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Technical Review of Molten Salt Oxidation

for the
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Office of Environmental Management

MASTER

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EXECUTIVE SUMMARY

MOLTEN SALT OXIDATION FOR MIXED WASTE

The Office of Technology Development (OTD, EM-50) was charged in early October, 1993 with conducting a technical review of Molten Salt Oxidation (MSO) by the Assistant Secretary for Environmental Restoration and Waste Management of the U.S. Department of Energy. To conduct the review, OTD organized a Technical Review Panel for MSO. The Panel was directed to provide the Assistant Secretary with its recommendations before November 25, 1993. Recommendations were requested on two questions:

- (1) Is MSO a sufficiently promising thermal treatment alternative technology to be advanced to a pilot plant, and
- (2) How does MSO technology compare with other alternative technologies?

MSO Panel Recommendations

The Panel's recommendations are based on the technical material provided by the MSO proponents and by the material presented during technical presentations. It should be noted that there may be other technical material existing throughout the DOE complex on molten sodium carbonate processes whose examination was precluded by time constraints for this review.

- The Panel supports the continuation of development of MSO at the same time as conceptual design is proceeding. However, outstanding technical issues were identified that must be addressed before proceeding with Title I design.
- Following successful resolution of the technical issues raised in this report and after a second independent panel review, this Panel recommended proceeding with the balance of design.

Due to time constraints, it was impossible for the Panel to respond in a thorough and responsible manner to its second charge to compare MSO with other alternatives to incineration. It is noted that such a comparison may be possible after the second phase of the EM-50 Integrated Thermal Treatment Study (ITTS) is completed in mid-1994.

- The Panel also recommended that a detailed review of other potential alternatives to incineration be conducted with the same scrutiny as MSO. It is important that these reviews occur for several reasons:
 1. MSO appears to have capability to effectively and efficiently treat only a limited portion of DOE's MLLW (other alternatives may have similar shortcomings); and
 2. Incineration may still be necessary (and be the best method) to treat some of DOE's MLLW. Incineration will have a better chance of being accepted by the public after its perceived shortcomings are addressed and other alternatives are rigorously evaluated so that all alternatives can be compared on a consistent basis.

Before such reviews can occur, criteria for evaluation of technology must be refined for screening and selection purposes.

MSO Technical Attributes

The Panel observed several attractive technical attributes of MSO for application to DOE mixed waste:

1. Extensive development work and scale-up has been documented on coal gasification and hazardous waste which forms a strong experience base for this process. It clearly is applicable to DOE wastes such as organic liquids and low-ash wastes.

2. MSO also possesses a potential to successfully process difficult-to-treat wastes such as nuclear grade graphite and tributyl phosphate, and it may be suitable for other problem waste streams such as sodium metal.
3. MSO operating systems may be constructed in relatively small units for small quantity generators.
4. The public perception of the technology could be favorable if acceptable performance data are developed in a forthright manner and fairly presented; however, the premise that MSO will be treated differently than incineration, by either regulators or the public, is untested. MSO will likely require compliance with regulations for incineration.

MSO only as an Offgas Treatment System

Alternative uses of MSO include various applications for treatment of off gases coming from various thermal treatment units, (e.g., rotary kiln incinerators).

The Panel noted that insufficient work has been done on using MSO for offgas treatment to make any recommendations. However, the Panel did note several concerns about this application:

1. The amount of salt carryover from the offgas treatment unit is likely to be high. Management of the salt adds to the complexity of the system compared to other flue gas cleaning systems.
2. The energy balances necessary to determine the method of control of the salt at the desired temperature have not been established.
3. The single stage scrubber system may not be sufficient alone. Additional air pollution control systems such as a fume incinerator for carbon monoxide emission control, may be required to meet emission standards.

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The Technical Review Panel consisted of: Jim Cudahy, Focus Environmental Inc. of Knoxville, TN; Terry Escarda, of the California Department of Toxic Substances Control; Frank Graham of the Westinghouse Savannah River Company; James E. Helt from the Argonne National Laboratory; David M. Martin from Iowa State University; William (Randy) Seeker of Energy & Environmental Research Corporation, Ginger Swartz from the Colorado Council on Rocky Flats; and Robert Thurnau from the EPA Risk Reduction Engineering Laboratory in Cincinnati. The technical analysis team was headed by Bill Quapp of EG&G Idaho, supported by Blaine Brown of EG&G and Fred Feizollahi of MK Environmental Service. Thanks are expressed to Gary Knight and Brad Grems of Waste Policy Institute who helped organize the Panel. Mr. Knight also coordinated input from the Panel to fashion both a draft and final version of this report.

Appreciation is also extended to the first MSO presenters panel arranged by Lawnie Taylor (EM-43): Johnny Moore, DOE-OR; the following personnel from Martin Marietta Energy Systems: Sladjana Crosley, Mac Toth, Bob Merriman, Roger Spence, Bob Hightower, and Ron Glass; Brendlyn Faison from ORNL; Jack Duray, Tim Carlson, and Cheri Bahrke from RUST Geotech Inc.; Mark Bohn from the National Renewable Energy Laboratory, John Consaga from the U.S. Naval Surface Warfare Center; Earl Leming representing the Tennessee Dept. of Environment & Conservation; Mark Polet from the Alberta Special Waste Management Corp.; Bill Olander from Teledyne Brown Engineering; and from Rockwell International, Dr. Rich Gay, Clyde Newman, Al Stewart, Henry Wieseneck, and Bruce Gillies. At the second presenting session, thanks are extended to Ron Cochran, Martyn Adamson, Ravi Upadhye, Oscar Krikorian, John Celeste, Bill Brummons, Virginia Oversby, and Ann Heywood from the Lawrence Livermore National Laboratory (LLNL). Thanks also to Richard Scott, DOE-SAN for coordinating the LLNL appearance before the Panel.

ACRONYMS AND ABBREVIATIONS

ACRS	Advisory Committee on Reactor Safeguards
AEA	Atomic Energy Act
AEC	Atomic Energy Commission
APC	Air pollution control
ARARs	Applicable or Relevant and Appropriate Requirements
BIF	Boiler and Industrial Furnace regulations (EPA)
BDAT	Best Demonstrated Available Technology
BTU	British Thermal Unit
C	Celsius
C ₁₄	Carbon 14
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act (the "Superfund" law)
CH	Contact handled
Cl	Chloride
Cl ₂	Chlorine
CO	Carbon monoxide
CO ₂	Carbon dioxide
CRADA	Cooperative Research and Development Agreement
CAMU	Corrective Action Management Unit (EPA reg)
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOIT	A Federal advisory committee involving the Western Governors' Association established to assist in demonstrating on-site innovative cleanup technologies
DRE	Destruction Removal Efficiencies
DWPF	Defense Waste Processing Facility
EM	Office of Environmental Management (EM-1) of DOE
EPA	U.S. Environmental Protection Agency
ER	Office of Environmental Restoration (EM-40) of DOE
ETEC	Energy Technology Engineering Center
FFCA	Federal Facilities Compliance Act of 1992
FY	Fiscal Year (October 1 to September 30)
HCl	Hydrogen Chloride
HEPA	High-efficiency particulate air
HWI	Hazardous waste incinerator
INEL	Idaho National Engineering Laboratory
ITTS	Integrated Thermal Treatment Study (by OTD)
LDRs	Land Disposal Restrictions under RCRA
LLNL	Lawrence Livermore National Laboratory
LLW	Low-level waste
MLLW	Mixed low-level radioactive waste
MSO	Molten Salt Oxidation
MWIR	Mixed Waste Inventory Report, 1993
NaCl	Sodium chloride
Na ₂ CO ₃	Sodium carbonate
nCi/g	nanno-Curies per gram
NESHAPS	National Emission Standards for Hazardous Pollutants
NO _x	Oxides of nitrogen
OR	DOE Oak Ridge Operations Office
ORNL	Oak Ridge National Laboratory
OTD	Office of Technology Development (EM-50) of DOE
PCBs	Polychlorinated Biphenyls
PEIS	Programmatic Environmental Impact Statement
PICs	Products of incomplete combustion
R&D	Research and Development
RCRA	Resource Conservation and Recovery Act
RFP	Rocky Flats Plant
RH	Remote handled
SCF	Standard cubic foot
SNL	Sandia National Laboratory
SRS	Savannah River Site
TCLP	Toxicity Characteristic Leaching Procedure (RCRA)
TIDE	Technical Innovation Development Engineering (a private company)
TRU	Transuranic
TSCA	Toxic Substances Control Act
VOCs	Volatile Organic Compounds
WIPP	Waste Isolation Pilot Plant

1.0 INTRODUCTION

1.1 BACKGROUND

This report contains the findings of a Technical Review Panel (the "Panel") assembled by the Office of Environmental Restoration and Waste Management (EM) of the U.S. Department of Energy (DOE) to conduct a technical review of the molten salt oxidation (MSO) process which has been studied by the DOE for use as a potential technology for treatment of mixed low-level radioactive waste (MLLW). MLLW is broadly characterized as liquid, sludge, and solid material contaminated with substances that are regulated pursuant to the Atomic Energy Act (AEA), the Resource Conservation and Recovery Act (RCRA), and the Toxic Substances Control Act (TSCA). MLLW generated from environmental restoration (ER) activities is also regulated under CERCLA.

Operations-related MLLW is managed by DOE's Office of Waste Management (EM-30). ER-related waste is managed by the Office of Environmental Restoration (EM-40). Data used by the Programmatic Environmental Impact Statement (PEIS) being prepared by EM indicate that volume of the current waste inventory plus 20 years projection of the operations-related MLLW is approximately 1.5 million cubic meters¹. A specific projection of the ER-related MLLW volumes is not available at this time, but it is believed to be about the same magnitude as the operations-related MLLW.

EPA's Best Demonstrated Available Technology (BDAT) under RCRA for many hazardous wastes is incineration. It has been shown to be effective in destroying RCRA and TSCA material. However, public pressure has caused state and Federal regulators to consider tightening emission standards on incineration units. In May 1993, EPA announced a de facto moratorium on the permitting of new incinerators until new emission standards are established. Accordingly, DOE-EM and its Office of Technology Development (OTD) (EM-50) are exploring alternatives to incineration to address the large amounts of existing hazardous and mixed waste inventories. One of these potential technical alternatives is MSO.

In October, 1993, the Assistant Secretary for Environmental Management (EM-1) directed EM-50 to conduct a technical review of MSO and report the results of the review to him prior to November 25, 1993. EM-50 put together an MSO Technical Review Panel, from both inside and outside the DOE complex, to study material and hear presentations on MSO, and to conduct a technical review of the technology's attributes.

1.2 PANEL MEMBERS

The Panel consisted of representatives from DOE installations, EPA, academia, state regulators, and private firms. A list of the Panel members, including a summary of their professional affiliations and experience, is provided at Appendix A.

1.3 SCOPE OF PANEL'S REVIEW

The Panel reviewed application of the MSO process to MLLW streams (as delineated in Section 3 of this Report) to determine if the technology was sufficiently promising as an alternative to incineration to be advanced to a pilot plant stage.

The Panel members had access to a large portion of the publicly available reports, papers, and other documents related to the MSO process. A listing of these documents is presented in the Bibliography of this report. However, other than a cursory computer literature search, the short time available in which to conduct the review did not permit an exhaustive search for all available technical data on MSO using sodium carbonate. Several representatives from DOE M&O contractors, national laboratories, Department of Defense (DoD), Rockwell International, and U.S. and Canadian commercial firms made presentations to the Panel on the MSO technology during a meeting on October 25-28, 1993 (see list provided in Appendix B). Lawrence Livermore National Laboratory (LLNL) investigators made similar presentations on November 15, 1993. It is acknowledged that MSO work is also being done at the Los Alamos National Laboratory (LANL), and perhaps elsewhere, but it was the Panel's understanding that the LANL work is not directed at mixed waste processing.

¹ Calculated from data contained in DOE Mixed Waste Inventory Report (MWIR) which covers MLLW from approximately 50 installations within DOE Complex.

The Panel considered all aspects of the technology from a technical point of view. Items specifically addressed were:

- Technical Maturity of the Process
- Implementation History
- Adequacy of Experimental Data for Design Purposes
- Applicability to DOE Waste Streams
- Effectiveness of Waste Destruction
- Emissions Control and Solid Residue Disposal
- Project Design Status

1.4 REVIEW LIMITATIONS AND QUALIFICATIONS

The Panel review was focused on using the MSO process as: 1) a stand-alone technology and 2) an air pollution control (APC) system. It did not compare MSO with other alternative treatment technologies, (e.g., molten metal, wet-air oxidation, super-critical water oxidation, acid digestion, and steam reforming). Some of the presentations made to the Panel contained a comparison of the MSO process with incineration technology, but the schedule restrictions did not allow the Panel to conduct a thorough analysis of MSO compared to the aforementioned alternatives. Additionally, there has been far more development work done on MSO than on other alternatives to incineration.

The purpose of the review was to assess only the potential application of the MSO process to DOE MLLW streams and whether it is prudent to carry the technology to the next phase of development. Panel members firmly believed that this review should not be construed as an endorsement of MSO as the best alternative for treating MLLW.

Furthermore, the Panel believed that other attractive alternatives should be subjected to a technical review in the same manner as that conducted by this Panel. This review process should be conducted in a timely manner to ensure other promising technologies receive similar technical scrutiny as part of the development process.

The majority of the MSO emissions data presented to the Panel was based upon experiments conducted by Rockwell during the 1970s and early 1980s before current environmental regulations were in effect. Only limited emissions data have been developed by Rockwell and LLNL within the last five years. It should be noted that the Panel made its recommendations from the written and oral material presented to it by MSO proponents.

2.0 BACKGROUND

MSO has been in the development stage, both within and without the Federal government, intermittently since the 1950s.

2.1 MOLTEN SALT OXIDATION HISTORY

Rockwell International ("Rockwell") was hired by the Atomic Energy Commission in the 1950s to do work using molten fluorides to process nuclear fuels. Much of this work centered on basic chemistry and properties of molten salts and gave Rockwell a background in operating and researching with molten salts.

Rockwell's work evolved into experimenting with molten sodium carbonate on coal to scrub sulfur dioxide from that fossil fuel's flue gas, as well as a catalyst for gasifying coal. This latter work accelerated following the oil crises of 1973-74 but was later de-emphasized following the decline in oil prices of the early 1980s. However, during the coal gasification work, it became apparent that complete oxidation of organic and carbon-based materials could be achieved in the salt melt. This prompted Rockwell to begin testing the technology on treatment of hazardous organic wastes which led to bench tests (2 lb/hr) on a number of organics including chlordane and polychlorinated biphenyls (PCBs), among others. Demonstration scale tests ranging from 150 to 2,000 lb/hr were run on gas streams, combustible solids, and numerous organic forms.

However, funding became limited beginning in the late 1970s as less expensive incineration systems became available, causing Rockwell to discontinue MSO testing in 1982. When alternatives to incineration for mixed waste were sought, Rockwell and LLNL began further studies.

In 1991, a peer review was conducted on MSO, that was published in January 1992. The review evaluated the advantages and disadvantages of MSO as compared to incineration (not to other alternatives) and identified MSO as having "benefits as an off-gas secondary treatment system (dry scrubber) for thermal treatment." The review identified the following issues that needed to be addressed: "characterization of metal and PICs emissions; use of MSO as an off-gas dry scrubber; shielding requirements for mixed waste; recycle and disposal requirements for the waste salt and ash; refined waste-handling systems; acceptance criteria for water; criticality of actinide wastes; maintainability/reliability of operations and materials of construction; and adverse reactions with certain wastes." Based on the advice and opinions of the Peer Review Panel, the report's contractor, Chem-Nuclear Geotech, Inc., recommended that a Task Force be created "to foster and implement the Peer Review Panel's strategic plan."

2.2 MSO PROCESS

The basic concept of MSO is a combined chemical and thermal waste treatment technology which (1) feeds wastes and air into a ceramic-lined vessel containing a bed of molten salt at 900° - 1000° C, (2) oxidizes organic wastes, (3) uses the heat of oxidation to keep the salt molten, (4) neutralizes acid gas precursors in the bed, and (5) discharges the salt for disposal or for processing and recycling. Figure 1 represents a simplified diagram of the MSO reactor concept.

The molten salt bed: (1) acts as a dispersing medium for both the waste being processed and the air or oxygen used in the processing; (2) provides a catalyst for the oxidation reactions and accelerates the destruction of organic material; (3) enhances completeness of the chemical reactions by providing better physical contact and a stable heat transfer medium that resists thermal surges; (4) helps retain soot and char in the melt for more complete reaction; and (5) retains most of the ash, radionuclides, and other noncombustible material associated with the waste in the salt bed.

Sodium carbonate, or sodium carbonate mixed with other salts (e.g., potassium carbonate), is typical of the salts used in the melt. During system start-up, it is necessary to load and preheat the vessel before charging with salt. The operating temperature may range from 700 to 1200° C, but 900 to 1000° C is the most effective processing range. At these temperatures, the molten salt has a viscosity similar to water. While most waste materials that are appropriate for treatment by MSO will have sufficient heat of oxidation to keep the salt molten, some wastes especially those with large water content, may require supplemental heat such as natural gas or fuel oil.

Under steady state conditions, a melt overflow stream leaves the bed continuously to purge ash and sodium chloride. An equal amount of sodium carbonate is used to make up for the bed losses. The salt melt generally retains most of the

Figure 1. Molten Oxidation System

metals and radionuclides although there is insufficient information available on the fate of currently regulated metals. Gases are passed through an APC system (tested so far is a system comprised of a baghouse and a HEPA filter). The carryover salts and other impurities are removed from the baghouse for disposal or for processing and recycle.

The molten salt is typically discharged when it accumulates impurities (ash) of approximately 20 percent or a dissolved impurities content high enough to have a negative effect on acid gas retention or other operating parameters.

Undissolved impurities include various metal oxides and silicates. Dissolved impurities are primarily salts such as sodium chloride, sulfate, or phosphate. If sodium carbonate recycle is utilized, the partitioning of impurities and recycling operation must be designed for the specific impurities involved.

3.0 CHARACTERIZATION OF DOE WASTE

The panel reviewed application of the MSO process to MLLW. From a radiological hazards standpoint, MLLW may be classified into several sub-categories which are listed below. The Panel did not consider the application of MSO to remote handled (RH) and transuranic (TRU) MLLW as defined below. Safety and design requirements for handling RH and TRU wastes are complex, and more detailed reviews will be needed if the MSO process is to be considered for potential application to these wastes.

Subcategories of wastes considered are as follows:

- 1) Non-alpha MLLW. The primary radioactive contamination of this waste is from very low levels of fission products. The waste is contact handled (CH) and exists at most installations involved in the R&D or operations related to nuclear reactors. From a radiation safety standpoint, the main concern is minor amounts of shielding to minimize personnel exposure to gamma radiation. The waste contains some level of RCRA characteristic or listed hazardous waste in addition to the radionuclides.
- 2) Alpha-MLLW (uranium). The primary radioactive contamination of this waste are uranium and daughter product isotopes. The waste exists at most DOE installations involved in R&D or production related to the conversion of uranium and fabrication of uranium fuel. This waste is CH, but more sophisticated confinement is essential to avoid worker inhalation exposure.
- 3) Alpha-MLLW (TRU). The primary radioactive contamination of this waste is alpha radioactivity from plutonium, americium, and daughter products. This waste has a transuranic concentration of >10 nCi/g but <100 nCi/g. The waste exists at most DOE installations involved in R&D or production of nuclear weapons. This waste is CH, but a great degree of confinement is needed to avoid personnel inhalation exposure.
- 4) TRU MLLW. This waste has the same properties as the TRU contaminated alpha-MLLW (see subcategory 3 above) with the exception that the TRU concentrations are greater than 100 nCi/g. TRU waste is subject to a management approach which is based on final disposal in the Waste Isolation Pilot Plant (WIPP) facility in Carlsbad, New Mexico.
- 5) RH MLLW. This RH waste can be either non-alpha or alpha-MLLW, but the gamma radiation level is high and will require shielding to minimize personnel exposure to gamma radiation.

From a chemical hazards regulatory standpoint, MLLW may be grouped into two subcategories: RCRA MLLW and TSCA MLLW. The Panel reviewed MSO for application to both wastes.

The other type of characterization for MLLW is associated with the physical media. The waste stored and generated in the DOE complex consists of a wide variety of liquids, solids, and some gases. Most of these materials are common industrial chemicals, supplies, and materials of construction. Detailed data on the physical media are not available from all DOE sites. However, to assess the effectiveness of mixed waste treatment systems, a database has been developed for the Integrated Thermal Treatment System (ITTS) study (a 1993 EM-50 mass balance/flow sheet study to evaluate performance, on a standardized basis, of various thermal treatment options; this study is, as yet, unpublished). This database is derived from the 1993 DOE Mixed Waste Inventory Report (MWIR) on quantities of mixed waste stored at all DOE sites (see Bibliography). Data from the ten largest DOE sites were examined and loaded into a spreadsheet file for subsequent analysis. Not all data were available in the MWIR that are required to conduct a good mass balance.

