this system use proven equipment that is commercially available. The system employs a rotary kiln incinerator using air as combustion gas. This is similar to treatment systems used by DOE at the TSCA incinerator at Oak Ridge National Laboratory (ORNL), Oak Ridge, Tennessee. The air pollution control (APC) subsystem is based on dry filtration followed by wet offgas scrubbing. The Scientific Ecology Group (SEG) incineration facility at Oak Ridge uses this general approach in its APC. Solid residues from the system are stabilized by a combination of vitrification and polymer solidification. Vitrification additives, if required, are introduced as part of the feedstock to the kiln; contaminated soil from environmental restoration

programs may be used as an additive. System A-1 has twelve subsystems, which are described below. A perspective view of the major components of the system is shown in Figures 2-1 and 2-2.

2.1.1.1 Receiving and Preparation Subsystem. This subsystem has cranes and forklift trucks to unload waste containers from incoming vehicles. The physical state of the waste in containers is identified by a real-time radiography (RTR) unit. The wastes are classified either as sorting required (SR) waste or sorting not required (SNR) waste. A passive/active neutron (PAN) assay unit determines the level of TRU contamination of the waste. A segmented gamma scanning (SGS) unit is used to assay beta and gamma radioactivity. A computer software and bar code scanning unit records and tracks the waste. Containers of SNR waste are moved directly to the thermal treatment subsystem. If the container of SR waste has restricted items, it is passed through a sorting train. The container is decapped by a saw mounted on a gantry robot. After decapping, the container is emptied on a sorting table equipped with master-slave and hydraulic manipulators used for removing restricted materials, such as large pieces of metal and lead, and mercury containers. The segregated waste is sent to the appropriate treatment subsystems. For purposes of this study, approximately 50% of the waste was assumed to require sorting. Figure 2-3 shows a FAD for the receiving and preparation subsystem. Figures 2-4 and 2-5 show perspective views of the two main areas of the subsystem.

2.1.1.2 Incineration Subsystem. This subsystem receives combustible and noncombustible solids, sludges, and organic liquids. Some of the sludge from the aqueous waste treatment subsystem is also fed to the unit for drying and subsequent solidification with ash. Unless special precautions are taken, sludges have a tendency to form small surface-hardened balls during drying that resist complete destruction of organic material. This tendency can be countered by introducing the sludge into the rotary kiln as small particles (<1/4 in. in diameter) or by introducing it with other wastes. The subsystem consists of a feed preparation shredder, a characterization unit, a natural gas and air fired rotary kiln, a secondary combustion chamber (SCC), an air blower, and the associated combustion and feedstock preparation equipment. The size reduction unit shreds incoming waste in drums and boxes and feeds it to a series of transport bins and hoppers. Empty wooden boxes are also shredded, but empty metal containers are sent to the metal treatment subsystem. The contents of each hopper are sampled, characterized, and fed to the incinerator. Incineration takes place in a negative air pressure environment. The incinerator has a set of special graphite and steel seals designed to minimize air in-leakage.³ A metal housing around the incinerator unit provides secondary

confinement. Figure 2-6 shows the incineration subsystem FAD, and Figure 2-7 shows a perspective view.

2.1.1.3 Incineration Air Pollution Control (APC) Subsystem. This subsystem has a dry gas filtration unit, a wet gas scrubbing unit, and a system for continuous emissions monitoring (CEM). In the dry gas filtration unit, the gas is partly quenched by water jets and filtered in either a baghouse or through high-temperature ceramic filters followed by high-efficiency particulate air (HEPA) filters. A charcoal or activated carbon filter is added in front of the HEPA filter to remove any trace quantities of mercury that might be present in the offgas. The wet offgas unit consists of a complete water quench, followed by hydrosonic and packed bed scrubbers for removal of acid gas. A system to remove nitrogen oxides and dioxins is also included. The CEM unit monitors and records the quantities of CO, CO₂, O₂, particulates, and other compounds discharged from the stack, to check compliance with air discharge permits. A continuous radiation sampling device is also included at the stack discharge. Figure 2-8 shows the APC subsystem FAD, and Figure 2-7 shows a perspective view.

2.1.1.4 Lead Recovery Subsystem. This subsystem has a decontamination train and an electrically-heated roasting oven. The decontamination train has mechanical devices, including saws, shears, and sanders, to cut the lead waste and to remove metal cladding from lead. Decontamination of lead takes place in scarfing and abrasive blasting booths. The oven is used to melt lead that cannot be decontaminated by mechanical means. The furnace APC subsystem has dry gas filtration similar to that of the APC subsystem provided for the rotary kiln. Figure 2-9 shows the FAD for the lead recovery subsystem, and Figure 2-10 shows a perspective view.

2.1.1.5 Mercury Amalgamation Subsystem. This subsystem uses a retort followed by a condenser to reclaim mercury from contaminated solids. After mercury removal, the solids are sent to the primary stabilization subsystem. Offgas from the mercury condenser is treated in a secondary combustion chamber and a wet-dry APC system similar to the incineration APC. Recovered elemental mercury is either recycled or amalgamated with zinc or copper in an amalgamation reactor. Figure 2-11 shows the FAD for the mercury amalgamation subsystem, and Figure 2-12 shows a perspective view.

2.1.1.6 Metal Decontamination Subsystem. This subsystem has a decontamination train. The decontamination train has size reduction tools (plasma torch, saw, and shear) and is

provided with abrasive liquid blasting booths designed to remove entrained and surface contamination. It is assumed that dry ice blasting is used to reduce the quantity of liquid waste generated. Figure 2-13 shows the FAD for the metal decontamination subsystem, and Figure 2-14 shows a perspective view.

2.1.1.7 Metal Melting Subsystem. This subsystem includes a size reduction unit operation. Metals that cannot be decontaminated by mechanical means (surface blasting, grinding, etc.) are sent to this subsystem. In the induction melter, most radioactive material goes into the molten slag, which is cast in a container, cooled, and sent for inspection, assay, and shipment to storage or disposal facilities. Clean molten metal is poured into an ingot, cooled, and sent for recycling. The induction melter APC subsystem has a train for dry gas filtration similar to the APC subsystem provided for the thermal treatment unit. Figure 2-15 shows the FAD for the metal melting subsystem, and Figure 2-16 shows a perspective view.

2.1.1.8 Special Waste Treatment Subsystem. It is assumed that there will be special wastes that require capabilities not included in the basic system. The treatment subsystem for special waste is located in a room equipped with a crane and all utilities needed for installing treatment systems for special wastes. Special treatment systems will be identified and provided on a case-by-case basis during facility operation. An equipment cost allowance of \$3 million is included in the cost estimates.

2.1.1.9 Aqueous Waste Treatment Subsystem. This subsystem collects and treats input aqueous waste, which could include wastewater having corrosive properties or contaminated with dissolved solids, suspended solids, organic compounds, or heavy metals. In addition, this subsystem treats the system's secondary aqueous wastes, such as the slurry from the APC subsystem scrubber blowdown, sludge from abrasive blasting in the metal decontamination subsystem, rinse water from container washdown, and water from equipment and floor drains.

The incoming aqueous waste is classified as having high levels of total organic carbon (TOC), high levels of total dissolved solids (TDS), or low levels of TDS, and then stored in the appropriate batch tank. The primary treatment train for high-TOC waste involves removing gross organics (using flotation thickeners or coalescers), filtering out suspended solids (using back flushable filters), removing dissolved organics (using carbon filtration or ozonators), and removing and polishing dissolved solids (using ion exchange). An alternative for treating high-TOC waste is to feed it to the

thermal treatment subsystem. For liquids with high levels of TDS, the treatment train involves neutralization, filtering out suspended solids, and removing dissolved solids, probably by evaporation. For liquids with low levels of TDS, the primary treatment train consists of filtering out suspended solids, removing dissolved organics (using carbon filter or ozonators), and removing dissolved solids (by ion exchange).

Liquid wastes with mercury contamination are treated by precipitation and filtration using sulfur-impregnated carbon filters. Also, the ion exchange vessels will have mercury-selective resins to capture mercury.

In addition to the primary treatment trains, each waste type can be routed to or bypass a given treatment unit. The aqueous waste treatment subsystem concentrates all sludge waste produced by the various treatment trains and sends it to the stabilization subsystem. Spent ion exchange resin from treatment processes is dewatered and sent to the thermal treatment subsystem or to the stabilization subsystem.

Figure 2-17 shows the FAD for the aqueous waste treatment subsystem, and Figure 2-18 shows a perspective view.

2.1.1.10 Primary Stabilization Subsystem. This subsystem uses vitrification to convert the incinerator ash to a waste form suitable for disposal. In vitrification, soil (including contaminated soil from a DOE installation) or chemical additives (SiO_2 , Al_2O_3 , Fe_2O_3 , etc.) are metered into the rotary kiln to act as glass formers. The additives are added in quantities proportional to the weight of expected bottom ash. In order to add the proper quantity, the input waste must be characterized well enough to predict the quantity of ash. The kiln mixes the soil with the ash and discharges the mixture into a storage hopper. The mixture is metered from the hopper into a melter furnace. The melter furnace vitrifies the ash and soil mixture and discharges the molten mixture into a container. The container is cooled, capped, and sent to a swiping and decontamination station. If surface contamination is found, the container is washed by high-pressure water jets. The inspected container is sent for assay, certification, and shipping to storage or disposal facilities. The melter furnace APC unit has a dry gas filtration train similar to the dry APC subsystem provided for the rotary kiln. Figure 2-19 shows the FAD for the primary stabilization subsystem, and Figure 2-20 shows a perspective view.

Research conducted at Idaho National Engineering Laboratory (INEL)^{4,5,6} has shown that the residue after combustion, when combined with about 40 to 50% soil, will form a good glass or ceramic waste form. Although this conclusion may not hold for all wastes processed in a short campaign, it does imply a considerable latitude in composition for making the ash residue into glass or ceramic. Testing on bench-scale melters at INEL has shown that drying the soil before placing it in a melter results in less violent melter startup. Thus, the soil is introduced into the incinerator and dried. As an additional benefit, any organic carbon will be eliminated and carbonates will be disassociated.

Unpublished work by Krikorian at Lawrence Livermore National Laboratory (LLNL) has shown a reduction in actinide volatility in the presence of SiO_2 .

2.1.1.11 Secondary Stabilization Subsystem. This subsystem receives treated residues that are not suitable for processing by the primary stabilization subsystem, such as salts having a low melting point or fly ash with a salt concentration exceeding the limits specified for vitrification when it is the primary stabilization method. Stabilization of salts involves polymer encapsulation using sulfur cement, polyethylene, or polymerizing agents produced by Dow Chemical Company. The subsystem has a dryer that removes water from the incoming waste. The dried powder and polymer are metered into an extruder that heats and mixes the polymer with powdered waste. The extruder feeds the mixture into a drum. When filling is complete, the drum is capped and sent to a swiping and decontamination station. If surface contamination is detected, the container is washed by high-pressure water jets or blasts of dry ice. The inspected container is sent for assay, certification, and shipping to storage or disposal facilities.

Bulk secondary waste, such as spent filters, is compacted and macro-encapsulated by grouting techniques. Figure 2-21 shows the FAD for the secondary stabilization subsystem, and Figure 2-22 shows a perspective view.

2.1.1.12 Certify and Ship Subsystem. This subsystem characterizes the physical and radiological properties of the packaged waste to allow certification in accordance with transportation, storage, and disposal requirements. The containers of packaged waste for shipment are weighed. An RTR unit examines the container to ensure that the matrix is homogeneous and has no free water. If TRU or alpha contaminated waste is processed, the TRU concentration is measured by a PAN assay unit. An SGS unit is used to assay the beta and gamma radioactivity. After inspection, the waste is

either sent to a temporary storage area or loaded onto a truck for offsite or onsite shipment. Figure 2-23 shows the FAD for the certify and ship subsystem, and Figure 2-24 shows a perspective view.

2.1.2 System A-2: Oxygen Combustion Gas

System A-2 is the same as System A-1 except that the incinerator is equipped to use commercially pure oxygen as the combustion gas. The APC subsystem has a smaller capacity, since oxygen combustion creates lower volumes and velocities of incineration offgas than does air combustion. The overall process for System A-2 is the same as for System A-1.

2.1.3 System A-3: Wet Air Pollution Control Subsystem

System A-3 is the same as System A-1 except that the APC subsystem uses all wet filtration and cleaning techniques. The dry gas filtration unit (baghouse) is eliminated. The overall process for System A-3 is the same as that for System A-1.

2.1.4 System A-4: CO₂ Retention

System A-4 is basically the same as System A-1 except that the incinerator uses oxygen as the combustion gas, and a different APC configuration is used. This APC subsystem treats offgas by the conventional dry filtration means and then removes carbon dioxide by absorption into lime in a fluidized bed. The water formed in the incinerator is condensed and sent to the aqueous waste treatment subsystem. The remaining gas is enriched with oxygen and rerouted to the incinerator for additional treatment of toxic materials. The CO₂ retention concept is being developed at the Argonne National Laboratory.⁷ The lime (or dolomite) is recycled as many as ten times using a lime recovery system whose main component is a calciner. During recovery the calcium carbonate is reheated to release the CO₂. The CO₂ is then monitored and discharged to the atmosphere. Alternatively, the calcium carbonate can be calcined at a remote place, in which case the only offgas released to the atmosphere on a continuous basis close to the thermal treatment equipment is the inert gas that enters with the oxygen or leaks into the system. The CaCO₃ could also be disposed as a solid, which would incur additional disposal costs. Compressed gas storage tanks are included for these gases.

While the overall process for this system is the same as that for System A-1, System A-4's receiving and preparation subsystem is different from System A-1's because bulk metals, slag, and tar

formers need to be removed as part of that step. The capacity of System A-4's aqueous waste treatment subsystem is slightly larger than that of the baseline system in order to handle the water condensed from the offgas.

2.1.5 System A-5: Polymer Stabilization

System A-5 is the same as System A-1 except that primary stabilization method uses polymers in place of vitrification. In this case, all solid residues are stabilized by polymers as described in Section 2.1.1.11. However, bottom ash and fly ash stabilized residues are kept separate for purposes of tracking transuranic activity.

2.1.6 System A-6: Maximum Recycling

System A-6 is designed to minimize the volume of waste requiring disposal. The standard rotary kiln, which uses air as the combustion gas, is preceded by a feedstock preparation subsystem that maximizes decontamination to permit recycling of waste materials, containers, bulk metals, and process chemicals. Containers and some bulk metals are recovered, decontaminated, and recycled within the facility to the extent possible. Aqueous secondary waste streams, except for acid gas scrubber blowdown, are treated in an aqueous waste treatment subsystem. The blowdown from the acid gas scrubber is processed through a salt splitting system to produce a caustic and hydrochloric acid. The caustic can be recycled to the beginning of the wet section of the APC subsystem. Salt splitting is a specially-designed electrodialysis process that results in caustic being regenerated for reuse within the system. Activated carbon filters in the offgas line are recycled using a retorting process, which removes the mercury. HEPA filters in the offgas line use stainless steel cloth that is reusable after cleaning.

2.2 System B: Pyrolysis

System B-1 combines an indirect fired, electrically heated, rotary kiln pyrolyzer and a secondary combustion chamber using oxygen combustion gas with the vitrification unit. Electrical heating and burning in oxygen starved-pyrolysis minimizes production of offgas. The pyrolysis gas is oxidized with pure oxygen in the SCC, which is followed by a standard wet-dry APC subsystem. System B-1 uses a standard feedstock preparation subsystem. Solid residues from the pyrolyzer are treated by vitrification. An oxygen lance would be used in the vitrifier to assure burnout of carbon

from the pyrolyzer. The offgas from the vitrification unit is fed to the pyrolyzer SCC inlet, thus eliminating a separate APC subsystem for the primary stabilization subsystem. Aqueous secondary waste streams are treated in an aqueous waste treatment subsystem. Organics recovered from aqueous treatment are recycled to the thermal treatment unit. Sludges resulting from precipitation and filtration are transferred to the primary stabilization subsystem or, if necessary, to a secondary, polymer-based stabilization subsystem. The treated water is recycled in the system, as required, for process use. Differences between this system and the baseline system are outlined below.

2.2.1 Receiving and Preparation Subsystem

The receiving and preparation subsystem is the same as that of the baseline system except that sorting requirements are substantially greater. This is due to limits on the noncombustible material that can be present in the pyrolyzer feed material. Most of the noncombustible bulk material needs to be separated from the waste before it can be fed into the pyrolyzer.

2.2.2 Main Thermal Treatment Subsystem

This subsystem differs from that of the baseline system by integrating a pyrolyzer unit and SCC with the vitrification unit. Noncombustible waste is fed to a dryer along with soil or other additives, and then fed to the melter for vitrification. Combustible waste undergoes partial combustion by being heated in an oxygen-starved chamber. The resulting gases are burned in an SCC to which oxygen is added in stoichiometric proportions. The pyrolyzer operates at a temperature of 1,200°F, and the SCC at a temperature of 2,200°F. The ash from the pyrolyzer is fed to the vitrification unit. This ash is typically a char with a high carbon content, which could pose a problem for the melter. Oxygen must be supplied to the melter for combustion of the carbon. Burning carbon in the vitrifier will create gas pockets in the slag, which makes the waste form less dense. The melter offgas also goes to the SCC.

2.2.3 APC Subsystem

As with System A-1, the APC subsystem is based on dry filtration followed by wet offgas scrubbing. However, this APC subsystem has a smaller capacity, since indirectly heated oxygen combustion creates lower volumes and velocities of offgas than does air combustion. The smaller

quantity of offgas and the lower temperature created by pyrolysis also result in a smaller quantity of fly ash.

2.2.4 Primary Stabilization Subsystem

As indicated before, the vitrifier is part of the incineration subsystem. The primary stabilization subsystem performs only cooling and packaging of slag.

2.3 System C: Plasma Furnace

System C-1 combines a plasma furnace with an SCC, both of which use air as the combustion gas. The plasma furnace performs three functions simultaneously: thermal treatment, vitrification, and metal melting. The SCC is followed by a standard dry/wet APC subsystem. The plasma furnace requires only that bulk lead and mercury be removed (for separate treatment) and that boxes, large metals, and debris be reduced in size to fit into the feed handling system and the plasma chamber; thus, feedstock preparation is minimal. Solid residues from the plasma furnace, including radionuclides, can be drawn off in two streams: a molten glass stream containing the vitrified ash components, and a molten metal stream. Aqueous secondary waste streams are treated in an aqueous waste treatment subsystem. Organics recovered from aqueous waste treatment are recycled to the plasma furnace. Sludges resulting from precipitation and filtration are transferred to either the plasma furnace or, if necessary, to a secondary, polymer-based stabilization subsystem. The treated water is recycled into the system, as required, for process use. Differences between this system and the baseline system are outlined below.

2.3.1 Receiving and Preparation Subsystem

System C-1 requires minimal processing during receiving and feedstock preparation. Bulk lead and mercury need to be removed and treated separately. Large pieces of bulk metal (steel, etc.) that require melting and other debris need only to be reduced in size sufficiently to fit the feed handling system and the plasma chamber. Metal not requiring melting is sent to a decontamination subsystem.

2.3.2 Incineration Subsystem

The main component of the incineration subsystem is a plasma furnace, which uses an electric arc. The arc produces a highly energized plasma that breaks the chemical bonds of waste materials. Plasma systems usually operate in a pyrolytic or starved-air mode in an attempt to minimize high-temperature formation of undesirable oxides of nitrogen. The offgases are burned in an SCC using air as the combustion gas.

2.3.3 APC Subsystem

The APC subsystem has a smaller capacity than that of the baseline system, since the volume of offgas generated per unit mass of waste is smaller. (Even lower quantities of combustion gas could be obtained if oxygen were used instead of air.) It is likely that the capability to reduce levels of oxides of nitrogen in the offgas will be required.

2.3.4 Primary Stabilization Subsystem

An acceptable waste form is produced during incineration. The waste is slowly cooled in a slag chamber operating at an elevated temperature. After cooling, the waste form is moved to storage. This process will require the use of contaminated soil or glass-forming additives to enhance the physical properties of the waste form.

2.4 System D: CO₂ Retention

System D-1 combines a substoichiometric, fixed-hearth primary combustor (frequently referred to as a controlled-air incinerator) with an SCC, both of which use oxygen as the combustion gas. This system uses a fluidized bed absorber to absorb the carbon dioxide in the lime after treatment in a conventional APC. The calcium carbonate (or dolomite) is monitored for RCRA materials, temporarily stored in silos, and later roasted to recover the lime. The carbon dioxide released by the roasting operation is again monitored for RCRA and radioactive compounds and released to the atmosphere. The lime can be recycled up to ten times. The net result of the process is a delay in the release of CO₂. This delay allows the offgas to be sampled for RCRA metals and radionuclides. The calcium carbonate could also be calcined at a remote location to shift the release of CO₂ away from the MLLW treatment facility. A third alternative is to landfill the calcium carbonate, which would

essentially eliminate the release of CO₂ to the atmosphere. The incineration subsystem is preceded by a standard feedstock preparation subsystem in which special precautions are taken to remove large pieces of metal and other noncombustibles. Solid residues from the incineration subsystem are treated by vitrification or polymer solidification. Aqueous secondary waste streams are treated in an aqueous treatment subsystem. Organics recovered from aqueous waste treatment are recycled to the primary incinerator. Sludges resulting from precipitation and filtration are transferred to either the primary stabilization subsystem or, if necessary, to a secondary, polymer-based stabilization subsystem. The treated water is recycled into the system, as required, for process use. Differences between this system and the baseline system are outlined below.

2.4.1 Receiving and Preparation Subsystem

Receiving and preparation includes procedures to remove bulk metals and slag and tar formers.

2.4.2 Incineration Subsystem

System D-1 employs a fixed-hearth incinerator in which waste is transported over a hearth by a ram feeder or other conventional type of feeder. A screw conveyor stirs the ash pile and eventually moves it to one or more ash ports. Combustible waste is heated in an oxygen-starved atmosphere, where it is volatilized and undergoes partial combustion. The resulting energy-bearing gases are burned in an SCC that runs on excess O₂.

2.4.3 APC Subsystem

System D-1 uses a special delayed-release APC subsystem that treats incineration offgas by conventional means and then removes carbon dioxide by absorption into lime in a fluidized bed. Water vapor formed in the incinerator is condensed, and the remaining gas is stored, sampled, and (if it meets requirements) discharged to the atmosphere. The lime (or dolomite) can be recycled up to ten times using a lime recovery system whose main component is a calciner. After ten cycles, the lime is disposed as waste. The lime is stabilized before disposal, using the secondary stabilization process, on the premise that it might contain RCRA metals and be subject to land disposal restriction regulations.

2.4.4 Aqueous Waste Treatment Subsystem

This subsystem handles the water condensed from the offgas. This subsystem is smaller than that of the baseline because liquid waste from the scrubber has been eliminated.

2.4.5 Primary Stabilization Subsystem

This subsystem is the same as in the baseline system except that noncombustible materials in the feed must be dried. Soil is mixed with ash coming from the incinerator. Dryers are needed to remove water from the soil, sludge, and other materials before vitrification.

2.5 System E: Thermal Desorption

System E-1 takes advantage of RCRA land disposal regulations that allow treatment of waste classified as debris by grouting only. Waste classified as process residues requires incineration. System E-1 is based on a standard rotary kiln incinerator that uses air as the combustion gas. The kiln is preceded by a standard feedstock preparation subsystem and followed by a standard dry/wet APC subsystem. Ash from this system goes to a vitrification unit.^h The incineration subsystem is standard except for a thermal desorption step parallel to the thermal treatment unit. The desorber separates volatile organic compounds (VOCs) from debris as defined by RCRA. Soil can also be treated by the parallel thermal desorber. Waste components vaporized in the thermal desorber are condensed to a liquid and sent to the rotary kiln. Solid residues from this system are stabilized by grouting. Solids from the desorber are shredded and microencapsulated by grouting. Aqueous secondary waste streams are treated in an aqueous waste treatment subsystem. Organics recovered from aqueous waste treatment are recycled to the rotary kiln. Sludges resulting from precipitation and filtration are transferred to either the primary stabilization subsystem or, if necessary, to a secondary, polymer-based stabilization subsystem. The treated water is recycled in the system, as required, for process use. Differences from the baseline system are outlined below.

h. Subsequent evaluation of the mass flow rates and economics indicated that the ash feed rate to the vitrification unit is too low; hence, it would be more economical to grout the ash. As a result, the vitrification unit will be eliminated in the future update of this system.

2.5.1 Receiving and Preparation Subsystem

The receiving and preparation subsystem is similar to that of the baseline system but more waste characterization and segregation are required.

2.5.2 Incineration Subsystem

Incineration equipment is the same as in the baseline system except that a smaller rotary kiln unit is used.

2.5.3 Thermal Desorption Subsystem

This subsystem, which uses an indirectly-heated calciner for thermal desorption, separates VOCs from the feedstock before waste is fed to the stabilization subsystem. Waste components vaporized in the thermal desorber are treated in an APC consisting of a stripper and condensers. Captured organic liquids are sent to the incineration subsystem. Solid residues from the desorber are sent to a debris grouting subsystem.

2.5.4 Debris Grouting Subsystem

The debris grouting subsystem stabilizes debris by mixing the shredded waste with grout consisting of cement, water, and sand. The mixture is poured into drums and allowed to cure. Once the grout has solidified, the drums are capped, washed, and moved to the certify and ship subsystem.

Figure 2-1. Typical arrangement of integrated thermal treatment system.

Figure 2-2. Perspective view of integrated thermal treatment system (Systems A-1 through A-6).

Figure 2-4. Perspective view of receiving and unloading area of the receiving and preparation subsystem for rotary kiln using air (System A-1).

Figure 2-5. Perspective view of the decap, sort, and dump cell of the receiving and preparation subsystem for rotary kiln using air (System A-1).

Figure 2-6. FAD for the incineration system for rotary kiln, air (Systems A-1) and rotary kiln using oxygen (System A-2).

NOTE: WALLS NOT SHOWN FOR CLARITY

EQUIPMENT LIST

- ① PORTABLE WASTE HOPPERS
- ② SHREDDER
- ③ WASTE STREAM SAMPLER
- ④ WASTE FEEDER
- ⑤ INTAKE HOPPER
- ⑥ SOIL FEED CONVEYOR
- ⑦ ROTARY KILN INCINERATOR
- ⑧ ASH COOLING CHAMBER
- ⑨ PORTABLE ASH HOPPER (HIDDEN)
- ⑩ SECONDARY COMBUSTION CHAMBER
- ⑪ QUENCH CHAMBER
- ⑫ DRY FILTER BAGHOUSE
- ⑬ CARBON FILTERS
- ⑭ HEPA FILTERS
- ⑮ HYDROSONIC SCRUBBER
- ⑯ PACKED TOWER MIST ELIMINATOR
- ⑰ HEAT EXCHANGERS
- ⑱ DENOX CATALYTIC REACTOR
- ⑲ FAN AND STACK
- ⑳ OVERHEAD CRANE
- ㉑ WASTE CONTAINER HOIST
- ㉒ DUST COLLECTOR

Figure 2-7. Perspective view of the incineration and air pollution control subsystems for rotary kiln using air (System A-1).

Figure 2-10. Perspective view of lead recovery subsystem for rotary kiln using air (System A-1).

Figure 2-11. FAD for mercury amalgamation subsystem for rotary kiln using air (System A-1).

NOTE: WALLS NOT SHOWN FOR CLARITY

Figure 2-12. Perspective view of mercury amalgamation subsystem for rotary kiln using air (System A-1).

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Figure 2-14. Perspective view of metal decontamination subsystem for rotary kiln using air (System A-1).

Figure 2-15. FAD for metal melting subsystem for rotary kiln using air (System A-1).

Figure 2-16. Perspective view of metal melting subsystem for rotary kiln using air (System A-1).

Figure 2-17. FAD for aqueous waste treatment subsystem for rotary kiln using air (System A-1).

EQUIPMENT LIST

- ① BATCH TANKS WITH AGITATOR (TYP 4)
- ② OIL AND WATER SEPARATOR
- ③ SOLIDS FILTER
- ④ NEUTRALIZER TANK WITH AGITATOR
- ⑤ REACTOR TANK WITH AGITATOR
- ⑥ SETTLING TANK
- ⑦ EVAPORATOR UNIT
- ⑧ CONDENSER
- ⑨ CONDENSED WATER TANK
- ⑩ VAPOR PHASE CARBON FILTER
- ⑪ VACUUM PUMP
- ⑫ BATCH STILL
- ⑬ STILL CONDENSER
- ⑭ VAPOR PHASE CARBON FILTER
- ⑮ ION EXCHANGE UNIT
- ⑯ UV AND PEROXIDE UNIT
- ⑰ CARBON FILTER DRUMS

NOTE: WALLS NOT SHOWN FOR CLARITY

Figure 2-18. Perspective view of aqueous waste treatment subsystem for rotary kiln using air (System A-1).

Figure 2-20. Perspective view of primary stabilization subsystem for rotary kiln using air (System A-1).

Figure 2-21. FAD for secondary stabilization subsystem for rotary kiln using air (System A-1).

Figure 2-22. Perspective view of secondary stabilization subsystem for rotary kiln using air (System A-1).

Figure 2-23. FAD for certify and ship subsystem for rotary kiln using air (System A-1).

Figure 2-24. Perspective view of certify and ship subsystem for rotary kiln using air (System A-1).

3. MASS FLOW RATES OF THE SYSTEMS

This section summarizes the mass flow rates of the major inputs and outputs of the systems; detailed information on mass flow rates is presented in the process functional diagrams (Appendix B). As indicated in the Introduction, the mass balance data shown in this section will be revised, in the Phase 2 report, to incorporate waste inventory data used in Phase 2. This revision is needed in order to have a uniform basis for comparison of all systems studied in Phases 1 and 2.

The mass flow rates used in this preconceptual design study are based on many assumptions. These assumptions, discussed below, must be validated or revised as more system information becomes available in future developmental and design activities.

3.1 System Input Feed Rates

Appendix A lists the types and quantities of waste in DOE's inventory. These data provide the basis for the system waste feed rates presented in Table 1-4 (Table 1-4 includes both alpha and nonalpha MLLW). The feed rate calculations are based on the assumption of one ton per hour for the main thermal treatment train, uniformly fed over 4,032 hours of operation per year for 20 years. The hours of operation are based on 3 shifts per day, 240 days per year (i.e., 8 months of operation and 4 months of shutdown for routine maintenance and upkeep) at about 70% of operating availability (i.e., 30% of the time). In practice, some of the unit operations might not operate on a three-shift basis, and a batch approach instead of continuous operation might be used to process waste streams that have a low feed rate. Because of uncertainty in the data, the capacities of the modules are slightly greater than required by the data. Due to differences between the main thermal treatment subsystems, the mass flows to the various subsystems differ as shown in Figures 3-1, 3-2, and 3-3.

3.2 System Secondary Waste

Only major secondary waste streams have been included in the calculations. These are wastes produced within the facility, such as APC scrubber salts, decontamination subsystem sludge, and spent lime from CO₂ retention systems. Other secondary waste streams include:

- Housekeeping trash, disposable garments, and equipment maintenance waste.

Figure 3-1. Waste fractions fed to subsystems of rotary kiln and plasma systems (Systems A-1 through A-6 and C-1).

Figure 3-2. Waste fractions fed to subsystems of indirectly fired pyrolyzer and fixed hearth systems (Systems B-1 and D-1).

Figure 3-3. Waste fractions fed to subsystems of rotary kiln system with debris grouting (System E-1).