Using process knowledge and personal contacts, together with the available data, estimates were made to develop the waste characteristics down to the physical media level. This data for the ten largest DOE sites are shown in Appendix C.

Table 1 lists the combined waste from the ten largest DOE sites and shows the waste types that were judged amenable to processing by MSO technology based on the technical presentations heard by the Panel. This information is shown graphically in Figure 2. Criteria for suitability for MSO included high organic content and estimated ash residual less than 10%. Additional information on the ITTS Waste Database is provided in Appendix C.

The ITTS database represents about 95% of the waste of the ten largest DOE sites but only about 52% of the total described in the MWIR. Although additional data will be added to the database in FY94, as presently constructed, it is

Table 1. PHYSICAL MATRIX DISTRIBUTION FOR THE DEPARTMENT OF ENERGY LLMW

Physical Matrix	Total Mass (kg)	Treatable by MSO
Cardboard	180,050	Yes
Cloth	608,534	Yes
FRP Box	1,959,820	Yes
Graphite	11,048	Yes
Halogenated Org. Liquids	325,434	Yes
Leaded Rubber	60,696	Yes
Non-halogenated Org. Liquids	312,041	Yes
Oil	161,214	Yes
Organic Sludge	6,036,995	Yes
Paper	972,574	Yes
PE/PP	1,266,112	Yes
Plastic N.O.S.	242,089	Yes
PVC	129,599	Yes
Rubber	193,474	Yes
TFE	6,224	Yes
Wood	312,361	Yes
Treatable by MSO	12,778,264	
Absorbed Inorganics	1,640,012	No
Absorbed Organics	763,654	No
Aqueous Cyanide	103,782	No
Aqueous Organics	41,297,371	No
Aqueous TC Metals	6,786,035	No
Asbestos	64,205	No
Asphalts	28,518	No
Batteries (Pb, Cd)	102,017	No
Beryllium	1,064	No
Bulk (nontoxic) Metals	3,714,494	No
Bulk Barium	50,400	No
Bulk Cadmium	792	No
Bulk Mercury	828,427	No
Cemented Inorganic Sludge	9,787,837	No
Cemented Organic Sludge	4,267,883	No
Cemented Resins	2,580	No
Ceramics (molds & crucibles)	15,004	No
Concrete	623,519	No
Diatomaceous Earth	215,540	No
Drums	15,004,584	No
Firebrick	95,010	No
Flooring Materials	4,549	No
Glass Raschig Rings	105,354	No
Halide Salts	49,611	No
Incinerator Ash	281,259	No
Inorganic Labpacks	16,097	No
Inorganic Sludge	38,756,447	No
Lead Shielding	868,451	No
Metal Fines & Turnings	95,849	No
Misc. Glass	277,415	No
Nitrate Salts	1,704	No
Organic Labpacks	12,087	No
Paint Residues	26,712	No
Resins	3,090	No
Salts	291,397	No
Sheetrock	170,372	No
Soil/Dirt	8,123,931	No
Sulfate Salts	231	No
Tantalum (INEL)	23,100	No
Uranium Compounds	725,829	No
Not Compatible with MSO	135,226,215	
Total DOE LLMW	148,004,479	

Figure 2. Physical Matrix Distribution for Department of Energy

is believed to be adequate for the purposes of the ITTS study and for this review. As shown on Figure 3, only about 9% of the DOE waste is suitable for treatment by MSO. Figure 4 shows the types of material contained in the MSO treatable wastes.

As shown on these figures, only a relatively small fraction (9%) of the currently stored waste at the ten largest DOE sites is suitable for destruction by MSO technology (this waste is generally the easiest waste to treat by incineration as well). The balance of the waste will require treatment by other processes than MSO.

To develop the above referenced data, the database was "sorted" much as containers having heterogeneous contents would be sorted prior to feeding such wastes into an MSO thermal treatment unit. All steel containers (bins, barrels, etc.) were considered not treatable by MSO (of course, the containers could have had their contents emptied). Fiberglass reinforced wooden boxes were assumed treatable by MSO. It is of interest that the container mass (drums and boxes) in this database represents 11.5% (17×10^6 kgs) of the total database mass shown on Table 1.

Figure 5 shows a comparison of the MSO treatable waste quantities of waste located at each of these 10 sites. Additional breakdown of the wastes by type for each site is provided in Appendix C.

It is also appropriate to note that the total database shown on Table 1 consists of over 48×10^6 kg of water with contaminants (almost one-third of the total mass). Although treatment of aqueous wastes by thermal treatment appears to be technically possible, there are lower cost alternatives that do not require as much energy. Another recently developed database was prepared for the DOE PEIS alternative analysis. This database was also based on MWIR. A comparison of the ITTS and PEIS databases was conducted as a partial quality check since good waste characterization data do not exist creating a data base for conducting mass balance requires a lot of judgement and interpretation.

Appendix D has been prepared using PEIS database information derived from the MWIR by Sandia National Laboratory (SNL). The purpose of the SNL report is to estimate the treatment capacity requirements for processing the MLLW. The processing rate algorithm is heavily biased by future rate projections for several sites: K-25 and Y-12 at Oak Ridge and the Savannah River Site. Differences in the way the ITTS database and the SNL PEIS database were generated prohibit direct comparison. However, looking at the processing capacity requirement (stored plus projected inventories), the PEIS database indicates that 8.5% by volume of the waste is MSO treatable (ITTS database is mass based). For the stored portion of the PEIS database, only 1.3% by volume is treatable using MSO. This contrasts to the 9% by mass estimate in the ITTS database of highly sorted waste.

Figure 3. Distribution of the Department of Energy LLMW Amenable to MSO Treatment

Figure 4. Physical Matrix Distribution of the MSO Treatable LLMW throughout the DOE Complex

Figure 5. Distribution of MSO Treatable Wastes throughout the DOE Complex

4.0 ISSUES & RATIONALE: MSO AS A WASTE DESTRUCTION SYSTEM

4.1 WASTE TYPES SUITABLE FOR MSO

4.1.1 Generic

There are several DOE waste streams that may lend themselves to MSO technology in preference to other methods (including incineration). The most notable is this system's unique ability to completely oxidize graphite. While this material may be viable for direct disposal, oxidization of the graphite, and storage of the residue would result in a large volume reduction.

Other graphite/carbide materials such as silicon carbide reactor fuels and graphite reactor materials, although treatable by MSO, are not suitable for a MSO treatment system. The concentration of Carbon-14 in the offgas may be too large to allow release of the CO₂ to the atmosphere, and the radioactivity associated with silicon carbide fuels is also too high for a CH mixed waste treatment system.

Low ash liquids, although best suited for incineration, are good candidates for MSO. There is a large quantity of waste solvents, which contains small amounts of TRU and corrosion products both at Hanford and Savannah River (SRS) (about 10,000 gallons at SRS). Additional large quantities of liquid wastes are at the Oak Ridge sites and are currently being burned in the TSCA incinerator.

After operation begins, the Defense Waste Processing Facility (DWPF) at SRS will generate about 150 gallons of benzene per day. This benzene would also be a suitable feed for MSO. Other DOE sites also project future generation of organic liquids. These projections and a comparison to the stored waste inventories are presented in Appendix D.

MSO is not a good treatment option for low BTU, high ash waste streams or for waste with very high chlorine content. For high chlorine wastes, the present data indicate that CO levels are too high at approximately 20% chloride in the melt.

4.1.2 Applicability of Specific Wastes for the MSO Process

Cemented Sludge. Cemented sludge, such as those currently stored at ORNL, INEL, and RFP, is not recommended as a feed for the MSO process due to the high ash and low energy content (requires supplemental fuel).

Graphite Waste. Crucible graphite may be suitable for processing by MSO.

ER Waste. Soils and other contaminated, non-combustible debris are not a suitable feed for the MSO process due to high ash and low energy content.

Leaded Gloves. Plutonium contaminated leaded gloves are readily treatable with MSO as are tributyl phosphate and ion exchange resins.

Aluminum. High levels of aluminum metal in the waste can pose a problem, as can sodium fluoride, since they may cause corrosion of the alumina-based refractory.

4.1.3 Pretreatment

Treatment for Mercury. As with most other thermal treatment technologies, mercury is not expected to be captured by the process. Hence, this type of waste should not be processed by MSO without pre-treatment or post-treatment capture in the APC system.

Pretreatment of Sludge. Filter cake and other thick sludges may have to be diluted to facilitate pumping into the molten bed. Since copious amounts of water can not be used (due to excess steam release and energy requirements, an adequate substitute may need to be investigated).

Pretreatment of Solids. Solids must be sorted to remove most metals and size reduced to less than 1/4-inch to facilitate pumping into the molten bed. Solids not meeting the size criteria could plug the feed injection nozzle. Equipment proposed for accomplishing the size reduction function are rotary knife shredders, hammer mills, ball mills, air classifiers, screens, and the related conveying devices. These operations generate dust, and the proposed equipment will require frequent maintenance. For alpha-MLLW (i.e., TRU concentrations of > 10 nCi/g and < 100 nCi/g) the level of design complexity required for alpha confinement during pretreatment may be very costly.

The level of complexity and cost for processing some DOE solid waste (e.g., stored waste), may preclude MSO being applied to these wastes. Examples of complexities are:

- Sorting of waste (manual or remote) will be required.
- The feed material must be reduced to 1/4-inch size to allow pneumatic conveyance into the MSO bed. Shredders, hammer mills, screens, and material handling equipment are proposed for size reduction and feeding of the waste. These components require extensive maintenance which will be difficult for applications requiring glove box or alpha cell operations.
- Much of the solid waste includes plastic and cotton clothing, bags, gloves, and other material containing thin sheets of plastic. The proposed shredding/hammer mill technique needs to be demonstrated on this category of waste.

4.1.4 Characterization

Pre-characterization of the input waste is needed to monitor and control several important process parameters including chemical reactivity, chloride control, and ash concentration in the bed. For optimum process control (viscosity and NaCl build up, an elemental analysis of all input waste was proposed to the Panel. For liquid and most other homogeneous waste this may be acceptable. However, for drums containing non-homogeneous solids, an elemental analysis will not be practical and would be very costly.

The Panel was told that the MSO process can also be operated with minimal waste characterization. In this case, the proposed method for monitoring salt reactivity is: a) monitor molten salt reactivity breakthrough point by monitoring effluent gases (e.g., Cl_2 and CO) and; b) monitor ash concentration by a combination of remote instrument indication by a bubbler type viscosity meter and visual observation of the molten salt overflow by a video camera. Less characterization at the expense of less optimum monitoring of the bed parameters may not be acceptable. Minimal characterization will increase the probability of process failures (e.g., bed freezing) and/or discharge of pollutants to the atmosphere. Minimal characterization will require the ash control (and bed viscosity) to be conservatively operated. This will further increase the salt discharge and residual management problems (recycle or disposal).

4.2 MSO REACTOR CONCEPT

Issues of greatest concern identified with the MSO reactor are: (1) over-pressurization of the MSO vessel; (2) potential adverse reaction of certain wastes with the molten salt; (3) conditions that may cause freeze-up of salt melt within the MSO reactor or ancillary systems during off-normal operating conditions; and (4) verification of removal efficiencies and assessment of emissions during operation.

Other comments relative to the reactor itself include:

- 1) Retention data for radioactive species and heavy metals in the melt are still unknown.
- 2) Melt viscosity is a function of ash composition. More data are needed on the impact of ash composition on operation (e.g., sparging, mechanical properties, salt bleed/recycle, metals retention).
- 3) Melt can be tailored (depending on salt chemical composition and oxidation potential) to waste streams for small quantity, hard-to-treat wastes. This can be determined by collecting data on small treatability tests.

- 4) For extended operation, metals may build up in the reactor vessel. It is known that lead and aluminum may separate and form separate metallic phases in the salt melt. It is not known how this may affect operations.
- 5) Fundamental effects of features such as vessel design (e.g., shape, volume, space velocity in the melt, the plenum) need to be better understood. More fundamental studies — both analytical and experimental — should be conducted to develop better basic understanding of the physics and thermodynamics of the process. It is unknown whether additional depth of injection of waste would improve the oxidation of carbon and reduction in products of incomplete combustion (PICs), if it will reduce CO, or if it will lower carryover of the salt.

4.3 PERFORMANCE

Based on experience and comments from state regulators on both the Panel and the MSO presenters, the Panel concluded that the MSO process will be permitted under Subpart X of RCRA for miscellaneous thermal treatment. Under Subpart X, it is probable that the MSO process will be permitted using current and future RCRA hazardous waste incinerator (HWI) emissions standards and operating conditions.

While considerable regulatory emissions data are available on MSO, much of this data was obtained in the 1970s and early 1980s. Consequently, while there is a lot of information, much of it centers on RCRA performance type data from the early 1980s, such as Destruction Removal Efficiencies (DREs), hydrogen chloride (HCl), and particulate. While recent testing at DOE's Energy Technology Engineering Center (ETEC) on waste oil resulted in data on PICs, other highly visible areas such as dioxins/furans and EPA regulated metals have either never been tested for or tested to provide only limited data.

It is very important that a bench-scale (6-inch diameter unit) test program for sampling and analysis of dioxins and furans be developed before implementation of the pilot scale (33-inch diameter unit proposed for ORNL/up to 18-inch unit for LLNL). The wastes fed to the MSO unit during this testing need to include at least one common DOE chlorinated aromatic waste constituent.

In addition, as part of the bench and/or pilot development program, the following regulatory emissions parameters need to be researched:

4.3.1 Products of Incomplete Combustion

The MSO process produces excellent DRE and HCl removal efficiencies. The recent bench-scale test for PICs at the ETEC facility and the burning of shredded rubber tires at the LLNL unit showed, however, that the MSO process will generate PICs. As shown in Table 2, methyl chloride, methylene chloride, and phenol were present in the ETEC process offgas at levels as high or higher than typically found in hazardous waste incinerator (HWI) offgas. Benzene and toluene were generated at lower levels. Naphthalene, a very common HWI PIC, was also present in the MSO offgas, but high naphthalene lab and field blanks were also obtained. Benzoic acid, a non-hazardous PIC was found at extremely high levels, but also with very high lab and field blanks. It appears feasible that both phenol and benzoic acid would be probable reaction products from benzene and/or toluene during a carbonate catalyzed oxidation. Additional research is recommended during the bench and/or pilot phase on hazardous and non-hazardous PIC formation during the MSO process. The Panel is unsure whether higher melt residence times will be required to obtain lower PIC levels.

Table 2. MOLTEN SALT AND INCINERATOR PIC DATA

Products of Incomplete Combustion (PICs)	PIC Concentration in nG per Liter MSO(a)
Methylene Chloride	1.7-363
Methyl Chloride	6.4-88
Benzene	<.05-2.6
Toluene	<.05-1.8
Phenol	1,030-1,570
Naphthalene (b)	3,360-23,410
Benzoic Acid (b)	20,840-40,450

- (a) - "Destruction and Removal Efficiency Demonstration of the Rocketdyne Molten Salt Unit", Accurex Environmental, Anaheim, CA, January 11, 1993
- (b) - High Field and Lab Blanks

4.3.2 Carbon Monoxide

The Panel was told that when sodium chloride was above 20% in the melt, high levels of CO are produced during the MSO process. Since a maximum CO emission of 100 ppm on a one-hour rolling average will likely be required, additional design data need to be obtained on CO emissions to determine if an afterburner or second stage MSO needs to be added to achieve appropriate CO regulatory emission levels.

4.3.3 EPA-regulated Metals

Because Rockwell stopped development work on the MSO process in the early 1980s, there has only been a small amount of work done with EPA regulated metals in the waste feeds. Because of the current and future emphasis on metal emissions from thermal treatment processes, these emissions over the MSO operational temperature range need to be evaluated. PIC and CO emission control will likely require higher melt temperatures. These higher temperatures will, however, also increase the metal vapor pressures in the melt and possibly result in higher metal emissions to the APC device.

4.3.4 Oxides of Nitrogen

For a flameless process, oxides of nitrogen (NOx) emission levels from ETEC demonstration tests were surprisingly high. Additional work needs to be done on wastes that do not contain any organic nitrogen to determine NOx levels in the MSO operational temperature range. It is not certain how waste without nitrogen is the organic compound will affect NOx emissions or how those emissions will match up with Clean Air Act requirements. It is also uncertain whether the higher MSO melt temperatures (1000°C) will generate high NOx emissions or whether the process will require NOx removal after the MSO reactor.

4.3.5 Radionuclides

Melt emission data for the most important DOE radionuclides need to be developed. The Panel was uncertain as to whether there are other radionuclides like cesium that are vaporized from the melt at significant levels.

4.4 RESIDUALS

Residual material discharged from the bed of the molten salt reactor is composed of ash, sodium chloride, sulfates, lithium, potassium and/or sodium carbonate. Many different types of salt compounds could be used as bed material; however, in these discussions sodium carbonate will be discussed in this report since all of Rockwell's work on wastes in an MSO process has used this material. While LLNL discussed the use of salt mixtures, no data were presented to the Panel regarding tests utilizing other salt mixtures. Disposal of the discharged salts was portrayed as the standard mode of operation. Presentations indicated that partitioning of the salt and the molten residue is a straight-forward option to achieve salt recycle. Although salt recycle has been previously used in another application, it did not involve nuclear or waste materials and the required radioactive contaminant control.

As discussed in Section 2.2 (MSO Process), the oxidation is accomplished via mixing of the waste in the hot turbulent bed of molten salt. The bed viscosity is lowest (turbulence highest) when it consists of only fresh sodium carbonate (or whatever the base salt used). As ash accumulates, the bed viscosity decreases and salt must be discharged to prevent ash accumulation from exceeding 20 percent by weight. Rockwell's process purges the bed continuously at a rate of 50 lb/hr to assure ash accumulation is maintained below 20%. If a high ash waste is processed, the purge rate may have to be increased accordingly.

Bed purging is also necessary for high chloride wastes to assure that sufficient Na_2CO_3 is available to neutralize the acid gas precursors. For most wastes, the ash build-up is more limiting than sodium carbonate depletion. Therefore, bed management based on bed viscosity limits would be the usual mode of operation.

4.4.1 Disposal Without Recycle

Disposing of the residue without recycle of the unspent salt is the simplest processing scheme; however, this also leads to the greatest mass of residuals. The MSO process has two operating parameters that affect the generation of residuals: ash and chlorine content in the waste (the presence of RCRA metals may also impact residuals).

The molten salt bed operations depend on the reaction between the sodium carbonate and chloride in the waste to produce an acid free gas emission. Chlorine breakthrough is not reached until the sodium carbonate bed is almost completely exhausted, that is, when there is very little Na_2CO_3 left to react with the hydrogen chloride.

Ash increases the melt viscosity which, in turn, affects the efficiency of the oxidation process. A 20% ash-to-bed mass ratio was proposed to the Panel as a practical upper limit for ash. For some conditions — where the aluminum (Al) and silicon (Si) oxides are about equal — this ash limit decreases to about 5%. Since this condition will increase the residue mass-to-ash ratio 5 to 1 to 20 to 1, it is important to have some idea on how often this might occur. (Note: The ash is the basic residue discharged from an incinerator. In MSO, sodium carbonate is also discharged.)

Thus, either ash content or chloride content in the molten bed can limit the operation and require the addition of sodium carbonate to purge the bed. Typically, the bed has been kept at a maximum sodium chloride content of 90%. Under ash limiting feed conditions, the mass of residue would be at least 5 times as high as the mass of the ash in the waste fed to the process. For some ash conditions in the melt where the Si and Al oxide content is similar, the ash fraction producing unacceptably high viscosity may be as low as 5%. In this case, the mass of the unspent Na_2CO_3 may be as much as 20 times the ash mass.

For the MSO treatable mixed wastes shown on Table 1, the ash was calculated to be 6.3% in an elemental analysis presented in Appendix D. As briefly discussed in Appendix C, this waste stream is derived from extensive "sorting" of wastes at 10 of the DOE sites and "shipped" to the MSO processing facility. In reality, the sorting and shipping would be prohibitively expensive, if even permitted by state regulators. However, for this review, the elemental analysis was performed to estimate the ratio of disposal volumes for this "hand picked" waste stream with and without sodium carbonate recycle.

In each case, assuming the residues required stabilization prior to disposal, the residues were mixed with polyethylene on a 1:1 mass ratio basis. For this relatively low ash "average composition waste" stream, the disposal mass ratio was 1.59 for the no recycle to recycle options (i.e., 59% more mass disposal without recycle) (Appendix D).