- Spent baghouse and ventilation and HEPA filter elements.
- Accumulations in equipment drains and floor drains, and other liquids generated during routine flushing and cleanup of the systems, including floor wash-downs.
- Machinery oil and decontamination solutions generated during equipment replacement and maintenance.
- Spent refractory lining from thermal treatment units.
- Spent activated carbon beds, ion-exchange resins, and other filter media used in the facility.

Final waste output resulting from treatment of these secondary waste streams is estimated to be the same for all systems. Hence, it is not expected to affect the outcome of the systems comparison. For cost estimating purposes, the final waste output from these other secondary waste is assumed to be 1 cubic foot per hour.

3.3 Key Assumptions for Mass Flow Calculations

The key assumptions for mass flow calculations are as follows.

- Densities:
 - Vitrified waste = 187 lbs/ft³
 - Polymer stabilized ash = 94 lbs/ft³
 - Polymer stabilized salts = 80 lbs/ft³
 - Polymer stabilized lime = 96.5 lbs/ft³
 - Grout stabilized debris = 126.6 lbs/ft³
- Mercury content:
 - Elemental mercury comprises 5% of stream designated as mercury-contaminated waste
 - Mercury concentration in the remaining 95% of the stream is 5%

- Stabilization formulas:
 - Vitrification = By mass, one part soil or glass-forming additives to two parts waste (secondary residue [ash] or untreated inorganic waste)
 - Polymer = One part polymer to one part waste
 - Grout = Two parts grout to one part waste
- Lime recycling in CO₂ retention systems:
 - Lime recycling = 90% (10% rejected)
- Salt recovery process:
 - Salt cracking efficiency = 90% (10% rejected)
- Metal recovery process (System A-6):
 - Metal separated from the incinerator feed comprises 7% of the input waste
- Thermal desorption process:
 - Organics recovered during desorption comprise 5% of the feed
- Ash content:
 - Ash from combined combustible and noncombustible waste (feedstock to rotary kiln incinerator in Systems A-1 to A-6) comprises 57.3% of the feed
 - Ash from combustible waste (feedstock to pyrolyzer in System B-1, fixed-hearth in System D-1, and rotary kiln incinerator in System E-1) comprises 7% of the feed
 - Lime discarded as waste after calcining comprises 10% of the feed
- Rotary kiln incinerator and plasma furnace feed rates (Systems A-1 to A-6 and C-1):
 - An incinerator feed rate of 1 T/hr was selected. This feed consists of 1,146 lbs/hr (57.3%) of noncombustible waste, 374 lbs/hr (18.7%) of combustible waste, and 480 lbs/hr (24.0%) of absorbed water.
- Incinerator feed rate for Systems B-1, D-1, and E-1:
 - 468 lbs/hr of combustible waste.

3.4 Mass Balance Calculation Results

Figure 3-4 shows the stabilized waste output from each of the ten systems, and Figure 3-5 shows the total offgas discharged from each system. The information in Figures 3-4 and 3-5 is based on the mass flow rates shown in Figures 3-6 through 3-20. Figures 3-6 through 3-10 are simplified flow sheets containing mass flow rate summaries for the major subsystems. Figures 3-11 through 3-20 contain mass flow rates for the ten systems.

The results of the mass balance calculations demonstrate some significant trends with regard to minimizing offgas. Oxygen combustion provides the most offgas reduction. Retention of CO₂ provides additional assurance that harmful pollutants are not released into the atmosphere. (The cost of either feature adds less than 10% to life-cycle cost.) Minimizing the volume of offgas can provide important benefits: reduced particulate carryover, reduced size and cost of APC equipment, and possible reduction of public concerns over the thermal treatment process.

3.5 Energy Balance Results

A rough estimate of the system energy balance was made for the main thermal treatment and the vitrification subsystems to determine if energy demands are reasonable. A conservative waste heat value of 2,000 British thermal units (Btu) per pound was used in the energy balance calculations. The results showed that, with the exception of the plasma-arc system, the typical energy input is reasonably small, 62 to 250 lbs/hr of methane gas (1.33-5.38 million Btu/hr) for the incinerator and 0.5 MW of electricity for the vitrification unit. The plasma-arc system has the highest energy demand, about 1.5 MW of electricity. At the conclusion of the Phase 2 studies, a more rigorous energy balance for all systems is expected to be completed.

- A-1 Rotary kiln, air
- A-2 Rotary kiln, oxygen
- A-3 Rotary kiln, air, wet APC
- A-4 Rotary kiln, oxygen, CO₂ retention
- A-5 Rotary kiln, air, polymer stabilization
- A-6 Rotary kiln, oxygen, maximum recycling
- B-1 Pyrolyzer, oxygen
- C-1 Plasma arc furnace
- D-1 Fixed hearth, oxygen, CO₂ retention
- E-1 Rotary kiln, air, thermal desorber

Figure 3-4. Stabilized waste output volumes.

- A-1 Rotary kiln, air
- A-2 Rotary kiln, oxygen
- A-3 Rotary kiln, air, wet APC
- A-4 Rotary kiln, oxygen, CO₂ retention
- A-5 Rotary kiln, air, polymer stabilization
- A-6 Rotary kiln, oxygen, maximum recycling
- B-1 Pyrolyzer, oxygen
- C-1 Plasma arc furnace
- D-1 Fixed hearth, oxygen, CO₂ retention
- E-1 Rotary kiln, air, thermal desorber

Figure 3-5. Offgas output volumes.

Figure 3-6. General mass flow rates (lbs/hr) for metal decontamination subsystem.

Figure 3-7. General mass flow rates (lbs/hr) for metal melting subsystem.

Figure 3-8. General mass flow rates (lbs/hr) for lead recovery subsystem.

Figure 3-9. General mass flow rates (lbs/hr) for aqueous waste treatment subsystem.

Figure 3-10. General mass flow rates (lbs/hr) for mercury amalgamation subsystem.

*WATER CONTENT NOT INCLUDED
 **INFILTRATION AIR INCLUDED
 SOIL ADDITIVE = 50% OF FEED TO VITRIFICATION.

Figure 3-11. General mass flow rates (lbs/hr) for rotary kiln using air; baseline system (System A-1).

• WATER CONTENT NOT INCLUDED
 SOIL ADDITIVE = 50% OF FEED TO VITRIFICATION

Figure 3-12. General mass flow rates (lbs/hr) for rotary kiln using oxygen (System A-2).

*WATER CONTENT NOT INCLUDED
 **INFILTRATION AIR INCLUDED
 SOIL ADDITIVE = 50% OF FEED TO VITRIFICATION

Figure 3-13. General mass flow rates (lbs/hr) for rotary kiln using air and wet APC (System A-3).

*WATER CONTENT NOT INCLUDED

SOIL ADDITIVE = 50% OF FEED TO VITRIFICATION
20% LIME TO STABILIZATION
80% LIME TO RECYCLE

Figure 3-14. General mass flow rates (lbs/hr) for rotary kiln using oxygen and CO₂ retention (System A-4).

Figure 3-15. General mass flow rates (lbs/hr) for rotary kiln using air and polymer stabilization (System A-5).

- 1) ASSUME 7% OF INPUT WASTE IS METALLIC MATERIAL THAT IS SEPARATED
- 2) ASSUME 10% SALT DUMP
- 3) SOIL ADDITIVE = 50% OF FEED TO VITRIFICATION

Figure 3-16. General mass flow rates (lbs/hr) for rotary kiln using oxygen and maximum recycling (System A-6).

Figure 3-17. General mass flow rates (lbs/hr) for pyrolyzer using oxygen (System B-1).

Figure 3-18. General mass flow rates (lbs/hr) for plasma arc furnace (System C-1).

Figure 3-19. General mass flow rates (lbs/hr) for fixed hearth using oxygen and CO₂ retention (System D-1).

Figure 3-20. General mass flow rates (lbs/hr) for rotary kiln using air and thermal desorber (System E-1).

4. LIFE-CYCLE COST ESTIMATES AND SENSITIVITY ANALYSIS

This section contains a summary of planning level life-cycle cost estimates for the ten systems. PLCC estimates include both treatment and disposal costs. Transportation costs have been included on a generic basis in Section 4.8 since they are a small fraction (~5%) of the total life-cycle costs.

For comparison purposes, the systems are arbitrarily sized at 1 T/hr nominal capacity. This size of system will treat most of the stored alpha and nonalpha MLLW in a 20-year period. For smaller systems, the cost versus capacity curves from the Waste Management Facilities Cost Information Report⁸ should be used. Since one system is used for the entire inventory, the facility is designed for alpha waste--the alternative is to provide two facilities, one for alpha and one for nonalpha MLLW.

4.1 Estimating Methods, Basis, and Assumptions

Figure 4-1 shows the steps used in cost estimation. Cost information in this report was obtained during the 3rd Quarter of 1993. The information is based on the currently available knowledge about waste processing requirements, technology availability, and cost data. The information may need to be updated when additional knowledge is gained in these areas. All facilities are assumed to be government owned and contractor operated.

The PLCC estimates are based on the assumption that the operating life of the facility is 20 years, which is equal to 80,640 operating hours. The treatment unit rates are obtained by dividing the total PLCC estimate by the total operating hours per year.

4.2 Treatment Facility PLCC Estimate Summaries

The PLCC estimate for each facility has six components (see Figure 4-1), each estimated separately. Discussions of the cost components are presented below.

Figure 4-1. Diagram of cost estimating approach.

4.2.1 Studies and Bench-Scale Tests and Demonstration

Costs for the first (studies and bench-scale tests) and second (demonstration) cost components are obtained by estimating the cost of research manpower, equipment, and facility needs.

4.2.2 Facility Capital Costs

The third cost component, production facility construction costs (also referred to as facility capital cost or "line-item" cost), consists of five key subcomponents, which are described below.

4.2.2.1 Design. The design subcomponent includes Title 1, or preliminary design, and Title 2, or detailed design. Design is estimated at 25% of facility construction cost for a facility handling alpha MLLW.

4.2.2.2 Inspection. This subcomponent includes Title 3, or engineering support, during construction. Inspection is estimated at 7% of the facility construction cost.

4.2.2.3 Project management. This subcomponent includes project management costs incurred both by DOE and the site management and operations contractor. Project management is estimated at 10% of facility construction cost.

4.2.2.4 Construction cost. Facility construction cost estimates are based on the preconceptual design package developed for the subsystems and the integrated facilities. The package includes a process functional diagram with mass flow rates, a functional allocation diagram, a scoping study layout (SSL), and a summary of functional and operational requirements. Construction costs are divided into the following three parts:

- **Building and structures.** These costs are estimated by multiplying building unit costs by the square footage allocated to each subsystem in the SSLs. Assumed unit rates for the various categories of buildings are: \$1,700 per square foot for triple-confinement alpha cells (used for alpha waste processing areas); \$800 per square foot for double-confinement alpha cells (used for alpha equipment pull-out areas); \$800 per square foot for operating areas next to alpha cells; \$420 per square foot for packaged waste handling areas (truck bay or drum storage); \$420 per square foot for the process area for nonalpha waste; \$420 per square foot for the operator and packaged waste handling areas for nonalpha waste;

\$180 per square foot for office area; and \$420 per square foot for the analytical laboratory. Building unit rates include all materials and labor needed for constructing the building shell, including utilities, lighting, HVAC (heating, ventilation, and air conditioning), and site development costs. It is assumed that all utilities (power, sanitary and storm sewers, site communication and alarms) and access roads are within 100 feet from the outer walls of the treatment facility. Special steel supports, foundations, and ventilation ducts and hoods required by the process components are not included in the standard building unit rates. These rates do include costs for imposing stringent DOE health and safety standards to facility construction.

- **Equipment.** Cost estimates for major equipment were obtained from a similar facility, by soliciting budgetary costs from suppliers, or by making engineering judgments. Costs estimated for equipment installation are based on individual requirements of the equipment. Allowances for electrical, instrumentation, and mechanical bulks are estimated as a percentage of the total equipment purchase costs.
- **Indirect costs.** Indirect costs include subcontractor overhead and fee. This is estimated at 29% of the total cost of the building, structures, and equipment.

4.2.2.5 Construction management. This subcomponent is estimated at 17% of construction costs, which is the sum of the building, equipment, and indirect costs. Construction management includes materials and services procurement and control activities, which are usually handled by the site construction management contractor.

Allowances for project scope change or management reserve are 10% of construction costs.

Because the costs are a planning-level estimate, a 25% contingency is included. The contingency is applied to the total of all components in the production facility construction cost.

4.2.3 Preconstruction and Preoperational Activities

This cost component (operations budget funded activitiesⁱ) includes conceptual design, safety assurance, National Environmental Policy Act (NEPA) compliance efforts and permitting, preparation for operation, and project management costs. Costs for conceptual design and safety assurance (safety analysis reports) are estimated to be 1.5% and 1%, respectively, of the facility construction cost. The costs for an environmental impact statement for NEPA compliance and for RCRA, TSCA, Clean Air Act (CAA), state, local and other permits are estimated at \$6 million. All other subcomponents of the cost of the preconstruction and preoperational activities, including preoperation readiness reviews, facility start-up, operator hiring, and training costs, are assumed to be equal to 1 year of total facility operating costs.

4.2.4 Operating and Maintenance Costs

These costs have four subcomponents: operating labor; utilities; consumable materials; and maintenance labor, parts, and equipment. The costs of first three subcomponents are estimated by analyzing the requirements of each facility at the subsystem level (see Tables 4-1 and 4-2 for administration and operations staffs for the baseline system^j). The maintenance subcomponent costs are estimated as a percentage of the original equipment installed at the facility. The annual costs for spare parts and replacement equipment are estimated to be about 7% of the original equipment purchase cost, while annual maintenance labor is estimated to be 250% of the cost of spare parts and replacement.

4.2.5. Decontamination and Decommissioning

This cost component is estimated by multiplying a unit rate of \$450 per square foot, taken from Schleuter⁹ by the square footage of the total facility.

i. Preconstruction and preoperation activity costs are referred to as "operations budget funded activities" because they are not part of typical capital expenditure budgets funded by Congress.

j. The total operating manpower compares well with data obtained during a telephone conversation with personnel from a commercial hazardous nonradioactive waste incineration facility in Utah.

Table 4-1. Estimated facility administration staff for the baseline system, rotary kiln using air (System A-1).

Job	FTE workers
Accountant	1
Secretary and clerk	2
Document control	2
Manager, dayshift	2
Technical personnel	1
Communications	1
Environmental manager	1
Operations support and management	1
Quality control technicians	1
Security guard	4
Health physics technician	4
Testing laboratory	<u>7</u>
TOTAL	27

Table 4-2. Estimated facility operation staff for the baseline system, rotary kiln using air (System A-1).

Subsystem	Crews	Crew size	Number of 40-hour shifts	Total FTE workers
Receiving and preparation	7	4	4	112
Incineration	1	4	4	16
Air pollution control	1	1	4	4
Primary stabilization	1	4	4	16
Metal melting	1	4	1	4
Lead recovery	1	4	2	8
Metal decontamination	1	4	1	4
Aqueous waste treatment	1	4	4	16
Mercury amalgamation	1	4	1	4
Secondary stabilization	1	4	4	16
Special waste treatment	1	2	1	2
Support systems	1	1	4	<u>4</u>
TOTAL				206

4.2.6 Processing System PLCC Estimates

A breakdown of the construction cost per subsystem for the baseline system (System A-1) is presented in Figure 4-2. Life-cycle costs for subsystems in the baseline system are shown in Figure 4-3. Figure 4-4 summarizes unit rates for the subsystems for the baseline system. Figure 4-5 shows capital cost estimates for the ten systems. PLCC estimates for the ten systems are summarized in Figure 4-6 and shown in Table 4-3. Treatment unit cost estimates for the ten systems based on the total waste to be processed by the facility are shown in Figure 4-7; the normalized life cycle costs are shown in Figure 4-8. (For convenience in reading the text, the remaining figures and tables in this chapter are grouped at the end of the chapter. The figures begin on page 85 and the tables on page 96.)

4.3 Disposal Cost Summaries

Disposal costs were estimated based on a unit rate of \$243 per cubic foot for burial in an engineered (above-ground or below-ground vault) disposal facility. As shown in Figure 4-9, System A-6 (rotary kiln incineration with maximum recycling) has the lowest disposal cost, while System E-1 (rotary kiln with debris grouting), at about four times greater, has the highest.

4.4 Total System Life-Cycle Costs

The total system life-cycle cost estimate is the sum of the treatment and disposal costs (see Table 4-4 and Figure 4-10). Another component of system life-cycle cost, transportation, is discussed in a later subsection of this report.

4.5 Sensitivity Analysis

The overall system (treatment and disposal) PLCC estimates for the baseline system (System A-1, rotary kiln, air) were analyzed for sensitivity to several system cost components and subcomponents, viz. studies, bench-scale tests and demonstration; building; equipment; preconstruction and preoperation; operation and maintenance; decontamination and decommissioning; and disposal costs. Results, shown in Figure 4-11, are discussed below.

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Studies, bench-scale tests, and demonstration cost components. As shown in Figure 4-11, the PLCC estimate has a low sensitivity to variations in these cost components. Doubling these cost components results in less than a 5% increase in the overall PLCC estimate.

Building cost subcomponent. Doubling the building costs subcomponent results in an increase of about 10% in the overall PLCC estimate.

Equipment cost subcomponent. Doubling this cost subcomponent results in an increase of less than 15% in the overall PLCC estimate.

Preconstruction and preoperation cost component. The PLCC estimate has a low sensitivity to variation in this cost component--doubling it will result in about a 5% increase in the overall PLCC estimate.

Operating and maintenance cost component. Figure 4-11 shows that the PLCC estimate is highly sensitive to the operations and maintenance cost component. A 100% increase in the cost of operations and maintenance will result in a 65% increase in the overall PLCC estimate.

Decontamination and decommissioning cost component. The PLCC estimate has a low sensitivity to the D&D cost component. A 100% increase in D&D cost will result in an increase of less than 5% in the overall PLCC estimate.

Disposal costs. If the estimated disposal cost of \$243/ft³ is doubled, the total life-cycle cost will increase by about 11%.

4.6 Economic Impact of Stabilization Technology

Cost analyses were performed to determine sensitivity of the PLCC estimates to three different stabilization technologies: polymer solidification, vitrification, and cement solidification. As shown in Figure 4-12, the lowest life-cycle unit cost is for vitrification, about \$13/lb. The highest cost is for cement, about \$16/lb. The cost for polymer stabilization is about \$14/lb.

4.7 Economic Impact of Delisting Scrubber Salts

Delisting of the scrubber salts will reduce the overall treatment and disposal cost by \$0.35 per pound of input waste. This is based on the conservative assumption that the delisted waste will be disposed in a shallow-land low-level waste burial facility without stabilization. If the entire vitrified waste residue is disposed in a non-RCRA low-level waste facility at a cost of \$100/ft³, then the overall savings could be about \$1/lb which is about 8% of the total life-cycle cost.

4.8 Transportation Cost

A rough estimate of transportation costs was made to determine the magnitude of this cost component. The estimate is based on the following assumptions:

- About 60% of the waste is shipped to the treatment facility from waste generators located 1,000 miles from the facility.
- The treated waste is disposed at the same location it is treated.
- The waste containers are contact handled, do not require special over-pack, and are shipped in enclosed trailers.
- The waste has an average density of 35 lbs/ft³.
- The volume of waste transported in each shipment is 290 ft³.
- The cost for shipment is \$4/mile per shipment.¹⁰
- Fixed shipping costs are \$880/shipment.

Based on these assumptions, the cost of transportation is calculated to be about \$0.29/lb of input waste (\$54.45 million for 188,780,000 lbs of waste).

Figure 4-2. Facility capital cost estimates for the subsystems of rotary kiln using air (System A-1).

Figure 4-3. Life-cycle cost estimates for subsystems of rotary kiln using air (System A-1).

Figure 4-4. Unit rate cost estimates for subsystems of rotary kiln using air (System A-1).

Figure 4-5. Capital cost estimates for the ten systems.

Figure 4-6. PLCC estimates for the ten systems.

Figure 4-7. Treatment unit cost estimates for the ten systems.

NOTE:

- A-1 Rotary kiln, air
- A-2 Rotary kiln, oxygen
- A-3 Rotary kiln, air, wet APC
- A-4 Rotary kiln, oxygen, CO₂ retention
- A-5 Rotary kiln, air, polymer stabilization
- A-6 Rotary kiln, oxygen, maximum recycling
- B-1 Pyrolyzer, oxygen
- C-1 Plasma arc furnace
- D-1 Fixed hearth, oxygen, CO₂ retention
- E-1 Rotary kiln, air, thermal desorber

Figure 4-8. Normalized life cycle costs for the main thermal treatment line.

Figure 4-9. Disposal cost estimates for the systems.

Figure 4-10 Total life-cycle (treatment and disposal) cost for the ten systems.

LEGEND

- ◆ Studies, bench-scale tests and demonstration cost component
- Building cost component
- ▲ Equipment cost component
- Operations budget funded activities cost component
- Operation and maintenance cost component
- ▲ Decontamination and decommissioning cost component
- Disposal cost component

Figure 4-11. Results of sensitivity analysis.

Figure 4-12. Disposal costs associated with the three stabilization options for rotary kiln using air (System A-1).

Table 4-3. Planning level life-cycle cost estimates for the ITTS Study – Phase I Systems

Cost component	Cost Items	Cost (x 1000) System A-1
1.0 Studies and bench-scale test costs		
1.1 Manpower costs during research		\$18,900
1.2 Equipment costs		\$2,200
1.3 Installation costs		\$1,100
1.4 Project management before title 1	(10 % of 1.1 through 1.3)	\$2,220
1.5 Contingency	(25 % of 1.1 through 1.4)	\$6,105
Subtotal 1.0		\$30,525
2.0 Demonstration costs		
2.1 Manpower costs during demonstration		\$10,800
2.2 Design cost	(30 % of 2.5)	\$7,740
2.3 Inspection cost	(7 % of 2.5)	\$1,806
2.4 Project management	(10 % of 2.5)	\$2,580
2.5 Construction cost		
2.5.1 Building structure costs		\$3,000
2.5.2 Equipment costs		\$17,000
2.5.3 Indirect	(29 % of 2.5.1 & 2.5.2)	\$5,800
Subtotal of 2.5		\$25,800
2.6 Construction management costs	(17 % of 2.5)	\$4,412
2.7 Management reserve	(10 % of 2.5)	\$2,580
2.8 Contingency	(25 % of 2.1 through 2.7)	\$13,930
Subtotal 2.0		\$69,648
3.0 Production facility construction costs		
3.1 Design cost	(25 % of 3.4)	\$68,616
3.2 Inspection cost	(7 % of 3.4)	\$19,212
3.3 Project management	(10 % of 3.4)	\$27,446
3.4 Construction cost		
3.4.1 Building structure costs		\$88,175
3.4.2 Equipment costs		\$124,586
3.4.3 Indirect	(29 % of 3.4.1 & 3.4.2)	\$61,701
Subtotal of 3.4		\$274,462
3.5 Construction management	(17 % of 3.4)	\$46,933
3.6 Management reserve	(10 % of 3.4)	\$27,446
3.7 Contingency	(25 % of 3.1 through 3.5)	\$109,167
Subtotal 3.0		\$573,282
4.0 Operations budget funded activities (see Sect. 7)		
4.1 Conceptual design	(1.5 % of 3.0)	\$8,599
4.2 Safety assurance	(1 % of 3.0)	\$5,733
4.3 NEPA permitting (\$ 6 million for EIS, \$1 million for EA)		\$6,000
4.4 Preparation for operations	(100 % of 5.0)	\$68,639
4.5 Project management	(10 % of 4.1 through 4.4)	\$8,897
Subtotal 4.0		\$97,868
Total initial cost (1.0, 2.0, 3.0 & 4.0)		\$771,323
5.0 Operating and maintenance costs		
5.1 Annual operating costs		\$36,120
5.2 Annual utility costs		\$816
5.3 Annual material costs		\$5,155
5.4 Annual maintenance costs		\$12,820
5.5 Contingency	(25 % of 5.1 through 5.4)	\$13,728
5.6 Subtotal 5.0		\$68,639
5.7 Total 20 year O & M cost (20 times Subtotal 5.0)		\$1,372,780
6.0 Decontamination & decommissioning		\$54,171
7.0 ROM life cycle costs (20 years operation)		\$2,198,274
Percent difference from Baseline System		0.00%

Table 4-3. Continued.

Cost component	Cost Items	Cost (x 1000) System A-2
1.0 Studies and bench-scale test costs		
1.1 Manpower costs during research		\$18,900
1.2 Equipment costs		\$2,200
1.3 Installation costs		\$1,100
1.4 Project management before title 1	(10 % of 1.1 through 1.3)	\$2,220
1.5 Contingency	(25 % of 1.1 through 1.4)	\$6,105
Subtotal 1.0		\$30,525
2.0 Demonstration costs		
2.1 Manpower costs during demonstration		\$10,800
2.2 Design cost	(30 % of 2.5)	\$7,740
2.3 Inspection cost	(7 % of 2.5)	\$1,806
2.4 Project management	(10 % of 2.5)	\$2,580
2.5 Construction cost		
2.5.1 Building structure costs		\$3,000
2.5.2 Equipment costs		\$17,000
2.5.3 Indirect	(29 % of 2.5.1 & 2.5.2)	\$5,800
Subtotal of 2.5		\$25,800
2.6 Construction management costs	(17 % of 2.5)	\$4,412
2.7 Management reserve	(10 % of 2.5)	\$2,580
2.8 Contingency	(25 % of 2.1 through 2.7)	\$13,930
Subtotal 2.0		\$69,648
3.0 Production facility construction costs		
3.1 Design cost	(25 % of 3.4)	\$66,394
3.2 Inspection cost	(7 % of 3.4)	\$18,590
3.3 Project management	(10 % of 3.4)	\$26,558
3.4 Construction cost		
3.4.1 Building structure costs		\$86,975
3.4.2 Equipment costs		\$118,898
3.4.3 Indirect	(29 % of 3.4.1 & 3.4.2)	\$59,703
Subtotal of 3.4		\$265,576
3.5 Construction management	(17 % of 3.4)	\$45,413
3.6 Management reserve	(10 % of 3.4)	\$26,558
3.7 Contingency	(25 % of 3.1 through 3.5)	\$105,633
Subtotal 3.0		\$554,722
4.0 Operations budget funded activities (see Sect. 7)		
4.1 Conceptual design	(1.5 % of 3.0)	\$8,321
4.2 Safety assurance	(1 % of 3.0)	\$5,547
4.3 NEPA permitting (\$ 6 million for EIS, \$1 million for EA)		\$6,000
4.4 Preparation for operations	(100 % of 5.0)	\$69,485
4.5 Project management	(10 % of 4.1 through 4.4)	\$8,935
Subtotal 4.0		\$98,288
Total initial cost (1.0, 2.0, 3.0 & 4.0)		\$753,183
5.0 Operating and maintenance costs		
5.1 Annual operating costs		\$36,120
5.2 Annual utility costs		\$786
5.3 Annual material costs		\$6,429
5.4 Annual maintenance costs		\$12,253
5.5 Contingency	(25 % of 5.1 through 5.4)	\$13,897
5.6 Subtotal 5.0		\$69,485
5.7 Total 20 year O & M cost (20 times Subtotal 5.0)		\$1,389,700
6.0 Decontamination & decommissioning		\$53,776
7.0 ROM life cycle costs (20 years operation)		\$2,196,659
Percent difference from Baseline System		-0.07%

Table 4-3. Continued.

Cost component	Cost Items	Cost (x 1000) System A-3
1.0 Studies and bench-scale test costs		
1.1 Manpower costs during research		\$19,050
1.2 Equipment costs		\$2,200
1.3 Installation costs		\$1,100
1.4 Project management before title 1	(10 % of 1.1 through 1.3)	\$2,235
1.5 Contingency	(25 % of 1.1 through 1.4)	\$6,146
Subtotal 1.0		\$30,731
2.0 Demonstration costs		
2.1 Manpower costs during demonstration		\$10,800
2.2 Design cost	(30 % of 2.5)	\$7,160
2.3 Inspection cost	(7 % of 2.5)	\$1,671
2.4 Project management	(10 % of 2.5)	\$2,387
2.5 Construction cost		
2.5.1 Building structure costs		\$2,500
2.5.2 Equipment costs		\$16,000
2.5.3 Indirect	(29 % of 2.5.1 & 2.5.2)	\$5,365
Subtotal of 2.5		\$23,865
2.6 Construction management costs	(17 % of 2.5)	\$4,081
2.7 Management reserve	(10 % of 2.5)	\$2,387
2.8 Contingency	(25 % of 2.1 through 2.7)	\$13,088
Subtotal 2.0		\$65,439
3.0 Production facility construction costs		
3.1 Design cost	(25 % of 3.4)	\$67,180
3.2 Inspection cost	(7 % of 3.4)	\$18,810
3.3 Project management	(10 % of 3.4)	\$26,872
3.4 Construction cost		
3.4.1 Building structure costs		\$86,975
3.4.2 Equipment costs		\$121,336
3.4.3 Indirect	(29 % of 3.4.1 & 3.4.2)	\$60,410
Subtotal of 3.4		\$268,721
3.5 Construction management	(17 % of 3.4)	\$45,951
3.6 Management reserve	(10 % of 3.4)	\$26,872
3.7 Contingency	(25 % of 3.1 through 3.5)	\$106,884
Subtotal 3.0		\$561,290
4.0 Operations budget funded activities (see Sect. 7)		
4.1 Conceptual design	(1.5 % of 3.0)	\$8,419
4.2 Safety assurance	(1 % of 3.0)	\$5,613
4.3 NEPA permitting (\$ 6 million for EIS, \$1 million for EA)		\$6,000
4.4 Preparation for operations	(100 % of 5.0)	\$68,310
4.5 Project management	(10 % of 4.1 through 4.4)	\$8,834
Subtotal 4.0		\$97,176
Total initial cost (1.0, 2.0, 3.0 & 4.0)		\$754,636
5.0 Operating and maintenance costs		
5.1 Annual operating costs		\$36,120
5.2 Annual utility costs		\$822
5.3 Annual material costs		\$5,197
5.4 Annual maintenance costs		\$12,509
5.5 Contingency	(25 % of 5.1 through 5.4)	\$13,662
5.6 Subtotal 5.0		\$68,310
5.7 Total 20 year O & M cost (20 times Subtotal 5.0)		\$1,366,200
6.0 Decontamination & decommissioning		\$53,776
7.0 ROM life cycle costs (20 years operation)		\$2,174,612
Percent difference from Baseline System		-1.08%

Table 4-3. Continued.