This same effect on waste disposal can also be seen for other waste streams as shown in Table 3.

Table 3. Comparison of Disposed Waste mass and volume from the MSO waste treatment system for different wastes (masses after stabilization with polyethylene)

Waste Type (1000 kg)	Disposal w/o Recycle	Disposal with Recycle	Disposal Non-Recycle/ Recycle Mass Ratio
Oil			
1% ash	100 kg	63 kg	1.59
0.5% Cl	0.07 m3	0.04 m3	
Organic Sludge			
10.5% ash	1,000 kg	529 kg	1.89
10 % Cl	0.69 m3	0.36 m3	
Rubber			
20 % ash	2,000 kg	516 kg	3.88
1.3% Cl	1.37 m3	0.35 m3	
MSO Average			
6.3% ash	1,000 kg	629 kg	1.59
8.0% Cl	0.69 m3	0.43 m3	

At an ash mass of 20%, the mass of the residue from the MSO bed is approximately the same as the mass of the waste input. After stabilization for disposal, assuming polyethylene is used, the final waste form mass will be approximately twice the mass of the residue discharged from the MSO process as illustrated in Figure 6 for the no-recycle case.

The volume of the waste generated after polymer stabilization is shown as a function of ash and chlorine content for the 20% ash limit in Figure 7 (assumed densities of NaCl, Na₂CO₃, and polymer are 125, 125, and 70 lb/ft³, respectively).

Finally, there have been numerous suggestions concerning the best final waste form for the salt/waste mixture. Polyethylene or polyester encapsulation is one option, sulfur polymer cement is another; LLNL suggests a "hockey puck" (sintered) form type configuration; ORNL has contracted with a local commercial firm to fashion a leach-resistance brick (the "TIDE Brick") as an innocuous waste form. This form is produced by using C-grade fly ash as a pozzuolanic agent for salt stabilization. Each deserves further study before MSO is proven at pilot scale.

4.4.2 Disposal With Recycle

Adding recycle of Na₂CO₃ complicates the MSO process significantly but will dramatically lessen the amount of waste for disposal. Several additional unit operations would be necessary to dissolve the mixture of NaCl, Na₂CO₃, and ash and to separate each of these constituents. The process uses aqueous dissolution and selective crystallization to separate the sodium chloride from the sodium carbonate and sulfate. The ash would also be separated by filtering the solids from the aqueous salt solution. The Na₂CO₃ is recycled to the front end of the process. NaCl and ash would be disposed separately after drying and processing to be made suitable further treatment before disposal. The ash would be radioactive, have RCRA metal content, and require some type of stabilization. The sodium chloride salt would have limited impurities but still require disposal as LLW. Requirements for stabilization are uncertain, but for this review, polyethylene is assumed appropriate.

With recycle, the theoretical ash and discharged salt mass is identical to an incineration system (considering similar stoichiometric efficiencies). This mass is the lowest attainable. The residues (salt and ash) would have to be stabilized for disposal. Figures 8 and 9 show the mass and volume of the stabilized residues as a function of the ash and chlorine content.

Figure 6. CALCUALTION OF MASS DISPOSED (RESIDUE & POLYMER) FOR NO SALT RECYCLE AND 20% ASH LIMIT

Chlorine in Feed					
	0.0		0.1		0.2
	0.3		0.4		0.6 Mass Frac Cl in Waste

Figure 7. CALCULATION OF VOLUME DISPOSED (RESIDUE & POLYMER) FOR NO SALT RECYCLE AND 20% ASH LIMIT

Figure 8. CALCULATION OF VOLUME DISPOSED (RESIDUE & POLYMER) FOR SALT RECYCLE AND 20% ASH LIMIT

Figure 9. TOTAL VOLUME DISPOSED (RESIDUE & POLYMER) SALT RECYCLE AND 20% ASH LIMIT

The Panel was told that the salt recycle option contributes approximately one-third the total cost. The cost of the recycle facility option must be compared to the costs of the additional residue disposal if no recycle is used. This comparison is obviously dependent on the ash and chlorine content in the waste.

Recycle of the salt also adds processing risk. The potential for steam explosions caused by the salt overflow into water exists. However, the Panel was told that the risk could be controlled by choosing and maintaining proper operating conditions. It is uncertain what implications this has for obtaining mixed waste operating permits for MSO.

Other considerations that would have to be resolved include handling of the solid precipitates, the potential for plugging of lines, and remote operability. Operating experience exists with the recycle loop, but the reliability of the recycle operation for use with radioactive materials has not been demonstrated.

4.5 AIR POLLUTION CONTROL

The emissions presented to an APC system from a MSO melt are expected to be a significant challenge to the collection devices. The fumes liberated from a carbonate/chloride molten salt bed are expected to be in the area of 2 to 6 grains/SCF under the reactor conditions of 900° to 1000° C with a bed velocity of 2 ft/sec. A dry APC system, such as a baghouse as proposed, may be the most applicable system to control MSO emissions due to the high removal efficiencies (> 99%) required.

Three questions associated with the salt fumes entering the baghouse require resolution are:

- particle size distribution of the inlet particulate
- radioactive composition of the inlet particulate
- mercury content.

If the radioactive material remains suspended in the melt, the APC problems are straight forward and can be achieved by state-of-the-art technology. The load on the baghouse is high but is not an insurmountable problem. If radioactivity is carried over to the baghouse, some will inevitably pass on to the HEPA filters. Using appropriate prefilters, capture of radionuclides should present no unique problems.

There exists considerable mercury in the DOE MLLW inventory. As shown on Table 1, the stored waste contains over 800,000 kg. Although careful waste sorting should be employed to eliminate this waste prior to any thermal treatment system, some inevitably will be fed into the MSO system.

Consequently, the MSO APC system may have to be designed to capture mercury by the addition of activated carbon injection upstream of the baghouse or by carbon filters upstream of the HEPA filters.

4.6 OPERATIONAL PROBLEMS

MSO has an operational advantage over other possible non-incineration alternatives in that it has been tested for years at the lab and pilot scale by Rockwell. It appears to be a very forgiving system and tolerant of a wide range of feed rate fluctuations. However, its high thermal inertia implies that MSO may be slow in correcting faults or possible upsets, as well as resistant to upsets from changes in feed conditions.

4.6.1 Corrosion

The ceramic-lined wall of the vessel in the Rockwell design concept appears to be adequate for a lightly loaded system. Corrosion enhancement due to certain waste stream components may occur. Alpha alumina may not be the best choice for the vessel refractory due to the alpha-beta conversion of alumina and resultant spalling. Alternatives and corrosion rate data were not presented, but some work has been done. Localized corrosion in the bottom of the vessel due to retained elemental metal may also occur. System design should account for this possibility. Corrosion in critical areas such as the feeder nozzle was not discussed.

LLNL has given some consideration to the use of metallic vessels coated with a thin refractory oxide. This concept provides some potential advantages relative to the initial heating of the vessel and melting of the salt. The Panel recognized the potential advantages but believed that metal vessels represent too high a risk of corrosion failure for MSO at this time.

4.6.2 Materials of Construction

The Rockwell system proposes a ceramic-lined MSO vessel. Thermal shock and phase change in alumina will continue to be a problem.

4.6.3 Plugging of Ducts

Salt fume build-up in the flue has been successfully controlled in lightly loaded systems. Production systems may be problematic. Plugging of the feeder, etc. by frozen salt has occasionally been a problem. Careful design for prevention of plugging is essential.

4.6.4 Salt Recycle

The lack of mass balance examples greatly interfered with the Panel's ability to make objective judgements. The lack of complete, quantitative mass balance examples raises important questions that must be answered before committing to scale-up. Salt recycle may be the most difficult challenge to the success of MSO technology because of the number of process steps required to handle the salt and the radionuclides.

Fume loss can be a significant problem, and thorough and complete mass balance calculations must be conducted. These fume quantities can nearly double the waste quantities previously discussed for the no recycle option.

4.7 CONTROL

Important process control parameters were identified: temperature, oxidizer, waste feed rate, melt depth, melt viscosity, offgas composition - O₂, CO₂, CO, PICs, etc.

No feedback control loops were discussed or planned. Operation of this system without carefully thought-out control should not be attempted. Design and operating problems can be expected in trying to use real-time monitors whose probes must be drilled through the ceramic liner of the vessel and operated in high operating temperatures and corrosive conditions.

4.8 NON-TECHNICAL

4.8.1 Regulatory Acceptance Issues

Regulatory acceptance of MSO will be a key criterion in implementing MSO as a treatment alternative. Regulators recognize that regulatory mandates such as the RCRA Land Disposal Restrictions (LDRs) and the FFCA are driving DOE to quickly develop and deploy cost-effective methods to treat mixed wastes to standards that will allow disposal of the residue. Regulators further recognize that testing at the pilot plant level and the costs of permitting, construction, operation, maintenance, and residue disposal will be crucial for determining the scope of application of the technology. One regulatory issue that has not been addressed is the potential necessity of a Clean Air Act Title V operating permit for a pilot plant operation.

In general, the technology appears ready to be implemented at pilot scale if the basic technical issues regarding PICs, CO, NOx; salt carry-over; metal volatilities; and final waste form and salt recycling have either been addressed at bench-scale level or can be done at pilot scale level under a range of operating conditions.

In the near future, regulatory acceptance of MSO and other alternatives to incineration will likely be based on the following:

- 1) **Public Acceptance:** In particular, the public must be shown that alternatives have been adequately screened for consideration. Competing alternatives must be given opportunity for pilot scale evaluation in a similar time frame as MSO. The public must be given an opportunity to become familiar with MSO.
- 2) **Adequacy of Data:** The fundamental technical issues regarding waste stream analysis and applicability, performance efficiency, emissions and final forms identification, monitoring and inspection feasibility, considerations of the requirements due to the radioactive portions of the waste, and worker safety have not all been addressed at bench scale.
- 3) **Site-specific Requirements:** Individual states' regulatory and storage/disposal facilities' waste acceptance criteria data needs do not seem to have been identified and addressed as needed at the bench scale level. It is uncertain if they can be addressed at the pilot plant level. Furthermore, delisting, heavily dependent on process knowledge, may be crucial to implementing any alternative. Little has been presented regarding any bench scale testing that examined delisting criteria.
- 4) **Performance Standards:** MSO, and other thermal treatment alternatives, will likely be held to performance standards equivalent to those for incinerators. Therefore, as the EPA revises and implements its draft Combustion Strategy, incineration alternatives may be held to tighter standards than presently exist, particularly for particulates, metals, and dioxin. The Panel was not shown data indicating that MSO has the ability to meet existing standards in bench scale tests. The data presented indicate that the investigators might coordinate with other lab and DOE personnel in understanding and realizing RCRA limitations on dioxin emissions to, among other issues, test for dioxins in the MSO process.
- 5) **Emissions/Performance Compliance Monitoring Feasibility:** Cost effective compliance monitoring is of great concern to the states; the regulatory agencies have limited resources for monitoring compliance, and public acceptance will demand enforceable monitoring strategies. In particular, citizen interest groups are pushing for other continuous emissions monitoring parameters in addition to CO. Any pilot scale testing program design should address this.
- 6) **Residue Volumes/Salt Recycling:** The regulatory agencies will certainly encourage efforts to minimize the final forms volumes to as little as possible. In fact, treatment to a final form that has a significant volume reduction without secondary waste stream generation may be a prerequisite to prevent prolonging the disposal problem. Any recycling exemption request will be closely scrutinized to ensure that viable markets exist.

In summary, the only potential "show-stoppers" for regulatory acceptance to go forward with an MSO pilot plant at this time appear to be:

- 1) Dioxin, PIC and CO concerns, salt carryover, metal volatilities
- 2) Public acceptance (opportunity to review/comment on data/plans)
- 3) Lack of agreement on appropriate waste streams treatable by MSO (mostly a function of costs)

Items (1) and (3) may be resolved through expeditious bench scale testing.

4.8.2 Public Acceptance Factors

Early and ongoing citizen participation will add value to the MSO review process. The basic problems DOE faces in introducing any new technology to the public are: 1) bridging the knowledge gap between scientists and engineers and the general public; and 2) educating those on the technical/ technology side of the issue to the equal importance of public perceptions.

In the past, too little attention and funding have been directed to innovative methods of clean up. Some changes have recently occurred in this arena, and the restoration of \$10M for innovative technology research in the FY94 Energy and Water Appropriations bill is a positive step forward. Additionally, the Mixed Waste Working Group of the DOIT advisory committee has recommended that ".....plans developed under the FFCA must include schedules that provide for the testing and development of new technologies."

In the case of MSO, sufficiency of the technology will be weighed by the public in terms of volume of offgas emissions, products of incomplete combustion, generation of secondary waste streams, and the analysis of the maximum credible accident scenario as related to failure rates for the technology. Additionally, ability to incorporate real time monitoring of the chemical and radioactive characteristics of the offgas will be an essential issue related to public acceptance of any new technology.

Recent "signals" from the public indicate that many citizens are open to the possibility of utilizing newly developed thermal processes that are not in the category of incineration. However, it is probable that, before endorsing any thermal process, the public will call for development of waste characterization technologies that ensure treatment is safe and effective.

The Panel was told about the possible portability of the MSO process. Citizens have voiced an interest in more mobile treatment systems. Such mobility could come a long way in addressing the "Not-in-My-Back-Yard" (NIMBY) syndrome and may help resolve some of the social justice issues that have long plagued the placement of hazardous and radioactive waste treatment facilities. In general, citizens believe that past experience with treatment and storage of such wastes has resulted in major environmental problems. Communities are skeptical, at best, of the technical merits and safety record of existing technologies. Garnering public acceptability of MSO will be largely dependent on the DOE's ability to alleviate or eliminate environmental and safety hazards and successfully prove that they have done so. Portability of the system may help to assure a community that mixed wastes will not be shipped to their neighborhood as a designated long-term treatment center and may help alleviate the fear of continued accumulation of mixed wastes in their community.

In more general terms, an R&D effort related to MSO may gain public support because citizens recognize that, without a truly aggressive approach to development of new technologies, the situation cannot improve. The effort by the Panel to establish communication with the non-scientific public and to inquire what their technology preferences might be is an important first step. The effort should be expanded by EM to investigate additional technologies and develop a public outreach program that might include:

- a) assurance that community concerns are of primary importance in terms of investigations and selection of treatment technologies;
- b) development of a stakeholder outreach team or a one-person public liaison that would initiate, organize, facilitate, and implement public education systems related to innovative technology review;
- c) a process whereby communities hosting technology demonstrations have the opportunity to participate in the monitoring of the technology in its prototype, demonstration, and pilot phases; and
- d) addition of a wider range of "publics" in technical review sessions.

Another possible technical area affecting the public acceptance of alternative technologies is the risks involved in scale up to the technology too quickly. Such risks include: 1) fatal flaws may not be identified at bench scale (unlikely in the case of MSO), 2) DOE may become committed to one technology too quickly, and 3) costs of scale-up may be significantly higher than necessary. However, most importantly, public acceptance not only might not be gained, it may be lost if the public perceives that only one technology is being investigated and funded at the expense of other alternatives. In addition, the public will not accept a technology if bench scale concerns are not addressed and if the public does not have enough time to become familiar with the technology.

5.0 ISSUES & RATIONALE: MSO ONLY AS AN OFFGAS TREATMENT SYSTEM

It has been suggested that the MSO process can be used as an APC system to destroy contaminants produced by a conventional thermal treatment system, and funds are anticipated to permit investigators to begin testing MSO for this purpose. A number of issues arose among the Panel members when it discussed this proposition:

- There needs to be a test representing a true comparison to existing flue gas cleaning devices for organic and acid gas control; (it would still need a HEPA for particulate and radionuclide control and carbon for mercury capture).
- MSO bench tests have been operated at lower temperatures than the levels required to achieve requisite DREs for pollutants (700-800° C versus 1000° C).
- It appears to be a complicated and expensive system compared to already-proven APC systems.
- The results on CO emission levels need to be improved.
- Good bench scale data do not exist.
- Salt carryover will actually increase particulate loading to the final filter control.

The following issues need to be addressed further before development work begins:

- PICs (dioxin has never been measured)
- Continuous performance assurance
- Waste analysis plan and characterization requirement
- When nitrates are in the waste feed, the NO_x emissions do not seem to meet air pollution standards
- Hg, Cd, As, and Pb behaviors are still not known.

Given the foregoing, the Panel's conclusions are that further bench scale tests are needed to accomplish proof of concept before scale-up is attempted use of MSO as an APC device. Additionally, system mass balances and an economic comparison with alternative APC systems should be conducted.

6.0 TECHNICAL RECOMMENDATIONS

The MSO application appears to have potential as an alternative for treatment of mixed waste; however, many questions remain to be answered before major resources are committed to construction of the proposed pilot system. Critical technology gaps that could potentially prevent permitting as a RCRA waste processing system must be resolved.

Data presented to the panel indicated lack of understanding of the molten process with regard to the impact of chlorides on CO emissions. In reactions involving both oxidation and reduction, emission control seems to be more difficult. Future research efforts should focus on these issues.

In view of the Panel's concern related to two potential "show stoppers" related to MSO — dioxin and CO generation — the Panel suggests that bench scale testing be used to demonstrate that these pollutants can be controlled to RCRA emission limits prior to commencing Title I design.

Taking into consideration the potential benefits of this technology for processing certain waste streams, the Panel recommends bench-scale tests and engineering/economic studies to study the issues and concerns raised by this (and the previous review) Panel. Two of these studies should include:

- (1) Simple thermodynamic models describing MSO reactor operation, including the equilibrium vapor pressures for candidate waste stream reaction products, and
- (2) Conceptual design of system feedback process control including the rationale behind the parameters to be measured and/or controlled.

Such continued work could permit the acquisition of necessary data on the following areas:

- Treatment of Metals
- Build-up of reduced metals in the melt
- Metallic lead's corrosive attack on the refractory brick
- The behavior of other metals (especially Hg) in high chloride systems (metal chlorides may be soluble in water if salt is recycled)
- Offgas characteristics if Hg is present

The Panel emphasized the importance of addressing the waste form and disposal options as part of the technology development. Normally, minimization of the final waste volume is an objective because of cost incentives. However, the trade-offs must be considered among many effects, e.g., processing costs, final volume and disposal costs, the capability of waste forms to meet final disposal criteria, and the release of other effluents. This must be coupled with consideration of the amounts of material requiring disposal particularly if little volume reduction is achieved to produce a disposable waste form.

The technical recommendations of the Panel will require considerable managerial direction to accomplish given the differences in viewpoints of the involved laboratories on the ancillary requirements to support MSO. There is need for both bench-scale testing and pilot-scale testing that can be done on a cooperative basis to acquire technical information on performance and engineering. With the differences in approaches and evidence that the previous peer review recommendations have not led to resolution of several technical issues, the Panel suggested that other methods are needed to bring a unified program focus on the technical information and engineering data needed to design, construct, and operate MSO (e.g., feasibility, process and engineering flowsheets, energy balances, and economic incentives).

One suggestion is to create an independent, standing committee which is committed to technical and engineering oversight of MSO development work to enhance the probability of success. This would provide program managers with independent input on the technical priorities and requirements for success. Models of similar activities exist (e.g., the Advisory Committee on Reactor Safety (ACRS) for the NRC, the Technical Review Board for the Civilian Radioactive Waste Program, etc). Such a committee could bring technical emphasis and scientific discipline to selected EM programs. This is particularly important in light of the growing opinion that alternatives to incineration appear attractive to the public and regulators. However, there is insufficient corresponding information available to place incineration and other alternatives to the best perspective for selection of the mixed waste treatment method applicable to portions or all of the waste at a particular site.

If the MSO standing committee is not adopted, the Panel recommended that other alternatives besides MSO receive reviews of comparable scrutiny by an independent panel similar to this Panel. Due to the six week period in which the Panel had to complete its evaluation, it was impossible to respond to its charge to compare MSO with other incineration alternatives in a thorough manner. The EM-50 ITTS study is expected to have completed such an analysis by mid-1994.

Additionally, the Panel is recommending that a second review of MSO be undertaken in the late Fall of 1994 to ensure that the remaining R&D questions have been resolved prior to commencement of Title I design of an MSO pilot plant. This would be an advantageous opportunity to conduct a more comprehensive alternative comparison. It is important that such review occur for several reasons:

1. MSO appears to only have potential to effectively and efficiently treat a limited portion of DOE's MLLW;
2. Public, and to a lesser degree, regulatory acceptance of any alternative will depend on thorough and consistent comparisons of all viable alternatives;
3. All other factors being roughly equal, final choices of alternatives may be based on costs (throughput versus technology versus dollars invested); however, costs cannot be used for comparison unless alternatives are rigorously and consistently evaluated; and
4. Incineration may still be necessary (and be the best method) to treat some of DOE's MLLW. Incineration will have a chance of being accepted by the public only after its perceived shortcomings are addressed and other alternatives are rigorously evaluated so that all alternatives can be compared on a consistent basis.

At least two major items are required before such reviews can occur:

1. Technology selection criteria must be refined for technology screening and selection purposes. The Panel noted that somewhat fragmented attempts to do this already exist within DOE. In particular, the DOIT Committee project has worked on this; and
2. The MWIR must be refined to allow matching technologies with waste types and amounts. This is being done, to some degree, in the ITTS study.

Whether or not an independent committee or a second panel is used, other alternatives to incineration should receive a similar review as MSO — and should be compared scientifically with the latest incineration concepts and capabilities. In addition, some type of scientific peer review is needed — at least annually. For the complete overview of alternatives, the Panel strongly recommended that a prestigious scientific body, such as the National Academy of Sciences, would ensure that, as much as possible, the true technical merits of alternative technologies were fully evaluated and credible. This body should also be requested to evaluate the merits and demerits of incineration of MLLW, as well.

Throughout the Panel review, it was apparent that DOE laboratory and contractor personnel showed a high level of technical proficiency but a lower level of understanding of the impact of the regulatory process and performance standards on developing design goals. The Panel recommends that all future alternative technology R&D projects ensure that someone knowledgeable in these areas be involved early in the project so that data gaps and potentially fatal flaws are identified and prevented at the bench scale level prior to deciding whether or not to go to pilot scale is necessary.

7.0 SUMMARY

7.1 MSO FOR MIXED WASTE

The Office of Technology Development (OTD, EM-50) was charged in early October, 1993 with conducting a technical review of Molten Salt Oxidation (MSO) by the Assistant Secretary for Environmental Management of the U.S. Department of Energy. To conduct the review, OTD organized a Technical Review Panel for MSO. The Panel was directed to provide the Assistant Secretary with its recommendations before November 25, 1993. Recommendations were requested on two questions:

- (1) Is MSO a sufficiently promising thermal treatment alternative technology to be advanced to a pilot plant, and
- (2) How does MSO technology compare with other alternative technologies?

Accordingly, the task of the Panel was undertaken using two mutually supportive approaches: (1) an expert technical review and (2) a numerical analysis of MSO flowsheets and options.

Considered were:

- (1) types and amounts of mixed waste that can be processed by MSO,
- (2) projected performance of MSO to meet regulatory requirements for air emissions, liquid effluents (if any), and waste disposal,
- (3) capability to gain public acceptance as a treatment alternative,
- (4) operability, reliability, and technical issues that require resolution for radioactive use, and
- (5) observations that could enhance success if the Panel supported advancement of the technology.

The Panel supported the importance of studying treatment alternatives for mixed wastes. Perspective is needed on the available options for resolving the DOE mixed waste problem. However, the problem is so diverse that any one technology will not be applicable to the treatment of all kinds of mixed waste.

7.1.1 MSO Technical Attributes

The Panel observed several attractive technical attributes of MSO for DOE mixed waste:

1. Extensive development work and scale-up has been documented on coal gasification and hazardous waste which forms a strong experience base for this process. It clearly is applicable to DOE wastes such as organic liquids and low-ash wastes.
2. It also possesses potential to successfully process difficult-to-treat wastes such as nuclear grade graphite and tributyl phosphate and may be suitable for other problem waste streams such as sodium metal.
3. MSO operating systems may be constructed in relatively small units for small quantity generators.
4. The public perception of the technology could be favorable if acceptable performance data are developed in a forthright manner and fairly presented; however, the premise that MSO will be treated differently than incineration, by either regulators or the public, is untested.

7.1.2 MSO Panel Observations

The results of experiments on MSO show considerable promise for application to certain types of mixed waste including some problematic wastes difficult to treat by other alternatives. For this reason, MSO should be pursued on an R&D basis. While there are a great deal of MSO data, much of this data is on coal, not waste, and was obtained during the 1970s and early 1980s. Consequently, much of these data were not generated to show compliance with EPA-regulated pollutants such as dioxins, PICs, EPA regulated metals, CO, and NOx, that were implemented as requirements or proposed requirements during the late 1980s and early 1990s.

Another basic concern is the lack of sufficient operating data to proceed directly to a pilot plant facility for radioactive waste. Although any one technical issue cannot be considered an absolute "show stopper", the collective issues show that the risk of proceeding with investment in a pilot plant can be reduced by acquiring more bench-scale data before pilot-scale final design is completed.

However, the Panel also believed that there are risks to delaying pilot scale work, and it is important to develop MSO and other alternative technologies so that there is adequate treatment for MLLW located throughout the DOE complex. MSO and other alternative technologies must be pursued in parallel to assure that comparable performance data are developed. Alternatives need to be considered at several DOE sites because of the controversial nature of current approaches to the treatment of mixed waste. Moreover, DOE managers must select proven technologies to meet the mandates of the FFCA. Time delays mean the accumulation of non-productive costs without making available alternative technologies that may be necessary to back up existing approaches if they are unsuccessful.

The Panel reviewed the progress on MSO technology and found no additional issues not previously identified by the 1991 MSO peer review panel report published in January 1992. However, those common issues have not been fully resolved, and several represent key technical and economic risks.

7.1.3 Technical and Operational Issues

7.1.3.1 Applicable Waste Types

The important factors for considering the types of waste that are treatable by MSO include: (1) ash content, (2) chlorine content, and (3) volatile metal content. From existing data, the Panel estimated that approximately 10% of the waste existing in the DOE complex may be treatable by MSO. However at some sites, such as ORNL, this figure may approach 30% and 33% at LLNL.

Viscosity of the melt at operating temperatures increases as the ash (chemical) content increases. Certain ratios of aluminum to silicon are influential. Ash and chloride accumulates in the melt. Ash accumulations must be limited to about 20 weight percent. Sodium carbonate must be added to keep the melt concentration to an operable value. The discharged ash/chloride/ carbonate becomes a waste unless steps are taken to separate the unspent sodium carbonate for recycle.

Without recycle, the volumes of waste for disposal are large (perhaps five times as much as would be generated from incineration). The current DOE data bases on waste types have insufficient information on ash and chloride content to assess specific waste. Partial ash and chloride information from other DOE studies were used to develop some estimates of the final volume of waste. On a mass basis, the MSO non-recycle process residue with stabilization for disposal was 60% of the incoming waste mass. With recycle, the final waste mass was 38% of the incoming waste mass. The final volume, depending on the ash and chloride content of incoming waste can vary from less than the initial volume to more than the initial volume. The final volume and mass of waste produced by MSO needs to be clarified for a number of waste types as well as the operable limits of the melt concerning ash and chloride content. These affect the final waste form.

7.1.3.2 Final Waste Form

Assessment and selection of the final waste form is needed to keep the volume as low as practical. Without salt recycle, waste disposal will be expensive but may be warranted depending upon the types and amounts of specific waste to be treated. Development of an acceptable waste form for LDR disposal or delisting of materials in the waste is also needed. While final waste form options exist, they have not been assessed relative to system operating constraints.

The fly-ash/fused salt stabilization process (TIDE Brick) appears attractive, but a full complement of TCLP and other leachability tests must be conducted to support risk assessment for disposal. The same applies to the alternative of incorporating salt into polyethylene or similar binders. LLNL has shown that a sintered ceramic waste form could be produced from the ash after separation from the salt. Uncertainty exists on the economic tradeoffs for salt recovery and recycle as compared to once-through salt processing.

7.1.3.3 Process Performance

The control of emissions may be marginal without further attention to the full complement of APC devices to meet State, EPA, and DOE regulations. The foremost concern is the possibility of the formation of dioxins/furans while processing chlorinated waste. The absence or presence of dioxins/furans in the MSO offgas needs to be determined. No measurements of dioxins and furan emissions have been made by the developers in any tests to date.

It now appears that more extensive APC devices than are currently proposed may be required to eliminate emissions with waste streams containing higher levels of chlorine. The capability of the MSO process to meet all incinerator regulations must be evaluated while treating realistic combinations of DOE wastes. The bench scale data generated to date indicate that CO levels higher than those allowed for incinerators are emitted at moderate chlorine levels in the molten salt bed. The completion of engineering mass and energy balance and flowsheet options is needed for the wastes to be treated. The selection of the favored options should guide proposed experimental work and the conceptual design.

Adequacy, performance, and reliability of gross sorting, shredding, grinding, fine sorting, and feeding systems need to be established. Such feeding systems are also needed for several of the alternatives to incineration and need to be pursued collectively to support each of the alternatives.

7.1.4 Public and Regulatory Acceptance

The public requires assurance that treatment alternatives have been adequately explored and are capable of performing properly on the type and volume of waste on each DOE site. If successful operation at low excess air can be demonstrated, then MSO offers an alternative that has relatively low gas release. Although MSO is not an incinerator, but a chemical process that may be favorably perceived by the public, it should be capable of meeting all of the existing incinerator standards and any new standards that are currently being developed and promulgated for incinerators. At present the data indicate that MSO may have trouble meeting some of these standards. Final acceptance of MSO may be dependent on communication with the public throughout its development. Of paramount importance is designing experiments and facilities that foster the concept of this or any other process. MSO must be shown to be well engineered, forgiving of upsets, and safe. Further, the issue of waste disposal must be resolved as part of the technology and not promoted as something DOE will solve later.

7.1.5 Other Observations

The Panel was charged to compare the performance of MSO with other alternatives to incineration; however, the extremely tight time frame limited its ability to do so. Some opinions were expressed on alternative technologies but must be verified by similar technical panel reviews. It seems appropriate that each credible alternative should receive similar scrutiny. The Panel also suggests that DOE commission a full-scale evaluation of incineration and alternative technologies (on a similar technical basis) by an independent, prestigious scientific body. This is recommended only when sufficient data are available to put the alternatives into perspective for technical and public consumption.

The Panel noted the growing international and DoD interest in molten salt technology. Commitments for test facilities have been made, and potential industrial facilities are pending. A competitive international market for application of molten salt may exist. However, these markets do not present the same challenge to the process as DOE mixed waste.

It should be further noted that the Canadian company interested in MSO recognizes its applicability to selected (low ash) waste streams. MSO's current appeal to them is for small-sized units, as well as any public acceptance benefits that may accrue.

7.1.6 Summary of MSO Panel Conclusions

The Panel's recommendations are based on the technical material provided by the MSO proponents and by the material presented during technical presentations. It should be noted that there may be other material existing throughout the DOE complex on molten sodium carbonate processes whose examination was precluded by time constraints. Although the Panel has some reservations about moving ahead with a pilot plant, it understands that budget requests must be in place before final design concepts can be completed.

Therefore, the Panel offers the following recommendations:

- The Panel supports the continuation of development of MSO at the same time as conceptual design is proceeding. However, assurance must be provided that outstanding technical issues (section 7.1.7) be addressed at bench scale before proceeding with Title I design. The R&D activity must be well organized, adequately funded, and focused. Emphasis should be on parametric experiments responding to technical/environmental issues raised in this report.
- Following successful resolution of the technical issues raised in this report and as affirmed by a second independent review panel, this Panel recommends proceeding with the balance of design. A second technical review panel should convene a year from now to evaluate the progress made on resolution of issues and review readiness to proceed. At that time, response to the issues raised by this Panel as well as remaining issues raised by the MSO peer review published in January 1992, should be evaluated.

Due to time constraints, it was impossible for the Panel to respond to its second charge in a thorough and responsible manner (i.e., to compare MSO with other alternatives to incineration). It is noted that such a comparison may prove possible after the second phase of the EM-50 ITTS study is completed sometime in mid-1994.

- The Panel also recommends that a detailed review of other potential alternatives to incineration be conducted with the same scrutiny as MSO. This could entail commissioning a similar review panel as this one and/or the incorporation of a prestigious group such as the National Academy of Sciences to review incineration and competing alternatives once sufficient data are available. This may prove impossible for a couple of years until development work on the less mature alternatives is produced to permit a reasonable performance comparison.

Such a review is important because MSO's application is limited complex-wide, public and regulatory acceptance depends on thorough and consistent comparisons of all incineration alternatives, final choices may be based on costs, and incineration may be the best (or only) alternative to destruction of some wastes. But, before another review is conducted, technology selection criteria must be refined, and the MWIR must be improved to permit matching technologies with waste types and amounts.

7.1.7 Outstanding Technical Issues

A summary of the outstanding technical issues is as follows:

- A detailed review of other potential alternatives to incineration should be conducted so that all alternatives are rigorously evaluated for comparison on a consistent basis
- A test program for sampling and analysis of dioxins and furans should be developed before implementation of the pilot scale
- Additional research is recommended during the bench and/or pilot phase on hazardous and non-hazardous PIC formation during the MSO process
- Additional work needs to be done on wastes that do not contain any organic nitrogen to determine NO_x levels in the MSO operational temperature range
- Melt emission data for the most important DOE radionuclides need to be developed

- Study the occurrence rate in which the residue mass-to-ash ratio goes from 5 to 1 to 20 to 1
- Design of system feedback process controls
- Data on reduced metals in the melt and metals behavior (especially Hg) in high chloride systems
- Data on off-gas characteristics if Hg is present
- Studies on waste form and disposal
- DOE data bases on waste types have insufficient information on ash and chloride content to assess specific waste and should be expanded
- Reliability of the recycle operation for use with radioactive materials has to be demonstrated
- Research on the following as they affect salt fumes entering the APC baghouse: particle size distribution, radioactive composition of particles, and mercury content
- Corrosion in critical areas of the MSO system
- Thermal shock and phase change in alumina refractory studies
- Design of equipment to minimize salt plugging
- Salt recycle design and operation
- Fundamental bench scale data adequacy on technical issues: waste stream analysis and applicability, performance efficiency, emissions and final waste forms identification, monitoring and inspection feasibility, radioactive considerations, and worker safety
- Improve performance to meet RCRA emissions and monitoring requirements
- Real time monitoring of the chemical and radioactive characteristics of the off-gas
- Application as a mobile treatment system
- Impact of chlorides in the melt on CO emissions
- Equilibrium vapor pressure and other thermodynamic models
- Engineering/economic and full life-cycle cost studies
- Completion of mass and energy balance and flowsheet options
- Characterization: adequacy, performance, and reliability of gross sorting, shredding, grinding, and feeding
- Similar studies and tests (to equalize the knowledge basis for comparison purposes) of other alternatives to incineration

7.2 MSO ONLY AS AN OFFGAS TREATMENT SYSTEM

Alternative uses of MSO include various applications for treatment of offgases coming from various thermal treatment units (e.g., rotary kiln incinerators).

The Panel noted that insufficient work has been done on using MSO for offgas treatment to make any recommendations. However, the Panel did note several concerns about this application:

1. The amount of salt carry-over from the offgas treatment unit is likely to be high. Management of the salt adds to the complexity of the system as compared to other flue gas cleaning systems.
2. The energy balances necessary to determine the method of control of the salt at the desired temperature have not been established.
3. The single stage scrubber system may not be sufficient alone. Additional air pollution control systems may be required to meet emission standards.

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ITTS and PEIS databases**
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APPENDIX A - Professional Profiles

JAMES J. CUDAHY, P.E.
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EDUCATION

- M.B.A. Michigan State University, 1967
- M.S. Chemical Engineering, University of Delaware, 1966
- B.S. Chemical Engineering, Newark College of Engineering, 1963

CERTIFICATIONS

- Licensed Professional Engineer in Louisiana, Michigan, and Delaware

CURRENT PROFESSIONAL HIGHLIGHTS

Mr. Cudahy is a chemical engineer with 25 years of experience in the chemical industry and as an environmental engineering consultant. His chemical industry experience includes research, marketing, and production work, with over 5 years spent in technical and supervisory chemical production positions. As an Environmental Engineering Consultant, he has specialized for 20 years in incineration and various other aspects of solid and hazardous waste management, permitting, and soil clean-up technologies. He has authored over 80 publications and presentations in these areas, has served as an expert witness, and has chaired sessions on incineration, permitting and soil clean-up at international conferences. He has served on national and local committees involved with the environmental aspects of industrial and hazardous wastes, incinerator metals emissions, the development of EPA incineration guidance documents, energy recovery from waste incineration, and environmental quality. He publishes an annual survey on mobile thermal treatment contractor experience.

EXPERIENCE

Professional Employment: 25 years

Waste or Environment Fields:

- President and Senior Consultant, Focus Environmental Inc., Knoxville, TN. Responsible for high level environmental consulting in the areas of process engineering design, operations, and permitting with an emphasis on market analysis, technology evaluation, public education, and legal support, 1989 - present.
- Director, Business Development, Thermal Treatment Systems IT Corporation, Knoxville, TN. Defined market needs and potential winning strategies in the areas of fixed and transportable hazardous waste incineration systems. Required staying current on latest developments in thermal treatment and appropriate regulations, 1985 - 1988.

APPENDIX A - Professional Profiles

TERRY ESCARDA
Waste Management Engineer
California Department of Toxic Substances Control

EDUCATION

- B.S. Environmental Resources Engineering, University of California (Humboldt), 1988

CURRENT PROFESSIONAL HIGHLIGHTS

Mr. Escarda is a Waste Management Engineer with the California Department of Toxic Substances Control. He was a hazardous waste treatment, storage, and disposal permit writer for nearly three years with the Department's Region 1 Office where he was responsible for maintaining land disposal permits for the Chemical Waste Management Kettleman Hills Facility and the Pacific Gas & Electric Company Morro Bay Facility. For the last two years he has worked in the department's Hazardous Waste Reduction Grant Program where he was responsible for developing Requests for Proposals, evaluating proposals, and managing research grant contracts. Terry is currently involved in writing research, development, and demonstration (RD&D) permits for such projects as mixed waste (hazardous/radioactive) management, lead-acid battery recycling, and alternative battery development. He is the RD&D permit writer for the Lawrence Livermore National Lab Mixed Waste Management Facility, where technologies such as molten salt oxidation (MSO) will be demonstrated and evaluated for effectiveness in treating mixed waste. He also serves on the Western Governors' Association Develop On-Site Innovative Technologies Committee mixed waste group, and will be the regulatory liaison for a proposed joint project with Southern California Edison and Rockwell to evaluate MSO's effectiveness in treating a variety of waste streams.

EXPERIENCE

Professional Employment: 6 years

Waste or Environmental Fields:

- Waste Management Engineer, California Department of Toxic Substances Control, Sacramento, CA, 1988-present.
- Environmental Engineer, Oscar Larson and Associates, Eureka, CA, 1987-1988.

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FRANK GRAHAM
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EDUCATION

- B.S. Chemical Engineering, University of Florida, 1963

CURRENT PROFESSIONAL HIGHLIGHTS

Mr. Graham is currently responsible for Pu/U separations process and equipment improvements, including dissolving, solvent extraction, and metal production. He developed hardware for electrochemical recovery of plutonium from residues such as incinerator ash. He also developed a plan and coordinated development of technology to allow the New Special Recovery area to recover plutonium from pits and co-chaired a task force which prepared a conceptual design of a pyrochemical (molten salt) plutonium facility designed to supplement the SRS (Savannah River Site) aqueous capacity. Mr. Graham is currently the manager of the Chemical Technical Technology Group of the Hydrogen and Chemical Technology Section. This group has been responsible for development of improved plutonium separation and recovery techniques as well as troubleshooting of the SRS Separations Area problems. Recently, the scope of the group has been broadened to assist in other SRS areas in the fields of chemistry and chemical engineering. This includes improvements in waste treatment and assistance with unique problems in the Defense Waste Processing Facility. The group consists of 14 professionals and 15 technical analysts with an administrative support group. Mr. Graham also serves on the board of the Actinide Separation Conference, which is an annual conference dealing with new and improved technological developments including molten salt techniques. He also serves as the site representative on SUBWOG 30 which is a technology exchange group with the British on plutonium issues, primarily molten salt purification technology.

EXPERIENCE

Professional Employment: 30 years

Waste of Environmental Fields:

- Manager, Chemical Technology Group of the Hydrogen and Chemical Technology Section, Savannah River Site, 1982-present.
- Research Engineer, involved in product and yield improvements, moving new concepts from the laboratory to the pilot plant stage and strategic cost studies for new plant expansion and acquisitions, duPont, 1963-1981.

APPENDIX A - Professional Profiles

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EDUCATION

- Ph.D. Chemical Engineering, Iowa State University, 1976
- M.S. Chemical Engineering, University of Southern California, 1971
- B.S. Chemical Engineering, Iowa State University, 1969

CURRENT PROFESSIONAL HIGHLIGHTS

Dr. Helt is currently the Director of the Argonne Environmental Management Program Office and Section Head for the Hazardous Waste Program Section in the Chemical Technology Division (CTD). The scope of the Environmental Management Program Office includes all of the DOE/EM at the laboratory, including high-level, low-level, and mixed wastes. Programs supported by the Nuclear Regulatory Commission are also within the scope of this office. Dr. Helt's research interest in crystallization has included studies of nucleation, growth kinetics, population balances of particulate processes, effects of additives and surface active agents, and process modelling and control.