Cost component	Cost Items	Cost (x 1000) System A-4
1.0 Studies and bench-scale test costs		
1.1 Manpower costs during research		\$19,950
1.2 Equipment costs		\$2,400
1.3 Installation costs		\$1,700
1.4 Project management before title 1 (10 % of 1.1 through 1.3)		\$2,405
1.5 Contingency (25 % of 1.1 through 1.4)		\$6,614
Subtotal 1.0		\$33,069
2.0 Demonstration costs		
2.1 Manpower costs during demonstration		\$10,800
2.2 Design cost (30 % of 2.5)		\$10,062
2.3 Inspection cost (7 % of 2.5)		\$2,348
2.4 Project management (10 % of 2.5)		\$3,354
2.5 Construction cost		
2.5.1 Building structure costs		\$4,000
2.5.2 Equipment costs		\$22,000
2.5.3 Indirect (29 % of 2.5.1 & 2.5.2)		\$7,540
Subtotal of 2.5		\$33,540
2.6 Construction management costs (17 % of 2.5)		\$5,735
2.7 Management reserve (10 % of 2.5)		\$3,354
2.8 Contingency (25 % of 2.1 through 2.7)		\$17,298
Subtotal 2.0		\$86,491
3.0 Production facility construction costs		
3.1 Design cost (25 % of 3.4)		\$68,992
3.2 Inspection cost (7 % of 3.4)		\$19,318
3.3 Project management (10 % of 3.4)		\$27,597
3.4 Construction cost		
3.4.1 Building structure costs		\$86,975
3.4.2 Equipment costs		\$126,954
3.4.3 Indirect (29 % of 3.4.1 & 3.4.2)		\$62,039
Subtotal of 3.4		\$275,968
3.5 Construction management (17 % of 3.4)		\$47,191
3.6 Management reserve (10 % of 3.4)		\$27,597
3.7 Contingency (25 % of 3.1 through 3.5)		\$109,767
Subtotal 3.0		\$576,430
4.0 Operations budget funded activities (see Sect. 7)		
4.1 Conceptual design (1.5 % of 3.0)		\$8,646
4.2 Safety assurance (1 % of 3.0)		\$5,764
4.3 NEPA permitting (\$ 6 million for EIS, \$1 million for EA)		\$6,000
4.4 Preparation for operations (100 % of 5.0)		\$73,758
4.5 Project management (10 % of 4.1 through 4.4)		\$9,417
Subtotal 4.0		\$103,585
Total initial cost (1.0, 2.0, 3.0 & 4.0)		\$799,575
5.0 Operating and maintenance costs		
5.1 Annual operating costs		\$36,680
5.2 Annual utility costs		\$1,382
5.3 Annual material costs		\$7,861
5.4 Annual maintenance costs		\$13,083
5.5 Contingency (25 % of 5.1 through 5.4)		\$14,752
5.6 Subtotal 5.0		\$73,758
5.7 Total 20 year O & M cost (20 times Subtotal 5.0)		\$1,475,160
6.0 Decontamination & decommissioning		\$73,776
7.0 ROM life cycle costs (20 years operation)		\$2,328,511
Percent difference from Baseline System		5.92%

Table 4-3. Continued.

Cost component	Cost Items	Cost (x 1000) System A-5
1.0 Studies and bench-scale test costs		
1.1 Manpower costs during research		\$16,050
1.2 Equipment costs		\$1,700
1.3 Installation costs		\$1,000
1.4 Project management before title 1	(10 % of 1.1 through 1.3)	\$1,875
1.5 Contingency	(25 % of 1.1 through 1.4)	\$5,156
Subtotal 1.0		\$25,781
2.0 Demonstration costs		
2.1 Manpower costs during demonstration		\$10,800
2.2 Design cost	(30 % of 2.5)	\$7,740
2.3 Inspection cost	(7 % of 2.5)	\$1,806
2.4 Project management	(10 % of 2.5)	\$2,580
2.5 Construction cost		
2.5.1 Building structure costs		\$3,000
2.5.2 Equipment costs		\$17,000
2.5.3 Indirect	(29 % of 2.5.1 & 2.5.2)	\$5,800
Subtotal of 2.5		\$25,800
2.6 Construction management costs	(17 % of 2.5)	\$4,412
2.7 Management reserve	(10 % of 2.5)	\$2,580
2.8 Contingency	(25 % of 2.1 through 2.7)	\$13,930
Subtotal 2.0		\$69,648
3.0 Production facility construction costs		
3.1 Design cost	(25 % of 3.4)	\$61,014
3.2 Inspection cost	(7 % of 3.4)	\$17,084
3.3 Project management	(10 % of 3.4)	\$24,406
3.4 Construction cost		
3.4.1 Building structure costs		\$82,471
3.4.2 Equipment costs		\$106,719
3.4.3 Indirect	(29 % of 3.4.1 & 3.4.2)	\$54,865
Subtotal of 3.4		\$244,055
3.5 Construction management	(17 % of 3.4)	\$41,733
3.6 Management reserve	(10 % of 3.4)	\$24,406
3.7 Contingency	(25 % of 3.1 through 3.5)	\$97,073
Subtotal 3.0		\$509,771
4.0 Operations budget funded activities (see Sect. 7)		
4.1 Conceptual design	(1.5 % of 3.0)	\$7,647
4.2 Safety assurance	(1 % of 3.0)	\$5,098
4.3 NEPA permitting (\$ 6 million for EIS, \$1 million for EA)		\$6,000
4.4 Preparation for operations	(100 % of 5.0)	\$68,054
4.5 Project management	(10 % of 4.1 through 4.4)	\$8,680
Subtotal 4.0		\$95,479
Total initial cost (1.0, 2.0, 3.0 & 4.0)		\$700,679
5.0 Operating and maintenance costs		
5.1 Annual operating costs		\$37,240
5.2 Annual utility costs		\$769
5.3 Annual material costs		\$5,497
5.4 Annual maintenance costs		\$10,937
5.5 Contingency	(25 % of 5.1 through 5.4)	\$13,611
5.6 Subtotal 5.0		\$68,054
5.7 Total 20 year O & M cost (20 times Subtotal 5.0)		\$1,361,080
6.0 Decontamination & decommissioning		\$52,497
7.0 ROM life cycle costs (20 years operation)		\$2,114,256
Percent difference from Baseline System		-3.82%

Table 4-3. Continued.

Cost component	Cost Items	Cost (x 1000) System A-6
1.0 Studies and bench-scale test costs		
1.1 Manpower costs during research		\$20,550
1.2 Equipment costs		\$2,600
1.3 Installation costs		\$1,300
1.4 Project management before title 1	(10 % of 1.1 through 1.3)	\$2,445
1.5 Contingency	(25 % of 1.1 through 1.4)	\$6,724
Subtotal 1.0		\$33,619
2.0 Demonstration costs		
2.1 Manpower costs during demonstration		\$10,800
2.2 Design cost	(30 % of 2.5)	\$7,740
2.3 Inspection cost	(7 % of 2.5)	\$1,806
2.4 Project management	(10 % of 2.5)	\$2,580
2.5 Construction cost		
2.5.1 Building structure costs		\$3,000
2.5.2 Equipment costs		\$17,000
2.5.3 Indirect	(29 % of 2.5.1 & 2.5.2)	\$5,800
Subtotal of 2.5		\$25,800
2.6 Construction management costs	(17 % of 2.5)	\$4,412
2.7 Management reserve	(10 % of 2.5)	\$2,580
2.8 Contingency	(25 % of 2.1 through 2.7)	\$13,930
Subtotal 2.0		\$69,648
3.0 Production facility construction costs		
3.1 Design cost	(25 % of 3.4)	\$70,397
3.2 Inspection cost	(7 % of 3.4)	\$19,711
3.3 Project management	(10 % of 3.4)	\$28,159
3.4 Construction cost		
3.4.1 Building structure costs		\$89,607
3.4.2 Equipment costs		\$128,678
3.4.3 Indirect	(29 % of 3.4.1 & 3.4.2)	\$63,303
Subtotal of 3.4		\$281,588
3.5 Construction management	(17 % of 3.4)	\$48,152
3.6 Management reserve	(10 % of 3.4)	\$28,159
3.7 Contingency	(25 % of 3.1 through 3.5)	\$112,002
Subtotal 3.0		\$588,168
4.0 Operations budget funded activities (see Sect. 7)		
4.1 Conceptual design	(1.5 % of 3.0)	\$8,823
4.2 Safety assurance	(1 % of 3.0)	\$5,882
4.3 NEPA permitting (\$ 6 million for EIS, \$1 million for EA)		\$6,000
4.4 Preparation for operations	(100 % of 5.0)	\$71,026
4.5 Project management	(10 % of 4.1 through 4.4)	\$9,173
Subtotal 4.0		\$100,904
Total initial cost (1.0, 2.0, 3.0 & 4.0)		\$792,339
5.0 Operating and maintenance costs		
5.1 Annual operating costs		\$37,240
5.2 Annual utility costs		\$866
5.3 Annual material costs		\$5,275
5.4 Annual maintenance costs		\$13,440
5.5 Contingency	(25 % of 5.1 through 5.4)	\$14,205
5.6 Subtotal 5.0		\$71,026
5.7 Total 20 year O & M cost (20 times Subtotal 5.0)		\$1,420,520
6.0 Decontamination & decommissioning		\$54,467
7.0 ROM life cycle costs (20 years operation)		\$2,267,326
Percent difference from Baseline System		3.14%

Table 4-3. Continued.

Cost component	Cost Items	Cost (x 1000) System B-1
1.0 Studies and bench-scale test costs		
1.1 Manpower costs during research		\$18,900
1.2 Equipment costs		\$2,200
1.3 Installation costs		\$1,100
1.4 Project management before title 1	(10 % of 1.1 through 1.3)	\$2,220
1.5 Contingency	(25 % of 1.1 through 1.4)	\$6,105
Subtotal 1.0		\$30,525
2.0 Demonstration costs		
2.1 Manpower costs during demonstration		\$10,800
2.2 Design cost	(30 % of 2.5)	\$10,062
2.3 Inspection cost	(7 % of 2.5)	\$2,348
2.4 Project management	(10 % of 2.5)	\$3,354
2.5 Construction cost		
2.5.1 Building structure costs		\$4,000
2.5.2 Equipment costs		\$22,000
2.5.3 Indirect	(29 % of 2.5.1 & 2.5.2)	\$7,540
Subtotal of 2.5		\$33,540
2.6 Construction management costs	(17 % of 2.5)	\$5,735
2.7 Management reserve	(10 % of 2.5)	\$3,354
2.8 Contingency	(25 % of 2.1 through 2.7)	\$17,298
Subtotal 2.0		\$86,491
3.0 Production facility construction costs		
3.1 Design cost	(25 % of 3.4)	\$67,707
3.2 Inspection cost	(7 % of 3.4)	\$18,958
3.3 Project management	(10 % of 3.4)	\$27,083
3.4 Construction cost		
3.4.1 Building structure costs		\$85,055
3.4.2 Equipment costs		\$124,888
3.4.3 Indirect	(29 % of 3.4.1 & 3.4.2)	\$60,883
Subtotal of 3.4		\$270,826
3.5 Construction management	(17 % of 3.4)	\$46,311
3.6 Management reserve	(10 % of 3.4)	\$27,083
3.7 Contingency	(25 % of 3.1 through 3.5)	\$107,721
Subtotal 3.0		\$565,689
4.0 Operations budget funded activities (see Sect. 7)		
4.1 Conceptual design	(1.5 % of 3.0)	\$8,485
4.2 Safety assurance	(1 % of 3.0)	\$5,657
4.3 NEPA permitting (\$ 6 million for EIS, \$1 million for EA)		\$6,000
4.4 Preparation for operations	(100 % of 5.0)	\$76,691
4.5 Project management	(10 % of 4.1 through 4.4)	\$9,683
Subtotal 4.0		\$106,516
Total initial cost (1.0, 2.0, 3.0 & 4.0)		\$789,221
5.0 Operating and maintenance costs		
5.1 Annual operating costs		\$41,440
5.2 Annual utility costs		\$796
5.3 Annual material costs		\$6,129
5.4 Annual maintenance costs		\$12,988
5.5 Contingency	(25 % of 5.1 through 5.4)	\$15,338
5.6 Subtotal 5.0		\$76,691
5.7 Total 20 year O & M cost (20 times Subtotal 5.0)		\$1,533,820
6.0 Decontamination & decommissioning		\$53,144
7.0 ROM life cycle costs (20 years operation)		\$2,376,185
Percent difference from Baseline System		8.09%

Table 4-3. Continued.

Cost component	Cost Items	Cost (x 1000) System C-1
1.0 Studies and bench-scale test costs		
1.1 Manpower costs during research		\$18,900
1.2 Equipment costs		\$2,200
1.3 Installation costs		\$1,100
1.4 Project management before title 1 (10 % of 1.1 through 1.3)		\$2,220
1.5 Contingency (25 % of 1.1 through 1.4)		\$6,105
Subtotal 1.0		\$30,525
2.0 Demonstration costs		
2.1 Manpower costs during demonstration		\$10,800
2.2 Design cost (30 % of 2.5)		\$7,740
2.3 Inspection cost (7 % of 2.5)		\$1,806
2.4 Project management (10 % of 2.5)		\$2,580
2.5 Construction cost		
2.5.1 Building structure costs		\$3,000
2.5.2 Equipment costs		\$17,000
2.5.3 Indirect (29 % of 2.5.1 & 2.5.2)		\$5,800
Subtotal of 2.5		\$25,800
2.6 Construction management costs (17 % of 2.5)		\$4,412
2.7 Management reserve (10 % of 2.5)		\$2,580
2.8 Contingency (25 % of 2.1 through 2.7)		\$13,930
Subtotal 2.0		\$69,648
3.0 Production facility construction costs		
3.1 Design cost (25 % of 3.4)		\$57,726
3.2 Inspection cost (7 % of 3.4)		\$16,163
3.3 Project management (10 % of 3.4)		\$23,090
3.4 Construction cost		
3.4.1 Building structure costs		\$81,411
3.4.2 Equipment costs		\$97,584
3.4.3 Indirect (29 % of 3.4.1 & 3.4.2)		\$51,909
Subtotal of 3.4		\$230,904
3.5 Construction management (17 % of 3.4)		\$39,485
3.6 Management reserve (10 % of 3.4)		\$23,090
3.7 Contingency (25 % of 3.1 through 3.5)		\$91,842
Subtotal 3.0		\$482,300
4.0 Operations budget funded activities (see Sect. 7)		
4.1 Conceptual design (1.5 % of 3.0)		\$7,235
4.2 Safety assurance (1 % of 3.0)		\$4,823
4.3 NEPA permitting (\$ 6 million for EIS, \$1 million for EA)		\$6,000
4.4 Preparation for operations (100 % of 5.0)		\$65,730
4.5 Project management (10 % of 4.1 through 4.4)		\$8,379
Subtotal 4.0		\$92,167
Total initial cost (1.0, 2.0, 3.0 & 4.0)		\$674,640
5.0 Operating and maintenance costs		
5.1 Annual operating costs		\$36,120
5.2 Annual utility costs		\$1,213
5.3 Annual material costs		\$5,204
5.4 Annual maintenance costs		\$10,047
5.5 Contingency (25 % of 5.1 through 5.4)		\$13,146
5.6 Subtotal 5.0		\$65,730
5.7 Total 20 year O & M cost (20 times Subtotal 5.0)		\$1,314,600
6.0 Decontamination & decommissioning		\$51,943
7.0 ROM life cycle costs (20 years operation)		\$2,041,183
Percent difference from Baseline System		-7.15%

Table 4-3. Continued.

Cost component	Cost Items	Cost (x 1000) System D-1
1.0	Studies and bench-scale test costs	
1.1	Manpower costs during research	\$19,800
1.2	Equipment costs	\$2,400
1.3	Installation costs	\$1,600
1.4	Project management before title 1 (10 % of 1.1 through 1.3)	\$2,380
1.5	Contingency (25 % of 1.1 through 1.4)	\$6,545
	Subtotal 1.0	\$32,725
2.0	Demonstration costs	
2.1	Manpower costs during demonstration	\$10,800
2.2	Design cost (30 % of 2.5)	\$6,966
2.3	Inspection cost (7 % of 2.5)	\$1,625
2.4	Project management (10 % of 2.5)	\$2,322
2.5	Construction cost	
2.5.1	Building structure costs	\$3,000
2.5.2	Equipment costs	\$15,000
2.5.3	Indirect (29 % of 2.5.1 & 2.5.2)	\$5,220
	Subtotal of 2.5	\$23,220
2.6	Construction management costs (17 % of 2.5)	\$3,971
2.7	Management reserve (10 % of 2.5)	\$2,322
2.8	Contingency (25 % of 2.1 through 2.7)	\$12,807
	Subtotal 2.0	\$64,033
3.0	Production facility construction costs	
3.1	Design cost (25 % of 3.4)	\$77,040
3.2	Inspection cost (7 % of 3.4)	\$21,571
3.3	Project management (10 % of 3.4)	\$30,816
3.4	Construction cost	
3.4.1	Building structure costs	\$102,415
3.4.2	Equipment costs	\$136,467
3.4.3	Indirect (29 % of 3.4.1 & 3.4.2)	\$69,276
	Subtotal of 3.4	\$308,158
3.5	Construction management (17 % of 3.4)	\$52,695
3.6	Management reserve (10 % of 3.4)	\$30,816
3.7	Contingency (25 % of 3.1 through 3.5)	\$122,570
	Subtotal 3.0	\$643,666
4.0	Operations budget funded activities (see Sect. 7)	
4.1	Conceptual design (1.5 % of 3.0)	\$9,655
4.2	Safety assurance (1 % of 3.0)	\$6,437
4.3	NEPA permitting (\$ 6 million for EIS, \$1 million for EA)	\$6,000
4.4	Preparation for operations (100 % of 5.0)	\$80,684
4.5	Project management (10 % of 4.1 through 4.4)	\$10,278
	Subtotal 4.0	\$113,054
	Total initial cost (1.0, 2.0, 3.0 & 4.0)	\$853,478
5.0	Operating and maintenance costs	
5.1	Annual operating costs	\$42,000
5.2	Annual utility costs	\$1,356
5.3	Annual material costs	\$7,019
5.4	Annual maintenance costs	\$14,172
5.5	Contingency (25 % of 5.1 through 5.4)	\$16,137
5.6	Subtotal 5.0	\$80,684
5.7	Total 20 year O & M cost (20 times Subtotal 5.0)	\$1,613,680
6.0	Decontamination & decommissioning	\$69,813
7.0	ROM life cycle costs (20 years operation)	\$2,536,971
	Percent difference from Baseline System	15.41%

Table 4-3. Continued.

Cost component	Cost Items	Cost (x 1000) System E-1
1.0 Studies and bench-scale test costs		
1.1 Manpower costs during research		\$19,800
1.2 Equipment costs		\$2,200
1.3 Installation costs		\$1,100
1.4 Project management before title 1	(10 % of 1.1 through 1.3)	\$2,310
1.5 Contingency	(25 % of 1.1 through 1.4)	\$6,353
Subtotal 1.0		\$31,763
2.0 Demonstration costs		
2.1 Manpower costs during demonstration		\$10,800
2.2 Design cost	(30 % of 2.5)	\$6,889
2.3 Inspection cost	(7 % of 2.5)	\$1,607
2.4 Project management	(10 % of 2.5)	\$2,296
2.5 Construction cost		
2.5.1 Building structure costs		\$2,800
2.5.2 Equipment costs		\$15,000
2.5.3 Indirect	(29 % of 2.5.1 & 2.5.2)	\$5,162
Subtotal of 2.5		\$22,962
2.6 Construction management costs	(17 % of 2.5)	\$3,927
2.7 Management reserve	(10 % of 2.5)	\$2,296
2.8 Contingency	(25 % of 2.1 through 2.7)	\$12,694
Subtotal 2.0		\$63,471
3.0 Production facility construction costs		
3.1 Design cost	(25 % of 3.4)	\$68,158
3.2 Inspection cost	(7 % of 3.4)	\$19,084
3.3 Project management	(10 % of 3.4)	\$27,263
3.4 Construction cost		
3.4.1 Building structure costs		\$85,775
3.4.2 Equipment costs		\$125,566
3.4.3 Indirect	(29 % of 3.4.1 & 3.4.2)	\$61,289
Subtotal of 3.4		\$272,630
3.5 Construction management	(17 % of 3.4)	\$46,620
3.6 Management reserve	(10 % of 3.4)	\$27,263
3.7 Contingency	(25 % of 3.1 through 3.5)	\$108,439
Subtotal 3.0		\$569,457
4.0 Operations budget funded activities (see Sect. 7)		
4.1 Conceptual design	(1.5 % of 3.0)	\$8,542
4.2 Safety assurance	(1 % of 3.0)	\$5,695
4.3 NEPA permitting (\$ 6 million for EIS, \$1 million for EA)		\$6,000
4.4 Preparation for operations	(100 % of 5.0)	\$72,121
4.5 Project management	(10 % of 4.1 through 4.4)	\$9,236
Subtotal 4.0		\$101,594
Total initial cost (1.0, 2.0, 3.0 & 4.0)		\$766,285
5.0 Operating and maintenance costs		
5.1 Annual operating costs		\$37,800
5.2 Annual utility costs		\$1,114
5.3 Annual material costs		\$5,585
5.4 Annual maintenance costs		\$13,198
5.5 Contingency	(25 % of 5.1 through 5.4)	\$14,424
5.6 Subtotal 5.0		\$72,121
5.7 Total 20 year O & M cost (20 times Subtotal 5.0)		\$1,442,420
6.0 Decontamination & decommissioning		\$53,380
7.0 ROM life cycle costs (20 years operation)		\$2,262,085
Percent difference from Baseline System		2.90%

Table 4-4. Total system life-cycle cost estimates.

System (note a)	Treatment cost			Disposal volume generation (ft ³ /hr)	Final waste volume (ft ³)	Disposal cost (\$millions)	Total treatment and disposal life-cycle cost (\$Millions)
	Unit rate (\$/lb)	Normalized (1.000 = System A-1)	Total (\$millions)				
A-1	11.64	1.000	2,198.27	11.3	911,232	221.43	2,419.70
A-2	11.64	1.000	2,196.66	11.3	911,232	221.43	2,418.09
A-3	11.52	0.990	2,174.61	13.7	1,104,768	268.46	2,443.07
A-4	12.33	1.060	2,328.51	12.9	1,040,256	252.78	2,581.29
A-5	11.20	0.962	2,114.26	26.5	2,136,960	519.28	2,663.54
A-6	12.01	1.032	2,267.33	8.5	685,440	166.56	2,433.89
B-1	12.59	1.081	2,376.19	11.3	911,232	221.43	2,597.62
C-1	10.81	0.929	2,041.18	11.3	911,232	221.43	2,262.61
D-1	13.44	1.155	2,536.97	11.5	927,360	225.36	2,762.33
E-1	11.98	1.029	2,262.09	33.7	2,717,568	660.37	2,922.46

(a) Legend:

SYSTEM:

- A-1 Rotary kiln, air
- A-2 Rotary kiln, oxygen
- A-3 Rotary kiln, air, wet APC
- A-4 Rotary kiln, oxygen, CO₂ retention
- A-5 Rotary kiln, air, polymer stabilization
- A-6 Rotary kiln, air, maximum recycling
- B-1 Pyrolyzer, oxygen
- C-1 Plasma arc furnace
- D-1 Fixed hearth, oxygen, CO₂ retention
- E-1 Rotary kiln, air, thermal desorber

5. SYSTEMS EVALUATION

The goal of evaluating the systems is to qualitatively assess technology risks, including system maturity and developmental work needed to make the system ready for detailed design, and to review the overall system concept with respect to treatment objectives. Key issues related to system compliance are identified and discussed. Subsystems are evaluated against technology risks in the same manner as systems, except that public acceptance is not considered for the subsystems. These evaluations considered processing of alpha and nonalpha MLLW. The discussions apply to both waste categories except when a specific category is mentioned. The judgements made in this section are obviously those of the authors and do not represent any DOE policy.

5.1 Technology Risk

In broad terms, evaluation of technology risk assesses the probability that the system or subsystem will meet the established objectives, described below.

- **Technical Objectives.** The technology should be well developed and should provide reasonable assurance that the established requirements (see Appendix A) will be met. Compliance with these objectives is evaluated by reviewing the technology and hardware used. Areas of noncompliance or uncertainties are identified, and the need for further investigations, studies, and demonstration is stated.
- **Environmental, Safety and Health (ES&H) Objectives.** Waste treatment operations should provide for protection of both the worker and the public environment, safety, and health.
- **Institutional Objectives.** The technology must be received positively by the public and regulatory and permitting agencies.
- **Cost Objectives.** The technology should have reasonable costs and a low probability of cost overruns.

- **Schedule Objectives.** The technology should be fully developed and ready for detailed design by 1996. The technology must have a low probability of causing schedule delays.

5.2 Evaluation of Systems Based on Conventional Rotary Kiln (System A)

5.2.1 Baseline System (System A-1).

System A-1 is composed of the most well-developed commercial technologies. A majority of the components have been used in hazardous waste applications and are available from several vendors.

The system has twelve major subsystems. The receiving and preparation subsystem uses segmented gamma scanning and passive/active neutron assay units, a real-time radiography inspection unit, gantry robots, hydraulic and master-slave manipulators, sorting tables, and remotely operated vehicles.

Key technologies used for the incineration and APC subsystems are a rotary kiln incinerator; a dry offgas unit equipped with a quenching unit, a baghouse, activated carbon absorbers for mercury removal, and HEPA filters; and a wet offgas unit equipped with a hydrosonic scrubber and packed-tower acid-gas scrubbers.

The lead recovery subsystem uses mechanical tools, decontamination booths, and a melter equipped with a standard dry APC. The amalgamation subsystem uses a vacuum retort with a mercury condenser and separator, a secondary combustion unit with a standard dry APC train, and an amalgamation reactor. The metal decontamination subsystem uses an abrasive blasting booth. The metal melting subsystem uses an induction melter with a dry APC unit.

The aqueous waste treatment subsystem uses commercially available precipitators, solids filters, ion-exchange vessels, carbon filters, and evaporators.

The primary stabilization system uses a melter with a standard dry APC unit for vitrification of bottom ash and fly ash. While a specific melter type has not been specified, costs for a centrifugal

hearth plasma melter were used for estimating purposes. The secondary stabilization system uses commercially available dryers and extruders to dry the incoming waste and mix it with polymer.

5.2.1.1 System Technology Risks. In the evaluations presented below, the system is considered for processing either alpha or nonalpha MLLW.

5.2.1.1.1 Evaluation for technical objectives—The following comments are noted when reviewing the system against the requirements specified in Appendix A of this report.

Compliance with permitting regulations. No technical problems related to permitting of the baseline system are anticipated. Rotary kiln incinerators using APCs similar to those in the baseline system have been previously permitted under RCRA, CAA, and many state and local regulations. The system is designed to meet the TSCA performance standards established for polychlorinated biphenyls (PCBs). Components essential to achieving the required performance (the secondary combustion chamber and the APC subsystem) have successfully been used for destroying PCBs.

Compliance with proposed emission limits. Although it is expected that the system will ultimately meet the proposed emission standards given in Appendix A, several areas could require further development, demonstration, and testing. These areas are discussed below.

Mercury removal. The thermal treatment and APC subsystems design strategy for mercury removal is to minimize mercury in the fly ash and the scrubbing liquor (mercury contamination in the fly ash complicates its stabilization by vitrification, and mercury contamination in the scrubber liquor will result in extra steps in the aqueous waste treatment). Thus, a carbon bed filter is placed downstream of the baghouse to capture the mercury in the dry offgas. The activated carbon bed is impregnated with various materials (e.g., sulfur) to remove up to 90% of the mercury in the dry offgas. However, to ensure the effectiveness of this process, two specific design problems must be resolved through further design studies, development, or process demonstration. These two problems consist of (1) cooling the gas to about 150°F just before carbon filtration and (2) removing condensate in the flue gas just before the HEPA filters.

Lead removal. Both organic and inorganic lead compounds are expected to be volatilized during thermal destruction in the incinerator. The APC system does not have any specific feature for lead removal. Preliminary reviews indicate that lead and its compounds will be removed either in the

baghouse or by the scrubbers. EPA has put emphasis on reducing airborne lead discharged from incinerators. Acurex Environmental Corporation recently tested trace metals distribution for the EPA at the Incineration Research Facility using various APC equipment configurations.^k The study showed that the fraction of lead in scrubber exit flue gas could range from 5% to 80% of the input. Additional study of the fate of lead compounds in the APC is needed. The investigation should facilitate development of design options for high lead removal efficiencies.

Actinides. Actinide volatility and the removal efficiencies of various APC designs are both unknown; further studies and demonstrations are needed. To comply with health and safety standards, the concentrations of the actinides discharged from the APCs must be extremely low, perhaps below detection limits. Preliminary studies show that most of the actinides in the incoming waste stream will remain with the bottom ash. A small fraction could volatilize^l or be entrained in the incinerator unit and exhaust to the offgas train, where they would be separated along with the fly ash. Actinides could once again volatilize when the bottom ash and fly ash are stabilized in the vitrifier. Studies have also indicated that actinide volatility may decrease when they are combined with aluminosilicates. Actinide volatility in complex mixtures of ash and soil are unknown, but will be lower than for pure substances.

Dioxins.^l Dioxins or furans are not expected in the DOE wastes considered in this study. There are, however, conditions within the thermal treatment system that are conducive to the formation of dioxins. Limiting dioxin discharges to the atmosphere is, therefore, a two-step process. First, exposing products of incomplete combustion to conditions favorable to dioxin formation must be discouraged and, second, measures must be taken to capture those dioxins that are formed before they leave the system. Investigations have shown that dioxins are readily formed if products of incomplete combustion during incineration are exposed for even short times to temperatures ranging between 600°F and 400°F when chlorine is present. As a consequence, the offgas leaving the secondary combustion chamber should be cooled through this range as quickly as possible. This is most

k. Unpublished work.

l. To obtain a rough estimate of the amount of actinides to be removed by the incinerator and vitrifier APCs, a thermodynamic analysis of uranium (U), plutonium (Pu) and americium (Am) volatilization was performed at LLNL (Krikorian, 1993, unpublished work). The results show that pure U, Pu, and Am volatilize in the incinerator secondary combustor at a temperature of 1,366 K and that volatilization increases as the quantities of chlorides and fluorides in the feed increases. The actinide concentrations in the incinerator offgas exhaust could range from 3.0×10^{-6} to 3.2×10^{-4} kg of actinide per kg of offgas for U, 2.1×10^{-9} to 3.2×10^{-7} for Pu, and 1.1×10^{-12} to 1.6×10^{-10} for Am. The actinide concentrations in the vitrifier offgas exhaust (with a melt temperature of 1,873 K) will be higher and could be about 6.0×10^{-3} kg of actinide per kg of offgas for U, 1.3×10^{-7} for Pu, and 6.5×10^{-11} for Am.

efficiently accomplished using a direct contact cooler. In this system, a spray cooler is used to cool the offgas from about 2,200 to 350°F to avoid damage to the baghouse filter material and to minimize dioxin formation. In addition, the carbon absorber for mercury removal may also remove dioxins. This should be investigated in more detail. Chemical analysis indicates that introducing sulfur into the hot offgas stream could inhibit the formation of both dioxins and furans. This could easily be accomplished by using coal with a moderate sulfur content as an auxiliary fuel.

Oxides of nitrogen. Elevated temperatures, an oxidizing atmosphere, and extended residence time all favor the formation of oxides of nitrogen in the secondary combustion chamber. While the quantities of nitrogen oxides produced by the thermal treatment system will not exceed those of an average sized industrial boiler, their abatement will have to be addressed. Technology to meet the current abatement requirements is commercially available. As the restrictions become greater, technology to meet the challenge will be developed to serve the fossil-fueled power industry. Combustion with oxygen instead of air almost completely eliminates this concern.

Compliance with proposed characterization requirements. The feedstock characterization unit proposed for this system needs engineering development. The current approach to characterization is based on a remotely operated on-line grab sampler, mounted at the shredder discharge port, and an analytical laboratory, which receives samples via a pneumatic tube conveyor. Several grab samples are obtained from the waste discharged from the shredder to each transport hopper. Once the waste in the hopper has been characterized, the operator will be able to accept or reject it and to control the feeding sequence of the waste. This concept, which has not been tested before, will require further engineering development and demonstration for integration into the overall system design and to assure regulatory agency acceptance of the process.

Compliance with functional and operational requirements. Although technologies used in the system are well developed, there are some system-wide design concerns that require resolution through additional studies and engineering development (some might also require demonstration). These concerns are not considered to be detrimental to the overall system effectiveness, and there is a high probability that they can be satisfactorily resolved through system engineering (i.e., investigation of alternatives) and developmental efforts. The areas of concerns are discussed below.