EXPERIENCE

Professional Employment: 22 years

Waste or Environmental Fields: 22 years

- Director of Argonne Environmental Management Program Office and Section Head for Hazardous Waste Program Section in Chemical Technology Division; Argonne National Laboratory, 1990-present.
- Group Leader for the Municipal and Hazardous Waste Technologies Group, Chemical Technology Division, 1987-1990.
- Group Leader for the Municipal Solid Waste Group, Chemical Technology Division, 1984-1987.
- Principal Investigator and Task Manager for thermochemical systems in the Energy from Municipal Waste Program, 1982-1984.
- Fluidized Combustion Section, Chemical Technology Division, 1980-1982.
- Assistant Professor of Chemical Engineering, North Carolina State University, 1987-1980.
- Graduate Teaching Assistant, Iowa State University, 1973-1976.
- Engineer, Rockwell International, Atomics International Division, 1969-1973.

APPENDIX A - Professional Profiles

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EDUCATION

- Ph.D. Ceramic Engineering, Iowa State University, 1966
- B.S. Glass Technology, State University of New York, College of Ceramics at Alfred University, 1962

CURRENT PROFESSIONAL HIGHLIGHTS

EXPERIENCE

Professional Employment: 27 years

Waste or Environmental Fields:

Academic

- Professor, Materials Science and Engineering Department, Iowa State University, 1982-present.
- Associate, Ames Lab, Metallurgy & Ceramics Division, 1981-present.
- Associate Professor, Materials Science & Engineering Department, Iowa State University, 1977-1982.
- Assistant Professor, Materials Science and Engineering Department, Iowa State University, 1972-1977.
- Visiting Professor, Ceramic Engineering, Iowa State University, 1971-1972.

Industrial and other Non-Academic Experience

- Network Coordinator, ECIL (1/4 time), 1989-present.
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- Assistant Professor, ERI, Iowa State University, (1/2 time), 1972-1977.
- Administrative Head, Materials Engineering Group, Iowa State University, 1974-1975.
- General Manager, Associated Crafts Company, Pittsburgh, PA, 1970-1971.
- Science Advisor to the Commander, U.S. Army in Vietnam, 11/69 - 1/70.
- Senior Staff Scientist, AVCO Applied Technology Division, Lowell, ME, 1968-1970.
- Captain, U.S. Army Chemical Corps, Research at USA Natick Labs, 9/66-7/68.
- Glass Technologist, B.F. Drakenfeld, Inc., Washington, PA, Summer 1962

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- Senior Staff Scientist, AVCO Applied Technology Division, Lowell, ME, 1968-1970.
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AFFILIATIONS, AWARDS

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APPENDIX A - Professional Profiles

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- Ph.D. Engineering, Kansas State University, 1978
- M.S. Nuclear Engineering, Kansas State University, 1976
- B.S. Physics/Mathematics, New Mexico State University, 1974

CURRENT PROFESSIONAL HIGHLIGHTS

Dr. Seeker is the Senior Vice President and a member of the Board of Directors of Energy and Environmental Research Corporation (EER). He directs over 60 technical personnel located in three offices and his Division conducts over six million dollars annually in widely diverse areas such as Performance Evaluation, Regulations and Permitting, Engineering Analysis, and Environmental System Research and Development. Dr. Seeker received his Ph.D. in Engineering (nuclear and chemical) from Kansas State University where he received the outstanding graduate student award and a National Science Foundation travel award to present his thesis research in England. He has authored over 100 technical papers on various aspects of environmental systems and was invited to present the plenary lecture on combustion in practical systems at the Twenty Third International Symposium on Combustion held in Orlean, France in the summer of 1990. He currently serves on the EPA's Science Advisory Board and is a member of the Environmental Engineering committee and the Research Strategy Advisory Committee. He has been involved with all aspects of contract research, process development and engineering, and full scale technology demonstration. Dr. Seeker has been principal investigator and program manager of numerous multifaceted programs involved with a wide diversity of subjects. He has been largely responsible for sales and for much of the contract administration on contract research and development for his Division. Dr. Seeker has provided Congressional testimony, participated on various distinguished panels, and given numerous lectures.

EXPERIENCE

Professional Employment: 15 years

Waste or Environmental Fields:

- Senior Vice President, Energy and Environmental Research Corporation, present.
- Technical Chair of the ASME/EPA workshop on Continuous Performance Assurance our Metals, Cincinnati, OH, Sept. 1993.
- Co-Organizer of ASME/EPA workshop on Toxic Metals Emissions, Cincinnati, OH, Nov. 1991.
- Program Advisory Committee and Session Chairman of 1992 Incineration Conference, Albuquerque, NM, 1992.
- Technical Advisory Committee to University of California Davis, NIEHS Superfund Research Center, 1991.
- NSF Panel on Research Needs in the Formation and Control of Fine Particulate, Washington, D.C., 1990.
- EPA Review Workshop on Core Combustion Program Development, Durham, NC, 1989.
- NSF Panel on Research Needs on the Monitoring of Waste combustion Systems, UC San Diego, 1988.
- Technical Organizing Committee chairman of Second International Congress on Toxic Combustion Byproducts (held in Salt Lake City, March 26-29, 1991).
- Editor of "Toxic Combustion Byproducts: Formation and Control" (published by Combustion Science and Technology, 1990).
- Technical Organizing Chairman for the First International Congress on Toxic Combustion Byproducts: Formation and Control (held Aug. 2-4, 1989).

APPENDIX A - Professional Profiles

- Chairman of Technical Advisory Panel on Waste Treatment Thrust of the UCLA National Science Foundation Engineering Research Center (1988-1991).
- NATO Advanced Research Workshop on Fundamentals of Physical-Chemistry of Pulverized Coal Combustion (Invited chairman of Pollution Formation, 1986, Les Arcs, France).
- National Science Foundation Panel member on Research Needs in Hazardous Waste Thermal Destruction (1986, Drexel University).
- Technical Advisory Panel of California Air Resource Board on Hazardous Waste Incineration (1985).
- Fuels Research Executive Committee of ASME
- Scientific Advisory Committee of LSU Hazardous Waste Research Center (chairman, 1985-1986).
- Executive Committee of the Western States Section of the Combustion Institute (1985-1988).

AFFILIATIONS, AWARDS

- American Institute of Chemical Engineers
- American Nuclear Society
- American Physics Society
- American Society of Mechanical Engineers
- The Combustion Institute
- Phi Kappa Phi and Sigma Xi

PATENTS, PUBLICATIONS

- 5,116,584 May 26, 1992. "Methods for Enlarging the Useful Temperature Windows for NO_x Control in Combustion Systems"
- 5,139,755 August 18, 1992. "Advanced Reburning for Reduction of NO_x Emissions in Combustion Systems" W.R. Seeker, S.L. Chen, and J.C. Kramlich.
- Dr. Seeker has written over 200 technical papers, journal articles and reports on a variety of environmental studies.

APPENDIX A - Professional Profiles

VIRGINIA SWARTZ
Executive Director, Colorado Council on Rocky Flats
Golden, Colorado

EDUCATION

- M.A. Candidate, Language and Communication, Regis University
Thesis: Bridging the Scientific and Public Communication Paradigms: An Epistemological Approach
- B.A. English/Communication, Fort Lewis College

CURRENT PROFESSIONAL HIGHLIGHTS

Ms. Swartz is currently the Executive Director, Colorado Council on Rocky Flats, Golden, CO. She was awarded a 1993 Gates Foundation Fellowship to Harvard University, John F. Kennedy School of Government, Senior Executive Management Program. She has developed and managed non-profit and quasi-governmental corporations and service agencies including strategic and long range planning responsibilities, and state/federal grant and management. Ms. Swartz was appointed as executive director of an environmental restoration/waste management (ER/WM) citizens advisory board by Governor Roy Romer and Congressman David E. Skaggs. Her experience includes the areas of environmental restoration and waste management issues for Department of Energy/nuclear weapons complex. Her leadership and training include State and Local Government Leadership Training, Harvard University, long range planning, and participation as a working member and/or facilitator of numerous boards, work teams and focus groups on environmental issues. She has highly developed communication skills and extensive experience in facilitation and consensus building. Ms. Swartz is the principle author/editor/publisher of "The Handbook on Rocky Flats" and has written various other publications. She is a recognized citizen participation professional.

EXPERIENCE

Professional Employment: 23 years

Waste or Environmental Fields:

- Executive Director, Colorado Council on Rocky Flats, Denver, Colorado
- Executive Director, Archuleta County Education Center, Pagosa Springs, Colorado
- Executive Director, Southwest Land Alliance, Pagosa Springs, Colorado
- Project Coordinator, Pagosa Springs, Economic Renewal Project Rocky Mt. Institute, Aspen, Colorado
- Project Liaison, East Fork Joint Venture, Pagosa Springs, Colorado
- Project Coordinator, Alamosa Creek Restoration, La Jara, Colorado
- Project Coordinator, East Fork River Restoration Project, Pagosa Springs, Colorado

PATENTS, PUBLICATIONS

- Ms. Swartz has written numerous technical papers, journal articles, and reports in the area of citizen participation and citizen advisory boards.

APPENDIX A - Professional Profiles

ROBERT C. THURNAU
Chief, Technology Research
U.S. Environmental Protection Agency
Risk Reduction Engineering Laboratory
Cincinnati, Ohio

EDUCATION

- M.S. Chemistry, Wilkes College, 1969
- B.S. Chemistry, Syracuse University, 1966

CURRENT PROFESSIONAL HIGHLIGHTS

Mr. Thurnau is currently the Chief of the Thermal Destruction Branch. He has organized, directed, implemented and led EPA's coordinated national research, development and demonstration projects in the area of hazardous waste incineration. This was accomplished by supervising and leading the incineration research activities at the Incineration Research Facility (IRF) located in Jefferson, Arkansas and at the Risk Reduction Engineering Laboratory in Cincinnati, Ohio. As a result he has thorough understanding of the thermal destruction mechanisms responsible for: metals partitioning, POHC/PIC relationships, air pollution control device (APCD) performance and incineration performance.

EXPERIENCE

Professional Employment: 23 years

Waste or Environmental Fields:

- Thermal Destruction Branch Chief, EPA, Risk Reduction Engineering Laboratory, Cincinnati, OH. Thermal Destruction Branch, 1992-present.
- Technology Research Section Chief, EPA, Risk Reduction Engineering Laboratory, Cincinnati, OH. Technology Research Section, April 1988-1992.
- BDAT Treatment Research, Project Manager, EPA, Cincinnati, OH. Developed performance data on the treatment technologies applicable to contaminated Superfund soils and debris, June 1986 - April 1988.
- Chief, Analytical Support Group, Section Chief, EPA, Cincinnati, OH. Provided, directed and supervised the technical activities of the staff in the Analytical Support Group, September 1982 - June 1986.
- Synthetic Fuels, Program Manager, EPA, Cincinnati, OH. A national research program addressing the development and application of air pollution control technologies to the retorting of oil shale and the gasification of coal was carried out, October 1977 - September 1982.
- Drinking Water Research, Research Chemist, EPA, Cincinnati, OH. Required planning, organizing and conducting research relative to the quality of drinking water and the control of its deterioration as it was supplied to a distribution system, June 1973 - October 1977.
- Thermal Degradation Manager, Manager, EPA, Cincinnati, OH. Responsible for all the ORD thermal research connected with the Solid Waste Research Laboratory, June 1970 - June 1973.

APPENDIX A - Professional Profiles

WILLIAM J. QUAPP
Engineering, Technical Staff Consultant
EG&G Idaho, Inc.

EDUCATION

- M.S. Mechanical Engineering, San Jose State University, 1970
- B.S. General Science, San Diego State University, 1966

CERTIFICATIONS

- Registered Professional Nuclear Engineer, California

CURRENT PROFESSIONAL HIGHLIGHTS

Mr. Quapp has 26 years of experience in engineering, management and business development in waste management, system engineering, nuclear system design, and safety and risk analysis. He has organized projects and development project costs and schedules. His expertise includes system engineering and life cycle cost analysis, solving complex engineering problems, assembling and managing technical staff and proposals, and managing large projects. He managed the conduct of system engineering studies for buried and stored mixed wastes. He organized and managed a \$15M waste technology demonstration program. He also developed technical approach and managed accident analysis and probabilistic risk assessment for establishing the safety basis for the N Reactor. He has managed multi-disciplinary teams of 35 engineers and scientists to plan, conduct, and analyze reactor safety research programs. He has been instrumental in identifying requirements for, and barriers to, privatization of DOE waste treatment facilities. Mr. Quapp has developed system designs and life cycle cost estimates for buried waste, mixed waste and transuranic contaminated waste streams.

EXPERIENCE

Professional Employment: 26 years

Waste or Environmental Fields:

- Engineering, Technical Staff Consultant, EG&G, Idaho, Inc., September 1992 - present.
- Manager, Waste Technology Engineering, EG&G, Idaho, Inc., May 1990 - August 1990.
- Manager, Business Development, EG&G, Idaho, Inc., 1984.
- Manager, Strategic Planning, EG&G, Idaho, Inc., 1981 - 1983.
- Manager, Thermohydraulic Testing, Idaho, Inc., 1979 - 1980.
- Manager, Nuclear Fuels Research, EG&G, Idaho, Inc., 1976 - 1978.
- Senior Research Engineer, EG&G, Idaho, Inc., 1973 - 1975.
- Manager, Environmental Assessment, Westinghouse Idaho Nuclear Co., 1989 - 1990.
- Manager, Analysis & PRA, Director, Graphite Life Extension Task Force, Director Strategic Planning, Director, Fuels Programs, Westinghouse Hanford Co., 1985 - 1989.

AFFILIATIONS, AWARDS

- Member and Speaker, Washington Site Study Group

APPENDIX A - Professional Profiles

BLAINE W. BROWN
Senior Engineering Specialist
EG&G, Idaho, Inc.
Idaho Falls, ID

EDUCATION

- Ph.D. Chemical Engineering, Brigham Young University, 1985
- B.S. Chemical Engineering, University of Utah, 1981
- B. S. Fuels Engineering, University of Utah, 1981

CERTIFICATIONS

- Licensed Professional Engineer in Idaho

CURRENT PROFESSIONAL HIGHLIGHTS

EXPERIENCE

Professional Employment: 12 years

Waste or Environmental Fields:

- Senior Engineering Specialist, Chemical and Process Engineering, EG&G Idaho, Inc., Idaho Falls, ID. Repackaging calculations for WERF incinerator. Modeled release of VOCs from drum venting operations. Assessed treatment alternatives of aqueous NPR fuel process waste. Assessed treatment alternatives of aqueous NPR fuel process waste. Wrote management plan for alpha-contaminated mixed low-level waste. Investigated treatment alternatives for mixed waste streams, 1992-present.
- Senior Project Engineer, Industrial Conservation Programs, EG&G Idaho, Inc., Idaho Falls, Idaho. Provided project management direction and technical expertise to DOE Office of Industrial Technologies for industrial energy conservation. Waste characterization and non-thermal treatment plan for Rocky Flats Plant. Technical review of program proposals. Identified new research program areas. Conducted site inspections of various facilities. Responsible for technical monitoring and program guidance of subcontractor performance, 1985 - 1988.
- Engineering Specialist, Chemical and Process Engineering, EG&G, Idaho, Inc., Idaho Falls, Idaho. Waste remediation support activities for hazardous and radioactive wastes at the Idaho National Engineering Laboratory. Design and pilot plant testing of mixed waste treatment facility. Flowsheet modeling using ASPEN. Process design and engineering of waste treatment facilities. Numerical simulation of diffusion processes. Thermodynamic modeling of chemical reactions occurring in waste retrieval and in-situ processing. Assessment of substitution of nonhazardous for hazardous materials, 1985 - 1988.
- Graduate Research Assistant, Combustion Laboratory, Brigham Young University, Provo, Utah. Responsible for test program and facility upgrading of coal gasifier. Measured and analyzed experimental data. Determined effect of coal type on entrained gasification, 1981-1985.
- Summer Engineer, Kennecott Research Center, Salt Lake City, Utah. Responsible for statistical analysis in materials technology, 1981.
- Summer Technician, Hercules Aerospace Division, Salt Lake City, Utah. Product engineering and advanced studies. Nozzle erosion, shaped charge studies, 1979 - 1980.

APPENDIX A - Professional Profiles

AFFILIATIONS, AWARDS

- Affiliate Faculty Member, University of Idaho, Department of Chemical Engineering
- Member, American Institute of Chemical Engineers
- Member, Combustion Institute, Western States Section
- Outstanding Achievement Award, EG&G

PATENTS, PUBLICATIONS

- Dr. Brown has written numerous technical papers, journal articles, and reports.

APPENDIX A - Professional Profiles

FRED FEIZOLLAHI
Project Manager
MK Environmental Services
San Francisco, California

EDUCATION

- B.S. Mechanical Engineering, University of Maryland, 1970
- Chemical Engineering Graduate Studies, University of Maryland, 1970-1972

CERTIFICATIONS

- Register Professional Engineer, California

CURRENT PROFESSIONAL HIGHLIGHTS

Mr. Feizollahi has 23 years of remedial action/environmental restoration and hazardous/radioactive waste management experience. His expertise includes designs, construction and operation of nuclear and chemical waste management facilities including liquid, gaseous and solid waste processing/storage, transportation, and disposal. Mr. Feizollahi has held Project Manager, Project Engineer, Technical Leader, and Process Group Supervising Engineering positions on several waste management, remedial action/environmental restoration projects. Currently, he is a Project Manager on a DOE radioactive waste treatment design and cost estimating project involving integration with several DOE field and headquarter offices and DOE site management contractors. He manages development of design concepts and planning life cycle costs (PLCC) for treatment, storage, and disposal of seven different DOE waste streams: low-level waste (LLW), mixed low-level waste (MLLW), alpha-LLW/LLMW, transuranic (TRU), Greater-Than-Class C (GTCC), DOE equivalent, and spent nuclear fuel. Treatment technologies considered by this project include incineration, solidification, vitrification, metal-melting, supercompaction, sizing/decontamination and wet-air oxidation. Mr. Feizollahi is also a Project Manager on FMC-San Jose sites final remedial action project. His responsibilities include remedial design, remedial action, and final closure of three facilities. Remediation technologies employed include bio-remediation, vapor extraction and stabilization of VOCs, TPH, PCBs and lead contaminated soil. He has overall responsibility for planning, control and execution of remedial activities performed by both the home and field offices personnel. Mr. Feizollahi is also a Technical Specialist on a DOE integrated thermal treatment study covering various options for treatment of mixed waste. He supervised the preparation of facility design and cost estimates for various treatment options including incineration, vitrification, solidification, mercury separation, lead recovery and metal decontamination.

EXPERIENCE

Professional Employment: 23 years

Waste or Environmental Fields:

- Project Manager, MK Environmental Services, San Francisco, CA., 1991-present.
- Bechtel, San Francisco, CA. 1982 - 1991.
- Halliburton/NUS, Gaithersburg, MD and San Francisco, CA. 1977-1982.
- Hittman (currently Westinghouse/SEG) Columbia, MD. 1973-1977.
- Whitman, Requardt & Associates, Baltimore, MD. 1970-1973.

AFFILIATIONS, AWARDS

- Technical Program Chairman, 1987, 1989 and 1991 ASME Joint International Waste Management Conference.

APPENDIX A - Professional Profiles

PATENTS, PUBLICATIONS

- Mr. Feizollahi has written numerous technical papers, journal articles and reports on hazardous, radioactive, and mixed waste management.

APPENDIX B - Presenters to the Technical Review Panel

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APPENDIX B - MSO Technical Review Panel, October 25-27, 1993

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6633 Canoga Avenue
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APPENDIX B - LLNL Attendees

Ron Cochran	LLNL Executive Officer	510-422-5153
Ann Heywood	ER/WM-AT Program Leader	510-422-8203
Martyn Adamson	Section Leader - Waste Treatment Technologies	510-423-2024
Virginia Oversby	Principal Investigator - Final Waste Forms	510-423-2228
Ravi Upadhye	Principal Investigator - Molten Salt Oxidation	510-423-1299
Oscar Krikorian	Principal investigator - Metal Volatility	510-422-8076
Bill Brummond	Lead Engineer - MSO	510-423-6866
John Celeste	MWMF Systems Integration Engineer	510-422-1685

**APPENDIX C - Evaluation of Current Stored DOE Low-Level Mixed
Wastes Amenable to Molten Salt Oxidation**

November 10, 1993

Prepared by:

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*Prepared for the
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**APPENDIX C - Evaluation of Current Stored DOE Low-Level Mixed
Wastes Amenable to Molten Salt Oxidation**

APPENDIX C - Evaluation of Current Stored DOE Low-Level Mixed Wastes Amenable to Molten Salt Oxidation

1.0 INTRODUCTION

The DOE and its contractors have compiled a large variety of databases for an equally large number of purposes. Most of these databases are compiled to report information on regulated substances to the proper authorities. Reference 1 is a current example of such a database.