Soundness of the concept for mercury management. The concept for managing mercury is untested. Two crucial parameters, level of mercury contamination in the feedstock and the removal

efficiency of the activated carbon filters, are not known. The strategy for managing mercury is to remove all elemental bulk mercury or any bulk mercury compounds and to feed the remaining mercury-contaminated waste to the incinerator. In the incinerator, mercury volatilizes and flows with the offgas to the APC. The mercury is then captured by activated carbon filters. Once the removal efficiency of the activated carbon filters under system operating conditions is known, the maximum allowable mercury in the feedstock can be determined. Current DOE waste inventory data indicate that a large part of the inventory has mercury contamination, but very little is known about the concentrations. This introduces a high level of uncertainty regarding the quantity of mercury contamination allowable in the incinerator feedstock. The exact design of the system for managing mercury may not be established until more details on the concentrations are available.

Temperature profile to achieve optimum performance. The temperature profiles for the incinerator and the APC train require further study. The temperature profile is critical in minimizing dioxin formation, mercury management, and RCRA metals removal strategies.

Compliance with the facility design requirements. The system is known to comply with a majority of the design requirements. However, a major area of concern is the design for alpha confinement. To process alpha MLLW, further studies are needed to refine facility layout concepts and confinement levels in the process, maintenance, and operating areas. Two or three levels of confinement are needed when processing alpha MLLW. The concept used in the preconceptual system layouts is to place equipment in air-tight cells that have three levels of confinement. Personnel access to the cells is through airlock doors. Personnel entering alpha cells must wear Level A protective equipment, including self-contained breathing equipment. Large corridors are provided next to each cell for equipment pull-out and maintenance. In this corridor, major equipment is disassembled, decontaminated (if required), and sent to the maintenance shop for further repair. This confinement approach has seldom been used by DOE, and further evaluation is needed.

5.2.1.1.2 Evaluation for safety and health objectives—The alpha cell concept described above is expected to ensure that the environmental, health, and safety objectives will be met when processing alpha waste. For nonalpha MLLW, the ES&H objectives can be met by one or two levels of confinement, depending on the potential for release of radioactivity to the environment. Two main ES&H concerns when processing alpha MLLW are the acceptability of the rotary kiln and the volatilization of actinides. These two issues are discussed below.

Acceptability of rotary kiln for alpha MLLW. This kiln is a bulky piece of equipment with many rotating parts. Major maintenance (e.g., replacing refractory brick) could result in high worker exposure. A solution to this problem is to use designs that allow remote maintenance. Another concern about rotary kilns is leakage through the seals. Leakage from the seals during "puffs" could introduce alpha contamination in the alpha cell and cause further complications during maintenance. A solution to this is to place a secondary housing around the rotary kiln seal (these devices are commercially available). Another solution is to increase the volume of the kiln to about twice the normal size so that combustion excursions can be tolerated with minimal leakage outside. Yet another method for reducing excursions is fine shredding and mixing to produce a continuous homogenous feed stream. All three of these strategies can be employed to minimize risks. In addition to the reduction in puffs from operation, these strategies will increase refractory lifetime. The expense of an oversized kiln is minimal.

Actinide volatilization. Actinide volatilization and potential release to the atmosphere is the greatest ES&H concern for the system when it is used for alpha MLLW. Even a small release of the toxic radionuclides uranium, plutonium, and americium through the stack could cause concern regarding public exposure. This area must be studied further as indicated earlier in this section.

5.2.1.1.3 Evaluation for institutional objectives—This system includes a state-of-the-art APC subsystem that has high decontamination and removal efficiencies. A rotary kiln incinerator is already in operation at ORNL. The Consolidated Incineration Facility at the Savannah River Site is also based on a rotary kiln incinerator concept. This experience should help the thermal treatment subsystem gain acceptance by the public and permitting agencies. Another factor that might help in gaining public acceptance is the leach-resistant, high-integrity waste form produced by this system. This waste form will prevent release of hazardous materials to groundwater over the long term. However, it should be recognized that, in general, the public and state and local permitting agencies are not receptive to incinerators. Site selection for an incinerator is a critical element affecting success. Distance from population centers and prime recreation areas is essential.

5.2.1.1.4 Evaluation for cost objectives—For nonalpha MLLW, the cost risk is low because of previous application of this system to this type of waste. However, the risk of cost overruns when the system is applied to alpha MLLW (plutonium) is high. This is largely because most system components must be further developed to allow ease of decontamination and maintenance for application in an alpha cell environment.

5.2.1.1.5 Evaluation for schedule objectives—The baseline system is expected to be ready for detailed design within the specified schedule. Significant developmental problems resulting in long delays are not expected.

5.2.1.2 Subsystem Technology Risks.

5.2.1.2.1 Receiving and preparation subsystem—This subsystem has three major functions: (1) receiving and unloading waste packages from the incoming vehicles; (2) assay and nondestructive examination of the waste containers; and (3) decapping, dumping, and sorting of the wastes. The latter two functions will require extensive system concept development, components development, hardware engineering, and system integration. Consequently, there are moderate technical, ES&H, cost, and schedule risks associated with this subsystem. Components that are commercially available but require engineering development and demonstration on a system integration level were noted on the FAD, Figure 2-3.

The first function, receiving and unloading, can be accomplished using well-known designs and commercially available equipment. The remaining two functions, assay and nondestructive examination, and decapping, dumping and sorting, will require further development, particularly to handle alpha MLLW.^m Systems engineering and integration and hardware development are needed. The sorting operation will require extensive development. The preconceptual design presented in this study is based on robotic sorting, which has not been tested. Manual sorting and automated sorting devices (e.g., trommels, air classifiers, eddy current devices, magnetic separators) need examination and evaluation.

If this preconceptual design is to be successful in achieving the intended goals, the hardware listed below must be developed and tested for use in the intended system environment.

Real-time radiography. A state-of-the art RTR system has been used on an experimental basis at the Radioactive Waste Management Complex (RWMC) at INEL. The RTR design should be enhanced and data interpretations assessed based on the experience gained at INEL.

m. The Hanford waste receiving and packaging facility and the INEL waste characterization facilities projects, which are in Title I and II design stages, have already done engineering development work on most of the components needed for accomplishing the functions of this subsystem.

Alpha-radiation assay. Alpha radiation detectors based on PAN assay devices are currently used for DOE facilities. The PAN device, while suitable for TRU waste (>100 nCi/g), has questionable accuracy at lower ranges of alpha contamination. Better resolution systems capable of supporting this throughput are needed.

Sorting table. A rotary table suitable for manipulator sorting (for alpha MLLW) or hand sorting (for nonalpha LLW) is proposed. The manipulator sorting concept, which has not been used or tested before on wastes with the anticipated levels of contamination, will require engineering development.

Container decapping device. For alpha MLLW, remote decapping of the containers is desirable. Manual decapping could become labor intensive since the operators would have to wear personal protective equipment with self-contained breathing apparatus. To develop a remote decapping system, engineering review of various options and selection of a workable concept for the intended application is needed.

5.2.1.2.2 Incineration Subsystem—The incineration subsystem has three major functions: waste preparation, characterization, and incineration. When used for nonalpha MLLW, these functions can be accomplished by well-developed commercial technologies. However, equipment engineering development work will be needed when the subsystem is to be used for alpha MLLW. Hence, the technology risk for this subsystem is judged to be low when it is used for processing nonalpha MLLW and moderate when used for alpha MLLW. The FAD for this subsystem, Figure 2-6, notes components that are commercially available but require engineering development and demonstration on a system integration level. Some of the development needs for this subsystem are discussed below.

Shredders and other feed preparation equipment. Since a rotary kiln is an adaptable incinerator that can accept both combustible and noncombustible waste, its feed preparation needs are minimal. A single-stage low-speed shredder (such as that manufactured by KOMAR) can perform the required preparation. However, large shredders are mechanically complex and require frequent maintenance and upkeep. This presents some problems for the subsystem when it is used for alpha MLLW. Another concern is the potential for fire in the shredder, which might require using a blanket of inert gas inside the shredder housing. Hence, developmental work to improve equipment safety, reliability, and ease of maintenance is needed.

Solids separation. The current design concept for the system is to minimize upfront sorting by feeding the intact containers (drums or boxes) directly to the shredder unit. After shredding, the entire waste stream, consisting of combustible and noncombustible material (e.g., soil, metals), is fed to the rotary kiln. Some post-shredder sorting to recover metals, as an alternative to this approach, would require additional in-cell solids separation and material handling equipment (e.g., magnetic belts, eddy current devices), which is not desirable when the subsystem is used for alpha waste. However, for nonalpha MLLW there may be some advantages to the metal recovery, and this alternative should be investigated further.

Rotary kiln incinerators. Although rotary kiln incineration technology is well developed, some areas could be further improved to enhance ease of maintenance and operation and to improve reliability. This is especially true when the subsystem is specified for processing alpha MLLW. Key areas for improvement are rotary seals and refractory lining life. Advanced, commercially available seals have not been used in this application.

Characterization. A method for characterizing the incinerator feed was discussed on page 111. As indicated, the concept proposed must be developed further. A characterization concept for bottom ash may also be needed, since it appears that knowledge of ash properties may be required to establish the mixture ratio with soil or glass-forming additives.

5.2.1.2.3 Incineration APC subsystem—The APC is the most important unit in the system because it must ensure that offgas released to the environment has minimal pollution. This subsystem has to remove four major types of pollutants from the incineration offgas: particulates, acid gas, RCRA metals, and radioactivity. Most of the equipment (except monitoring equipment) used in this subsystem is well developed and widely used in industry. However, extensive development will be required for system integration. And, although the proposed design is believed to be state-of-the art with high efficiency contaminant removal, several areas will need further study and development before the final system design can be completed. The performance of the design should be verified and enhanced through large-scale demonstrations. APC subsystem components that are commercially available but require engineering development and demonstration on a system integration level are noted in Figure 2-8. The main concerns with regard to this subsystem are discussed below.

Induced fan limitations. An additional booster fan may be needed at the midpoint of the APC subsystem. Because the APC has numerous components, the pressure drop across the treatment train may exceed the capability of a single induced-draft fan.

Temperature limitations of baghouse units in the APC subsystem. The APC subsystem operating strategy of preventing mercury contamination in fly ash may not be practical, because the gas must be cooled to meet the low temperature limits of baghouse units, where the fly ash is filtered out. At temperature of 400 to 450°F (the upper limit for typical baghouses), it is possible that some mercury will condense and drop out in the baghouse, thus contaminating the fly ash. This can be resolved by filtering out the fly ash at higher temperatures, well above the mercury condensation temperature. German and Japanese incinerators use high-temperature baghouses and ceramic filters for this purpose. Further investigation is needed to resolve this concern.

Temperature limitations of activated carbon filters for removing mercury. Design concerns regarding mercury-removal filters center around low offgas temperatures (150°F) required by vendors of (activated carbon) filters. The concerns are mostly due to complications from the additional step needed to cool the offgas before it enters the filters. Some potential problems include corrosion of the offgas cooling equipment and the effect of condensates on HEPA filtration. A potential solution is to install a shell-and-tube heat exchanger after the baghouse. To eliminate water in the HEPA filter, the offgas could be reheated. These solutions have not been incorporated in the present system preconceptual design pending further studies.

Stack discharge monitoring equipment. A real-time monitoring system must be developed to measure both RCRA metals and radioactive species leaving the stack. As stated previously, the public and regulatory agencies put great emphasis on this feature of the system. Real-time monitoring allows system shut-down in the event of malfunction, thus preventing uncontrolled release of pollutants.

Back-flushable stainless steel HEPA filters. Back-flushable stainless steel HEPA filters have been developed at DOE's Lawrence Livermore National Laboratory. Application of this technology to a high-level waste vitrification furnace is being investigated at Hanford Site. Similar investigations are needed on using stainless steel HEPA filters in the incineration APC subsystem. Additionally, the potential for corrosion of these filters and alternative materials of construction should be studied.

5.2.1.2.4 Lead Recovery Subsystem—*This subsystem is designed for removing radioactivity, in slag form, from contaminated lead.* Most of the equipment used in this subsystem is well developed and widely used in industry. However, the subsystem will require minor development to permit system integration. Components that are commercially available but require engineering development and demonstration on a system integration level are noted in Figure 2-9. While process studies and some bench-scale development work are required, the overall technology risk for this subsystem is judged to be low.

Many of the development efforts recommended for the incineration APC are also recommended for the lead recovery subsystem APC. The other area of development for this subsystem is treatment of lead gloves. These gloves are made of lead wool or thin layers of lead and synthetic rubber. The current APC system for the lead furnace does not have acid removal (scrubber) capability. Therefore, the system design may have to be modified to allow treatment of lead gloves.

5.2.1.2.5 Mercury amalgamation subsystem—Mercury recovery, recycling, and amalgamation are commercially available processes. The subsystem employs a retort which is used to vaporize mercury in a vacuum. The vaporized mercury is condensed in the offgas condenser and removed in a separator column. Any organic compounds vaporized in the vacuum furnace are also condensed in the condenser and removed separately. The condensed organics can be sent for thermal destruction by the incineration subsystem. The equipment used for this application is well developed and widely used in the industry; hence, the overall technology risk for this subsystem is judged to be low. The primary developmental need for this system is system integration. Components that are commercially available but require engineering development and demonstration on a system integration level are noted in Figure 2-11.

5.2.1.2.6 Metal decontamination subsystem—This subsystem uses an abrasive blasting booth to remove surface contamination. This technology is well developed and many units are currently in use by the nuclear industry. Hence, the technology risk associated with this subsystem is low. Only some of the equipment in the subsystem requires development in terms of system integration (see Figure 2-13).

5.2.1.2.7 Metal melting subsystem—The waste feed rate to this subsystem is very small. Hence, the need for this subsystem is in question. This subsystem could be viable if a single unit with equipment for fabrication of recovered steel is built for the waste for the entire DOE

Complex. The recovered metal can be recycled by fabricating it into containers that are reused at the facility, such as for final residue disposal. Such an option needs further evaluation, taking into account the cost savings from recycling versus the capital and operating costs.

The metal melting subsystem uses an induction furnace to melt the metals and various fluxes to force radioactive isotopes into a slag phase. This approach allows decontamination of metals to a level suitable for recycle and reuse. However, the use of fluxing agents needs further bench-scale testing and development.

Equipment for melting radioactively contaminated metal is well developed, and two units are known to be in use in the United States and Germany. In the U.S., SEG is recycling steel for DOE. The German facility, Simplekemp, recycles the metal for use as waste containers. Hence, the technology risk associated with this subsystem is low, though some of the equipment in the subsystem requires development for system integration (see Figure 2-15).

5.2.1.2.8 Special waste treatment subsystem—Equipment used in this subsystem will be designed and developed on a case-by-case basis. A detailed listing of the waste types to be treated must be obtained, and candidate processes must be studied as part of future tasks. The waste stream anticipated to be treated by this subsystem is reactive metal wastes, such as sodium-contaminated debris.

5.2.1.2.9 Aqueous-waste treatment subsystem—This subsystem uses commercially available processes and equipment. Development needs for this subsystem are minor. As a whole, the technology risk for this subsystem is judged to be low.

Mercury removal. The preconceptual design strategy for mercury removal for this subsystem is precipitation and filtration followed by removal of trace mercury by ion-exchange resins or activated carbon beds. This approach must be finalized after more accurate information about input waste properties is obtained.

5.2.1.2.10 Primary stabilization subsystem—This subsystem converts the incoming ash into a vitrified glass, rock, or ceramic material. There are minor technical uncertainties associated with the subsystem. The technology risk associated with this subsystem is judged to be moderate. Key developmental needs are discussed below. Components that are commercially available but

require engineering development and demonstration on a system integration level are noted in Figure 2-19.

Melt chemistry and vitrification formulations. Developmental work involving melt chemistry, thermodynamics, and waste formulation studies is underway at INEL. These efforts are aimed at getting a better understanding of the vitrification technology and optimizing the process. The work at INEL has yielded promising results, including several high-integrity, leach-resistant melt formulas. However, the experimental work must be extended to a large-scale prototype unit.

Melter furnace design. The melter technology proposed in this study is a plasma arc furnace. Other studies have selected different technologies such as a joule melter or electric arc furnace. Melter design must be finalized, and efforts on equipment enhancement for safety, reliability, maintainability, and system integration must be started. Pilot-scale testing is needed.

Capturing volatilized metals and actinides. A method to prevent the flow of volatilized metals and actinides to the melter offgas unit must be developed. In this study, a moving sand filter serving as a cold trap is proposed for installation above the melter cap, at the offgas intake duct. The filter adsorbs the volatilized metals. When the filter sand needs replacement, it is dumped into the furnace where it is vitrified with the waste. This method and other options must be studied further and tested on a bench-scale or in prototype test units.

Impact of carbon in ash. Bench-scale tests are needed to define the upper limit of carbon content in the ash and the effect of high carbon ash on the vitrification process and the resultant waste form. Pilot-scale tests using an oxygen lance to combust the carbon in the melter are needed.

5.2.1.2.11 Secondary stabilization subsystem—This subsystem uses a polymer agent for stabilizing salts recovered in the offgas scrubber. Developmental needs include selecting a polymer agent that can stabilize the salt while meeting the EPA-specified toxicity characteristic leaching procedure tests. The subsystem uses commercially available equipment. Hence, the technology risk associated with this subsystem is judged to be low.

5.2.1.2.12 Certify and ship subsystem—The certify and ship subsystem uses commercially available equipment except for the assay unit. The developmental need for this assay

unit is the same as that for the assay unit in the receiving and preparation subsystem. The technology risk associated with this subsystem is judged to be low.

5.2.2 Evaluation of Oxygen Combustion Gas System (System A-2)

System A-2 is the same as the baseline system except that oxygen, instead of air, is used as the combustion gas to minimize the volume of offgas discharged from the incineration subsystem. The system configuration is the same as that of the baseline system except that oxygen burners are used for the rotary kiln and the secondary combustion unit.

5.2.2.1 System Technology Risks.

5.2.2.1.1 Evaluation for technical objectives— When evaluating the system against the requirements specified in Appendix A of this report, the use of oxygen, instead of air, as the combustion gas raises the concern that system compliance with the concentration-based emission limits could be jeopardized because the same quantity of contaminants may be present in a smaller volume of offgas. However, once concentration-based emission limits are corrected to 7% O₂ or 12% CO₂, this should not be a concern, though NO_x emissions could be. More investigation is needed to measure the mass of pollutants discharged from the stack. If only the flow of dilution air is reduced but not the mass of pollutants, then the use of oxygen is not justified.

5.2.2.1.2 Evaluation for institutional objectives— The volume of offgas discharged to the atmosphere is lower than that of the baseline system. This might result in better acceptance of the thermal treatment facility by the public and by state and local regulatory agencies. However, as stated before, there are unanswered questions regarding the concentration of pollutants in the offgas.

5.2.2.2 Subsystem Technology Risks. The incineration subsystem may represent additional risk over and above that of the baseline system. Precise oxygen control in a rotary kiln incinerator is difficult to maintain. Because the drum rotates around the axis of the cylinder, dynamic seals are needed at each end. The effectiveness of advanced seals is critical to control air leaks into the kiln.

Although past design practices allowed "leaky" seals on a rotary kiln to provide part of the combustion air supply, this practice has been changing over recent years. Now, nearly all major rotary

kiln vendors offer advanced seal designs that limit uncontrolled leakage. Some designs have cavities that can be pressurized with air or steam to ensure that all leakage is inward. Others put negative pressure on the seal and route the effluent gases to the APC. Thus, it appears as though seal leakage can be controlled. This risk is small to moderate.

Although an oxygen-fired furnace has been used in many chemical and metallurgical applications, oxygen-fired rotary kilns have had very limited application to treating hazardous waste.

Key areas requiring system integration or development are the oxygen burner design, flame propagation and control, prevention of ash slagging, and NO_x control. Ash slagging could occur frequently due to the high temperature of the oxygen flame; however, this issue could become moot if the system were designed for slagging operation.

5.2.3 Evaluation of Wet Air Pollution Control System (System A-3)

The wet APC system is a minor variation of the baseline system. The APC in this system does not have a dry filtration step. This change has been made to study the effects of using a totally wet APC subsystem.

5.2.3.1 System Technology Risks. Compared with the baseline system, there are only minor differences in technology risk, which are described below.

5.2.3.1.1 Evaluation for technical objectives—Further studies are needed to resolve questions related to mercury management, since the mercury discharged from the incinerator will be captured by the wet scrubber. The scrubber liquor may need an additional treatment step for mercury removal before it is sent to the polymer stabilization subsystem. The baseline aqueous waste treatment subsystem has mercury removal capability, but the capacity must be increased.

5.2.3.1.2 Evaluation for ES&H objectives—The system is slightly less desirable than the baseline system from the ES&H standpoint. This is largely due to a higher final waste volume produced from the system due to capture of fly ash in the scrubber liquor. The mixture of fly ash and scrubber salt solids cannot be sent to the vitrification subsystem because of the low boiling temperature of the salt. Hence, the solids must be stabilized using polymer, resulting in a higher volume of waste.

5.2.3.2 Subsystems Technology Risks. The additional technology risks associated with the subsystems center on the APC subsystem. Although it does not use dry filtration and is much simpler, the concerns about mercury management, discussed above, must be addressed.

5.2.4 Evaluation of CO₂ Retention System (System A-4)

In System A-4 a CO₂ retention feature has been added to the end of the APC. This provides the capability to delay the discharge of offgas from the APC. The delay is accomplished by absorbing CO₂ in lime and desorbing it later in a calciner. The CO₂ retention unit acts as a check point for the offgas discharge and helps prevent inadvertent discharge of pollutants to the atmosphere.

The system configuration has three major differences from the baseline system. The incinerator uses an oxygen burner; the APC subsystem has only a dry filtration unit; and a new feature, CO₂ retention, is added at the end of the APC subsystem.

5.2.4.1 System Technology Risks. The overall system technology risk is higher than that of the baseline system. Some of the issues contributing to the higher risk are discussed below.

5.2.4.1.1 Evaluation for technical objectives

Compliance with proposed emission limits. A key concern is the fate of the RCRA metals. Since the APC subsystem is based on dry filtration only, the metals are either absorbed in the lime bed, separated and removed with the condensed water, or recycled back to the furnace. It is not known if any of the metal compounds absorbed by the lime will vaporize when the spent lime is calcined. Section 5.2.4.2 discusses the potential problems with this circuit. More detailed evaluation of the metals-removal aspect of this system is needed.

Compliance with functional and operational requirements. This delayed-release system is designed to allow sampling of the offgas before release. To successfully accomplish this desired function, many aspects of the system will require further development. Examples include development of an incineration unit that has zero air inleakage, development of sampling methods for detecting EPA-controlled pollutants in the spent lime (needed to prevent release of these pollutants to the environment when the lime is calcined to desorb the CO₂), development of methods for separating and releasing accumulated inert gaseous and solid compounds (e.g., nitrogen), determining the fate of

radionuclides in the system, and development and integration of process controls. The inability to control air leakage is a potential obstacle to the delayed-release function, which is the system's main advantage.

5.2.4.1.2 Evaluation for institutional objectives—Under ideal conditions, the volume of the offgas discharged to the atmosphere could be about one tenth of the volume discharged by the baseline system. Moreover, the system holds the CO₂ gas for a specified period of time, allowing release to the atmosphere only after it is confirmed that it meets the discharge criteria. Hence, inadvertent release of pollutants to the environment can be prevented. If found to be feasible, it is possible that the system will be received positively by the public and the state and local regulatory agencies.

5.2.4.1.3 Evaluation for cost and schedule objectives—The CO₂ retention subsystem technology is in its infancy. Hence, the cost of the system, including the cost of disposing of the final waste, cannot be estimated accurately at this time. Likewise, there are many uncertainties in the process development timing.

5.2.4.2 Subsystems Technology Risks. Differences in technology risks associated with the subsystems, compared with those of the baseline system, are described below.

5.2.4.2.1 Incineration subsystem—The main concern about the incineration subsystem is the potential for air leakage to the incinerator. Because the drum rotates around the axis of the cylinder, dynamic seals are needed at each end. As a result, there tends to be uncontrolled air leakage into the kiln which makes precise oxygen control difficult.ⁿ Several kiln vendors have advanced rotary kiln seal technology considerably since these results were obtained (See discussion in Section 5.2.2.2).

It is estimated that the air leakage rate from a rotary kiln could be as high as 1,000 lbs/hr, as has been learned from the performance of hazardous waste incinerators. This rate will result in a build up of approximately 800 lbs/hr of nitrogen in the system. During the first hour of operation, the

n. The TSCA incinerator at DOE's Oak Ridge K-25 Plant uses an overlapping spring plate seal (known to be among the poorest available) that has been associated with air leakage of 8-10%.³ The Drexler seal, a positive-pressure seal, underwent bench-scale testing at ambient temperatures at INEL; the results indicate that this seal would leak 2½ standard cubic feet per minute (scfm) into the kiln (unpublished work).

system offgas recycle line will contain about 800 lbs of oxygen and 800 lbs of nitrogen. If all of this gas is recycled back to the kiln without bleeding, the gas flow rate in the APC will be increased by about 25% in the first hour of operation. A variable-rate APC unit could be used to minimize the bleed rate, but ultimately all of the inert gas, which will be mixed with a high percent of oxygen, will have to be discharged. High air inleakage renders the benefit of the oxygen recycling feature of this system questionable. In the mass balance calculation, all of the offgas (mostly O₂) from the CO₂ absorber is sent to holding tanks. In these tanks the gas is sampled and analyzed to ensure that it meets the discharge criteria before release. If it does not meet the criteria, the system is placed in a shutdown mode until the problem is fixed.

The oxygen-fired furnace is also a special case requiring unique design features. Although oxygen-fired furnaces have been used in many chemical and metallurgical applications, oxygen-fired rotary kilns have had very limited application in treating hazardous waste. Key areas requiring system integration or development are the oxygen burner design, flame control, combustion oxygen control, and ash slagging prevention. Ash slagging could occur frequently due to the high temperature of the oxygen flame.

5.2.4.2.2 CO₂ retention subsystem—Several areas of the CO₂ retention subsystem needing development were identified on page 123. Generally, this subsystem is considered to have a high technological risk. Although CO₂ absorption by lime is a well-known process, its application to the ITTS would be the first of its kind. Many areas will require development in a prototype environment before the feasibility of this process can be ascertained with confidence.

5.2.5 Evaluation of Polymer Stabilization System (System A-5)

Differences between System A-5 and the baseline system are that the vitrification subsystem has been eliminated in System A-5 and all solid residues are stabilized using polymer. This variation has been included to study the increase in final waste volume arising from the stabilization of all waste using polymer.

5.2.5.1 System Technology Risks. Differences in the technology risks associated with polymer stabilization compared with the baseline system are described below.

5.2.5.1.1 Evaluation for technical objectives—Eliminating the vitrification subsystem reduces technical uncertainty. The only concern is acceptability of a polymerized waste form for long-term isolation of alpha MLLW.

5.2.5.1.2 Evaluation for ES&H objectives—The system is less desirable than the baseline system from the ES&H standpoint. This is largely due to a higher final waste volume produced by the system. Polymerized waste is considered less stable and more leachable than vitrified waste. The system will also have a higher volume of final waste, requiring a larger disposal site.

5.2.5.1.3 Evaluation for institutional objectives—Because of the higher volume of final waste, the public and state and local agencies may view this system less favorably than the baseline system. However, the low temperature stabilization process results in lower total gaseous emissions for the facility.

5.2.5.2 Subsystems Technology Risks. The technology risks associated with the subsystems are slightly fewer than for the baseline system. This is because uncertainties with regard to the vitrification subsystem have been removed.

5.2.6 Evaluation of Maximum Recycling System (System A-6)

The maximum recycling system is the same as the baseline system except that several features have been added to minimize the overall volume of waste requiring disposal. The system configuration has three main differences from the baseline system: spent activated charcoal saturated with mercury is recycled, a metal solids separation unit is added to the feed preparation of the incineration subsystem to capture metals and send them for recycling, and a salt recovery subsystem is added to crack and recycle the scrubber salts.

5.2.6.1 System Technology Risks. The system has a higher technology risk than the baseline system as discussed below.

5.2.6.1.1 Evaluation for technical objectives—Technical objectives include compliance with functional and operational requirements. Adding metal recovery devices will complicate the incinerator feed preparation design, especially when the system is used for alpha

MLLW. Such devices will require engineering development to facilitate ease of decontamination and maintenance.

The capture of mercury from spent carbon will require further process development. This work is already in progress by suppliers of activated carbon.

A concept for salt cracking must be developed. An electrolytic separation process is proposed in this study. However, much more effort is needed to evaluate this and other options.

5.2.6.1.2 Evaluation for institutional objectives—Because of the waste minimization features of this system, it is anticipated that it will be received more positively by the public and the state and local regulatory bodies.

5.2.6.1.3 Evaluation for cost and schedule objectives—The salt recovery subsystem has not been fully defined, although it is considered to be a small part of the overall life-cycle cost. There are many uncertainties in process development timing.

5.2.6.2 Subsystems Technology Risks. The technology risks associated with the subsystems are higher than those of the baseline system. Some of the reasons for the higher risk are discussed below.

5.2.6.2.1 Incineration subsystem—As discussed above, the feed preparation unit has the added function of removing metals. This complicates the design for the front end of the incineration subsystem.

5.2.6.2.2 Salt recovery—Very little is known about the salt recovery process. The process efficiency, secondary waste volumes, and other key process parameters have not been established. A more detailed evaluation of the options is needed before the feasibility of a salt recovery process can be ascertained.

5.3 Evaluation of Pyrolysis System (System B-1)

The main objective of System B-1 is to limit the use of oxygen for combustion to provide the lowest possible volume of offgas from the system. This is accomplished by using a pyrolyzer and combining the vitrification and incineration APCs in a single unit. Another advantage of using a pyrolyzer is that a refractory lining for the incinerator is not needed because the pyrolyzer operates at lower temperatures (e.g., 900°F) than a rotary kiln.

The pyrolysis system differs from the baseline system in several ways. The incineration subsystem has an indirect-fired pyrolyzer operating at 900°F and an SCC operating at 2,200°F. Both units use oxygen for combustion. The vitrifier furnace has been included as an integral part of the incineration subsystem. A single APC is used for both the incineration and vitrification units. Only combustible waste is fed to the incinerator; noncombustible debris and other solid material are pretreated and fed directly to the vitrifier. Because of the need to sort the combustible from noncombustible material in the feedstock, a more extensive waste receiving and preparation subsystem has been provided.

5.3.1 System Technology Risks

The system has a greater technology risk than the baseline system as discussed below. Components are commercially available but require engineering development and demonstration on a system integration level.

5.3.1.1 Evaluation for Technical Objectives. Integration of the incinerator with the vitrifier and the use of a single APC for both units will complicate the process control. The entire assembly will have to be operated and controlled as a single unit. A failure in one component will result in shutting down the entire process. Hence the reliability and availability of the system may be lower than for the baseline system.

Since noncombustible material is fed directly to the vitrifier, it must be shredded and dried in a calciner to remove water vapor. The dryer adds to the mechanical and control complexity of the system. Trace organic compounds and solids (e.g., plastics) in the noncombustible material could further complicate the dryer operations. Vitrifier operation could also be complicated if organics are

introduced into the unit. Incomplete combustion in the pyrolyzer could result in a high-carbon ash, which might have an effect on the quality of the vitrified product.

5.3.1.2 Evaluation for Institutional Objectives. The volume of offgas discharged to the atmosphere is about one sixth of that of the baseline system. This may result in better acceptance of the thermal treatment facility by the public and the state and regulatory agencies.

5.3.2 Subsystems Technology Risks

The technology risks associated with the subsystems are greater than in the baseline system. The major reasons for the greater risk are presented below.

5.3.2.1 Receiving and preparation subsystem. As discussed above, the sorting function of this subsystem has a higher demand than that of the baseline system. This increases the complexity and size of the receiving and preparation subsystem.

5.3.2.2 Incineration subsystem. The pyrolysis-based incinerator, as presented, is in an advanced stage of development and is reasonably flexible. However, it does require that large bulk items and noncombustible material be removed from the feed stream. Treatment by pyrolysis works best when the composition of the feedstock is consistent. However, because of the large heat sink available, gradual changes in the heating value of the waste feed are easily tolerated. The pyrolyzer must be designed with the ability to keep the oxygen concentration in the pyrolysis chamber low enough to maintain true pyrolysis conditions. An evenly mixed and well-distributed underfire air flow in the pyrolyzer unit is needed to minimize carbon in the pyrolyzer ash. Low-temperature pyrolysis and the benefit of not using a refractory lining should be investigated further.

The pyrolyzer is similar in design to a rotary kiln in that a rotating barrel is used. Consequently, seal performance is critical to this application, as it is for the systems supplying oxygen to a rotary kiln. But, just as there are advanced seals for rotary kilns, those same seal designs could be adapted to the pyrolyzer. At the lower operating temperatures of the pyrolyzer, maintaining good seals should be easier than for a rotary kiln.

5.3.2.3 Vitrifier. There are no operating data to provide an estimate of the amount of carbon in the ash from the pyrolyzer. Nor are there any data on the limit for carbon in ash before the

quality of vitrified waste will be affected. Pyrolysis and vitrification tests are needed to determine these limits and to establish how effectively the carbon can be oxidized in the vitrification unit using an oxygen lance.

5.4 Evaluation of Plasma-Arc System (System C-1)

This system takes advantage of the plasma-arc furnace technology currently used in the metallurgical industry. This furnace is a versatile, high-temperature unit with the ability to control intake air flow rates. The plasma-arc system differs from the baseline system in several important ways. The incineration subsystem has a plasma-arc furnace and an electrically-heated SCC using air for combustion. The vitrification subsystem has been eliminated because the plasma furnace operates in a slagging mode. This means the ash is vitrified in the same furnace used for combustion. The metal melting subsystem has been eliminated because the plasma-arc furnace can also be used for metal melting.

5.4.1 System Technology Risks

Differences from the baseline system that affect technology risk are discussed below. Overall, the risks must be judged as higher based on the lack of commercial experience compared to the baseline system. Components are commercially available but require engineering development and demonstration on a system integration level.

5.4.1.1 Evaluation for Technical Objectives.

5.4.1.1.1 Compliance with emission limits—While a plasma-arc furnace system will have a higher efficiency for destroying the organic compounds, it complicates the management of volatilized metals. This is due to the high temperature created by the plasma arc. Development is needed to determine the fate of vaporized metals in the APC and methods for capturing them. Developmental efforts must also be directed to the volatilized actinides^o in the offgas. One solution

o. To obtain a rough estimate of the level of actinides in the plasma-arc furnace offgas, a thermodynamic analysis of U, Pu, and Am volatilization was performed at LLNL (unpublished work by Krikorian, 1993). The results show that the primary source of actinide volatility would be the arc chamber. It is believed that fine particulate actinides flow through the SCC into the furnace exhaust. At a temperature of 1,773 K in the chamber, actinide concentrations in the SCC exhaust are calculated to be 1.5×10^{-3} to 4.8×10^{-3} kg of actinide per kg of offgas for U, 5.5×10^{-8} to 3.4×10^{-6} for Pu, and 2.7×10^{-11} to 1.7×10^{-9} for Am.

might be to add a moving sand filter in the furnace exhaust. Sand in the filter could act as a cold trap and capture some of the volatilized metals. After capture, the spent sand can be either reinserted in the melter or solidified separately.

5.4.1.1.2 Compliance with functional and operational requirements—The principal technology risks in this system are found in the plasma-arc furnace design. While this technology is in a very advanced state of development, it cannot at this time be considered commercial. A plasma vitrification unit is being developed that may be used to treat alpha waste from Pit 9 in the RWMC at INEL. Another full-scale facility for LLW treatment is in the startup stage in Switzerland. The intensity of the development work currently taking place indicates that plasma arc systems will be commercially available within the required time frame.

5.4.2 Subsystems Technology Risks

The technology risks associated with the subsystems are lower than in the baseline system. Key differences with the baseline system are discussed below.

Plasma systems appear simpler, in principle, than a rotary kiln such as used in the baseline system. However, no system has yet operated for more than 100 h on waste or surrogate waste materials. Electrode lifetime is a very limiting condition, resulting in substantial downtime for replacement. Consequently, the technology risk is higher than for the baseline system – at least until a system is operated for a few thousand hours with acceptably low downtime.

The plasma system considered here is a fixed hearth with few moving parts other than the torch; the same is not true for the centrifugal hearth melter proposed for Pit 9. That system has considerably more moving parts and complex seals. Again, operating histories are very limited in waste applications. Another advantage of the fixed hearth plasma concept is its closed design which facilitates contamination control.

The principal concern with operating plasma-arc furnaces is limited electrode life. Techniques for remote replacement of the electrode are being developed for the INEL Pit 9 project. The type of refractory lining in the furnace must also be investigated. However, its compact configuration and ability to accept a wide variety of waste types make it an ideal candidate for further development. Unlike many of the other thermal treatment systems, plasma-arc systems easily adapt to changes in

feedstock heating value and precise combustion oxygen control. Many such units are used in precision metallurgical melting applications.

5.5 Evaluation of Fixed-Hearth with CO₂ Retention System (System D-1)

System D-1 is designed to discharge the least amount of waste gases to the atmosphere. The fixed-hearth design allows better control of oxygen during combustion and minimizes air leakage, which is an important feature in a CO₂ retention process. The configuration of this system differs in a few ways from that of the baseline system. The incinerator uses a fixed-hearth controlled-air incinerator design. The unit is fired with oxygen gas. Only combustible waste is treated by the incineration subsystem. Noncombustible waste is sorted in the receiving and preparation subsystem and fed directly to the vitrification subsystem. A CO₂ retention unit has been added to delay the discharge of offgas from the incineration APC. This is done by absorbing CO₂ in lime and desorbing it later in a calciner unit. The CO₂ retention unit acts as a check point for the offgas discharge and helps prevent inadvertent discharge of some of the pollutants to the atmosphere during off-normal conditions of operation. Monitoring the calcium carbonate will identify undesirable contaminants.

5.5.1 System Technology Risks

As compared to the baseline system, System D-1 has a higher technology risk. Some reasons for the higher risk are discussed below.

5.5.1.1 Evaluation for technical objectives. The following differences with the baseline system are noted when reviewing the system against the requirements specified in Appendix A.

5.5.1.1.1 Compliance with proposed emission limits—Some of the concerns regarding emissions from this system are the same as for System A-4, which also has CO₂ retention. While it is generally believed that the system may reduce emissions, there are some areas of uncertainty that must be studied further. Key concerns are the low level of process maturity and the lack of enough operating data and knowledge to assess the feasibility and efficiency of the CO₂ retention process.

5.5.1.1.2 Compliance with functional and operational requirements—The system is designed to delay release of the offgas to allow sampling before release. To accomplish this, many aspects of the system will require further development. Examples include analytical methods for measuring EPA-controlled pollutants in the 90% of the lime that is recycled (to prevent release of pollutants to the environment when the lime is calcined to desorb the CO_2), methods for separating and releasing accumulated inert gaseous and solid compounds, and process controls. The fate of radionuclides in the system will also need to be determined.

Since the noncombustible waste is directly fed to the vitrification unit, a dryer must be added in front of the melter to remove water from the feedstock. Tests at INEL have shown that particulate carryover from the vitrifier to its oxygen system is substantially reduced if the feed is dried. Since complete separation of organics from the noncombustible feedstock may not be practical, the capability to remove acid gas (i.e., scrubbers) may have to be added to the vitrification subsystem. The need for a scrubber to capture volatilized salts must be evaluated.

By using a fixed-hearth furnace, oxygen in the system can be controlled much more precisely than in the CO_2 retention system that uses a rotary kiln (System A-4). Therefore, system problems arising out of air leakage are less of a concern in this system. The major leakage potential is around the feed chute. This will require effective airlocks.

5.5.1.2 Evaluation for institutional objectives. The volume of flue gas discharged to the atmosphere is about one tenth of the volume discharged by the baseline system. Moreover, the system holds the CO_2 gas for a specified period of time, allowing release to the atmosphere only after it is confirmed that the offgas meets the discharge criteria. Hence, inadvertent release of pollutants to the environment can be prevented. Overall, features of this system may result in better acceptance of a thermal treatment facility by the public and by state and local regulatory agencies.

5.5.1.3 Evaluation for cost and schedule objectives. Development of the CO_2 retention subsystem is in its infancy. Hence, the cost of the system, including the cost of disposing of the final waste, cannot be estimated accurately. In addition, there are many uncertainties in the process development timing.

5.5.2 Subsystems Technology Risks

The technology risks associated with the subsystems are higher than for the baseline system. Key reasons for this assessment are discussed below. Components are commercially available but require engineering development and demonstration on a system integration level.

5.5.2.1 Receiving and preparation subsystem. As discussed above, higher demands are placed on the sorting function of this subsystem than that of the baseline system. This increases the complexity and size of the receiving and preparation subsystem.

5.5.2.2 Incineration subsystem. Selection of a fixed-hearth furnace design that minimizes air leakage will be needed for successful CO₂ retention.

5.5.2.3 CO₂ retention subsystem. The main component of the CO₂ retention subsystem is a circulating fluidized bed of lime that absorbs carbon dioxide from the offgas stream, permitting delayed release. Although CO₂ absorption by lime is a well-known process, its application in the ITTS would be the first of its kind. Development in a prototype environment will be required before the feasibility of this process can be ascertained. Lime recycling is accomplished by heating the spent lime (CaCO₃) in a calciner. This process will require further operating data to better assess the lime recycling efficiency. A low efficiency could significantly affect the volume of final waste requiring disposal. Other CO₂ capture methods may also be suitable or superior to the lime-based process. Detailed process selection for CO₂ capture was beyond the scope of this study.

5.6 Evaluation of Thermal Desorption System (System E-1)

System E-1 is distinguished by thermal desorption of debris. The main objective of this system is to take advantage of the recent debris rules promulgated by EPA. These rules allow minimal processing and stabilization of a certain category of MLLW debris (trash-like material). This system is characterized by minimal processing.

System E-1 differs from the baseline system in important ways. A thermal desorber subsystem has been added for treating waste classified as debris under the EPA rule. The offgas from the desorber

unit is condensed and sent to the incinerator. A grout mixer stabilizes the solids discharged from the desorber.

5.6.1 System Technology Risks

The system has a higher technology risk than the baseline system as discussed below.

5.6.1.1 Evaluation for Technical Objectives. The sorting requirements of the thermal desorption subsystem add mechanical and process complexity to the overall system. This unit will be equal in size to the main incineration unit. This means that the overall facility will be larger than in the baseline system. The final waste volume will be higher than in the baseline system, and the waste form will be less stable.

A key operating concern for the system is the strategy of processing debris waste containing plastic material in a desorber unit. Unless operating temperatures are kept very low, the plastic material will have a tendency to melt in the desorber and stick to the desorber internals. It is also possible that the unit will be plugged by large pieces of agglomerated solids formed in the desorber. At low operating temperatures, the benefit of a thermal desorption process to remove organic material is limited.

5.6.1.2 Evaluation for Institutional Objectives. The volume of final waste requiring disposal is greater than that of the baseline system, but less offgas will be discharged to the atmosphere. The waste form is less stable than that produced by the baseline system. Therefore, the overall acceptability of this system by the public and state and local agencies could be lower than that of the baseline system.

5.6.2 Subsystems Technology Risks

Adding a thermal desorber subsystem results in higher technology risks for the subsystems than in the baseline system. Key areas of uncertainty are requirements for extensive sorting and the design strategy for thermal desorption. The treatment strategy will require further investigation and better definition. The operating temperature of the desorber must be studied further. Ways to avoid or accommodate plastic melting in the desorber while still getting good organic desorption must be developed. Components are commercially available but require engineering development and demonstration on a system integration level.

6. SYSTEMS COMPARISON

One of the objectives of the ITTS study is to conduct a quantitative comparison of the system attributes. A method for this comparison, called "figure-of-merit" (FOM) analysis, is described in this section. However, the actual comparison of the systems will be done at the end of the ITTS study so that the Phase 1 and Phase 2 systems can be compared together. The comparison results will be published later.

6.1 Comparison Methods and Criteria

The first step of the FOM analysis is to establish a set of system attributes specific to the analysis being performed. These attributes are referred to as comparison criteria or "performance measurables." Performance measurables are features that represent the overall effectiveness of the system when compared to other alternatives. Each measurable has a weighting factor assigned to it. Table 6-1 (page 141) lists the performance measurables, weighting factors, and evaluation guidelines.^p The weighting factors represent the relative importance of a performance measurable with respect to other measurables. The evaluator reviews system features relative to the given performance measurable using the scoring guidelines in Table 6-1. The evaluator then gives the system a score of 1 (least effective), 2 (moderately effective), or 3 (highly effective) for each measurable. The weighted score is the result of multiplying the raw score by the weighting factor. The scores are not connected with any conventional unit of measure. Rather, they are intended for evaluating the systems with respect to each other.

In comparing the systems, first the baseline system is assessed and scored. The remaining systems are evaluated and scored based on their differences from the baseline system. In evaluating the technical attributes of each system, all of its subsystems are considered but the core technology receives the most attention. The core technology is the main thermal treatment train, including waste feed preparation, thermal treatment, air pollution control, and the stabilization subsystems. Cost comparisons are based on the total system PLCC, which includes the cost of the main thermal treatment and the cost associated with all ancillary subsystems. Total system costs must be considered because each technology has a different impact on the size of the ancillary subsystems.

p. The performance measurable list, weighting factors, and scoring guidelines given in Table 6-1 are expected to receive a broader review when this report is published. Based on the comments received, the information given in Table 6-1 may be revised before final comparison of the ITTS systems at the end of Phase 2.

The performance measurables fall into six main risk categories: (1) technical risk, (2) environmental, safety, and health risk, (3) institutional and public acceptance risk, (4) cost risk, (5) operability and maintainability risk, and (6) schedule risk.

6.1.1 Technical Risk

System technical risks should be reviewed by evaluating the proposed hardware against the pre-established requirements. Well-developed technologies providing reasonable assurance that the established requirements will be met should receive the highest scores. Areas of potential noncompliance should be identified, and the need for further investigations, studies, and demonstration should be assessed.

In considering the commercial availability of the core technology, a high number of vendors is desirable, because competition is increased and the availability of equipment is not jeopardized as much by a vendor going out of business.

6.1.2 Environmental, Safety, and Health Risk

Environmental, safety, and health (ES&H) objectives are to protect the safety of the worker and the public and to protect the environment. Technologies that use a low-energy thermal process or low-pressure components should receive higher ES&H scores because of the lower risk of accidental release of hazardous material to the work place and to the environment.

Systems having low probability of releasing radioactive and toxic chemicals to the atmosphere should receive a high score. Lower offgas volume reduces the potential release of noxious and radioactive elements to the atmosphere, thus minimizing risk to public safety and health. A lower offgas release rate permits a system to operate at lower combustion chamber and exit velocities. While these lower velocities may provide marginally better heat-transfer and pressure-drop characteristics, the principal advantage is that at lower velocities there is less entrainment of solids. Lower concentrations of entrained particulate matter in the APC subsystem improve filter and scrubber operation.

Systems minimizing the volume of final waste and producing a high-integrity final waste form should receive high ES&H scores. These attributes minimize leaching of hazardous substances to the disposal media. The reduced release of leachate will enhance long-term public health and safety.

6.1.3 Institutional and Public Acceptance Risk

Permitting and licensing of first-of-a-kind systems could result in prolonged testing and pre-operation readiness periods. Hence, systems that use technologies that have been permitted and licensed in the past should receive high scores with respect to institutional and public acceptance risk.

A DOE objective is to achieve acceptance of the proposed technologies through public participation programs during NEPA and facility permitting steps. Technologies received positively by the public and the regulatory and permitting agencies should receive high scores. In the past, some incineration projects have not been viewed favorably because of concerns about possible air pollution resulting from incineration of hazardous materials. Technology evaluations should therefore include careful review of APC subsystems to determine that discharge of harmful pollutants to the environment will be reduced as much as possible.

From the institutional and public point of view, the most desirable feature of technologies is the ability to have real-time monitoring of gaseous combustion products discharged to the atmosphere. This feature can help operators recognize process upsets, and thereby prevent uncontrolled releases of pollutants. Technologies not received positively by the public and the regulatory agencies could result in prolonged permitting processes with the potential for cost overruns.^q

6.1.4 Cost Risk

The technology cost objectives are a reasonably low PLCC and a low probability of cost overruns during the system acquisition process. Project costs, including demonstration and facility construction, should be measurable at all stages. Cost confidence is achieved by using proven technologies. Conversely, technologies based on unproven and untested concepts pose a high risk of cost overruns.

q. This is evident from DOE's recent experience with incineration projects. Two incineration facilities, Controlled Air Incinerator at Los Alamos National Laboratory and Waste Experimental Reduction Facility at Idaho National Engineering Laboratory, are currently on hold awaiting further evaluation of permitting and safety issues. Only one DOE installation, Oak Ridge National Laboratory, has an operating incinerator. It took about 3 years to obtain all necessary permits for this incinerator. Another DOE installation, Savannah River Site, has completed the design and obtained the necessary permits for the Consolidated Incineration Facility (CIF). Construction of CIF was started recently, but the facility has been subjected to intervenor lawsuits, and more delays are expected. Two other DOE projects that failed to receive a permit were a proposed incineration project at Lawrence Livermore National Laboratory (canceled in 1990 due to opposition by the public and state agencies) and a completed incineration facility at Rocky Flats Plant. The permit at Rocky Flats Plant was denied in 1989, but efforts are underway to restart the permitting process.

Other key factors contributing to the system economics are the availability of construction materials, system compactness, and the use of commercial equipment. Volume reduction is also a main cost consideration, because the costs associated with disposing of secondary wastes represent a major cost in MLLW disposal. This study uses a disposal cost of \$243/ft³ for disposal in an engineered RCRA long-term storage facility.⁸ Actual costs for disposing MLLW at DOE sites are not available at this time, as no such facilities have ever been operated by DOE. However, both the Nevada and Hanford DOE sites are expected to accept MLLW in the future, and responses to telephone inquiries to these sites have indicated that they are anticipating costs of \$59/ft³ and \$160/ft³, respectively.¹¹ These estimates are preliminary and do not anticipate disposal in a fully engineered disposal facility. It also appears that the quoted costs may not be realistic. In the case of the Nevada Test Site, the State of Nevada recently filed suit to prohibit disposal of LLW at the site until an updated environmental impact statement is completed.¹²

It is clear from this study that systems producing smaller volumes will have advantages of economics and public and institutional acceptability with respect to disposing of the treatment residues. Furthermore, the better the final waste form, the easier it will be to achieve public acceptance.

6.1.5 Operability and Maintainability

Systems requiring complex mechanical, thermal, or chemical processes are difficult to operate and subject to frequent failures, resulting in low operating efficiency, low availability and reliability, and high maintenance. The extent to which waste feed must be sorted and shredded to produce an acceptable feedstock has a significant impact on a system's desirability. Manual sorting is labor intensive, and automated sorting requires highly sophisticated and costly instrumentation and involves high programmatic risks. Excessive shredding is mechanically demanding and significantly increases maintenance and utility costs. Systems using a rotary kiln or plasma hearth furnaces for primary thermal treatment require the least feed preparation. Typically, for these two types of system, more than 75-80% of the waste inventory is acceptable as feed to the primary thermal treatment unit, with only modest levels of preparation required. In contrast, fixed-hearth controlled-air incinerators and indirectly fired pyrolyzers require a well-sorted feed. As a result, the thermal treatment units in these two latter systems are capable of accepting only about 20-25% of the waste inventory.

6.1.6 Schedule Risks

The principal schedule objective is that the technologies can be fully developed and ready for starting detailed design by 1996. Also, there should be a low probability of schedule slips due to demonstration, testing, and evaluation requirements. As with cost risks, schedule risk can be reduced by using well-developed, proven, or promising technologies.

6.2 System Scores

Scoring of systems against performance measurables will be done in Phase 2 of the ITTS study when development of all systems is complete. The evaluations will represent the overall effectiveness of a particular system when compared with the baseline system. It should be kept in mind that the ITTS system comparison criteria, weighted scores, and scoring guides given in this report are subject to further review by DOE and the ITTS consultants and may be revised before the final comparison of the systems is conducted.

Table 6-1. Performance measurables, weighting factors, and scoring guidelines.

Performance Measurable	Weighting	Scoring Guideline		
	Factor (%)	Poor Score	Average Score	High Score
1 - Technical risk. <i>The level of the system maturity and the ability of the technology to treat the waste in accordance with applicable federal and state regulatory requirements, meet the emissions limits, and comply with the specified functional and operations requirements (30% total weighting factor).</i>				
1a - Development level. The level of development of the key system components.	12	Few of the key system components have been demonstrated.	More than half of the key system components have been demonstrated.	Almost all the system key components have been demonstrated
1b - System maturity. Previous application of the system in hazardous and radioactive waste industry.	12	A full-scale system based on the core technology has been used in other industries but not in hazardous or radioactive waste treatment.	A full-scale system based on the core technology has been used in hazardous waste but not radioactive waste treatment.	A full-scale system based on the core technology has been used by DOE for mixed waste treatment.
1c - Commercial availability. The number of suppliers for the system's core technology.	6	There are fewer than two vendors offering the core technology.	There are two to four vendors offering the core technology.	There are more than four vendors offering the core technology.

Table 6.1. Continued.

Performance Measurable	Weighting	Scoring Guideline		
	Factor (%)	Poor Score	Average Score	High Score
2 - Environmental, safety, and health risks (ES&H). <i>Ability of the system to protect the environment and the safety and health of workers and the public (20% total weighting factor).</i>				
2a - Waste form. The ability of the system to produce a waste form that protects the safety and health of the public during transportation and long-term disposal.	5	Produces a residue with a high leachability when stabilized with cement or polymer.	Produces a residue with a moderate leachability when stabilized with cement or polymer.	Produces a waste form such as glass, ceramic or rock, with low leachability.
2b - Emissions. The ability of the system to protect public safety and health by minimizing hazardous gaseous or liquid discharges to the environment.	5	Discharges a high quantity of noxious constituents in gaseous waste to the atmosphere during normal operation.	Discharges a moderate quantity of noxious constituents in gaseous waste to the atmosphere during normal operation.	Discharges a low quantity of noxious constituents in gaseous waste to the atmosphere during normal operation.
2c - Worker protection. The ability of the system to minimize worker exposure to hazardous or radioactive materials.	5	Has a high potential for exposing operators to radiation or other hazards.	Has a moderate potential for exposing operators to radiation or other hazards.	Has a low potential for exposing operators to radiation or other hazards.

Table 6.1. Continued.

Performance Measurable	Weighting Factor (%)	Scoring Guideline		
		Poor Score	Average Score	High Score
2d - Postulated accident releases. The ability to protect worker and public safety and health by minimizing accidental releases.	5	The core technology has high potential for explosion or other accidental failures resulting in accidental release of radioactivity.	The core technology has moderate potential for explosion or other accidental failures resulting in accidental release of radioactivity.	The core technology has low potential for explosion or other accidental failures resulting in accidental release of radioactivity.
3 - Institutional acceptance risk. <i>The acceptability of the core technology by the public and state and local permitting agencies (15% total weighting factor).</i>				
3a - Licensability and permitability. The acceptability of the technology by federal, state, and local permitting agencies.	8	Systems based on the core technology have not been permitted for waste processing under RCRA, CAA, or other environmental regulations.	Systems based on the core technology have been permitted for hazardous waste processing under RCRA, CAA, or other environmental regulations.	Systems based on the core technology have been permitted for radioactive and hazardous waste processing under RCRA, CAA, or other environmental regulations.

Table 6.1. Continued.

Performance Measurable	Weighting	Scoring Guideline		
	Factor (%)	Poor Score	Average Score	High Score
3b - Community acceptability. The degree to which the core technology can be expected to be acceptable to the public.	7	Serious public involvement and opposition can be expected.	Moderate public opposition can be expected, and the core technology will generally be acceptable to the public.	Core technology will probably be acceptable to the public.
4 - Cost risk. <i>The ability to define a reasonably accurate cost estimate for the system, and the probability that the system costs (including demonstration, testing, and evaluation and facility construction) will be acceptable and that system acquisition will not involve a major cost overrun (15% total score).</i>				
4a - Life-cycle cost. Relative comparison of estimates of the system life-cycle cost (i.e., demonstration, testing, and evaluation, facility construction, operation and maintenance, and decommissioning and decontaminations).	3	At the high end of the range of system PLCC estimates.	Around the average of PLCC estimates.	At the low end of the range of system PLCC estimates.

Table 6.1. Continued.

Performance Measurable	Weighting Factor (%)	Scoring Guideline		
		Poor Score	Average Score	High Score
4b - Cost confidence. The ability to accurately estimate the cost with minimal anticipation of overruns based on current knowledge about the core technology.	1	The core technology is a first-of-a kind, and a majority of the details are not developed to the level needed for accurate cost estimating.	The core technology has been used in hazardous waste treatment, and the engineering community is familiar with the technology.	The core technology has been used in radioactive waste treatment and the engineering community is familiar with the technology.
4c - Final waste volume. The ability of the system to minimize the volume of waste requiring disposal.	4	The system has a low volume reduction factor.	The system has a moderate volume reduction factor.	The system has a high volume reduction factor.
4d - Compactness. The ability of the system to fit in minimal building space.	1	The system takes up a large building space.	The system takes up a moderate building space.	The system takes up a small building space.
4e - Construction material. The simplicity and availability of construction material.	1	The core technology uses exotic alloys or other rarely produced construction material.	The core technology uses mostly common construction material.	The core technology uses all common construction material.

Table 6.1. Continued.

Performance Measurable	Weighting	Scoring Guideline		
	Factor (%)	Poor Score	Average Score	High Score
4f - Resource utilization. The minimal utilization of manpower, water, fuel, electrical power, and other resources by the system.	2	The core technology has high resource utilization.	The core technology has moderate resource utilization.	The core technology has low resource utilization.
4g - Final product recycling. The ability of the system to produce products that are recyclable, thus minimizing the final waste volume requiring disposal.	3	Little waste can be recycled.	A moderate amount of waste can be recycled.	A large amount of waste can be recycled.
5- Operability and maintainability. <i>Simplicity of the machinery and processes used by the core technology and the ability to maximize operating efficiency and minimize maintenance (10% total weighting factor).</i>				
5a - Feedstock sorting. The ability of the core technology to accept input waste with minimal sorting.	3	Input waste must be double sorted, first to remove combustible from noncombustible material, and then to remove undesired organic compounds.	Input waste must be single sorted to remove combustible from noncombustible material in the feed.	Input waste requires almost no sorting.

Table 6.1. Continued.

Performance Measurable	Weighting Factor (%)	Scoring Guideline		
		Poor Score	Average Score	High Score
5b - Feedstock characterization. The ability of the core technology to accept input waste with minimal physical and chemical characterization.	2	More than half the waste must be physically and chemically characterized.	Less than a tenth of the waste must be physically and chemically characterized.	Almost none of the waste requires characterization.
5c - Feedstock preparation. The ability of the core technology to accept waste with minimum shredding and sizing.	3	Input waste must be shredded to fine (smaller than a few millimeters) particles.	Input waste must be shredded to semifine (smaller than 1/8 inch) particles.	Input waste needs little or no shredding (particles larger than 3 inches).
5d - Mechanical, process, and control simplicity. The complexity level of mechanical, process, and control mechanisms used in the core technology.	2	The core technology uses complex mechanical and chemical processes requiring delicate control of process parameters.	The core technology uses moderately simple mechanical and chemical processes with moderately simple control of process parameters.	The core technology uses simple mechanical and chemical processes with simple control of process parameters.

Table 6.1. Continued.

Performance Measurable	Weighting	Scoring Guideline		
	Factor	Poor Score	Average Score	High Score
	(%)			
6 - Schedule risk. <i>The ability to define a reasonably accurate schedule for technology development and the probability that the system will meet the schedule objective of readiness for detailed design within 2 years (10% total weighted factor).</i>				
6a - Schedule compliance. The probability that the system will meet schedule objectives.	5	More than 2 years is required to develop the system concept and have enough information for detailed design of a full-scale operational facility.	About 2 years is required to develop the system concept and have enough information for detailed design for a full-scale operational facility.	Only minor developmental effort is necessary and system is ready for detailed design now.
6b - Schedule confidence. The ability to accurately estimate the schedule with minimal anticipation of overruns based on current knowledge about the core technology.	5	There are significant unresolved technical problems, and a firm schedule cannot be established for development.	Most technical problems have been resolved, and a reasonably firm schedule for development can be established.	Only minor developmental effort is needed, and a firm schedule can be established now.

7. DEMONSTRATION, TESTING, AND EVALUATION NEEDS

This section summarizes demonstration, testing, and evaluation activities (hereafter collectively referred to as the development program) that are needed to enhance the current thermal treatment technologies. First, a recommended mission and objectives for the development program are discussed. Second, a description of the suggested development program is given, as are areas that need further study and development. The authors recognize that many of the suggested research needs are being addressed by the DOE Mixed Waste Integrated Program (MWIP). These suggestions are provided as an independent view of the research needs. A detailed comparison of the MWIP scope and these needs was beyond the scope of the ITTS study.

7.1 Program Mission and Objectives

A suggested mission and objectives statement for the development program is presented below.

7.1.1 Mission

The recommended mission of the program is to conduct a prototype demonstration of an integrated thermal treatment system for management of MLLW currently being stored or generated throughout the DOE Complex. The size of the demonstration system should be large enough to provide reliable data for scale-up application (about 100-300 lbs/hr). The program should encompass the demonstration units and associated bench-scale test and evaluation activities, all executed to achieve the program objective.

7.1.2 Objective

The recommended objective of the program is to provide data and a technical basis for design of a production-scale integrated thermal treatment system for managing DOE's MLLW. This includes selecting the main thermal treatment unit, air pollution control system, and the associated support systems. The production-scale facility, on which the demonstration program is based, should (1) meet current and future regulatory criteria, (2) minimize public and worker health risks by minimizing releases to the environment, (3) produce a waste form that ensures long-term isolation from human contact once it is in a MLLW land disposal unit, and (4) optimize cost.

The demonstration program should (1) examine the newest technologies, (2) conduct necessary bench-scale tests and treatability studies, (3) select one or more technologies for prototype demonstration, and (4) provide all information needed for detailed design of the production facility.

7.2 Suggested Development Program

This section discusses the thermal treatment development needs. The development program consists of initial evaluation of technological options, conducting bench-scale tests, and selecting one or more parallel units for prototype demonstration. A facility (existing or new) could be provided to house the demonstration unit(s). The demonstration unit should be designed, fabricated, installed, and operated for a minimum of one year. At the end of this period, key design features of the production-scale facility will be defined and finalized. The demonstration facility may continue operation beyond the initial first year if it can help refine the design of the production facility.

The program should bring all current thermal treatment research and development and demonstration efforts under one umbrella. Accordingly, the program could be divided into the components discussed below. In addition, the program should be coordinated by a system integration group.