In order to adequately develop or evaluate treatment systems, more information on the waste characteristics is typically required. In general, since the regulated material (contaminant(s)) is often present in trace quantities, the most important information for treatment purposes is a detailed description of the physical materials with which the contaminants are commingled.

Thus, for the ITTS studies, the DOE MWIR database¹ was expanded to describe the physical matrices of DOE low-level mixed wastes in order to estimate the elemental analysis and evaluate various thermal treatment systems. The data used for this study represents the DOE stored mixed low level waste (MLLW) inventory through 1992.

For the Molten Salt Oxidation Review, this database was analyzed to assess the quantities and locations of waste that were deemed treatable by MSO. Criteria for selection of waste to be MSO treatable included high organic content with ash less than about 10%. Especially suitable are organic liquids.

APPENDIX C - Evaluation of Current Stored DOE Low-Level Mixed Wastes Amenable to Molten Salt Oxidation

2.0 WASTE CHARACTERIZATION

This database breaks down each nominal waste stream into what are believed to be the principal physical matrices (that is, the bulk materials). The physical matrices are the main drivers for selecting the appropriate treatment technology. This matrix information is, in turn, converted to elemental compositions. Elemental compositions are necessary in order to calculate mass and energy balances for the treatment processes. In collecting the DOE waste stream information contained in this model¹⁻⁶, it became apparent that the current level of waste characterization is inadequate. Much of the information reviewed contained data on the trace constituents that made the waste hazardous, but there is very little information on the major components (physical matrix) of the waste. Knowledge of the waste matrices is required to define the conceptual treatment approaches; however, to date many DOE sites are not adequately characterizing their waste streams. For the purpose of the ITTS, engineering judgement was used to estimate the waste matrices where good data were not available.

2.1 WASTE INVENTORY

One of the challenges of compiling the waste stream data was to convert all of the data to a single format that would facilitate transformation of listed descriptions into elemental compositions. The primary source of waste stream information was the 180 Day Report¹. This document was used for all of the DOE sites listed in the model except for the INEL. In order to meet the aggressive schedule of this project, the ITTS study participants selected ten DOE facilities that they felt would have waste inventories that, in total, represented the overall DOE complex waste inventory. The following additional simplifications were also employed:

- Data were only taken for the ten largest sites in terms of stored waste.
- TRU waste was excluded.
- Only the largest nominal waste matrices were selected for each site (See Table 1).
- Waste streams of only one cubic meter or less were excluded.

Table 2 lists the ten selected DOE facilities and the percentage of the waste from each facility incorporated into the ITTS model. These data show that the resulting quantities still represent approximately 96% of the total inventory for the ten selected sites.

Most of the stored wastes data contained in the 180 Day Report were based on waste quantities through the end of 1992, although data for some sites were only valid through 1991. In these cases annual generation rates were utilized to convert the data to the 1992 baseline. Since the database was to be linked to a mass balance program, the information needed to be in mass units. Consequently, bulk densities had to be estimated for the waste streams for which mass units were not reported. Bulk density estimations are documented within the model.

APPENDIX C - Evaluation of Current Stored DOE Low-Level Mixed Wastes Amenable to Molten Salt Oxidation

Table 1: General Waste Matrices Selected from 180-Day Report

DOE Facilities	General Waste Matrix Categories Contained within the 180-Day Report																			
	Organic Liquids	Aqueous Liquids	Organic Sludges/Particulates	Inorganic Sludges/Particulates	Cemented Solids	Soils	Organic Debris	Inorganic Debris	Heterogenous Debris	Lab Packs with Metals	Lab Packs without Metals	Reactive Metals	Explosives	Compressed Gases	Liquid Mercury	Elemental Lead	Beryllium Dust	Batteries	Multiple	Other
Lawrence Livermore National Laboratory	X	X		X	X				X											
Rocky Flats Plant	X	X		X	X			X												
Los Alamos National Laboratory	X	X						X	X											X
Fernald Environmental Management Project	X	X	X	X				X												
Savannah River Site	X			X			X									X				
K-25 Site ORNL			X	X															X	X
Y-12 Plant ORNL		X	X			X													X	
Oak Ridge National Laboratory		X																	X	X
Hanford Site				X			X		X							X				
Idaho National Engineering Laboratory		X	X	X		X	X	X	X	X						X			X	

Table 2: Representation of DOE Wastes from the Ten Selected Facilities

DOE Facility	Percent of Inventoried Waste Included
SRS	97
ORNL K-25	99
ORNL	94
ORNL Y-12	-100
HS	94
LLNL	90
RFP	-100
LANL	93
FEMP	95
INEL	100

APPENDIX C - Evaluation of Current Stored DOE Low-Level Mixed Wastes Amenable to Molten Salt Oxidation

The selection of only ten DOE facilities and the choice of only including the major waste streams from these facilities limits the ITTS model to only represent 51.8% of the total contact-handled, low-level mixed waste streams currently being stored throughout the DOE complex.

INEL waste characterization information was obtained from the "*Identification of a Treatment Process for the Idaho Waste Processing Facility Project--A Preconceptual Design Study*" report (referred to as the EG&G report)⁶. This report was used instead of the 180-Day report because the waste stream information was more detailed and included physical matrices. However, the EG&G report used a 1991 baseline. Since no waste generation rates were provided in this report, the INEL generation rates listed in the 180 Day Report were used to adjust the INEL data to the 1992 baseline. A new INEL waste characterization report⁸ has released in draft form and will be incorporated into the waste inventory portion of the model to provide the most current information available.

It was unclear in the 180 Day Report whether the waste masses listed included container mass or not. It was assumed that the mass for most of the waste streams included the container mass. A March 10, 1992 letter by Reva A. Hyde⁷ indicated that 55 gallon steel drums are the dominant container at the INEL, and that 4x4x7 FRP (fiberglass reinforced polyester) boxes represent the majority of the remaining waste containers. This was used as the basis for container selection in the ITTS Material Balance Model. Container types were assigned based on the waste characteristics (i.e., high density, powder, or liquid wastes were assigned to drums and the remaining wastes were assigned to FRP boxes). If information becomes available on the actual container type, the appropriate container type can be easily modified. The model is currently limited to these two container types (drums and FRP boxes).

The specifications for these two containers were obtained from the EG&G report⁶. Drums have a tare weight of 23.6 kg plus a 2.8 kg polyethylene (PE) liner. FRP boxes were simply assumed to be 97% wood and 3% PE; no differentiation is made between the polyethylene of the liner and the polyester coating. The contribution of the fiberglass to the waste matrices is neglected.

2.2 PHYSICAL MATRICES

The physical waste matrix is the main factor used in determining the appropriate waste treatment technology. Therefore, using the best available information (i.e., waste descriptions and process knowledge), the DOE waste streams were segregated into their appropriate physical waste matrices.

The INEL waste stream data, obtained from the EG&G Idaho report⁶, were already broken down into resolvable physical matrices. The matrices list from this report was used as the initial matrix list for the ITTS Material Balance Model. Other matrices were added to the database as needed while entering data from the 180 Day Report (See Table 3).

APPENDIX C - Evaluation of Current Stored DOE Low-Level Mixed Wastes Amenable to Molten Salt Oxidation

Assigning waste matrix distributions to the waste stream data contained in the 180 Day Report was particularly difficult. The descriptions of the individual waste streams are frequently nebulous and involve mixtures of numerous materials. These 180 Day Report waste stream descriptions as well as relevant personnel experience with mixed and radioactive wastes were used to assign the waste streams into their component physical matrices. Unsuccessful attempts were made to obtain accurate site specific physical waste matrix distribution information. A future task will involve sending each site a summary of the waste distribution assigned in the ITTS database. Should additional information be obtained that clarifies the actual matrix distribution of a given waste stream, the new distribution will be re-entered into the model.

Table 3: Selected Waste Matrices Contained within the ITTS Model

Glass Raschig Ring	Wood	Absorbed Organic
Misc. Glass	Cardboard	Absorbed Inorganic
Bulk (nontoxic) Metal	Organic Sludge	Soil/Dirt
Bulk Cadmium	Inorganic Sludge	Flooring Material
Bulk Barium	Cemented Organic Sludge	Asphalt
Uranium Compounds	Cemented Inorganic Sludge	Sheetrock
Beryllium	Cemented Resins	Concrete
Paint Residue	Resins	Metal Fines & Turnings
Lead Shielding	Leaded Rubber	Diatomaceous Earth
Rubber	Ceramics (Molds & Crucibles)	Bulk Mercury
Paper	Firebrick	Incinerator Ash
Clotn	Salts	Organic Labpacks
Oil	Halide Salts	Inorganic Labpacks
Plastic	Sulfate Salts	Tantalum (INEL)
PE/PP	Nitrate Salts	Non-Halogenated Organic Liquids
PVC	Aqueous Organics	Halogenated Organic Liquids
TFE	Aqueous Toxic Metals	Graphite
Batteries (Pb, Cd)	Aqueous Cyanides	

3.0 ELEMENTAL COMPOSITION

All waste matrices are converted to their elemental compositions. Elemental compositions are necessary in order to calculate mass and energy balances for the treatment processes. The elemental composition breakdowns for each physical matrix were obtained from numerous references and are shown in Table 4. All sources of information used to generate the elemental compositions are documented within the model.

Table 4: Physical Waste Matrices Treatable by MSO

	FRP Note 1		Cardboard, Cloth, Paper, and Wood Note 2		Graphite		Halogenated Organic Liquids		Leaded Rubber		Non-Halogenated Organic Liquids		Oil	
	Overall	Dry Basis	Overall	Dry Basis	Overall	Dry Basis	Overall	Dry Basis	Overall	Dry Basis	Overall	Dry Basis	Overall	Dry Basis
ORGANIC														
Carbon	42.78%	44.87%	41.47%	43.65%	100.00%	100.00%	14.94%	14.94%	2.78%	2.78%	80.14%	80.14%	82.52%	85.07%
Hydrogen	8.06%	8.37%	5.80%	6.11%	0.00%	0.00%	1.59%	1.59%	0.35%	0.35%	8.81%	8.81%	12.99%	13.40%
Oxygen	44.68%	46.93%	46.04%	48.46%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	11.04%	11.04%	0.00%	0.00%
Nitrogen	0.09%	0.10%	0.10%	0.10%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Sulfur	0.09%	0.09%	0.09%	0.10%	0.00%	0.00%	0.00%	0.00%	0.06%	0.06%	0.00%	0.00%	0.48%	0.51%
Chlorine	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	83.47%	83.47%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Fluorine	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Organic Subtotal	93.68%		93.50%		100.00%		100.00%		3.20%		100.00%		96.00%	
INORGANIC														
Water	4.85%	—	5.00%	—	0.00%	—	0.00%	—	0.00%	—	0.00%	—	3.00%	—
Glass Forming Inerts	1.47%	1.54%	1.50%	1.58%	0.00%	0.00%	0.00%	0.00%	0.80%	0.80%	0.00%	0.00%	1.00%	1.03%
Bulk Nontoxic Metal	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Arsenic (As)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Barium (Ba)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Berillium (Be)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Cadmium (Cd)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Chromium (Cr)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Lead (Pb)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	96.00%	96.00%	0.00%	0.00%	0.00%	0.00%
Mercury (Hg)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Selenium (Se)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Silver (Ag)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Tantalum (Ta)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Uranium (U)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Inorganic Subtotal	6.32%		6.50%		0.00%		0.00%		96.80%		0.00%		4.00%	
TOTAL WEIGHT PERCENT	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Table 4: Physical Waste Matrices Treatable by MSO (Continued)

	Organic Sludge		PE/PP		Plastics N.O.S		PVC		Rubber		TFE	
	Overall	Dry Basis	Overall	Dry Basis	Note 3		Overall	Dry Basis	Overall	Dry Basis	Overall	Dry Basis
ORGANIC												
Carbon	84.22%	87.60%	85.28%	85.28%	73.17%	73.54%	36.82%	37.57%	69.89%	69.89%	23.54%	23.54%
Hydrogen	10.91%	11.48%	14.32%	14.32%	11.90%	11.98%	4.64%	4.73%	8.80%	8.80%	1.98%	1.98%
Oxygen	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Nitrogen	0.00%	0.00%	0.00%	0.00%	0.03%	0.03%	0.11%	0.11%	0.00%	0.00%	0.00%	0.00%
Sulfur	0.07%	0.08%	0.00%	0.00%	0.02%	0.02%	0.10%	0.10%	1.31%	1.31%	0.00%	0.00%
Chlorine	9.78%	10.30%	0.00%	0.00%	13.59%	13.65%	54.34%	55.45%	0.00%	0.00%	0.00%	0.00%
Fluorine	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	74.48%	74.48%
Organic Subtotal	85.00%		89.60%		98.70%		98.00%		80.00%		100.00%	
INORGANIC												
Water	5.00%	—	0.00%	—	0.50%	—	2.00%	—	0.00%	—	0.00%	—
Glass Forming Inerts	3.00%	3.16%	0.40%	0.40%	0.80%	0.80%	2.00%	2.04%	20.00%	20.00%	0.00%	0.00%
Bulk Nontoxic Metal	5.00%	5.28%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Arsenic (As)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Barium (Ba)	0.50%	0.53%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Berillium (Be)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Cadmium (Cd)	0.50%	0.53%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Chromium (Cr)	1.00%	1.05%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Lead (Pb)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Mercury (Hg)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Selenium (Se)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Silver (Ag)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Tantalum (Ta)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Uranium (U)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Inorganic Subtotal	15.00%		0.40%		1.30%		4.00%		20.00%		0.00%	
TOTAL WEIGHT PERCENT	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Notes:

1. Assumed: 97% Wood, 3% PE. Since we have not been able to identify the amounts of fiberglass and metals in the FRP boxes, both the glass and metal content is neglected in this breakdown.
2. These materials are assumed to all have the same basic composition. The only quantifiable difference is in the amount of filler. Although the amount and type filler material varies significantly, both between categories and within a single category, the basic types and relative amounts of the filler materials is essentially the same.
3. Assume: 75% PE/PP, 25% PVC

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One of the essential pieces missing in the waste inventory puzzle is radionuclide information. Unfortunately, a document listing chemical, physical, and radionuclide data for the waste streams was not found¹⁻⁶. Waste stream information listed in documents that focus on radionuclide characteristics (i.e. high density, powder, or liquid wastes were assigned to drums and the remaining wastes were assigned to FRP boxes).

General radioactivity information was obtained from the IDB report³. This report does not list specific radioactivity data for DOE low-level mixed wastes; therefore, the radioactivity information on low-level wastes was applied to the wastes in the ITTS Material Balance Model. Assigning this data to a distribution of specific radionuclides was performed using information obtained from "*Radiation and Mixed Waste Incineration, Background Information Document Volume 2: Risks of Radiation Exposure.*"⁵ Radionuclides selected for inclusion in the model are summarized in Table 5.

Table 5: Radionuclides

Am-241	Pu-241
Ba-137	Ru-106
Ce-144	Rh-106
Co-58	Sb-125
Co-60	Sr-90
Cr-51	Tc-99
Cs-134	Te-125m
Cs-137	Th-234
Fe-59	U-235
Mn-54	U-238
Nb-95	Y-90
Pa-234	Zn-65
Pr-144	Zr-95
Pu-239	

4.0 DETERMINATION OF MSO TREATABLE FRACTION OF THE LLMW

All physical matrices determined to be low ash combustibles (~10% ash) were included as candidates for the MSO treatment process.⁹ These physical matrices amenable to the MSO treatment process are summarized in Table 6.

The organic sludge category was assumed to be ~10% ash therefore the organic sludge physical matrix was considered to be treatable by MSO. This ash percentage is dependent on the amount of inert materials contained in the organic sludge. It is not uncommon to have organic sludges that result in 50-70% ash after thermal treatment. For the purpose of this study, the dirt and/or inert materials contained within the organic sludge category are assumed to be oils and greases. However, characterization of the organic sludge category may reveal that this waste stream is not amenable to treatment within a MSO process due to high ash content.

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Table 6: Physical Matrices Amenable to MSO Treatment

Cardboard	Organic Sludge
Cloth	Paper
FRP Boxes	PE/PP
Graphite	Plastic N.O.S.
Halogenated Organic Liquids	PVC
Leaded Rubber	Rubber
Non-Halogenated Organic Liquids	TFE
Oil	Wood

The FRP boxes were also placed in the MSO treatable category. Fiberglass reinforced wooden boxes (FRP) are composed of primarily wood and resins. The glass content as well as any metal fasteners is assumed to be less than 10% of the mass. A factor that would limit the treatment of the FRP boxes through the MSO process would be the percentage of fiberglass contained in a FRP box which will contribute to the overall ash content of the MSO bed.

All waste streams identified as amenable to treatment through a MSO process will require extensive sorting. Most of the low-level mixed waste streams located through the DOE complex are comprised of multiple physical matrices. This means the MSO portion of the waste streams will need to be segregated from those wastes not treatable by MSO.

The MSO treatable waste quantity in this report is expected to be over estimated.

4.1 Results of Database Analysis for DOE Complex

The results of the database analysis to determine the fraction of DOE complex LLMW that are treatable by MSO are presented in Table 7. The quantities of the MSO waste by physical matrix is shown in Figure 1. The percentage of waste treatable by MSO is shown graphically in Figure 2 (9% of the waste in this database). The physical matrices and fractions of the materials that are believed to be treatable by MSO is shown in Figure 3. Finally, the distribution of MSO treatable waste around the DOE complex is shown in Figure 4.

4.2 Results of Database Analysis by Site

As noted previously, the ITTS Waste Database includes only the waste from the ten largest DOE sites at this time (ITTS Waste Database will be updated in FY 1994).

For the sites listed in Table 2, the waste streams were assessed to determine those amenable to MSO treatment. The results are shown in Tables 8-17 for each DOE site. A bar chart showing the compositional physical matrices of site wastes. The waste fraction treatable by MSO and a pie chart showing the distribution of the MSO waste by physical matrices for each site are shown in Figures 5-34.

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5.0 Conclusions

This analysis has identified that about nine percent of the currently sorted mixed low level waste is treatable by MSO technology. This determination was based on an estimate of the ash content of the physical materials in the ITTS database being less than 10%. Aqueous wastes were also excluded from the MSO treatability category.

To treat this fraction of the DOE waste, containers would have to be emptied, the waste sorted and shipped to the MSO facility.

The waste not treatable by MSO would have to be treated by some other process prior to disposal. Such processes include thermal desorption or incineration to destroy the RCRA organic component, if present, or stabilization to immobilize any characteristic wastes.

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6.0 REFERENCES

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8. Argyle, M.D., Rubert, A.L., Tozer, J.C., Meikle, L.; *INEL Radioactive Waste Stream Characterization Data*, DRAFT, EGG-WM-10909, August 1993.
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Table 7. Physical Matrix Distribution for the Department of Energy LLMW

Physical Matrix	Total Mass (kg)	Treatable by MSO
Cardboard	180,050	Yes
Cloth	608,534	Yes
FRP Box	1,959,820	Yes
Graphite	11,048	Yes
Halogenated Org. Liquids	325,434	Yes
Leaded Rubber	60,696	Yes
Non-halogenated Org. Liquids	312,041	Yes
Oil	181,214	Yes
Organic Sludge	6,036,995	Yes
Paper	972,574	Yes
PE/PP	1,266,112	Yes
Plastic N.O.S.	242,089	Yes
PVC	129,599	Yes
Rubber	193,474	Yes
TFE	6,224	Yes
Wood	312,361	Yes
Treatable by MSO	12,778,264	
Absorbed Inorganics	1,640,012	No
Absorbed Organics	763,654	No
Aqueous Cyanide	103,782	No
Aqueous Organics	41,297,371	No
Aqueous TC Metals	6,786,035	No
Asbestos	64,205	No
Asphalts	28,518	No
Batteries (Pb, Cd)	102,017	No
Beryllium	1,064	No
Bulk (nontoxic) Metals	3,714,494	No
Bulk Barium	50,400	No
Bulk Cadmium	792	No
Bulk Mercury	828,427	No
Cemented Inorganic Sludge	9,787,837	No
Cemented Organic Sludge	4,267,883	No
Cemented Resins	2,580	No
Ceramics (molds & crucibles)	15,004	No
Concrete	623,519	No
Diatomaceous Earth	215,540	No
Drums	15,004,584	No
Firebrick	95,010	No
Flooring Materials	4,549	No
Glass Raschig Rings	105,354	No
Halide Salts	49,611	No
Incinerator Ash	281,259	No
Inorganic Labpacks	16,097	No
Inorganic Sludge	38,756,447	No
Lead Shielding	868,451	No
Metal Fines & Turnings	95,849	No
Misc. Glass	277,415	No
Nitrate Salts	1,704	No
Organic Labpacks	12,087	No
Paint Residues	26,712	No
Resins	3,090	No
Salts	291,397	No
Sheetrock	170,372	No
Soil/Dirt	8,123,931	No
Sulfate Salts	231	No
Tantalum (INEL)	23,100	No
Uranium Compounds	725,829	No
Not Compatible with MSO	135,226,215	
Total DOE LLMW	148,004,479	

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Table 8. Physical Matrix Distribution for Oak Ridge National Laboratory

Physical Matrix	Total Mass (kg)	Treatable by MSO
Cardboard	3,271	Yes
Cloth	8,383	Yes
FRP Boxes	6,670	Yes
Halogenated Org. Liquids	17,530	Yes
Non-halogenated Org. Liquids	19,584	Yes
Organic Sludge	1,029	Yes
Paper	3,639	Yes
PE/PP	6,793	Yes
Rubber	3,271	Yes
Treatable by MSO	70,170	
Aqueous Organics	10,749	No
Aqueous TC Metals	61,094	No
Batteries (Pb, Cd)	8,675	No
Beryllium	602	No
Bulk (nontoxic) Metals	3,271	No
Bulk Mercury	2,403	No
Ceramics (molds & crucibles)	3,271	No
Drums	29,841	No
Inorganic Labpacks	15,730	No
Inorganic Sludge	3,350	No
Lead Shielding	2,661	No
Misc. Glass	10,064	No
Organic Labpacks	8,064	No
Salts	15,139	No
Soil/Dirt	17,183	No
Not Compatible with MSO	192,098	
Total LLMW at ORNL	262,268	

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Table 9. Physical Matrix Distribution for Y-12

Physical Matrix	Total Mass (kg)	Treatable by MSO
Cardboard	506	Yes
FRP Boxes	432,100	Yes
Halogenated Org. Liquids	88,559	Yes
Non-halogenated Org. Liquids	80,031	Yes
Organic Sludge	3,744,398	Yes
PE/PP	1,316	Yes
TFE	203	Yes
Treatable by MSO	4,347,114	
Aqueous Organics	69,991	No
Aqueous TC Metals	538,233	No
Batteries (Pb, Cd)	83,301	No
Beryllium	462	No
Bulk Mercury	825,703	No
Drums	1,053,373	No
Halide Salts	231	No
Inorganic Sludge	3,987,396	No
Lead Shielding	47,300	No
Misc. Glass	1,794	No
Nitrate Salts	231	No
Salts	34,207	No
Soil/Dirt	7,149,668	No
Sulfate Salts	231	No
Not Compatible with MSO	13,792,119	
Total LLMW at Y-12	18,139,233	

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Table 10. Physical Matrix Distribution for K-25

Physical Matrix	Total Mass (kg)	Treatable by MSO
Cardboard	51,584	Yes
Cloth	95,524	Yes
Halogenated Org. Liquids	71,643	Yes
Non-halogenated Org. Liquids	23,674	Yes
Organic Sludge	482,862	Yes
Paper	71,643	Yes
Plastic N.O.S.	75,464	Yes
Rubber	3,822	Yes
Wood	75,464	Yes
Treatable by MSO	951,680	
Aqueous Organics	98,906	No
Aqueous TC Metals	243,404	No
Asphalts	3,822	No
Bulk (nontoxic) Metals	7,643	No
Ceramics (molds & crucibles)	7,643	No
Concrete	3,822	No
Drums	4,002,722	No
Flooring Materials	3,822	No
Incinerator Ash	177,147	No
Inorganic Sludge	32,098,514	No
Misc. Glass	3,822	No
Salts	21,371	
Soil/Dirt	54,454	
Not Compatible with MSO	36,727,091	
Total LLMW at K-25	37,678,771	

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Table 11. Physical Matrix Distribution for Lawrence Livermore National Laboratory

Physical Matrix	Total Mass (kg)	Treatable by MSO
Cloth	497	Yes
FRP Boxes	2,320	Yes
Halogenated Org. Liquids	8,258	Yes
Non-halogenated Org. Liquids	82	Yes
Oil	37,677	Yes
Paper	3,972	Yes
Plastic N.O.S.	1,788	Yes
Rubber	497	Yes
Treatable by MSO	55,090	
Aqueous Organics	7,147	No
Aqueous TC Metals	21,272	No
Diatomaceous Earth	23,264	No
Drums	23,285	No
Inorganic Sludge	44,439	No
Misc. Glass	2,979	No
Organic Labpacks	327	No
Paint Residues	209	No
Soil/Dirt	4,164	No
Not Compatible with MSO	127,087	
Total LLMW at LLNL	182,177	

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Table 12. Physical Matrix Distribution for Savannah River Site

Physical Matrix	Total Mass (kg)	Treatable by MSO
Cloth	195,901	Yes
FRP Boxes	281,590	Yes
Halogenated Org. Liquids	2,492	Yes
Non-halogenated Org. Liquids	72,574	Yes
Oil	3,141	Yes
Paper	40,942	Yes
PE/PP	138,028	Yes
Plastic N.O.S.	6,162	Yes
Treatable by MSO	740,831	
Batteries (Pb, Cd)	9,974	No
Bulk (nontoxic) Metals	9,974	No
Drums	225,233	No
Inorganic Sludge	1,319,495	No
Lead Shielding	169,554	No
Misc. Glass	3,990	No
Soil/Dirt	26,451	No
Not Compatible with MSO	1,764,670	
Total LLMW at SRS	2,505,500	

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Table 13. Physical Matrix Distribution for Rocky Flats Plant

Physical Matrix	Total Mass (kg)	Treatable by MSO
Cloth	46,170	Yes
FRP Boxes	51,910	Yes
Graphite	903	Yes
Halogenated Org. Liquids	28,883	Yes
Non-halogenated Org. Liquids	8,759	Yes
Oil	95,151	Yes
Organic Sludge	980	Yes
Paper	10,558	Yes
Plastic N.O.S.	15,390	Yes
Treatable by MSO	258,703	
Absorbed Organics	27,810	No
Aqueous Cyanide	1,155	No
Aqueous Organics	40,883,220	No
Aqueous TC Metals	4,566,241	No
Asbestos	48	No
Asphalts	5,232	No
Bulk (nontoxic) Metals	17,125	No
Cemented Inorganic Sludge	8,793,384	No
Cemented Organic Sludge	3,843,180	No
Ceramics (molds & crucibles)	98	No
Concrete	95,832	No
Diatomaceous Earth	192,276	No
Drums	1,409,024	No
Glass Raschig Rings	1,100	No
Incinerator Ash	8,800	No
Inorganic Sludge	1,960	No
Lead Shielding	76,378	No
Leaded Rubber	6,080	No
Metal Fines & Turnings	95,849	No
Misc. Glass	3,401	No
Resins	1,960	No
Soil/Dirt	44,883	No
Tantalum (INEL)	98	No
Uranium Compounds	223,290	No
Not Compatible with MSO	60,298,421	
Total LLMW at RFP	60,557,124	

APPENDIX C - Evaluation of Current Stored DOE Low-Level Mixed Wastes Amenable to Molten Salt Oxidation

Table 14. Physical Matrix Distribution for Fernald Environmental Management Project

Physical Matrix	Total Mass (kg)	Treatable by MSO
Cardboard	376	Yes
Cloth	1,514	Yes
FRP Boxes	1,450	Yes
Halogenated Org. Liquids	56,851	Yes
Non-halogenated Org. Liquids	7,402	Yes
Oil	24,583	Yes
Organic Sludge	514,501	Yes
Paper	3,032	Yes
PE/PP	417	Yes
Plastic N.O.S.	376	Yes
Treatable by MSO	610,502	
Absorbed Organics	1,380	No
Aqueous Organics	216,810	No
Aqueous TC Metals	1,008,209	No
Asbestos	16	No
Bulk (nontoxic) Metals	1,580	No
Bulk Mercury	48	No
Cemented Inorganic Sludge	930	No
Ceramics (molds & crucibles)	432	No
Drums	413,981	No
Firebrick	647	No
Flooring Materials	657	No
Halide Salts	41,855	No
Incinerator Ash	83,764	No
Inorganic Sludge	35,766	No
Lead Shielding	4,966	No
Misc. Glass	1,705	No
Nitrate Salts	1,473	No
Paint Residues	26,246	No
Salts	108,451	No
Soil/Dirt	342,118	No
Uranium Compounds	502,539	No
Not Compatible with MSO	2,793,573	
Total LLMW at FEMP	3,404,075	

APPENDIX C - Evaluation of Current Stored DOE Low-Level Mixed Wastes Amenable to Molten Salt Oxidation

Table 15. Physical Matrix Distribution for the Hanford Site

Physical Matrix	Total Mass (kg)	Treatable by MSO
Cardboard	3,045	Yes
Cloth	123,314	Yes
FRP Boxes	2,320	Yes
Halogenated Org. Liquids	19,273	Yes
Non-halogenated Org. Liquids	57,820	Yes
Oil	662	Yes
Paper	121,602	Yes
Plastic N.O.S.	91,989	Yes
PVC	1,532	Yes
Rubber	670	Yes
TFE	209	Yes
Wood	30,620	Yes
Treatable by MSO	453,056	
Absorbed Inorganics	1,570,869	No
Absorbed Organics	369,581	No
Aqueous Cyanide	101,827	No
Asbestos	375	No
Asphalts	216	No
Batteries (Pb, Cd)	67	No
Bulk (nontoxic) Metals	19,561	No
Bulk Mercury	263	No
Ceramics (molds & crucibles)	674	No
Concrete	528	No
Drums	472,987	No
Flooring Materials	70	No
Halide Salts	7,525	No
Inorganic Labpacks	367	No
Inorganic Sludge	96,802	No
Lead Shielding	105,057	No
Misc. Glass	8,194	No
Organic Labpacks	3,695	No
Paint Residues	257	No
Salts	102,202	No
Soil/Dirt	62,813	No
Not Compatible with MSO	2,923,930	
Total LLMW at Hanford	3,376,986	

APPENDIX C - Evaluation of Current Stored DOE Low-Level Mixed Wastes Amenable to Molten Salt Oxidation

Table 16. Physical Matrix Distribution for Los Alamos National Laboratory

Physical Matrix	Total Mass (kg)	Treatable by MSO
Cardboard	280	Yes
Cloth	320	Yes
FRP Boxes	17,110	Yes
Halogenated Org. Liquids	31,945	Yes
Non-halogenated Org. Liquids	42,115	Yes
Organic Sludge	188,930	Yes
Paper	569	Yes
Plastic N.O.S.	259	Yes
Wood	218	Yes
Treatable by MSO	281,726	
Aqueous Cyanide	800	No
Aqueous Organics	3,865	No
Aqueous TC Metals	20,105	No
Bulk (nontoxic) Metals	203,556	No
Bulk Barium	50,400	No
Bulk Cadmium	792	No
Bulk Mercury	11	No
Drums	63,739	No
Inorganic Sludge	80,970	No
Lead Shielding	293,940	No
Misc. Glass	19,850	No
Soil/Dirt	447	No
Not Compatible with MSO	738,474	
Total LLMW at LANL	1,020,199	

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Table 17. Physical Matrix Distribution for Idaho National Engineering Laboratory

Physical Matrix	Total Mass (kg)	Treatable by MSO
Cardboard	121,008	Yes
Cloth	136,912	Yes
FRP Boxes	1,164,350	Yes
Graphite	10,145	Yes
Leaded Rubber	54,616	Yes
Organic Sludge	1,104,295	Yes
Paper	716,617	Yes
PE/PP	1,119,558	Yes
Plastic N.O.S.	50,661	Yes
PVC	128,066	Yes
Rubber	185,215	Yes
TFE	5,813	Yes
Wood	206,658	Yes
Treatable by MSO	5,003,314	
Absorbed Inorganics	69,143	No
Absorbed Organics	364,883	No
Aqueous Organics	6,683	No
Aqueous TC Metals	327,478	No
Asbestos	63,766	No
Asphalts	19,248	No
Bulk (nontoxic) Metals	3,451,784	No
Cemented Inorganic Sludge	993,523	No
Cemented Organic Sludge	424,703	No
Cemented Resins	2,580	No
Ceramics (molds & crucibles)	2,887	No
Concrete	523,338	No
Drums	889,762	No
Firebrick	94,363	No
Glass Raschig Rings	104,254	No
Incinerator Ash	11,549	No
Inorganic Sludge	1,087,756	No
Lead Shielding	168,597	No
Misc. Glass	221,617	No
Resins	1,130	No
Salts	10,026	No
Sheetrock	170,372	No
Soil/Dirt	421,751	No
Tantalum (INEEL)	23,003	No
Not Compatible with MSO	9,454,195	
Total alpha LLMW at INEL	14,457,509	

Figure 1. Physical Matrix Distribution for Department of Energy LLMW

Figure 2. Distribution of the Department of Energy LLMW Amenable to MSO Treatment

Figure 3. Physical Matrix Distribution of the MSO Treatable LLMW Throughout the DOE Complex

Figure 4. Distribution of MSO Treatable LLMW throughout the DOE Complex

Figure 5. Physical Matrix Distribution for Oak Ridge National Laboratory

Figure 6. Distribution of LLMW Amenable to MSO Treatment at ORNL

Figure 7. Physical Matrix Distribution of the MSO Treatable LLMW at ORNL

Figure 8. Physical Matrix Distribution for Y-12

Figure 9. Distribution of the Y-12 LLMW Amenable to MSO Treatment

Figure 10. Physical Matrix Distribution of the MSO Treatable LLMW at Y-12

Figure 11. Physical Matrix Distribution for K-25

Figure 12. Distribution of the K-25 LLMW Amenable to MSO Treatment

Figure 13. Physical Matrix Distribution of the MSO Treatable LLMW at the K-25

Figure 14. Physical Matrix Distribution for Lawrence Livermore National Laboratory

Figure 15. Distribution of LLMW Amenable to MSO Treatment at LLNL

Figure 16. Physical Matrix Distribution of the MSO Treatable LLMW at LLNL

Figure 17. Physical Matrix Distribution for Savannah River Site

Figure 18. Distribution of Savannah River Site LLMW Amenable to MSO Treatment

Figure 19. Physical Matrix Distribution of the MSO Treatable LLMW at SRS

Figure 20. Physical Matrix Distribution for Rocky Flats Plant

Figure 21. Distribution of Rocky Flats Plant LLMW Amenable to MSO Treatment

Figure 22. Physical Matrix Distribution of the MSO Treatable LLMW at RFP

Figure 23. Physical Matrix Distribution for Fernald Environmental Management Project

Figure 24. Distribution of the Fernald Environmental Management Project LLMW Amenable to MSO Treatment

Figure 25. Physical Matrix Distribution of the MSO Treatable LLMW at FEMP

Figure 26. Physical Matrix Distribution for the Hanford Site

Figure 27. Distribution of the Hanford Site LLMW Amenable to MSO Treatment

Figure 28. Physical Matrix Distribution of the MSO Treatable LLMW at the Hanford Site

Figure 29. Physical Matrix Distribution for Los Alamos National Laboratory

Figure 30. Distribution of LLMW Amenable to MSO Treatment at LANL

Figure 32. Physical Matrix Distribution for Idaho National Engineering Laboratory

Figure 33. Distribution of INEL LLMW Amenable to MSO Treatment

Figure 34. Physical Matrix Distribution of the MSO Treatable LLMW at the INEL

STORED WASTE ELEMENTAL ANALYSIS AND DISPOSAL VOLUME AND COST ANALYSIS

DataBase Description:

Table 1 provides the tabulation of the total ITTS Waste Database Inventory (Currently only the stored inventory of mixed LLW at the ten largest DOE Sites). The waste has been screened to determine the action treatable by Molten Salt Oxidation (MSO) technology. The data in Table 1 is derived from the Mixed Waste Inventory Report with additional engineering process knowledge and judgment used to divide the wastes into the physical matrices shown. The data are developed on the basis that the containers will be extensively sorted to allow the waste to be separated.

Elemental Analysis:

An elemental analysis was conducted on the MSO treatable materials derived from the ITTS database to assess the ash content and resultant disposal volumes associated with MSO treatment of these wastes. Once the physical matrices were known, an estimate of the elemental composition for each matrix was developed as presented in Table 2. From those matrices and the total mass in each waste matrix, the elemental composition can be calculated for this entire waste stream. The results of the elemental composition calculation is presented in Table 3.

Also shown in Table 3 is the waste volumes that would result from this waste stream for the MSO system with and without sodium carbonate recycle.

Assumptions used in this analysis include:

- Ash to salt ratio is limited to 20%
- Without recycle, the salt discharged is four times the mass of the ash
- With recycle, the only salt discharged is associated with neutralization of the acid gases (chlorine, fluorine and sulfur)
- All salt and ash discharged are stabilized in polyethylene at a mass ratio of 1:1.
- Disposal costs for MLLW is \$8400/m³ (\$240/c³).
- Disposal unit costs is based on the weight of the weight of waste treated. Costs include only the disposal fee -- no contribution for the cost of processing or the stabilization materials.

Based on these assumptions, the MSO solid effluents were calculated. After mixing with polymer, the volumes of waste for disposal were calculated. Then the cost of disposal was calculated. This information is also shown on Table 3.

This selected waste stream is calculated to have about 6.3% ash and about 7.7% acid gas precursors. Thus, the residuals consist of Na₂CO₃, NaCl, NaF, Na₂SO₄, and ash. After stabilization with polymer, the residuals represent a mass of about 60% of the waste feed mass treated by MSO for the no recycle option. For the recycle option, the residual mass is 38%. Both values are considered to be conservative on the low side as for these calculations, 100% stoichiometric efficiency is assumed. Realistic residuals will be somewhat higher.

Application to Other Waste Streams:

For waste streams with the same chlorine and other acid gas precursors and higher ash wastes the residuals will be higher and conversely, for lower ash wastes the residuals will be lower. In reality it is expected that limitations on sorting will always produce a higher ash and most likely this same effect will result in a lower chlorine concentration per incoming waste mass. This result will produce a larger difference between the mass of residuals for the recycle and non-recycle options.