7.2.1 Incinerator Demonstration

An Incineration Task Force should be established to address the problems associated with thermal methods of waste destruction. This task force should be made up of members not only from various DOE facilities, but also personnel from the EPA and possibly the Department of Defense (DOD). Tasks assigned to this Task Force would include:

- Treatability studies using bench-scale systems.
- Optimizing operation of incineration units (rotary kiln parallel with another technology) by treating surrogate waste.
- Preparing a detailed cost/benefit analysis for using oxygen in thermal treatment systems.
- Developing improved solids-handling systems for both feed to and discharge from the thermal treatment system.

- Developing improved air exclusion systems for the incineration subsystem.
- Running field tests to determine the correctness of volatility prediction techniques.
- Testing of ash slagging, and defining process parameters to prevent ash slagging.

The program should establish an incineration test facility, chosen from among the numerous incineration installations already in the DOE complex. With this facility, various matters affecting the public's concern about incineration of hazardous and mixed waste could be tested and evaluated. While the proposed plan is for a single facility, it is conceivable that the program may want to add support to ongoing projects at a number of sites.

The biggest drawback in using rotary kilns for destruction of hazardous wastes has been the leakage of seals. Testing is needed to demonstrate the efficacy of commercially-available advanced seals to allay public and regulator fears. The status of seal development needs to be assessed to determine if advanced graphite/steel seals are adequate, or if alternatives such as magnetic fluid seals should be developed and tested. The kiln seal studies being conducted at the Savannah River Site (SRS) on graphite face seals should be accelerated. A survey of U.S. and European rotary kiln seal performance development should be conducted. A focused Request for Proposal issued by the task force would call for incinerator system vendors to demonstrate innovative seal performance.

The bottom ash and fly ash produced by various units around the DOE complex should be characterized. This would aid in specifying the APC subsystem and in characterization of the feed to vitrification and polymerization stabilization steps.

Partition factors for volatile components of the waste must be determined. The program should review testing already done by others as well as initiate research and development work in physical chemistry and chemical engineering to establish the thermodynamic basis for the behavior of volatile inorganic compounds generated during incineration. In general these materials are metal chlorides and fluorides. This task could determine conditions that favor retention of volatile metals and salts in ash during combustion and vitrification. Particular attention should be paid to the carryover of mercury in the incineration and vitrification offgas. Potential additives for pyrochemical reduction of Hg^{+2} to Hg metal within the incinerator should be identified. Research into anaerobic thermal desorption for removing mercury and VOCs from combustible waste is recommended. Such a unit should have a temperature range capable of desorbing mercury metal and its sublimable sulfide and chloride salts. The relative

merits of nitrogen, CO₂, and superheated steam as an inert gas/heat transfer agent for such a system should be evaluated.

7.2.2 APC Demonstration

A multi-site Air Pollution Control Systems Task Force should be established to show that offgas from the various subsystems will be satisfactory for discharge to the atmosphere. Typical tasks of this component would include:

- Defining the analytical requirements for the system.
- Defining mercury removal and pre-HEPA filter designs and testing them in a demonstration-scale system.
- Optimizing the system design to minimize formation of dioxin and release of metals and products of incomplete combustion (PICs).
- Performing bench-scale or small pilot-scale studies of delayed CO₂ release systems and assessing the feasibility and economics of this concept.

7.2.2.1 Develop Analytical And Instrumentation Requirements. A working group supported by the Air Pollution Control Systems Task Force should be established to determine the analytical needs for both the liquid and gaseous APC process. This information would be turned over to the Analysis Task Force, which would, in turn, either locate appropriate equipment in the commercial market or develop it themselves.

7.2.2.2 Removal Of Volatilized Mercury And Its Salts From The Offgas Stream. How to remove mercury from the offgas stream and how to dispose of it are equally important questions to be answered by the program. Laboratory and thermodynamic modeling studies should be conducted to identify the types and quantities of mercury species expected to form from incineration of mercury-containing wastes. It should be assumed that mercury is not removed prior to incineration, that it is present in several forms when leaving the incineration subsystem, and that it has the potential to distribute itself throughout all segments of the APC subsystem of the ITTS. The APC subsystem should be developed to address all these aspects of mercury behavior. Technologies based on using impregnated carbon or alkaline scrubbing solutions to remove mercury from offgas deserve development focus.

Efficient mercury removal subsystems capable of high loading at elevated temperatures should be developed.

In the APC subsystem, mercury can probably be removed from the offgas using fixed beds of sulfur-impregnated activated carbon. Nucon International, Inc., sells this technology under the name Mersorb. One of the principal drawbacks of this technology, from the standpoint of ITTS, is that the treatment must be carried out at temperatures of 100°C or less to prevent oxidation of the sulfur with an oxygen-containing offgas. In addition, the relative humidity must be maintained below 90% to prevent condensation of moisture in the carbon. Offgas treated in this manner would have to be reheated before discharge to prevent plume formation. Brna and others¹³ fed powdered activated carbon and lime into offgas produced by a municipal waste combustor. They found that the carbon feed rate was the principal controlling factor and that it was directly proportional to mercury removal efficiency. They also determined that the source of carbon (coal, wood, or lignite), the location at which the carbon was added, addition of ammonia (to control nitrogen oxides), and variations in temperature (over the limited range) had little or no effect on mercury removal. The effect of lime addition was inconclusive. Lerner¹⁴ explained that an alkaline scrubber solution must contain an oxidizer (peroxide or hypochlorite) or must be maintained at a (relatively) low pH for the solution to effectively remove mercury from offgas. Beco Engineering Company markets a process called Alka/Sorb, which removes a major part of the mercury from offgas streams by injecting powdered lime and carbon into the offgas stream and collecting the solids in a baghouse.¹⁵

Other concepts for treating mercury in offgas, such as the formation of an amalgam using gold as developed by ADA Technologies^r should also be studied. Using zeolites for high-temperature adsorption of mercury vapor appears attractive but requires additional development. Zinc dithionate and amalgamated zinc dust should be evaluated for reducing Hg^{+2} , including the insoluble sulfide form, to metallic mercury.

Mercury can be removed from aqueous waste by the Mersorb process. Mersorb can be used over a broad pH range, and down to pH levels of 3 or 4. High concentrations of nontoxic metals in the liquid waste could make Mersorb prohibitively expensive in this application. Ion-exchange resins containing thiol groups to remove mercury from aqueous waste are commercially available. The SRS has used a thiol resin (Diolite GT-73) that is very selective for mercury in the cationic form.¹ Ionac SR-4 is another

r. ADA Technologies, Inc., Englewood, Colorado.

thiol resin that is commercially available. A thorough investigation should be made of technology to remove mercury from liquid streams.

7.2.2.3 Evaluate Systems For Minimizing Formation of Dioxins and Removing Metals and PICs From Offgas Stream. The effectiveness of the use of spray dryers and coolers should be evaluated to determine the feasibility of using lime or carbon to perform high-temperature offgas cleanup of metals and organics, particularly dioxins. Because metals and PICs have only recently become regulated, there is little information about them. One or more particulate and acid-gas control devices may be very effective at removing metals and PICs, so that charcoal absorption may not be necessary.

7.2.2.4 Evaluate the Delayed Offgas Release System. This concept offers the potential to capture nearly all of the combustion gases, in addition to the hazardous and radioactive particulates. These adsorbents can then be monitored for hazardous and radioactive materials. If the adsorbent is found to be clean, it can be reactivated for recycling, releasing the gases to the atmosphere. As originally presented, this system used lime as the adsorbent; however, if the delayed release concept is shown to be feasible, other absorbent materials such as methanol should be evaluated. The first step in this evaluation is to combine a technical feasibility study with a cost-benefit analysis for the lime absorbent case.

7.2.2.5 Identify, Define and Develop Treatment Technology for Secondary Waste Streams. A working group should be set up to identify and define all secondary waste streams emanating from the APCs. A working group should then be established to take this information and identify or develop treatment technologies for converting secondary waste streams to forms suitable for either disposal or recycling.

7.2.2.6 Develop Acceptable Alternatives to Conventional HEPA Filters. A working group should be established within the APC Systems Task Force to evaluate and test alternatives to conventional HEPA filters. This group would (1) determine the effectiveness of HEPA filters in the removal of the submicron-sized particles that make up fumes; (2) test and evaluate continuously renewable prefilters; (3) evaluate the use of ceramic filters as an alternative to bag-house prefilters; and (4) evaluate the bag-house prefilters used with the metal melters under evaluation.

7.2.3 Surrogate Waste Preparation

The surrogate waste component will prepare a mix of nonradioactive waste surrogates that would closely mimic the behavior of wastes in the DOE's MLLW inventory.

7.2.4 Waste Sorting Demonstration

A Waste Sorting Task Force made up of DOE and EPA personnel should be established by the program to evaluate solutions to problems associated with sorting the waste inventory into treatable parcels, especially problems associated with remote segregation of alpha MLLW. Waste from the surrogate waste component of the program can be used in prototype-scale sorting operations, as needed. Typical tasks assigned to this component would include:

- Reporting on the feasibility of segregating the inventory specified by the surrogate group.
- Testing the available robotics systems to determine whether automatic, noncontact sorting equipment is efficient and cost effective and whether the available commercial products could be adapted to the program's needs.

A working group made up of members of the Waste Sorting Task Force would be formed to establish a waste sorting facility. This facility would evaluate automated and robotic sorting of wastes. A multi-site task group is recommended to scope out available facilities and determine their merit, schedule, and likely installation cost using either existing or new buildings.

The waste sorting facility would provide an opportunity to work with the stakeholders and regulators to develop a characterization approach that is both rational and economical. The facility would be available to evaluate the instrumentation and remote equipment that would be considered for incorporation in the integrated systems. It would be used in evaluating worker risk as well as in determining the extent of sorting that would likely be required to maximize the efficiency of the thermal treatment unit selected.

The special needs of advanced thermal treatment systems, such as the additional sizing required by fluidized bed incinerators and molten salt oxidation systems, would also be addressed. These systems

also require removal of bulk metal from the waste stream. Time and motion studies would be performed to assess the practicality of extensive sorting prior to waste shredding.

7.2.5 Waste Characterization

One of the early responsibilities of the program would be to form an interagency Waste Characterization Task Force. This task force would be made up of representatives from EPA, U.S. Department of Defense (DOD), and DOE. It would address the problems associated with the current extensive waste analysis requirements imposed on thermal treatment systems, both problems associated with characterizing incoming wastes to meet the process needs and fulfill the regulatory criteria and sampling of the final waste form.^s Typical tasks assigned to this component would include:

- Defining a strategy for characterization of the heterogenous waste in the system.
- Developing new, or refining existing, technologies to meet the needs of the project after surveying the market.
- Testing the selected concepts in the demonstration unit.

The Waste Characterization Task Force could perform cost/benefit analyses of process-related alternatives to the currently required extensive characterization of wastes before disposal. Typical subjects of these analyses would include the use of more robust waste treatment or more extensive APCs, or the use of more redundancy in the APCs.

s. RCRA hazardous constituents (40 CFR 261, Appendix VIII) present in incinerator waste feed at concentrations in excess of 100 parts per million by weight (ppmw) must be identified. Guidance in terms of the detection limits that might be needed in the waste characterization analysis are provided in 47 FR 122 pg. 27525 et seq. (June 24, 1982). The background discussion of this notice states that EPA estimates that constituents in the waste feed in concentrations below 100 ppmw will be routinely detected by stack gas analysis. It further states that a waste concentration of 100 ppmw probably represents a lower limit beyond which a determination of a destruction removal efficiency (DRE) of 99.99%, as required by 40 CFR 264.343, would be difficult to document.

The waste analysis section of Interim Status Standards for Incinerators, 40 CFR 265.341, specifically requires that analyses must be made for the heating value of the waste, the halogen and sulfur content, and, unless there is written documented data showing their absence, lead and mercury. A recent publication, *Characterizing Heterogenous Wastes: Methods and Recommendations*, EPA 600/R-92/033 (February 1992), discusses some of the available statistical techniques that can be used on heterogeneous waste for quality assurance and quality control of data assessments. Additional information on this subject can be found in *Integrated Thermal Treatment System Study - Waste Characterization Requirements for Treatment and Disposal of Heterogenous Wastes* by Dalton, et al. (1993).

The program should establish a waste characterization test facility. Characterization methods would be evaluated to determine whether acceptable levels of waste characterization could be economically achieved using:

- Nondestructive assay such as neutron activation analysis and real-time organic vapor analysis;
- Specialized neutron interrogation to identify point sources of materials such as mercury.
- Shredding and bulk storage of wastes to facilitate mixing prior to sample selection and chemical assay.

7.2.6 Packaging

A package system will be developed for the facility that includes onsite and offsite handling of treated and untreated waste. A key area requiring development is the bins used for transporting the untreated waste within the thermal treatment facility. Packages for the final waste form must also be defined. These packages must meet offsite transportation, storage, and disposal requirements. Typical tasks of this component would include:

- Determining the needs and supply containers required for transporting wastes and intermediate waste forms between sites.
- Developing and providing containers for moving special materials (e.g., mercury adsorbent carbon canisters) within the facility.
- Developing performance-oriented packaging for transporting treated waste to disposal sites.

7.2.7 Size Reduction

A Size Reduction Task Force would be established within the project. It would be the responsibility of this task force to investigate and solve those problems associated with preparing the as-received waste for incineration. Methods for receiving the wastes and converting them into a form that can be introduced into the thermal treatment subsystem should be developed and tested. Typical tasks of this component would include:

- Developing (from information provided by commercial vendors) a device that will adequately shred the entire range of solid wastes in the inventory.

- Developing the process required to feed the entire range of liquids to the incineration subsystem.
- Developing the process required to feed the entire range of sludges to the incineration subsystem.

Shredding tests should be performed on simulated waste to evaluate shredding capabilities and specifications. The task group would be formed to plan and execute the shredding tests and determine the specifications for future shredding equipment, including the adaptations required to meet radioactive handling requirements.

Personnel from the Size Reduction Task Force would evaluate prior experience with the cryofracture of waste and determine whether technology development should be carried forward to provide a backup technology, particularly to support organic destruction technologies that require finely shredded feed (Phase 2 technologies such as supercritical water oxidation and molten salt oxidation).

7.2.8 Vitrification

The program should establish a Vitrification Task Force to evaluate and develop vitrification technology for use as both primary incineration and as primary stabilization. Typical tasks of this component would include:

- Performing bench-scale tests, as needed, to select one or two vitrifier designs for the demonstration facility.
- Testing one or more vitrification technologies in the demonstration facility.
- Optimizing vitrification technology for the primary stabilization subsystem.
- Determining the effect of occluded carbon on the production of a satisfactory glass waste form.
- Analyzing the effect of inorganic salts on vitrification processes.

7.2.8.1 Establish A Vitrification Development Facility. A vitrification development facility should be established whose primary focus would be understanding, predicting, and controlling the fate of RCRA metals and radionuclides as a function of the following parameters:

- **Melter temperature.** Thermodynamics show that reactions in which oxides are reduced to primary metals are favored at higher temperature and that primary metal vapor pressures increase with temperature. Existing codes such as SOLGASMIX, STEPSOL, and PYROSIM can be used to arrive at preliminary predictions. These should be used as a guide to design tests of vitrification units for the effect of temperature. Melter temperatures will also affect the volatility of radionuclides, but the extent is unknown.
- **Slag or glass composition.** Scoping crucible studies can be done to determine whether heavy metal retention is influenced by melt chemistry. If effects are found, then the favored compositions should be considered for vitrification flow sheet tests.
- **Carbon content of ash.** The ability to burn out carbon from the vitrification unit should be determined. Vitrification tests using an oxygen lance should be run with carbon in the feed. The extent to which carbon in the melter compromises the final waste form or complicates melter operation should be evaluated.
- **Redox conditions of melt.** Reducing conditions can promote volatilization of metals. Small-scale melter tests and crucible studies can be used to determine volatility. Release of metal compounds as a function of reducing conditions should be evaluated.
- **Cold cap conditions.** A cold top of incoming waste can capture RCRA metals. Melter tests with and without a cold top can be conducted to determine what effect a cold cap has on metal volatility. Melters should be evaluated to determine which types can be used to produce a stable cold cap.
- **Dry versus liquid feeding.** Tests with dry feeding versus liquid feeding can be done to determine impact on metal volatility. This work should be preceded by compiling and evaluating existing data from high-level waste programs at West Valley Demonstration Project, Savannah River Site, and Hanford Site.

- **Melter configuration and type.** Melters to be considered are the fixed-hearth plasma arc, AC and DC electric arc, centrifugal hearth plasma arc, and joule-heated melter. The type of melter can influence metal volatility. Off-gas emissions data need to be collected on melter systems being considered for vitrifying ash and sludge. This needs to be investigated in combination with cold cap effects.

Final waste form issues to be considered and evaluated at the vitrification development facility would include:

- **Treating metals in the reduced or oxidized form.** This involves choosing between stabilizing the metals as oxide in the slag or as metal. It may be advantageous to oxidize the RCRA metals to reduce their volatility and thereby assure compliance with land disposal restrictions. Metal oxides can dissolve into the glass and are less leachable. Crucible melt tests and small melter tests can be done to address this using relevant mixed waste compositions.
- **A study of thermodynamics of slag and metal thermochemistry.** Thermodynamic data would be surveyed to better understand the chemistries of slag and metal. Operating temperatures, redox conditions, and compositions can be optimized.

Melter design and operation issues that could be examined at the vitrification development facility include:

- **The range of feed compositions and physical properties.** The characteristics of the waste to be treated by vitrification, i.e. its size distribution, shape, density, and moisture content, should be optimized.
- **Electrode materials.** For Joule-heated melters, the corrosion and wear performance of electrode materials such as graphite, Inconel, molybdenum, and others, should be evaluated.
- **Corrosion of refractory materials.** Refractory materials designed to resist the effects of molten metal, basic slags (containing MgO or CaO), and acidic slags (SiO₂-bearing) should be evaluated. Refractory coatings applied using plasma sprays should be investigated for improved performance.

- **Maintenance requirements.** Evaluate options to minimize vitrification equipment maintenance in radioactive applications.
- **Metal withdrawal and management.** The current approach at the U.S. Bureau of Mines arc melter is to use an oxygen lance to melt the plug and drain the melter. This may not be the best option for radioactive service. Remote alternatives such as slide gates and freeze valves need to be evaluated. Also, oxidization of metals in the melter or arc furnace should be considered.
- **Evaluate Energy Sources.** Electrical melters should be compared with combustion melters. Particular attention should be paid to maintenance issues.

Issues related to using the melter for primary treatment and stabilization that could be addressed at the vitrification development facility would include:

- **Completeness of combustion.** The extent to which oxygen reacts with the pyrolyzed material, and with carbon within the slag or on the melted slag surface, should be evaluated.
- **Effect of cold cap during combustion.** A cold cap serves to keep volatile metals in the slag. However, gas release during combustion may interfere with the integrity of the cold cap. Testing to determine the dynamics and stability of the cold cap during combustion should be performed.
- **Ability to feed bulk metals and barrels.** There is a need to evaluate feed types and size distribution. The ability of various vitrification configurations to accommodate bulk objects and metals needs to be assessed.
- **Evaluate need to shred incoming waste.** Shredding offers the potential for more homogenous feed and more stable feed rates. Melter operational advantages need to be weighed against the added difficulty of shredding to determine its role in mixed waste treatment.
- **Viability of metals as a final waste form.** Alloys produced by metal melting in a reducing atmosphere during vitrification should be tested for compliance with land disposal restrictions

using the TCLP. Leaching of radionuclides also should be considered through standardized leaching (e.g. MCC-1) and corrosion tests.

- **Glass development or slag composition development to optimize leaching properties and waste loading (volume reduction).** Optimal glass or ceramic compositions should be determined through crucible melt studies.
- **Leach tests and behavior of waste form in disposal environment.** The relationship among data obtained through various standardized tests (e.g. PCT, MCC-1, and the American Nuclear Society tests), fractional release rates in a burial setting, and performance assessment methods should be determined. Radionuclide release tests should be related and standards should be set. Also, testing and performance assessment should be applied to RCRA metals. It should be verified that metal leach rates do not produce adverse health effects. Windows of acceptance (i.e., performance goals) and potential use of an improved final waste form should be defined to improve margins of public acceptance, performance assessment, and product variations.

7.2.8.2 Optimize Vitrification Of Bottom Ash And Fly Ash. The vitrification process should be optimized to produce an acceptable waste form from bottom and fly ash either individually or in combination. This work will determine the process' tolerance for variability in ash feed composition and the feed composition ranges that are acceptable (feed includes contaminated soils from DOE sites).

7.2.8.3 Offgas Characterization. The characteristics of offgas from vitrification, both with and without PICs in the ash, should be confirmed. In addition, the vitrifier's ability to handle PICs from ash from a pyrolyzer, as opposed to a conventional incinerator, should be examined.

7.2.8.4 Optimize Melter Design. Melters designed to accept shredded combustible waste directly charged to the melter should be tested. Such a melter would constitute the total thermal treatment unit at small-capacity sites. In addition, this task would evaluate the potential for a mobile unit that would be readily transportable from one site to another.

7.2.8.5 Evaluate The In-Can Melter Concept. The in-can ash melter concept should be field tested to evaluate its potential for directly supporting incinerators. Variations in configuration combining a close-coupled hearth and in-can melting arrangement should be evaluated. The feasibility of using in-

can melters at sites with low volumes of waste and a mobile in-can melter system should also be evaluated.

7.2.9 Alternative, Low-Temperature Waste Form Stabilization

An Alternative Stabilization Task Force should be established within the program. It would be the responsibility of the task force to develop and test stabilization methods other than vitrification for solid waste streams produced by the thermal treatment and APC subsystems. Typical tasks of this component would include:

- Bench-scale testing of formulations for primary and secondary stabilization.
- Testing and documenting the long-term durability of the waste forms produced by these processes.

The program should establish an alternative waste stabilization facility that would carry out tasks associated with the development and evaluation of stabilization methods other than vitrification. These tasks would address both polymer stabilization issues and durability testing methods.

7.2.9.1 Polymer Stabilization. The program should evaluate and develop polymer stabilization techniques to encapsulate wastes in sulfur cement, polyethylene, sulfur polymer cement, or polymer materials such as those manufactured by Dow Chemical Company. This component of the program would also include research and development on waste formulations, the relative merits of continuous extrusion and batch processes, the effects of carbon in ash, and the longevity of the final waste form.

7.2.9.2 Stabilization Of Special Materials. Methods for the stabilization and disposal of special materials should be developed. Particular attention should be paid to the problems associated with mercury and lead. The capability of polymer stabilization to immobilize mercury waste should be evaluated.

7.2.10 Waste Analysis

A Waste Analysis Task Force should be established by the program to identify or develop the analytical methods or instrumentation required by other components of the program. Much of this work

could be coordinated with the EPA laboratories in Las Vegas and Cincinnati. Typical tasks of this component would include:

- Developing and testing analytical methods and techniques for real-time measurement of stack discharges. Such techniques are currently unavailable.
- Developing improved methods of determining both the composition and quantity of compounds and components in various gas streams.

A major subgroup of the Waste Analysis Task Force would be responsible for identifying or developing analytical methods and instrumentation required. After determining the requirements, this group would identify the established methods and available instrumentation for meeting these needs. In particular, the group should investigate competing vendor instrumentation for on-line, real-time analysis for particulates (both total concentration and speciation), TOC, and acid gases. Where methods or instruments are not available, methods should be developed.

The need for real-time monitoring is demonstrated by inclusion of a delayed offgas release concept in this study. The need for holding, testing, and then releasing offgas is based on not being able to state with confidence, in real time, that the gas has been cleaned to acceptable levels. This issue is mitigated with real-time monitors, which have the additional advantages of being used for operation control and to demonstrate regulatory compliance.

Monitors must be in place for radioisotopes, combustibles, dioxins, and toxic metals (especially mercury).

In addition, this task force would determine the feasibility of assaying final waste forms for TRU content, as compared with measurements of the ash. The task force would also evaluate on-line instruments for measuring particulate matter and implement improvements in reliability and accuracy as needed. Laser sampling techniques for total particulate and for particulate characteristics are of special interest.

7.2.11 Program Integration

The program integration component, using a systems engineering approach, will maintain cognizance of the progress in the thermal treatment research program, conduct trade-off studies, coordinate the development and test programs, and act as an agent to assure technical quality. A key aspect of the program integration component is to ensure that the demonstration program is directed in a manner that meets the goals and objectives set by the program. Key activities of this component would include:

- Compiling data from demonstration and test events in a manner that is useful to the architects and engineers designing the production facility. This includes documenting and updating such things as system requirements, flow sheets, mass balance calculations, facility conceptual designs, and test reports.
- Performing reliability, maintainability, and availability studies.
- Performing cost trade-off studies.
- Supporting NEPA documentation, and communication and public interface activities.
- Supporting regulatory and permitting agency interface activities.
- Preparing safety analysis reports.
- Organizing peer reviews of research plans and results.
- Supporting program management, including task, budget, and schedule controls.

Thermal treatment is specified for many large, complex waste management projects currently being considered within the DOE Complex. An overwhelming amount of work is being undertaken by DOE sites. The expertise of the ITTS program could be used to quickly and efficiently integrate development data with the design of future thermal treatment systems that would best fill the client project's requirements.

7.2.11.1 Regulatory Agency Involvement. The regulatory agencies should be involved from the start of planning and testing. The characterization facility was noted as an example of situations in which the program could work with the regulators to determine a reasonable approach to handling DOE solid wastes.

7.2.11.2 Mobile Treatment Systems. The program should consider the range of wastes and the types of mobile units that are appropriate for sites with small volumes of waste. In this effort, the program should work with the Western Governors Association, state regulators, and EPA regional regulators to obtain permits for the use of mobile units for several locations, thereby saving on NEPA costs, permitting costs, etc.

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Appendix A

System Requirements

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Appendix A

System Requirements

Appendix A presents the system requirements, which are key elements of system evaluation and comparisons.

A-1. REGULATORY AND PERMITTING REQUIREMENTS

A-1.1 Nuclear Regulatory Commission Regulations

The Nuclear Regulatory Commission (NRC) authority under the Atomic Energy Act applies only to commercial facilities.

NRC's authority in regulating nuclear emissions is under the Atomic Energy Act of 1954, 42 USC 2011, and the Energy Organization Act of 1975, 42 USC 7101. NRC implements their regulations through 10 CFR Parts 20, 30, 40, 51, and 70.

A-1.2 National Environmental Policy Act

It is assumed that a full environmental impact statement will be needed for the integrated thermal treatment facility.

NEPA requirements are an integral part of any project planning process and are set forth in 42 USC 4330, 40 CFR 1500, and DOE Order 4700.1. NEPA is intended to ensure that every proposed action (in this case construction of a new thermal treatment facility) has been reviewed for significant effects to the quality of the human environment and that harmful effects of the environment have been minimized.

A-1.3 Toxic Substances Control Act

It is assumed that the main thermal unit in the integrated thermal treatment facility must conform to TSCA.

Polychlorinated biphenyl (PCB) waste should be thermally treated in accordance with operating requirements set forth in 40 CFR 761.60-761.70. These requirements will be written into a TSCA permit, which is supplementary to the permits required under RCRA and the Clean Air Act.

A-1.4 Comprehensive Environmental Response, Compensation, and Liability Act

It is assumed that the integrated thermal treatment facility will process only limited quantities of the waste covered by the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) but all of the RCRA waste.

CERCLA regulates most of the buried waste within DOE installations. Current plans call for the disinterment of most of this waste. All stored wastes at DOE installations comes under the purview of RCRA.

A-1.5 Resource Conservation and Recovery Act

A-1.5.1 Characteristic and Listed Hazardous Wastes

In this study it is assumed that listed waste will be treated by the thermal treatment facility. Characteristics waste should be pretreated if necessary and should be treated by an appropriate subsystem.

Section 3001 of RCRA gave the EPA a statutory mandate to identify and regulate as hazardous those solid wastes that could pose a threat to human health and the environment. Solid wastes that exhibit a characteristic or are listed must also be properly managed as hazardous wastes under RCRA Subtitle C, unless excluded from regulation or excluded from the definition of hazardous waste.

Regardless of whether the waste is listed or not, the generator must determine if the waste exhibits any of the four characteristics of hazardous waste by either (1) testing the waste or (2) applying engineering/process knowledge of the hazardous characteristic based on the materials or the processes used (§262.11(c)). The characteristics of hazardous waste are ignitability (§261.21), corrosivity (§261.22), reactivity (§261.23), and toxicity (§261.24).

A-1.5.2 Derived-From Rule

Management of secondary wastes shall be according to the EPA "derived from" rule.

The EPA has also implemented "mixture" and "derived from" rules to manage the residues from listed wastes. However, a recently successful court challenge to these "mixture" rules has prompted EPA to consider concentration-based exemption criteria for these residues. The "derived from" rules or some version of it will have significant impact on the management of secondary waste from the integrated thermal treatment facility.

A-1.5.3 Land Disposal Restrictions

In this study, it is assumed that residue from treatment of all waste is stabilized to meet the concentration-based extraction test (TCLP). This requirement is also a part of DOE Order 5820.1A.

On November 8, 1984, the Hazardous and Solid Waste Amendments (PL-98-616) became effective. EPA was required to establish treatment standards for all listed and hazardous waste destined for land disposal. Before these wastes can be disposed of (buried in a landfill) they must be treated to conform with applicable treatment standards.

Typically, treatment requirements are concentration based (40 CFR 268.41), according to which the hazardous constituents in question (in an extract of the waste) cannot exceed established threshold levels. In addition to concentration-based standards, technology-based standards are permitted for certain types of waste (40 CFR 268.42). These treatment standards were determined by assuming that wastes are treated using the best technology currently available for each waste type. These technologies are called the best demonstrated available technology. Unlike listed wastes, characteristic wastes can be reclassified as nonhazardous if they can be treated to remove the characteristic hazard. These wastes may then be buried in any municipal waste landfill. For DOE waste, this means that characteristic waste after treatment can be disposed of in existing low-level waste burial sites.

Listed waste will remain hazardous even after treatment. It must be disposed of in an interim status or newly permitted RCRA-conforming Subtitle C landfill. Such a landfill must have liners to

prevent waste migration, a system for collecting and removing leachate, and stormwater run-on and run-off control as discussed in the design and operating requirements in 40 CFR §§264/265.301 and 265.302.

Containerized ignitable wastes, however, may be placed in landfills provided that they are protected from any materials or conditions that could cause them to ignite (i.e., avoiding heat, providing a daily cover of soil or noncombustible material [§§264/265.312(b)]).

A-1.5.4 Delisting

Any waste stream that might be subject to delisting should be pursued according to the following requirements.

Delisting is used for listed wastes that have been treated and no longer pose a threat to human health or the environment. The intent behind delisting is to allow an exclusion pathway for the waste and to become regulated as nonhazardous (solid waste) if the final form of the listed waste does not exhibit characteristics of hazardous waste. In this study, some of the secondary waste streams are investigated for potential delisting.

If not delisted, the waste could pose several problems. Disposal construction costs could be higher, due to the need for special designs and complications associated with the long-term permitting process for RCRA Subtitle C landfills. Dual EPA/DOE oversight is required for mixed waste RCRA-type landfills. The long-term oversight (monitoring and maintenance) requirements for RCRA landfills are assumed to be the same as the DOE requirements for LLW facilities.

There are three major steps in the petition process: (1) submitting the petition, (2) technical review, and (3) promulgating the decision. Delisting is a full rulemaking process and typically takes about two years.

Anyone may submit a petition to delist a waste generated at a particular facility. Separate petitions must be submitted for waste generated at different facilities, even if the contributing processes and raw materials are similar. Upon receiving a petition, EPA will first confirm whether the petitioned waste is listed as a hazardous waste, and therefore, eligible for an exclusion.

During the technical review, EPA will first determine whether the waste meets all required criteria. Specifically, the waste (1) must not meet the criteria for which it was listed; (2) must not exhibit any of the hazardous waste characteristics; (3) must not exhibit any additional factors, including additional constituents, that would cause the waste to be a hazardous waste (unless EPA determines that such factors do not warrant characterizing the waste as hazardous); and (4) must equal or exceed the regulatory criteria for land disposal. Once the technical review is completed, EPA will decide whether to grant or deny the petition.

To reclassify a waste as nonhazardous and to delist it, EPA needs information from the petitioner assuring that several criteria are met. The waste (1) must not meet the criteria for which it was originally listed; (2) must not exhibit any of the hazardous waste characteristics; (3) must equal or exceed the regulatory criteria for land disposal; and (4) must not exhibit any additional properties of hazardous waste or otherwise pose a threat to human health or the environment.

Waste and waste management history information must be presented, including the type and volume of waste, waste management practices (past, present, and future), and the basis for waste listing. The physical form of the petitioned waste (e.g., sludge, liquid, solid, ash) must be described. It must

be specified whether the waste has been generated in the past or whether it is presently being generated. It must be specified how the waste will be managed if the delisting petition is granted. The petitioner should provide an estimate of the waste volume petitioned for delisting.

The petitioner should describe operations, process and materials contributions to the petitioned waste, and current waste management operations.

An analytical plan must be prepared that includes a complete list of the hazardous constituents of concern in the waste and a plan for waste testing. This section should precede the sampling plan.

Analytical data must be collected from a sufficient number of representative samples (no fewer than four). These data must be collected over a sufficient period of time to represent the variability and uniformity of the petitioned waste. EPA will review the information on waste sampling to determine if (1) the samples sufficiently represent the variability or uniformity of the petitioned waste; (2) the waste sampling was conducted by qualified personnel; and (3) quality control protocol was followed.

A-1.5.5 RCRA Permitting Requirements

Thermal units shall be permitted for RCRA regulations as described below.

A-1.5.5.1 General. 40 CFR 270.62 contains requirements for hazardous waste thermal treatment permits. It requires three things: (1) a description of conditions necessary to operate in compliance with performance standards of 40 CFR 264.343 during the permit period, (2) a description of restrictions on waste constituents, waste feed rates and operating parameters as described in 40 CFR 264.345, and (3) a proposal for a trial burn plan.

Pursuant to 40 CFR 270.62(b)(5), EPA will approve a trial burn if three conditions are met: (1) it is likely the performance standard for thermal treatment required by 40 CFR 264.343 can be met, (2) the trial burn will not present an imminent hazard to human health or the environment, and (3) the trial burn will help determine operating requirements of the thermal treatment unit under 40 CFR 264.345. EPA will then review the trial burn results and set the operating requirements in the final permit, in accordance with 40 CFR 264.345. Details of the complete EPA Hazardous Waste Permit Program can be found in 40 CFR 270. The final operating permit (issued by EPA in conjunction with the applicable state), will specify such parameters as operating conditions, waste feed composition, stack emission limits, monitoring requirements, and waste feed rate.

A-1.5.5.2 RCRA Operating Permits Needed for Thermal Treatment Units. The permit issued by EPA will specify a set of operating requirements. These are specified on a case-by-case basis and largely based on data from the trial burn. These requirements are discussed in 40 CFR 264.345

Each set of operating requirements will specify the composition of the waste feed, including acceptable variations in the physical or chemical properties of the waste feed that will not effect compliance with the performance requirement of Part 264.343 to which the operating requirements apply. For each such waste feed, the permit will specify acceptable operating limits on several conditions. These conditions include the level of CO in the stack exhaust, waste feed rate, combustion temperature, an appropriate indicator of combustion gas velocity, allowable variations in thermal treatment system design or operating procedures, and other operating requirements necessary to ensure that the performance standards of Part 264.343 are met.

During startup and shutdown of a thermal treatment unit, hazardous waste must not be fed into the thermal treatment unit unless the thermal treatment unit is operating within the conditions of operation (temperature, air feed rate, etc.) specified in the permit.

Fugitive emissions from the combustion zone must be controlled by one of three means: (1) keeping the combustion zone totally sealed against fugitive emissions, (2) maintaining a combustion zone pressure lower than atmosphere pressure, or (3) an alternate means of control. The alternate means of control must be demonstrated (with Part B of the permit applications) to provide fugitive emissions control equivalent to maintenance of combustion zone pressure lower than atmospheric pressure.

The thermal treatment unit must be operated with a functioning system to automatically cut off waste feed when operating conditions deviate from limits established by this section of 40 CFR.

The thermal treatment unit must cease operation when changes in waste feed, thermal treatment unit design, or operating conditions exceed limits designated in its permit.

A-1.5.6 RCRA Permit Trial Burn Requirements

Thermal treatment shall be subject to trial burn as specified below:

A-1.5.6.1 Requirements for Trial Burn Plan. 40 CFR 270.62(b)(2) describes information that must be included in a trial burn plan.

Each waste, mixture of waste, or mixture to be treated must be described. The description must include heat value in the form and composition in which the waste will be treated, viscosity (or description of physical state), and identification of 40 CFR 261 (Appendix VII, attachment) hazardous constituents and their approximate quantities.

Engineering features must be described including linear dimensions (including cross sectional area of thermal treatment chamber); auxiliary fuel (type/feed); automatic waste feed cutoff system(s); stack gas monitoring and control equipment; capacity of prime mover; burner design; construction materials; and locations and descriptions of temperature, pressure, and flow indicators and control devices.

Sampling and monitoring procedures must be described including location, equipment to be used, sampling frequency, and analytical procedures to be used.

Test protocol (duration and quantity) must be described in detail for each waste to be treated.

Planned operation conditions for any pollution control equipment must be described.

Procedures for rapidly stopping waste feed, shutting down the thermal treatment unit, and controlling emissions in the event of equipment malfunction must be described.

Temperature ranges, waste feed rate, and gas velocity that will be varied (affects destruction and removal efficiencies) must be described.

A-1.5.6.2 Required Trial Burn Information. Data on numerous parameters must be collected during a trial burn.

The trial burn principal organic hazardous constituents (POHC)s in the waste feed to the thermal treatment unit must be analyzed and quantified.

The exhaust gas must be analyzed quantitatively for the concentrations and mass emissions of the trial POHCs, O₂ and hydrogen chloride (HCl).

Scrubber water (if any), ash residues, and other residues must be analyzed quantitatively for the purpose of estimating the fate of the trial POHCs.

DRE must be calculated in accordance with the DRE formula specified in Part 264.343(a) of this chapter.

If emissions of HCl exceed a rate of 1.8 kilograms per hour (kg/hr) (4 pounds per hour [lbs/hr]), then HCl removal efficiency must be calculated in accordance with 40 CFR 264.343(c).

Sources of fugitive emissions and their means of control must be identified.

Average, maximum, and minimum temperatures and combustion gas velocity must be measured.

Carbon monoxide in the exhaust gas must be measured continuously .

A-1.5.7 RCRA Monitoring Requirements

According to 40 CFR 264.347, the following monitoring operations must be undertaken while thermally treating hazardous wastes.

Combustion temperature, waste feed rate, and the indicator of combustion gas velocity specified in the facility permit must be monitored on a continuous basis.

CO must be monitored on a continuous basis at a point in the thermal treatment unit downstream of the combustion zone and prior to release to the atmosphere.

Upon request by the regional administrator, sampling and analysis of the waste and exhaust emissions must be conducted to verify that the operating requirements established in the permit achieve the performance standards of 40 CFR 265.343.

The thermal treatment unit and associated equipment (pumps, valves, conveyors, pipes, etc.) must be subjected to thorough visual inspection, at least daily, for leaks, spills, fugitive emissions, and signs of tampering.

The emergency waste feed cutoff system and associated alarms must be tested at least weekly to verify operability, unless the applicant demonstrates to the regional administrator that weekly inspections will unduly restrict or upset operations and that less frequent inspection will be adequate. At a minimum, operational testing must be conducted monthly.

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A-1.6 Clean Air Act

A-1.6.1 Hazardous Air Pollutants

Section 112(c) of the Clean Air Act requires that all source categories, including thermal treatment, be identified and that technology-based emission standards be promulgated for each category.

RCRA metal emission standards for boilers and industrial furnaces are risk based. Stack rate emissions are limited to levels that provide an adequate margin of safety when dispersed by air currents between the stack and the nearest maximally exposed individual.

The maximum achievable control standards are to be based on the best technology currently available for the source category. Thermal treatment units have now been established as a source category.

A-1.6.2 Permits

Previously, operating permits were not required by federal law, though many state laws provided for such permits. Permits are now required for all major new sources. This permit process requires determining whether the facility is to be located in an area where national ambient air quality standards are met. It also requires engineering justification of facility emission rates, new source air quality impacts, and assessment of other risks to the environment. As a result, specific operating limits might be imposed.

A-1.6.3 National Ambient Air Quality Standards

Section 109(a) of the Clean Air Act (Ref 3) covers the National Ambient Air Quality Standards. 40 CFR 50 standards codified to date are shown in Table A-1.

Table A-1. National ambient air quality standards.

Pollutant	Averaging Period	Primary ($\mu\text{g}/\text{m}^3$)
CO	8 hours	10,000 (9 ppm)
	1 hour	40,000 (36 ppm)
Lead	3 months	1.5
Nitrogen dioxide	1 year	100 (0.053 ppm)
Ozone	1 hour	235 (0.12 ppm)
Particulate matter smaller than 10 microns	1 year	50
	24 hours	100
Sulfur dioxide	1 year	80 (0.03 ppm)
	24 hours	365 (0.14 ppm)
Beryllium	30 days	0.01 $\mu\text{g}/\text{m}^3$ (or 10 g/24 hours)

A-1.7 Clean Water Act

The Clean Water Act contains no standards for thermal treatment unit effluents. It will be several years before they are promulgated for review and comment.

A-2. PROPOSED EMISSIONS LIMITS

Tables A-2 and A-3 show emission limits for nonmetals and metals, respectively, for ITTS design. The bases for selection of these limits are discussed below.

A-2.1 Current Limits

According to 40 CFR 264.343, thermal treatment units, operated in accordance with the permit requirements, must meet the following performance standards.

A-2.1.1 Destruction Removal Efficiency

Destruction removal efficiency of 99.99% must be achieved for each POHC designated in the permit.

A-2.1.2 Dioxin

Destruction removal efficiency of 99.9999% must be achieved for dioxin type waste. This efficiency must be demonstrated on surrogate POHCs that are more difficult to treat than tetra-, penta-, and hexachlorodibenzo-p-dioxins and dibenzofurans.

A-2.1.3 Hydrochloric Acid

If the thermal treatment unit produces stack emissions of more than 1.8 kg/hr (4 lbs/hr) of HCl, then HCl emissions must be controlled. The rate of emission should be no greater than the larger of either 1.8 kg/hr or 1% of the HCl in the stack gas before the gas enters any pollution control equipment.

A-2.1.4 Particulate Matter

The thermal treatment unit treating hazardous waste must not emit particulate matter in excess of 180 mg per dry standard cubic meter (mg/dscm) (0.08 grains per dry standard cubic foot) when corrected for the amount of oxygen in the stack gas. (This will normally be held at 0.015 grains based on Municipal Waste Incinerator Standards and recent EPA policy.)

A-2.1.5 RCRA Emission Standards for Thermal Treatment Units

POHCs (40 CFR 264.342) are the primary indicators used by EPA in determining whether complete combustion has been obtained. One or more POHCs will be specified in the thermal treatment unit's permit from those listed in 40 CFR, Part 261, Appendix VII.

EPA has established a DRE of 99.99% for all POHCs except dioxins and PCBs.

EPA regulation of metals emissions will extend to hazardous waste thermal treatment units, under the omnibus provision, from a ruling made for treating hazardous wastes in boilers and industrial furnaces.

Table A-2. Proposed emission limits for nonmetals.

Pollutant	Regulatory limit	Averaging period of emission limit	Origin of limit (see notes)	Proposed level to be used by ITTS working group
CO	100 ppmv from thermal treatment unit		a,b	100 ppmv from thermal treatment unit
	35 ppmv from stack 9 ppmv from stack	1 hour 8 hour	k	35 ppmv from stack (1 hr period) 9 ppmv from stack (8 hr period)
Total hydrocarbons	20 ppmv		c	20 ppmv
Sulfur dioxide	100 $\mu\text{g}/\text{m}^3$	1 year	k	100 $\mu\text{g}/\text{m}^3$
Ozone	235 $\mu\text{g}/\text{m}^3$	1 hour	k	235 $\mu\text{g}/\text{m}^3$
Particles smaller than 10 microns	34 mg/m^3		d	34 mg/m^3
Sulfur dioxide	80 $\mu\text{g}/\text{m}^3$ 365 $\mu\text{g}/\text{m}^3$ 1,300 $\mu\text{g}/\text{m}^3$	1 year 24 hours 3 hours	k	365 ng/m^3 (24 hr period)
PCB	DRE of 99.9999%		f	DRE of 99.9999%
Radionuclides	10 mrem/yr	1 year	j	10 mrem/yr
POHCs	DRE of 99.99%		e,f	DRE of 99.999%
Dioxins	30 ng/m^3		g	0.1 ng/m^3
HCl	1.8 kg/hr	1 hour	h	1.8 kg/hr
Chlorine (Cl_2)	0.001 g/s		a,i	.001 g/s
Radon 222	3×10^{-9} $\mu\text{Ci}/\text{ml}$	1 year	l	3×10^{-9} $\mu\text{Ci}/\text{ml}$

Notes (a through l) on origins of limits are listed on the next page.

Table A-2. Continued.

- a. It is EPA's intent to extend the Boiler and Industrial Furnace (BIF), rule 56 FR 35 pg 7134-39, to hazardous waste thermal treatment units. This limit comes from the BIF rule. (See Section 2.3.)
 - b. 40 CFR 266.104, CO is corrected to 7% oxygen, dry basis. If CO is above 100 ppmv, the level of total hydrocarbons cannot exceed 20 ppmv. (See Section 2.3.)
 - c. 40 CFR 266.104
 - d. 40 CFR 264.344 currently calls for 180 mg/dscm. However, it is EPA's intent to lower this limit to at least 34 mg/dscm. Some states have already taken this approach in granting permits. (Also see Section 2.6.)
 - e. 40 CFR 264.343 (also see Section 2.5.)
 - f. The Clean Air Act, as interpreted by some states, is requiring an aggregate risk for carcinogens of 1×10^{-6} . By requiring a destruction removal efficiency of 99.999% instead of 99.99%, the spirit of these new requirements should easily be met.
 - g. The proposed European Economic Community limit is 0.1 ng/m^3 . Germany and the Netherlands have already adopted this standard. This is a technology-based standard, and technology is available to meet this low level. EPA, after lifting its current moratorium on permitting of thermal treatment units, can be expected to move down to substantially lower levels in the issuance of future permits. Currently, there is no set limit for dioxins, except for municipal waste thermal treatment units, where it is 30 ng/m^3 . The European Economic Community goal appears to be reasonable for the ITTS. (Also see Section 2.1.)
 - h. 40 CFR 264.343 restricts HCl to 1.8 kg/hr or 1% of the quantity of HCl in the stack before entering air-pollution-control devices, whichever is larger. As a conservative measure, the lower value was selected for the ITTS. (Also see Section 2.8.)
 - i. The EPA limits for chlorine and metals are risk-based emission limits in g/s. They were back calculated from maximum acceptable inhalation exposure doses (in $\mu\text{g/m}^3$) coupled to the expected dilution factor occurring between the stack outlet and the nearest maximally exposed individual. For the purpose of this study, it was assumed that the thermal treatment unit would have a 24-m-tall stack and would be located in a rural area having simple terrain. These risk-based limits for carcinogens are based on a cancer risk of 1×10^{-5} to the maximally exposed individual. Non-carcinogenic metals were based on the maximally exposed individual not being exposed to a demonstrable effect level times an arbitrary safety factor. For the purpose of the ITTS, risk-based limits for metals have been arbitrarily reduced by a factor of 10 to decrease the risk (for carcinogens) from 1×10^{-5} to 1×10^{-6} . This is consistent with EPA's concerns that risk-based standards allow too much metal to leave the stack and with EPA's long-term preference for adopting more-rigorous, technology-based standards.
 - j. 40 CFR, 61.92 restricts exposure of the public to an effective equivalent dose of 10 mrem/year.
 - k. National Primary and Secondary Ambient Air Quality Standards, 40 CFR 50.
 - l. 10 CFR 20, Appendix B. Limit applies at the boundary between the restricted and unrestricted areas. Concentration at stack may be higher depending on dilution, dispersion, and decay between stack and unrestricted area.
-

Table A-3. Proposed emission limits for metals.

Pollutant	EPA Limit	Averaging Period of Emission Limit	Origin of Limit (See Notes)	Proposed Level to be Used by ITTS Working Group (g/s averaged over 1 hour)
Antimony	0.061 g/s	1 hour	a	0.0061
Barium	10.0 g/s	1 hour	a	1.0
Nickel	0.0084 g/s	1 hour	a	0.00084
Mercury	0.016 g/s	1 hour	a	0.0016
Selenium	0.80 g/s	1 hour	a	0.080
Silver	0.61 g/s	1 hour	a	0.061
Arsenic	0.00047 g/s	1 hour	a	0.0000471
Thalium chlorides	0.061 g/s	1 hour	a	0.0061
Cadmium	0.00111 g/s	1 hour	a	0.000111
Lead	0.0177 g/s 1.5 $\mu\text{g}/\text{m}^3$	1 hour annual	a,c	0.00177
Beryllium	0.000833 g/s 0.0001155 g/s	1 hour 24 hours	a,d	0.00008333
Chromium	0.0001666 g/s	1 hour	a,b	0.0000166

a. The EPA limits for chlorine and metals are risk-based emission limits in g/s. They were back calculated from maximum acceptable inhalation exposure doses (in $\mu\text{g}/\text{m}^3$) coupled to the expected dilution factor occurring between the stack outlet and the nearest maximally exposed individual. For the purpose of this study, it was assumed that the thermal treatment unit would have a 24-m-tall stack and would be located in a rural area having simple terrain. These risk-based limits for carcinogens are based on a cancer risk of 1×10^{-5} to the maximally exposed individual. Noncarcinogenic metals were based on the maximally exposed individual not being exposed to a demonstrable effect level times an arbitrary safety factor. For the purpose of the ITTS, risk-based limits for metals have been arbitrarily reduced by a factor of 10 to decrease the risk (for carcinogens) from 1×10^{-5} to 1×10^{-6} . This is consistent with EPA's concerns that risk-based standards allow too much metal to leave the stack and with EPA's long-term preference for adopting more rigorous, technology-based standards.

b. Based on hexavalent chromium.

c. 40 CFR 50.12, national primary air standard for lead.

d. National emission standard for hazardous air pollutants, 40 CFR 61.

For purposes of assessing health risks from toxic metal and organic emissions EPA has established a registry of oral intake reference doses.

A-2.1.5.1 Carbon Monoxide. Generally accepted combustion theory holds that low levels of CO in flue gas, combined with low excess oxygen levels, indicate a thermal treatment unit is operating at high combustion efficiency. EPA believes it is necessary to limit CO levels to levels that are indicative of high combustion efficiency because the precise CO level that indicates significant failure to destroy products of incomplete combustion and POHCs is not known. EPA requires no finite level for CO provided that the concentration of hydrocarbons in the stack gas does not exceed a good operating practice-based limit of 20 ppmv. Otherwise, the limit is 100 ppmv of CO.

A-2.1.5.2 Dioxin. No finite standard for dioxins had been set on hazardous waste thermal treatment units prior to the interim standard set in May 1993.

A-2.2 EPA Draft Strategy of 1993

Final guidance is being developed for conducting risk assessments. Future permitting will require that these be site specific and that full consideration be given to risks from indirect exposures. Particulates will be restricted to 34 mg/dscm, a standard that already applies to newly constructed municipal waste thermal treatment units.

A-2.3 DRE for POHCs

EPA generally believes that a DRE of 99.99% "is protective of risks posed by emissions of organic constituents in the waste under virtually every scenario of which the agency is aware."

A-2.4 Carbon Monoxide and Hydrocarbons

The final boiler and industrial furnace (BIF) rule, FR 56 (35)7155 (1991), sets CO levels of 100 ppmv as indicative of good combustion. This is a technology-based standard that guarantees adequate combustion conditions and minimizes risk. Good combustion means lower levels of products of incomplete combustion, which in turn means less potential human exposure to carcinogens. Likewise, continuous hydrocarbon monitoring is required. If the level is kept below 20 ppmv, it is assumed that good combustion efficiency has been achieved.

A-2.5 Particulate Matter Smaller than 10 Microns

EPA has clearly stated in its May 1993 draft strategy document that the omnibus provision will be used to limit particulates to at least 34 mg/dscm.

A-2.6 Metals

EPA has clearly indicated its intent to apply the boiler and industrial feed metal emission standards, 56 FR 35 p. 7131 et seq., (1991), to hazardous waste thermal treatment units using the omnibus provision.

A-2.7 HCl

40 CFR 264.343 limits thermal treatment unit emissions of HCl to 4 lbs/hr or no more than 1 % of the quantity of HCl in the stack gas before it enters APC equipment, whichever is greater.

A-2.8 Dioxins

The German and Dutch governments limit dioxins and furans (summing all tetra through octo dioxins and furans and using 2,3,7,8 tetrachloro - dibenzo -p - dioxin equivalents) to 0.1 nanograms per cubic meter (ng/m³). This level, strictly a technology-based standard, is achievable using carbon filtration techniques.

A-3. PROPOSED CHARACTERIZATION REQUIREMENTS

Each step of the thermal treatment process will require characterization, starting with the individual waste containers and ending with the final waste forms, offgas, and scrubber solids.

A-3.1 Pretreatment Characterization

A-3.1.1 Non-Destructive Drum Assay Techniques

Current drum assay procedures for radionuclides can have errors of $\pm 100\%$ at the threshold level of 100 nanoCuries per gram (nCi/g) between TRU waste and LLW. This accuracy should be adequate for characterizing input feed to a thermal treatment unit. There are no EPA requirements for radionuclides related to nondestructive assaying.

X-ray radiography can be useful in presorting waste before processing. X-ray radiography and nuclear scanning devices are available at several sites, including Idaho National Engineering Laboratory (INEL).

A-3.1.2 Chemical Analysis for RCRA Organics and Hazardous Metals

40 CFR 264.31 (Waste Analysis) states that "throughout normal operation the owner operator (of an thermal treatment unit) must conduct sufficient waste analysis to verify that waste feed to the thermal treatment unit is within the physical and chemical limits specified in the permit.

56 FR 35 p. 7171 et seq. specifically addresses ten of the metals under the BIF rule and indicates that each of these must be analyzed if expected in the waste.

During the trial burn certain characterization requirements should be met (see previous discussion on trial burn, Section A-1.5.6).

Some guidance in terms of detection limits that might be needed in the waste characterization analysis is provided in 47 FR 122 p. 27528 et seq., which states that EPA estimates that constituents in the waste feed in concentrations below 100 ppm will be routinely detected by stack gas analysis and that a waste concentration of 100 ppm "probably represents a lower limit beyond which a determination of a destruction removal efficiency of 99.99% will be difficult to document."

EPA does not discourage the use of characterization to define waste feeds into various groups, and suggests that, by narrowing the class of waste feeds, less stringent operating requirements for easily combusted wastes can be utilized (46 FR 15 p. 7670 et seq.)

40 CFR 265.341 (Waste Analysis) specifically requires descriptions of the following for thermal treatment unit feed wastes: heating value of the waste, halogen and sulfur content, and lead and mercury (unless there is written documented data showing their absence).

40 CFR 265.13 requires a written analysis plan that provides for a detailed chemical or physical analysis of a representative sample.

40 CFR 264.13 (General Waste Analysis) requires a detailed chemical and physical analysis before treatment of a representative sample. Historical information from a facility's records of analysis performed before the effective date of the RCRA regulations, or studies conducted on hazardous wastes generated from processes similar to that which generated the waste to be managed (treated) at the facility, can be used in complying with this requirement. FR 46 (15) 7669 states "that analysis of waste feed that will actually be burned is more important than analysis of wastes as they are received or stored prior to blending as waste feed." **This statement, in effect, strongly encourages compositing and blending of wastes before treatment!**

For the ITTS it is proposed that batches of waste sufficient for 24-hour burn campaigns be shredded, composited, and mixed and that a complete suite of EPA SW-846 analyses be performed on this composite mix.

A-3.1.3 Analytical Methods

EPA SW-846 should be adapted to analysis of alpha-contaminated mixed waste. Several DOE laboratories are in the process of improving analytical methods for these purposes.

Unless otherwise specified, chemical analysis should be done using Test Method for Evaluating Solid Waste, Physical/Chemical Methods, third edition, SW-846, November 1986.

Methods for conventional stack gas sampling should comply with 40 CFR 60, Appendix A.

A-3.2 Characterizing Residues from Treatment

A-3.2.1 Offgas

A meeting held May 25-27, 1993, in Las Vegas, Nevada, sponsored in part by EM-50, titled "Characterization for Treatment of Containerized Low-Level Wastes," is expected to result in a definitive overview of offgas characterization technology. The report resulting from this conference should be consulted for defining sampling of offgas from a DOE thermal treatment facility.

A-3.2.2 Scrubber Salts

Existing EPA SW-846 analytical methods should be used for analyzing scrubber solutions.

A-3.3 Characterizing Post-Treatment Wastes

A-3.3.1 Bottom Ash and Fly Ash

Radioassay of TRU content will be required. Routine methods are available that should be readily adaptable to ash wastes.

Analysis for salt content may be needed to reach decision on how to formulate for conversion to the final waste form. Routine analysis methods should suffice.

Analysis for RCRA metals will not be needed since it can be assumed that the waste will have levels of regulatory concern.

Analysis for total carbon may be required to show the absence of organics. If carbon is present in significant quantities, further analyses could be required (e.g., thermal desorption/GC-MS).

A-3.3.2 Final Waste Form

EPA will require analysis for toxics in accordance with the TCLP (40 CFR 261, Appendix II) to show that the treatment to create a final waste form is effective in reducing the level to that acceptable for burial in mixed waste facility (meets RCRA Subtitle C landfill requirements). Using this test, if the concentration of any contaminant does not exceed the concentration listed in the table, the waste is acceptable for disposal as LLW. DOE has not yet decided what tests are appropriate for showing the long-term stability of stabilized waste forms.

A-5. FUNCTIONAL REQUIREMENTS

A-5.1 Input Waste

ITTS shall treat the wastes types described in Table A-4. The nominal capacity of the system shall be as shown in Table A-5.

The input waste assumed in the ITTS study is mixed radioactive waste as defined in the 1993 mixed-waste inventory report by the DOE, including alpha-contaminated MLLW, which contains a variety of anticipated hazardous materials. Detailed media compositions should be obtained by contacting representatives of the DOE installations where the waste is stored and produced. If media compositions are not available from some installations, the total defined waste inventory should be normalized to account for the total mixed waste inventory identified by the DOE.

To ensure the safety of personnel, the system for treating alpha LLW and alpha MLLW should be designed to accommodate input waste with radioactivity levels of TRU waste, which is waste with radioactivity exceeding 100 nCi/g. The primary design requirement stemming from this requirement is triple containment for control of alpha contamination. For nonalpha MLLW standard design criteria for contact handled radioactive LLW should be sufficient.

Part of the ITTS study consists of parametrically varying the concentrations of TRU radionuclides to test how these affect the performance and life-cycle cost of the system for treating TRU waste.

All waste considered in the ITTS study is contact-handled waste. If high-activity waste inside shielded containers is found, it will be rejected and returned to its point of origin. Consequently, the

Table A-4. Sources and types of input waste from the ten largest DOE installations and their first treatment step within the ITTS.

Source, Medium	Quantity (kg)	Primary technology	Aqueous treatment	Lead recovery	Mercury treatment	Metal melter	Metal decontamination	Special treatment
<u>Lawrence Livermore National Laboratory</u>								
Low-level mixed wash waters	21,272		•					
Stabilized sludges and particulates	34,468	•						
Low-level mixed inorganic trash-3	9,931	•						
Low-level mixed filter cake	33,235	•						
Low-level mixed soil and sand	4,174	•						
Low-level mixed oils	39,212	•						
Low-level mixed halogenated solvent	8,437	•						
Low-level mixed oils	5,024	•						
Low-level mixed organic liquids	818	•						
<u>Rocky Flats Plant</u>								
Solar pond water/LLW mixed	45,425,000		•					
Acid/LLW mixed	9,975		•					
Cyanides/LLW-mixed	1,155							•
Cemented composite chips/LLW mixed (327)	181,200	•						
Solidified process solids/LLW mixed (806)	9,600	•						
Combustibles/LLW mixed	102,600	•						
Soil and cleanup debris-LLW mixed (374)	52,320	•						
Filters/LLW mixed	2,880	•						
Metal/LLW mixed	84,300			•				
Glovebox parts with lead/LLW mixed	13,600			•				
Glass/LLW mixed	2,200	•						
Leaded gloves/LLW mixed	5,400			•				
Insulation/LLW mixed	190	•						
Heavy metal (non-SS) LLW mixed	1,950					•		
Pondcrete	7,676,760	•						
Saltcrete	4,591,020							•
Solidified bypass sludge/LLW mixed	549,360	•						
Roaster oxide/LLW mixed (069)	223,290							•
Incinerator ash(LLW)-mixed	8,800	•						
Particulate - sludge/LLW mixed	4,900	•						
Electrochemical milling sludge	2,100	•						
Turnings/LLW mixed (IDC 142)	1,950					•		
Fluidized bed incinerator oil	98,640	•						
Organics discard level LLW mixed (533)	27,810	•						
Miscellaneous liquids/LLW mixed	18,145		•					

Table A-4. (Continued).

Source, Medium	Quantity (kg)	Primary technology	Aqueous treatment	Lead recovery	Mercury treatment	Metal melter	Metal decontamination	Special treatment
PCB (liquid)/LLW mixed	1,045	•						
<u>Los Alamos National Laboratory</u>								
Analytical laboratory waste - lead	9,600		•					
Acids	6,120		•					
Analytical laboratory waste - chromium	4,600		•					
Analytical laboratory waste - barium	2,500		•					
Caustics	1,200		•					
Solvent contaminated debris -F002	2,180	•						
Decontamination waste - mercury	210				•			
Solvent contaminated debris -F003	200	•						
Lead	489,900			•				
Debris - barium	36,240					•		
Debris - barium	14,160					•		
Scrap metal - cadmium	7,920					•		
Ignitable liquids	39,700	•						
Spent solvents -F003	12,960	•						
Spent solvents -F002	18,415	•						
Spent solvents -F005	8,640	•						
Spent solvents -F001	12,905	•						
Dewatered treatment sludges	269,900	•						
Reactive solutions	2,000							•
<u>Fernald Environmental Management Project</u>								
Uranyl nitrate solutions in tanks	923,351		•					
Rainwater from waste pit area	25,527		•					
Hydrofluoric acid	78,466		•					
PC 49896 Itek universal developer	509		•					
Contaminated sump water	2,607		•					
U-contaminated water	2,232		•					
Lab-generated waste, acid digestates	1,141		•					
Spent fixer	436		•					
Filter material - sand, gravel, flyash	152,727	•						
Contaminated soil and rocks	30,128	•						
Nonrecoverable trash	7,529	•						
Lead solder joints	5,588			•				
Impure thorium nitrate (solid)	1,473							•

Table A-4. (Continued).