Table 1. Physical Matrix Distribution for the Department of Energy LLMW

Physical Matrix	Total Mass (kg)	Treatable by MSO
Cardboard	180,050	Yes
Cloth	608,534	Yes
FRP Box	1,959,820	Yes
Graphite	11,048	Yes
Halogenated Org. Liquids	325,434	Yes
Leaded Rubber	60,696	Yes
Non-halogenated Org. Liquids	312,041	Yes
Oil	161,214	Yes
Organic Sludge	6,036,995	Yes
Paper	972,574	Yes
PE/PP	1,266,112	Yes
Plastic N.O.S.	242,089	Yes
PVC	129,599	Yes
Rubber	193,474	Yes
TFE	6,224	Yes
Wood	312,361	Yes
Treatable by MSO	12,778,264	
Absorbed Inorganics	1,640,012	No
Absorbed Organics	763,654	No
Aqueous Cyanide	103,782	No
Aqueous Organics	41,297,371	No
Aqueous TC Metals	6,786,035	No
Asbestos	64,205	No
Asphalts	28,518	No
Batteries (Pb, Cd)	102,017	No
Beryllium	1,064	No
Bulk (nontoxic) Metals	3,714,494	No
Bulk Barium	50,400	No
Bulk Cadmium	792	No
Bulk Mercury	828,427	No
Cemented Inorganic Sludge	9,787,837	No
Cemented Organic Sludge	4,267,883	No
Cemented Resins	2,580	No
Ceramics (molds & crucibles)	15,004	No
Concrete	623,519	No
Diatomaceous Earth	215,540	No
Drums	15,004,584	No
Firebrick	95,010	No
Flooring Materials	4,549	No
Glass Raschig Rings	105,354	No
Halide Salts	49,611	No
Incinerator Ash	281,259	No
Inorganic Labpacks	16,097	No
Inorganic Sludge	38,756,447	No
Lead Shielding	868,451	No
Metal Fines & Turnings	95,849	No
Misc. Glass	277,415	No
Nitrate Salts	1,704	No
Organic Labpacks	12,087	No
Paint Residues	26,712	No
Resins	3,090	No
Salts	291,397	No
Sheetrock	170,372	No
Soil/Dirt	8,123,931	No
Sulfate Salts	231	No
Tantalum (INEL)	23,100	No
Uranium Compounds	725,829	No
Not Compatible with MSO	135,226,215	
Total DOE LLMW	148,004,479	

Table 2. Calculation of Elemental Composition from Physical Waste Matrices Treatable by MSO

	Total Elemental Mass kg	FRP		Cardboard, Cloth, Paper, and Wood		Graphite		Halogenated Organic Liquids		Leaded Rubber		Non-Halogenated Organic Liquids		Oil	
		1959820		2073519		11048		325434		60698		312041		161214	
		Note 1		Note 2											
		Overall	Dry Basis	Overall	Dry Basis	Overall	Dry Basis	Overall	Dry Basis	Overall	Dry Basis	Overall	Dry Basis	Overall	Dry Basis
ORGANIC															
Carbon	2142873	42.78%	44.97%	41.47%	43.65%	100.00%	100.00%	14.94%	14.94%	2.79%	2.79%	80.14%	80.14%	82.52%	85.07%
Hydrogen	292807	6.06%	6.37%	5.80%	6.11%	0.00%	0.00%	1.59%	1.59%	0.35%	0.35%	8.81%	8.81%	12.99%	13.40%
Oxygen	1864334	44.66%	46.93%	46.04%	48.46%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	11.04%	11.04%	0.00%	0.00%
Nitrogen	3845	0.09%	0.10%	0.10%	0.10%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Sulfur	4495	0.09%	0.09%	0.09%	0.10%	0.00%	0.00%	0.00%	0.00%	0.06%	0.06%	0.00%	0.00%	0.49%	0.51%
Chlorine	271635	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	83.47%	83.47%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Fluorine	0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Organic Subtotal (%)		93.68%		93.50%		100.00%		100.00%		3.20%		100.00%		98.00%	
Organic Mass	4579989														
INORGANIC															
Water	203564	4.85%	—	5.00%	—	0.00%	—	0.00%	—	0.00%	—	0.00%	—	3.00%	—
Glass Forming Inerts	61951	1.47%	1.54%	1.50%	1.58%	0.00%	0.00%	0.00%	0.00%	0.80%	0.80%	0.00%	0.00%	1.00%	1.03%
Bulk Nontoxic Metal	0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Arsenic (As)	0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Barium (Ba)	0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Berillium (Be)	0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Cadmium (Cd)	0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Chromium (Cr)	0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Lead (Pb)	58268	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	96.00%	96.00%	0.00%	0.00%	0.00%	0.00%
Mercury (Hg)	0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Selenium (Se)	0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Silver (Ag)	0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Tantalum (Ta)	0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Uranium (U)	0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Inorganic Subtotal (%)		6.32%		6.50%		0.00%		0.00%		96.80%		0.00%		4.00%	
Inorganic Mass	323783														
TOTAL WEIGHT PERCENT		100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Table 2. Calculation of Elemental Composition from Physical Waste Matrices Treatable by MSO (Continued)

	Total Elemental Mass kg	Organic Sludge 6036995		PE/PP 1266112		Plastics N.O.S 242089 Note 3		PVC 129599		Rubber 193474		TFE 6224	
		Overall	Dry Basis	Overall	Dry Basis	Overall	Dry Basis	Overall	Dry Basis	Overall	Dry Basis	Overall	Dry Basis
ORGANIC													
Carbon	5318428	64.22%	67.60%	85.28%	85.28%	73.17%	73.54%	36.82%	37.57%	69.89%	69.89%	23.54%	23.54%
Hydrogen	892138	10.91%	11.49%	14.32%	14.32%	11.90%	11.96%	4.64%	4.73%	8.80%	8.80%	1.98%	1.98%
Oxygen	0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Nitrogen	204	0.00%	0.00%	0.00%	0.00%	0.03%	0.03%	0.11%	0.11%	0.00%	0.00%	0.00%	0.00%
Sulfur	7167	0.07%	0.08%	0.00%	0.00%	0.02%	0.02%	0.10%	0.10%	1.31%	1.31%	0.00%	0.00%
Chlorine	694280	9.79%	10.30%	0.00%	0.00%	13.59%	13.65%	54.34%	55.45%	0.00%	0.00%	0.00%	0.00%
Fluorine	4636	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	74.48%	74.48%
Organic Subtotal (%)		85.00%		99.60%		98.70%		96.00%		80.00%		100.00%	
Organic Mass	6916853												
INORGANIC													
Water	305652	5.00%		0.00%		0.50%		2.00%		0.00%		0.00%	
Glass Forming Inerts	229398	3.00%	3.16%	0.40%	0.40%	0.80%	0.80%	2.00%	2.04%	20.00%	20.00%	0.00%	0.00%
Bulk Nontoxic Metal	301850	5.00%	5.26%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Arsenic (As)	0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Barium (Ba)	30185	0.50%	0.53%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Berillium (Be)	0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Cadmium (Cd)	30185	0.50%	0.53%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Chromium (Cr)	60370	1.00%	1.05%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Lead (Pb)	0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Mercury (Hg)	0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Selenium (Se)	0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Silver (Ag)	0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Tantalum (Ta)	0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Uranium (U)	0	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Inorganic Subtotal (%)		15.00%		0.40%		1.30%		4.00%		20.00%		0.00%	
Inorganic Mass	957640												
TOTAL WEIGHT PERCENT		100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%
Total Mass (kg)		12778265		Percent total		100.00%							
Dry Weight (kg)		12269049											

Notes:

1. Assumed: 97% Wood, 3% PE. Since we have not been able to identify the amounts of fiberglass and metals in the FRP boxes, both the glass and metal content is neglected in this breakdown.
2. These materials are assumed to all have the same basic composition. The only quantifiable difference is in the amount of filler. Although the amount and type filler material varies significantly, both between categories and within a single category, the basic types and relative amounts of the filler materials is essentially the same.
3. Assume: 75% PE/PP, 25% PVC

Table 3. Elemental Analysis and Disposal Cost Estimate for DOE Stored MML Waste Suitable for MSO Treatment

Total Elemental Mass	
Carbon	7461302
Hydrogen	1184945
Oxygen	1864334
Nitrogen	4049
Sulfur	11662
Chlorine	965915
Fluorine	4636
	0
Organic Mass (kg)	11496843
	0
Water	509216
Glass Forming Inerts	291349
Bulk Nontoxic Metal	301850
Arsenic (As)	0
Barium (Ba)	30185
Berillium (Be)	0
Cadmium (Cd)	30185
Chromium (Cr)	60370
Lead (Pb)	58268
Mercury (Hg)	0
Selenium (Se)	0
Silver (Ag)	0
Tantalum (Ta)	0
Uranium (U)	0
	0
Inorganic Mass (kg)	1281422
Total Mass (kg)	12778265
Total Ash	
Dry Basis	6.29%

Disposal Calculation w/o Recycle of Na ₂ CO ₃ (20% Ash Limit)			
Polymer to Ash + Salt Mass R _t	1		
Polymer Density (kg/m ³)	1121	Polymer Mass (kg)	3861033
Ash Density (kg/m ³)	2082	Ash Mass (kg)	772207
Salt Density (kg/m ³)	2082	Salt Mass (kg)	3088627
Weight Fraction Salt	0.8	Polymer Volume (m ³)	3444
Weight Fraction Ash	0.2	Ash Volume (m ³)	371
Disposal Cost/m ³	\$8,400	Salt Volume (m ³)	1484

Mass Disposed kg	Volume Disposed m ³	Disposal Cost \$ Millions	Disposal Cost \$ per kg waste
7722067	5299	\$45	\$3.48
Percent Original Waste Mass			
60%			

Disposal Cost With Na ₂ CO ₃ Recycle			
Polymer to Ash + Salt Mass R _t	1	Acid Gass Fraction	7.69%
Polymer Density (kg/m ³)	2082	Polymer Mass (kg)	2425943
Ash Density (kg/m ³)	2082	Ash Mass (kg)	772207
Salt Density (kg/m ³)	2082	Salt Mass (kg)	1653737
Weight Fraction Salt	0.8	Polymer Volume (m ³)	2164
Weight Fraction Ash	0.2	Ash Volume (m ³)	371
Disposal Cost/m ³	\$8,400	Salt Volume (m ³)	794

Mass Disposed kg	Volume Disposed m ³	Disposal Cost \$ Millions	Disposal Cost \$ per kg waste
4851887	3329	\$26	\$2.19
Percent Original Waste Mass			
38%			

COMPARISON OF WASTE INVENTORY INFORMATION IN THE ITTS AND PEIS DATABASES

To establish the reasonableness of the ITTS Database for the purpose of evaluating thermal treatment systems, a comparison of the waste in each database that is thought to be treatable by MSO technology was made. The waste information being used in the preparation of the PEIS is from the Mixed Waste Information Report (MWIR or 180 day report). The PEIS information develops a processing rate for purposes of developing treatment options and sizing facility options. The rate is as follows:

$$\text{Processing rate} = \frac{[\text{Stored Waste} + 4 (\text{Five Year Generation Rate Projection})]}{10 \text{ years}}$$

The ITTS Database has been using the Stored Waste Inventory from the MWIR through 1992. Figure 1 compares the Stored and Projected Generation processing rates for each site in the PEIS Database. The processing rate is shown to be dominated by the future projections for several sites. For ease of reading the same data shown in Figure I is presented on Figure 2 but on a logarithmic scale. Figure 3 shows the comparison between the MSO treatable waste in the ITTS and PEIS Databases. Although the numbers are somewhat different, they are comparable. The PEIS Database shows about 25% less MSO treatable waste than the ITTS Database.

Based on the processing rate estimates used in the PEIS, a considerably larger fraction of the DOE waste at some sites is expected to be MSO treatable. This is clearly seen based on Tables 1a and 1b (non alpha and alpha MLLW respectively) which presents the inventory of MSO treatable wastes processing rate for each of the 10 sites in the PEIS Database which are the same ITTS Database Sites. However, it is also true that on a weighted volume basis, the treatable fraction for the entire complex is about 8.5%.

For the stored waste in the PEIS Database, the processing rate information are shown on Tables 2a and 2b. For the projected generation waste in the PEIS Database, the processing rate data are shown in Tables 3a and 3b.

Much of this information is shown graphically in Figures 4 to 9.

Table 1a. CH/non-alpha Waste Volume for Organic Destruction

Large Generators

Waste volume includes stored waste and projected generation. Rate shown assumes a 10-year processing period.

Site Name	Organic Liquids		Organic Sludges / Particulates		Organic Debris [m³/yr]		Potential MSO** Input		Total Waste Volume For Each Site	Percentage of Total Waste Potentially Suitable for MSO at Each Site
	1*		3*		6*					
	m³/yr	kg/yr	m³/yr	kg/yr	m³/yr	kg/yr	m³/yr	kg/yr		
INEL	8	7,804	39	41,917	11	3,805	59	53,526	198	29.7%
Fernald	47	43,493	96	102,709	1	511	145	146,712	371	38.9%
Hanford			5	5,049			5	5,049	46,242	0.0%
LANL	77	71,540	27	28,783	13	4,433	117	104,756	278	42.0%
LLNL	61	56,535	1	1,502	0	3	62	58,040	191	32.6%
ORR, K-25 Site	807	751,662	317	337,202	62	21,259	1,185	1,110,124	2,067	57.3%
ORR, ORNL	1	1,305	2	1,619			3	2,924	131	2.2%
ORR,Y-12 Plant	1,642	1,530,437	1,845	1,964,904			3,487	3,495,341	5,204	67.0%
Paducah Gaseous Diffusion Plant	39	36,639	1	1,076	38	13,148	78	50,862	168	46.7%
Portsmouth Gaseous Diffusion Plant	131	121,949	6	6,529	87	29,849	223	158,326	2,352	9.5%
Rocky Flats Plant									4,583	0 %
SRS	308	287,037	0	426	40	13,639	348	301,102	5,498	6.3%
Total	3,121	2,908,401	2,340	2,491,715	251	86,646	5,711	5,486,761	67,283	8.5%

* Waste sub-category classification

** MSO = Molten Salt Oxidation

Assumed densities are: Organic Liquids = 932 kg/m³, Organic Sludges/Particulates = 1065 kg/m³, and Organic Debris = 345 kg/m³

Table 1b. CH/alpha Waste Volume for Organic Destruction

Large Generators

Waste volume includes stored waste and projected generation. Rate shown assumes a 10-year processing period.

Site Name	Organic Liquids		Organic Sludges / Particulates		Organic Debris [m³/yr]		Potential MSO** Input		Total Waste Volume For Each Site	Percentage of Total Waste Potentially Suitable for MSO at Each Site
	1*		3*		6*					
	m³/yr	kg/yr	m³/yr	kg/yr	m³/yr	kg/yr	m³/yr	kg/yr	m³/yr	
Fernald									371	0 %
Hanford			726	773,576	700	241,452	1,426	1,015,027	46,242	3.1%
INEL	0	30	140	149,526			140	149,556	198	71.0%
Rocky Flats Plant	17	15,919	0	40			17	15,959	4,583	0.4%
SRS	9	8,351			290	100,019	299	108,370	5,498	5.4%
LANL									278	0 %
LLNL									191	0 %
ORR, K-25 Site									2,067	0 %
ORR, ORNL									131	0 %
ORR,Y-12 Plant									5,204	0 %
Paducah Gaseous Diffusion Plant									168	0 %
Portsmouth Gaseous Diffusion Plant									2,352	0 %
Total	26	24,299	867	923,142	990	341,471	1,883	1,288,912	67,283	2.8%

* Waste sub-category classification

** MSO = Molten Salt Oxidation

Assumed densities are: Organic Liquids = 932 kg/m³, Organic Sludges/Particulates = 1065 kg/m³, and Organic Debris = 345 kg/m³

Table 2a. CH/non-alpha Waste Volume for Organic Destruction

Large Generators

Waste volume includes stored waste only. Rate shown assumes a 10-year processing period.

Site Name	Organic Liquids		Organic Sludges / Particulates		Organic Debris [m³/yr]		Potential MSO** Input		Total Waste Volume For Each Site	Percentage of Total Waste Potentially Suitable for MSO at Each Site
	1*		3*		6*					
	m³/yr	kg/yr	m³/yr	kg/yr	m³/yr	kg/yr	m³/yr	kg/yr		
INEL	3	2,635	1	702	1	463	5	3,799	198	2.4%
Fernald	16	14,980	96	102,112	0	166	112	117,257	371	30.3%
Hanford			0	65			0	65	46,242	0.0%
LANL	13	12,116	27	28,744	2	583	42	41,444	278	15.0%
LLNL	7	6,319	0	351	0	0	7	6,671	191	3.7%
ORR, K-25 Site	38	35,420	105	111,591	3	1,070	146	148,080	2,067	7.1%
ORR, ORNL	1	1,305	0	213			2	1,518	131	1.2%
ORR,Y-12 Plant	26	24,325	493	524,811			519	549,136	5,204	10.0%
Paducah Gaseous Diffusion Plant	3	3,061	1	1,076	2	604	6	4,740	168	3.6%
Portsmouth Gaseous Diffusion Plant	16	15,142	1	988	20	6,810	37	22,941	2,352	1.6%
Rocky Flats Plant									4,583	0 %
SRS	2	1,845			26	9,057	28	10,903	5,498	0.5%
Total	126	117,148	724	770,653	54	18,752	904	906,554	67,283	1.3%

* Waste sub-category classification

** MSO = Molten Salt Oxidation

Assumed densities are: Organic Liquids = 932 kg/m³, Organic Sludges/Particulates = 1065 kg/m³, and Organic Debris = 345 kg/m³

Table 2b. CH/alpha Waste Volume for Organic Destruction**Large Generators**

Waste volume includes stored waste only. Rate shown assumes a 10-year processing period.

Site Name	Organic Liquids		Organic Sludges / Particulates		Organic Debris [m³/yr]		Potential MSO** Input		Total Waste Volume For Each Site	Percentage of Total Waste Potentially Suitable for MSO at Each Site
	1*		3*		6*					
	m³/yr	kg/yr	m³/yr	kg/yr	m³/yr	kg/yr	m³/yr	kg/yr	m³/yr	
Fernald									371	0 %
Hanford			3	3,453	10	3,595	14	7,048	46,242	0.0%
INEL	0	30	140	149,526			140	149,556	198	71.0%
Rocky Flats Plant	16	14,875	0	40			16	14,915	4,583	0.3%
SRS	9	8,351			280	96,569	289	104,920	5,498	5.3%
LANL									278	0 %
LLNL									191	0 %
ORR, K-25 Site									2,067	0 %
ORR, ORNL									131	0 %
ORR,Y-12 Plant									5,204	0 %
Paducah Gaseous Diffusion Plant									168	0 %
Portsmouth Gaseous Diffusion Plant									2,352	0 %
Total	25	23,255	144	153,019	290	100,164	459	276,438	67,283	0.7%

* Waste sub-category classification

** MSO = Molten Salt Oxidation

Assumed densities are: Organic Liquids = 932 kg/m³, Organic Sludges/Particulates = 1065 kg/m³, and Organic Debris = 345 kg/m³

Table 3a. CH/non-alpha Waste Volume for Organic Destruction

Large Generators

Waste volume includes projected generation only. Rate shown assumes a 10-year processing period.

Site Name	Organic Liquids		Organic Sludges / Particulates		Organic Debris [m³/yr]		Potential MSO** Input		Total Waste Volume For Each Site	Percentage of Total Waste Potentially Suitable for MSO at Each Site
	1*		3*		6*					
	m³/yr	kg/yr	m³/yr	kg/yr	m³/yr	kg/yr	m³/yr	kg/yr		
Fernald	31	28,513	1	596	1	345	32	29,454	371	8.7%
INEL	6	5,169	39	41,216	10	3,342	54	49,726	198	27.3%
Hanford			5	4,984			5	4,984	46,242	0.0%
LANL	64	59,424	0	38	11	3,850	75	63,313	278	27.0%
LLNL	54	50,216	1	1,150	0	3	55	51,369	191	28.8%
ORR, K-25 Site	769	716,242	212	225,612	59	20,189	1,039	962,043	2,067	50.3%
ORR, ORNL			1	1,406			1	1,406	131	1.0%
ORR,Y-12 Plant	1,616	1,506,112	1,352	1,440,093			2,968	2,946,205	5,204	57.0%
Paducah Gaseous Diffusion Plant	36	33,578			36	12,544	72	46,122	168	43.1%
Portsmouth Gaseous Diffusion Plant	115	106,806	5	5,540	67	23,038	187	135,385	2,352	7.9%
Rocky Flats Plant									4,583	0 %
SRS	306	285,192	0	426	13	4,582	320	290,200	5,498	5.8%
Total	2,995	2,791,253	1,616	1,721,061	197	67,894	4,808	4,580,208	67,283	7.1%

* Waste sub-category classification

** MSO = Molten Salt Oxidation

Assumed densities are: Organic Liquids = 932 kg/m³, Organic Sludges/Particulates = 1065 kg/m³, and Organic Debris = 345 kg/m³

Table 3b. CH/alpha Waste Volume for Organic Destruction**Large Generators**

Waste volume includes projected generation only. Rate shown assumes a 10-year processing period.

Site Name	Organic Liquids		Organic Sludges / Particulates		Organic Debris [m³/yr]		Potential MSO** Input		Total Waste Volume For Each Site	Percentage of Total Waste Potentially Suitable for MSO at Each Site
	1*		3*		6*					
	m³/yr	kg/yr	m³/yr	kg/yr	m³/yr	kg/yr	m³/yr	kg/yr		
Fernald									371	0 %
Hanford			723	770,123	689	237,857	1,413	1,007,980	46,242	3.1%
Rocky Flats Plant	1	1,044					1	1,044	4,583	0.0%
SRS					10	3,450	10	3,450	5,498	0.2%
INEL									198	0 %
LANL									278	0 %
LLNL									191	0 %
ORR, K-25 Site									2,067	0 %
ORR, ORNL									131	0 %
ORR,Y-12 Plant									5,204	0 %
Paducah Gaseous Diffusion Plant									168	0 %
Portsmouth Gaseous Diffusion Plant									2,352	0 %
Total	1	1,044	723	770,123	699	241,307	1,424	1,012,473	67,283	2.1%

* Waste sub-category classification

** MSO = Molten Salt Oxidation

Assumed densities are: Organic Liquids = 932 kg/m³, Organic Sludges/Particulates = 1065 kg/m³, and Organic Debris = 345 kg/m³

Figure 1. Comparison of Stored Waste and Projected Generation

Figure 2. Comparison of Stored Waste and Projected Generation

Figure 3. Comparison of Stored Waste Between the PEIS and ITTS Database

Figure 4. Distribution of MSO Wastes (non-alpha) Stored Waste and Projected Generation

Figure 5. Distribution of MSO Wastes (alpha) Stored Waste and Projected Generation

Figure 6. Distribution of MSO Wastes (non-alpha) Stored Waste Only

Figure 7. Distribution of MSO Wastes (alpha) Stored Waste Only

Figure 8. Distribution of MSO Wastes (non-alpha) Projected Generation Only

Figure 9. Distribution of MSO Wastes (alpha) Projected Generation Only

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