Source, Medium	Quantity (kg)	Primary technology	Aqueous treatment	Lead recovery	Mercury treatment	Metal melter	Metal decontamination	Special treatment
Mercury-contam. floor tile and pipe insulation	821				•			
Contaminated metallic filter elements	825					•		
Contam. soil, rocks, bricks, and ceramics	2,158	•						
Roasted MgF_2 /other material	2,146							•
Elemental mercury (spill cleanup)	79				•			
Spill cleanups of oil and gas	83	•						
Grit blast	259,549	•						
Solidified furnace salts - nonchloride	91,901							•
Scrap U_3O_8 High F	383,697							•
Incinerator cinders	50,528	•						
U_3O_8 Rotexed Plant 8 furnace product	65,481							•
Roasted calcium-precipitated sump or	16,300	•						
Roasted off-site sump cake	13,286	•						
Furnace salt, nonchloride	9,838							•
Scrap salts	6,713							•
Furnace salt, chloride	12,771							•
Salt sludge, chloride	19,278							•
Sump cake	5,850	•						
Scrap salts and floor sweeping	2,160							•
U_3O_8 for reoxidation	2,858							•
Salt sludge, chloride	4,335							•
Scrap salts, high F	1,535							•
Scrap salts and floor sweepings	750							•
Process residues, trailer cakes	237	•						
Dust collector residues - high fluoride	404							•
Solvent sludge, trichlor, perchlor, etc.	79	•						
Salt sludge, chloride	353							•
Degreasing solvent	48,668	•						
Oil contaminated with solvents (Tank 5)	9,982	•						
Contaminated oil - insoluble	1,332	•						
1,1,1-trichloroethane still bottoms	6,440	•						
Used oil	4,379	•						
DAAP/solvent mixture	5,634	•						
Contaminated solvent	2,836	•						
Water/gas mixture tank #9	3,328		•					
Contaminated solvent - trichlor, perchlor	2,047	•						
Contaminated insoluble oil	2,199	•						

Table A-4. (Continued).

Source, Medium	Quantity (kg)	Primary technology	Aqueous treatment	Lead recovery	Mercury treatment	Metal melter	Metal decontamination	Special treatment
Methanol and cyclohexane mixture	1,653	•						
Contaminated oil, insoluble	2,095	•						
Contaminated insoluble oil	1,503	•						
Oil unknown generation	939	•						
Contaminated oil, insoluble gear oil	999	•						
Contaminated insoluble oil	1,154	•						
Lab waste, TCLP extract	1,260		•					
Bad paint from paint booth	397	•						
Clear dispersant, type H	89	•						
Nonchloride contaminated water or sump	524		•					
Biodenitrification surge lagoon sludge	326,591	•						
Discard process residues	139,525		•					
Sludges, oily	62,277	•						
Oil-contaminated wet sump or filter cake	22,620	•						
U ₃ O ₈ from box furnace	33,382							•
Sump cake - copper contaminated	32,330	•						
Oil-contaminated wet sump or filter cake	12,683	•						
Oily sludges	13,240	•						
Nonoily sludge for roasting	12,067	•						
Wet sump or filter cake - oil	9,066	•						
Scrap U ₃ O ₈ or ThO ₂ , high fluoride	12,428							•
Scrap U ₃ O ₈ - low F	5,042							•
Non-oily cleanout sludges for roasting	3,208	•						
Wet sump or filter cake - non-oily	2,618	•						
Incinerator cinders	2,154	•						
Roasted calcium-precip. sump and filter cakes	930	•						
Discard process residue	3,210	•						
Sludges, oily, for oxidation high free	2,502	•						
Oily oxidation sludges	2,181	•						
Sludges, oily, for oxidation, high free	1,280	•						
Sludges, oily	1,184	•						
Non-oily cleanout sludges for roasting	1,572	•						
Kerosene (diesel)/sludge/water from pump test	882	•						
Merco dry and oily merco dry	1,309	•						
Oily sludge	1,177	•						

Table A-4. (Continued).

Source, Medium	Quantity (kg)	Primary technology	Aqueous treatment	Lead recovery	Mercury treatment	Metal melter	Metal decontamination	Special treatment
<u>Savannah River Site</u>								
LLW lead	199,475			•				
Plating line sludge	987,817		•					
M Area plating line waste sludge (Tank 7)	291,545		•					
Mark 15 filtercake -F006	14,077	•						
Solvent waste < 100 nCi/g TRU RAD	388,110	•						
Filter paper take-up rolls (FPTUR)	28,950	•						
Thirds waste < 100 nCi/g TRU RAD	2,120	•						
Solvent-contaminated applicators (LLW)	1,572	•						
Tri-butyl-phosphate and n-paraffin	70,703	•						
Radioactive oil	8,897	•						
Scintillation solution	1,793	•						
Freon 11/oil	1,362	•						
Radioactive Freon 113	2,256	•						
<u>K-25 Plant, Oak Ridge National Reservation</u>								
B & C pond sludge, waste ID 126	31,561,469	•						
CNF sludge, waste ID 64	702,012	•						
Laboratory acids, waste ID 70	329,688		•					
Hazardous waste solid bulk, waste ID 122	76,433	•						
TSCA and IWS sludge, waste ID 133	260,758	•						
Laboratory bases, waste ID 71	27,358	•						
Photographic waste, silver K-ID-74	8,938		•					
Laboratory sludge, waste ID 73	2,954	•						
Y-12 hazardous waste solid/ORM-E	477,619	•						
TSCA incinerator ash, waste ID 85	123,795	•						
Laundry sludge, waste ID 134	30,303	•						
Corrosive solids (bulk), waste ID 161	21,371							•
TSCA solids, waste ID 159	53,352	•						
<u>Oak Ridge Natl. Lab., Oak Ridge Reservation</u>								
TCLP liquids	37,044		•					
Ignitable liquids	49,988	•						
Oil-contaminated materials	36,304	•						
Hazardous solids	2,018	•						
Corrosive liquids	11,625		•					
TCLP solids	13,306			•				

Table A-4. (Continued).

Source, Medium	Quantity (kg)	Primary technology	Aqueous treatment	Lead recovery	Mercury treatment	Metal melter	Metal decontamination	Special treatment
Discarded chemicals	5,009							•
Ignitable solids	3,682	•						
Hazardous waste liquids	1,361				•			
Miscellaneous waste materials	65,422							•
<u>Y-12 Plant, Oak Ridge Reservation</u>								
Corrosive liquids	14,016		•					
Solvent-contaminated solids and sludges	7,485,909	•						
Mercury-contaminated solids and liquids	1,367,507				•			
Liquid metal wastes	472,996				•			
Solid metal wastes	412,811	•						
Reactive solids	54,506	•						
Ignitable liquids	33,448	•						
U-contaminated combustible/residues	33,701	•						
Ignitable solids	19,833	•						
Ignitable liquids	21,963	•						
Ignitable solids	13,953	•						
Corrosive liquids	10,314		•					
Corrosive solids and sludges	7,385							•
Discarded commercial chemical products	5,506	•						
Solid commercial chemical products	4,619	•						
Corrosive solids and sludges	2,997	•						
Liquid commercial chemical products	1,005							•
TCLP organic solids	40,991	•						
Contaminated soil, sediments, and spoil	6,650,300	•						
<u>Hanford Site</u>								
Radioactive lead solids	122,684			•				
WA regulated TC metal organic solid debris	47,542	•						
TC metal organic solid debris	23,254	•						
WA regulated TC metal sludges/dry part.	18,354	•						
Solvent organic solid debris (CA)	13,488	•						
TC metal organic solid debris (CA)	10,975	•						
TC metal inorganic solid debris	9,766	•						
Non-TC metal/solvent organic solid debris	9,664	•						
TC metal inorganic solid debris (Hg, PCB)	10,008					•		
Solvent inorganic solid debris	8,876	•						

Table A-4. (Continued).

Source, Medium	Quantity (kg)	Primary technology	Aqueous treatment	Lead recovery	Mercury treatment	Metal melter	Metal decontamination	Special treatment
Solvent/TC metal organic solid debris (CA)	4,910	•						
TC metal inorganic glass solid debris (Hg)	4,600					•		
TC metal inorganic solid debris (CA)	3,514	•						
Solvent/TC metal organic solid debris	2,974	•						
Non-TC metal/solvent inorganic solid debris	2,183					•		
TC metal organic solid debris (Hg)	1,732	•						
TC metal inorganic solid debris (Hg)	1,346					•		
183-H solar basin waste, type 2	983,715	•						
183-H solar basin waste, type 3	572,393	•						
183-H solar basin waste, type 1	480,434	•						
WA non-TC metal non-solv. sludges/dry PA	138,288	•						
Non-TC metal/solvent sludges/dry part.	7,495	•						
TC metal sludges/dry particulate	27,059	•						
Solvent/TC metal organic solid debris Ca.Q	10,959	•						
Solvent organic solid debris	385,465	•						
Idaho National Engineering Laboratory								
Combustible	2,419,581	•						
Metal - steel and other structural metals	3,224,814						•	
Metal - special	18,037					•		
Glass	196,138	•						
Graphite molds and crucibles	11,387	•						
Molds and crucibles - other nonmetallic	3,465	•						
Uncemented inorganic sludges	1,201,093	•						
Uncemented organic sludges	1,134,872	•						
Cemented sludges and solutions	1,850,616	•						
Concrete and brick	573,681	•						
Salts	10,646							•
Leaded rubber	3,652			•				
Benelex and plexiglass	37,145	•						
Resins	4,521	•						
Mixed waste - paper, metal, glass	809,915	•						
Insulation and filters	424,184	•						
Soil, asphalt, sand, and ash	479,649	•						

Table A-5. Nominal capacity of the ITTS subsystems

Subsystem	Total Quantity (lbs)	Input Feed Rate ¹ (lbs/hr)	Nominal Capacity ³
Receiving and preparation	188,781,288	2,340	2,500 lbs/hr
Thermal treatment		1,940	2,000 lbs/hr
Combustible	36,601,300	453	468 lbs/hr
Noncombustible	119,914,000	1487	1,532 lbs/hr
Lead recovery (melting)	413,600	5	20 lbs/hr
Lead recovery (decontamination)	1,654,500	21	80 lbs/hr
Mercury amalgamation	4,063,800	50	100 lbs/hr
Metal decontamination	7,110,700	88	200 lbs/hr
Metal melting	218,800	3	100 lbs/hr
Special waste treatment	13,314,600	153	200 lbs/hr
Aqueous waste treatment ²	6,489,988	80	20 gpm

1. Feed rates are calculated based on having two integrated thermal treatment facilities, each operating 4,032 hours per year for ten years.

2. Solar pond water at Rocky Flats Plant, approximately 101,752,000 lbs, has been deleted as a feed to an integrated treatment facility. It is assumed that the pond waste will be treated at Rocky Flats by a system specially designed for this waste stream.

3. Nominal capacities account for secondary waste and are used for equipment sizing.

system will be designed with minimum shielding. Some shielding could be necessary in areas of the facility with concentrated TRU waste or fission-product radionuclides (e.g., thermal treatment ash). However, shielding is not considered to be a factor in the performance of the different systems.

A-5.2 Pretreatment

Waste pretreatment should be compatible with requirements of the primary waste treatment technology.

Bulk metals (e.g., ferrous metals and lead larger than about 10 cm) should be removed from the waste stream and sent to the appropriate treatment subsystem. Wire wastes should not be considered bulk metals. Lead in any form, typically blankets and wool, should be removed from the waste stream as best as reasonably possible and sent to the appropriate treatment unit. Bulk mercury and all waste suspected of mercury contamination should be sorted and sent to the mercury treatment subsystem.

Containers of potentially temperature sensitive materials, such as pressurized gas cylinders, should be set aside and safely depressurized, emptied, or otherwise made safe for the next step of treatment.

Containers of waste not requiring sorting should be processed intact if appropriate for the system (e.g., shredding followed by thermal treatment or direct placement in a plasma arc furnace).

Waste containers should be decontaminated or processed along with bulk metals if not processed along with waste.

Drums should be nondestructively monitored to determine plutonium content (which is desirable but not yet possible with today's technology) and gross liquid content. The shredder feeds shredded waste to a sampling bin where vapor samples should be taken online with direct readout of the vapor composition to provide an indication of the VOC content. The pretreatment operation should be blanketed with carbon dioxide or another inert gas. In-leakage quantities to the primary thermal treatment unit should be estimated. The units for waste preparation and thermal treatment should be capable of tolerating some level of explosive materials inadvertently fed to the thermal treatment unit, with limits to be defined.

A-5.3 Primary Treatment

A-5.3.1 Top-Level Requirements

The primary treatment system should have a high likelihood of public acceptance and regulatory approval.

Acceptable technologies are those having successfully completed the proof-of-principal phase or those that have successful operating experience in other industrial applications. Technologies must be ready for pilot-scale demonstration in 2 years, incorporation into a final design in 3 years, and construction in 5 years.

Combustible materials should be oxidized to achieve volume reduction and destruction of RCRA-controlled materials.

Noncombustible materials, such as inorganic sludge contaminated with solvent, should be treated to destroy RCRA-controlled contaminants, if present, and to remove moisture prior to stabilization by vitrification, if applicable.

Levels of substances in the offgas from primary treatment must meet requirements set forth in RCRA and TSCA. Temperatures and times of thermal treatment may differ from those set forth by the EPA, provided that process experience can demonstrate that the effluent meets RCRA and TSCA destruction efficiency requirements. These requirements should be met while keeping waste stream characterization to a minimum.

Parts of the system that process alpha-contaminated MLLW should operate at slightly negative pressure to avoid releasing contamination outside the units. Tolerable in-leakage should be provided for in the design requirements. For systems using air for combustion, the air supply should be taken from the innermost containment.

Thermal treatment systems used for alpha LLW, alpha MLLW, and TRU waste should have a tertiary containment system for all process steps from waste sorting through waste stabilization. Only two levels of containment are required for other processes involving materials with a limited potential for becoming airborne. This requirement should be carefully assessed to avoid potential worker inhalation risks.

No liquid effluent should be generated. Moisture should be discharged to building exhaust or the process stack.

Process monitoring and control should be recorded and audited, and be sufficiently responsive to prevent upsets or excessive reactions.

Air pollution control systems must meet or exceed current and anticipated regulations. Performance specifications should be set to meet or exceed current regulations by one order of magnitude (10 times).

Treatment and containment systems should be flexible enough to accommodate maximum process upsets and failures.

Bulk ferrous metals should be treated either by decontamination to free-release standards of DOE Order 5400.5 or by metal melting to assure destruction of any RCRA-controlled contaminants and removal of surface contamination by slagging. Metal melting free-release standards should have a scrap value. Metal treated by melting should be removed from the disposal stream and be considered recyclable for DOE purposes with zero economic value.

Bulk lead such as lead brick should be treated by surface decontamination if it is reasonably determined to have no activation products. Other lead, such as blankets, wool, and activated lead, should be treated by melting to remove combustible nonlead products and should be cast into blocks for reuse by DOE. The alternative to reuse may require treatment to EPA microencapsulation standards.

Mercury, if found to have radioactive contamination, should be treated by amalgamation. If not radioactive, elemental mercury should be recovered, probably by distillation and capture, and sold as scrap.

Aqueous waste should be treated to evaporate water and immobilize the contaminants into the final waste forms. Highly acidic or alkaline aqueous waste should be pretreated to return the pH to near neutral. Organic liquid waste should be treated by oxidation. If chloride salts are formed, these should be treated in a similar manner to salt residues from offgas treatment.

The system should be designed for a 20-year operating life, with particular attention being paid to ease of maintenance and selection of materials to avoid undue failures due to corrosion.

A-5.3.2 Derived Requirements

Versatile technologies are desirable. A versatile technology is one that can handle variations in waste type and has a minimum number of separate operations.

Five oxidation and thermal treatment technologies meet the implementability requirements: (1) fluidized bed thermal treatment, (2) rotary kiln thermal treatment, (3) plasma arc thermal treatment, (4) controlled air stationary or moving-hearth thermal treatment, and (5) indirectly heated pyrolytic thermal treatment.

The volume of effluent gases should be minimized to the extent possible. Ways to help achieve this include externally heating the primary pyrolysis unit, introducing oxygen instead of air to the combustion and vitrification units, recycling gases, and maintaining long residence times. For systems using a fluidized bed thermal treatment unit, emphasis should be placed on recycling any inert heat-transfer media, such as sand, soil, or sodium carbonate. Sealing should be accomplished by designing a containment chamber around the primary thermal treatment unit if a rotary kiln is used. The containment chamber should serve as the secondary seal for the unit and minimize in-leakage. Seals for the rotary kiln should be double seals with an internal pressure adjusted to be between kiln pressure and the outside secondary containment pressure. Combustion air should be taken from the secondary containment zone.

The feasibility of converting RCRA metals (and oxides) from chloride salts should be evaluated. The volatilization of metals should be kept to a minimum for systems that are designed to retain most metals in the bottom ash. Toxic secondary waste generated by the APC unit should be converted to nontoxic (nonRCRA-controlled) LLW if economic considerations support this. The APC unit should offer the best decontamination factor for radioactive materials and the best removal efficiency for toxic materials. The APC unit should provide redundancy of selected components to allow limited maintenance while keeping the system on line. Three stages of HEPA filtration should be used before the gas is discharged to the stack. The expendable filter materials in prefilters and HEPA filters should be appropriate for processing in the thermal treatment unit. For high volatility systems, high vapor pressure toxic metals should be captured in the APC unit.

APC systems should use either dry or semi-dry processes as the first step in order to produce a minimal quantity of radioactive wet effluent. If the solid secondary wastes from the APC system are to be vitrified, salts should be removed by aqueous washing if the salt concentration exceeds 3%. Alternatively, the solid effluents may be stabilized using a polymer process. Cement stabilization of wastes with a high salt content (percent salt to be determined) is not feasible.

Additives should be materials that enhance vitrification and simultaneously dispose of contaminated material; using soil from Superfund sites satisfies these criteria. Final secondary residues, if wet, should be dried and consolidated into a waste form suitable for near-surface disposal. The final waste form should allow easy movement and disposal, such as standard 55-gallon barrel size. The vitrification unit should consist of a module to allow easy replacement rather than maintenance (assuming this is less costly) and to allow easy expansion by adding additional modules rather than increasing the size of the unit.

Six vitrification technologies meet the implementability requirements: (1) joule melter, (2) electric arc furnace, (3) direct current plasma torch, (4) fossil-fueled melter, (5) slagging rotary kiln, and (6) high-frequency induction melter provided they can attain operating temperatures high enough (1,450° to 1,650° Celsius) to make aluminosilicate final waste forms with minimal fluxing agents.

Five low-temperature stabilization agents meet the implementability requirements: (1) Portland cement, (2) polymer made by Dow Chemical Company, (3) pozzolanic cement, (4) polyethylene, and (5) sulfur cement.

A-4.4 Output Waste Form

A-4.4.1 Top-Level Requirements

The characteristics of the system's primary and secondary waste output must meet current and anticipated disposal regulations, such as 40 CFR 268 for substances regulated by RCRA and DOE Order 5820.2A.

Shallow land burial is the assumed disposal option for LLW and treated MLLW. Engineered shallow land disposal is the assumed disposal option for alpha LLW and alpha MLLW. The report by Feizollahi and Shropshire (1992) contains preconceptual designs and PLCC estimates for the disposal facility.

For purposes of calculating transportation and disposal costs, it is assumed that the output LLW, MLLW, alpha LLW, and alpha MLLW will be shipped to and disposed at the Nevada Test Site. However, for purposes of selecting an output waste form, it should be assumed that the Nevada Test Site

might not be available; therefore, the final waste form should be stable so that it can be accepted at surface disposal facilities at other major DOE installations, including Hanford Site, Washington; INEL, Idaho; Oak Ridge Reservation, Tennessee; Los Alamos National Laboratory, New Mexico; and Savannah River Site, South Carolina.

The chosen final waste form should be able to satisfy performance assessment requirements for each site for alpha concentrations up to 99 nCi/g TRU materials. All wastes from other sites will be transported to one of these sites for disposal. An average cost of disposal will be used for all shipments. It is assumed that processing sites for transportation purposes will be located at Oak Ridge Reservation and INEL (i.e., there will be no transportation costs for wastes at these sites).

Disposal of TRU waste will be at the Waste Isolation Pilot Plant (WIPP).

A-4.4.2 Derived Requirements

The desired output waste form is a stable, leach resistant, high-integrity solid produced by one of two processes: vitrification or solidification. Vitrification is a high temperature process involving melting and casting to produce a rock-like material with properties of glass or ceramic. Solidification is a low-temperature process that produces a stable solid by mixing the ash or other residue with such agents as cement, polymer, or epoxy; bitumen should not be used.

Treatment of the ash should ensure that products of incomplete combustion are below an established target value. Waste forms not destined for WIPP must meet EPA leaching criteria as determined by the toxicity characteristic leaching procedure. This requirement is known to exceed the WIPP waste acceptance criteria if EPA grants no migration variance. At this time, such variance is only granted for the demonstration phase. Therefore, if the variance were not to be granted, all waste would have to meet EPA land disposal restrictions. Another driving requirement regarding treatment standards for waste bound for WIPP, in New Mexico, is that the State of New Mexico has the authority to establish the characterization requirements for the RCRA-controlled components of the waste. These requirements, which are not yet established, could be so onerous as to make full treatment less expensive.

It is assumed that the input waste contains EPA listed hazardous organics or other RCRA-controlled substances and characteristic waste. To simplify permitting, the process for producing the output waste should be considered the best demonstrated available technology by the EPA. The final waste form should be delistable to reduce the cost of disposal (Subtitle D versus Subtitle C) combined with the requirements of DOE 5820.2A for LLW.

If the waste qualifies as TRU waste, then the final waste forms should comply with WIPP waste acceptance criteria and TRUPACT II TRU packaging and shipping criteria.¹ The potential for gas generation should be minimized. If this requirement results in a significant increase in the final waste volume, this requirement should be reconsidered.

It is desirable that the output waste be packaged in 55-gallon drums meeting U.S. Department of Transportation (DOT) requirements. For vitrified waste, thick-walled steel containers will probably be required if the casting process involves pouring molten materials directly into the waste container. It is assumed that these containers can be qualified to meet DOT and TRUPACT II criteria or equivalent.

¹TRU waste can be shipped in other containers such as the TMI-2 fuel containers if heat loads or fissile material limits of the final waste form exceed the TRUPACT II limits.

Final waste forms must meet contact handling requirements with no additional shielding other than the shipping container.

A-5. OPERATIONAL REQUIREMENTS

A-5.1 Receiving

The treatment system will receive incoming solid and sludge waste in drums, metal bins, and wooden or fiberglass boxes shipped to the treatment facility by onsite or offsite transportation vehicles. Liquid waste will be shipped to the system either by a pipeline, in tank trucks, or in containers placed on wheeled vehicles.

A-5.2 Temporary Storage and Characterization

Incoming containers of solid or sludge will be unloaded from shipping vehicles, temporarily stored, characterized, logged, and recorded. Incoming liquid waste will be sampled, characterized, and temporarily stored. Characterization will identify the physical, chemical, and radiological properties of the waste to the extent needed by the treatment process. Characterization will identify containers with waste that will require sorting (SR waste), and waste that will not require sorting (SNR waste).

A-5.3 Preparation

The incoming volatile waste may be in the form of a solid, sludge, or liquid.

When ready for processing, the solid and sludge waste will be prepared to the extent needed by the thermal treatment unit. Depending on the type of thermal treatment unit, preparation can include removing waste from containers, and sorting, size reduction, and shredding. In general it is undesirable for such materials as bulk lead and mercury to enter the thermal treatment unit, because they are particularly hazardous volatile pollutants and are difficult to collect from the offgas. If these materials can be found using real-time radiography (RTR) performed on containers of intact waste, the containers will be emptied and the prohibited materials will be removed. Similarly, if RTR detects other bulk metals (e.g., steel, aluminum), these containers also will be emptied and the metals removed. This strategy minimizes challenges to the shredder system and, in the case of rotary kilns, minimizes physical assault on the kiln refractory.

Sorting of SR solid and sludge wastes can result in several waste streams, including lead, thermally treatable solids and sludges, noncombustible solids and sludges, bulk metals, elemental mercury, and waste requiring special treatment (e.g., chemically reactive waste or pressurized gas cylinders). Each waste stream will be conveyed to an appropriate treatment unit. Depending on the system configuration, more than one waste stream might go to the thermal treatment unit. Empty containers will be fed to one of the treatment units, or decontaminated for recycling or reuse, or undergo size reduction and be sent for stabilization.

Liquid waste will be separated into two categories: aqueous waste and organic thermally treatable waste. The limit of the organic concentration for thermally treatable waste depends on the thermal-treatment technology employed. Each type of liquid waste will be sent to an appropriate treatment train.

A-5.4 Treatment of Thermally Treatable Solids, Sludges and Organic Liquids

Thermally treatable solids and sludges will be prepared and then treated in a thermal treatment unit, where organics will be destroyed and discharged as offgas into the APC subsystem. The APC subsystem will treat the offgas to meet emission discharge limits and to ensure that minimal levels of contaminants are discharged to the environment. Solid residues from thermal treatment (bottom ash) and from the APC subsystem (flyash) will be sent to the stabilization subsystem. In some systems, such as the plasma furnace, flyash is returned to the furnace where it is vitrified together with bottom ash. Secondary aqueous waste from the APC subsystem will be sent to the aqueous-waste treatment subsystem.

A-5.5 Treatment of Lead Contaminated Solids and Sludges

Bulk lead or lead encased in steel will be decontaminated and recycled for reuse. Lead not amenable to decontamination will be melted along with fluxing additives which will be used to separate the contamination into a slag phase. Depending on the development of *de minimus* criteria in the future, the clean lead will be sent for recycling or reuse in the DOE complex. Contaminated lead that cannot be cleaned will be encapsulated and sent for disposal. The functional and operational requirements (F&OR) for gaseous emissions from lead melting are similar to requirements for the thermal treatment unit which treats solids and sludges.

A-5.6 Treatment of Mercury Contaminated Solids and Sludges

MLLW solids and sludges contaminated with low concentrations of elemental mercury will be sent to the thermal treatment subsystem. Specialized adsorption equipment in the APC subsystem capture the volatile mercury. The recovered mercury will be either chemically stabilized or will be amalgamated before disposal. Solids and sludges contaminated with significant amounts of mercury will be sent to a retort unit. Elemental mercury will be condensed and captured in the offgas system. The captured mercury will be stabilized by amalgamation if contaminated with radioactivity, or will be recycled. Bulk elemental mercury will also be recycled if not contaminated with radioactivity.

A-5.7 Treatment of Bulk Metals

Bulk metals will be decontaminated and released for recycling or reuse to the extent possible. Metals not suitable for recycling will be melted, and clean metals will be separated by drawing the contamination into a slag phase. Again depending on future *de minimus* contamination levels, the clean metals will be sent for recycling, and contaminated metals will be containerized and sent for disposal. The F&ORs for gaseous emissions from metal melting are similar to those for the thermal treatment subsystem which treats solids and sludges.

A-5.8 Treatment of Non-Thermally Treatable Solids and Sludges

Non-thermally treatable solids will be prepared (size reduction, etc.) and sent to the stabilization train.

A-5.9 Treatment of Liquid Waste

Liquid waste includes aqueous waste and organic liquid waste. Incoming aqueous waste will be treated to remove dissolved solids, suspended solids, and organic materials. Treated waste water will be returned to the process for recycling or reuse. The treatment byproduct will be concentrated. Concentrated organic liquid waste and sludge will be sent to the thermal treatment subsystem. Concentrated inorganic liquid waste will be sent for stabilization.

A-5.10 Treatment of Special Wastes

An area will be provided to house portable or specially designed units that can treat special wastes on a case-by-case basis.

A-5.11 Stabilization

Residues from the various treatment units will be stabilized and placed in a container suitable for disposal. The waste container will be inspected to ensure that surface radioactive contamination is below acceptable levels. Any loose contamination will be removed from the container and recycled to the stabilization process. After inspection, the container will be sent for assay, certification and shipping. The waste form produced by the stabilization process must meet transportation, storage, and disposal requirements imposed by the DOE, EPA, DOT, and the individual DOE disposal sites. It should also minimize release of toxic constituents to the environment.

A-5.12 Certification and Shipping of Packaged Waste

Filled waste containers will be inspected and assayed in accordance with transportation, storage, and disposal requirements. After inspection and assay, the containers will be certified, logged, recorded, and either sent to a temporary storage facility or loaded onto a transport vehicle for offsite or onsite shipping.

A-6. FACILITY DESIGN REQUIREMENTS

A-6.1 General Assumptions

Facilities handling MLLW are placed in seismic category 1. Buildings that handle MLLW are classified as moderate-hazard facilities (Kennedy et al. 1992, p.41). The facilities must be designed in accordance with applicable local, state, and federal regulations, including general design criteria for DOE facilities contained in DOE Order 6430.1. Specifically, RCRA places design constraints on storage and treatment facilities and places performance specifications on the waste stabilization.

All systems and critical operations related to handling alpha-contaminated MLLW are classified according to safety. They have high-quality, low-maintenance features to keep personnel exposure as low as reasonably achievable. Operations with alpha MLLW are confined, to the greatest extent practical, to remote cubicles.

The facilities' units should be designed to handle at least 125% of the expected mass flow rates, shown on PFDs for each system.

Public, employee, and environmental exposures to hazardous and radioactive material should be as low as reasonably achievable.

The scoping study layout (SSL) for each facility is based on two assumptions. Surge capacity for indoor storage of MLLW drums is 2-6 weeks. The preconceptual design of cubicles for areas for processing alpha-contaminated MLLW is based on a triple confinement system.

A-6.2 Treatment Facility Support Functions

Support functions for all treatment facilities include, but are not limited to, (1) nonprocess heating, ventilation, and air conditioning; (2) fire protection; (3) electrical systems (including emergency); (4) process control and data logging; (5) radiation instrumentation; (6) bulk chemical and additive supply and storage; (7) storm water runoff control; and (8) waste water treatment (hazardous, radioactive, and sanitary).

Input to the facility includes utilities, service water, normal and emergency power, and communications.

Laboratory and personnel decontamination areas are designed to handle radioactive material.

Structures housing personnel and nonradioactive components are constructed in accordance with the appropriate building code. Laboratories and personnel decontamination areas are designed for handling radioactive material.

A-6.3 Treatment Administration Support Facility Functions

Support functions for the administration facility include, but are not limited to, (1) security, (2) personnel decontamination (radioactive and hazardous), (3) noncontaminated maintenance, (4) health physics, (5) sanitary facilities, (6) work control and personnel support, (7) interior and external public relations and communications, (8) spill or emergency response provisions (hazardous and radioactive), (9) general analytical laboratory, (10) environmental field sampling, and (11) environmental regulatory reporting and records management.

The treatment facility should include the following interfaces: (1) facility communication; (2) alarm systems, including telephone, evacuation, fire, and security alarms; and (3) public address systems. All treatment processes are programmed for automatic shutdown if the fire system or the evacuation alarm is activated.

A-6.4 Facility Operation

The preconceptual designs are based on the assumption that MLLW inventories will be processed in treatment facilities, placed in storage facilities, and disposed of during a 20-year operating period. During this period, the treatment facility will operate 24 hours per day, 5 days per week, 240 days per year, at 70% of capacity during operation. This is equivalent to operating 168 days per year, or 4,032 hours per year of operation. In facilities with small capacities, where a three-shift operation is not justified, a single shift per day or part-time shifts are assumed.

A-7. REFERENCES

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