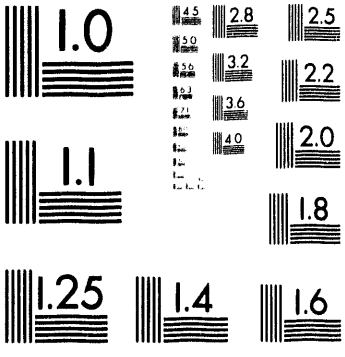
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Mixed-Waste Treatment — What About the Residuals?

A Comparative Analysis of MSO and Incineration

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ABSTRACT

Incineration currently is the best demonstrated available technology for the large inventory of U.S. Department of Energy (DOE) mixed waste. However, molten salt oxidation (MSO) is an alternative thermal treatment technology with the potential to treat a number of these wastes. Of concern for both technologies is the final waste forms, or residuals, that are generated by the treatment process. An evaluation of the two technologies focuses on 10 existing DOE waste streams and current hazardous-waste regulations, specifically for the delisting of "derived-from" residuals. Major findings include that final disposal options are more significantly impacted by the type of waste treated and existing regulations than by the type of treatment technology; typical DOE waste streams are not good candidates for delisting; and mass balance calculations indicate that MSO and incineration generate similar quantities (dry) and types of residuals.

OVERVIEW

The U.S. Department of Energy (DOE) has a large inventory of mixed waste (radioactive and hazardous components*) that will require treatment prior to final disposal. Incineration is currently the best demonstrated available technology (BDAT) for many of these waste streams; however, an alternative thermal treatment technology, molten salt oxidation (MSO),

*Mixed waste is defined as waste having a radioactive waste component regulated under the Atomic Energy Act and a hazardous waste component regulated under the Resource Conservation and Recovery Act.

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has significant potential to treat a certain segment of these wastes [1]. The basic MSO technology, shown in Figure 1, is a noncombustion process** combining chemical neutralization and thermal treatment for the treatment of organically contaminated mixed wastes. The molten salt, usually sodium carbonate or a blend of other salts, (1) acts as a dispersing medium for both the waste being processed and the air used in the processing; (2) enhances the oxidation reactions and accelerates the destruction of organic material; (3) enhances completeness of the chemical reactions by providing better contact over a relatively long time period and provides a stable heat-transfer medium that resists thermal surges; (4) neutralizes and retains acid gases and, thus, requires no wet off-gas scrubbing system; (5) helps retain soot and chars in the melt for more complete reaction; and (6) retains

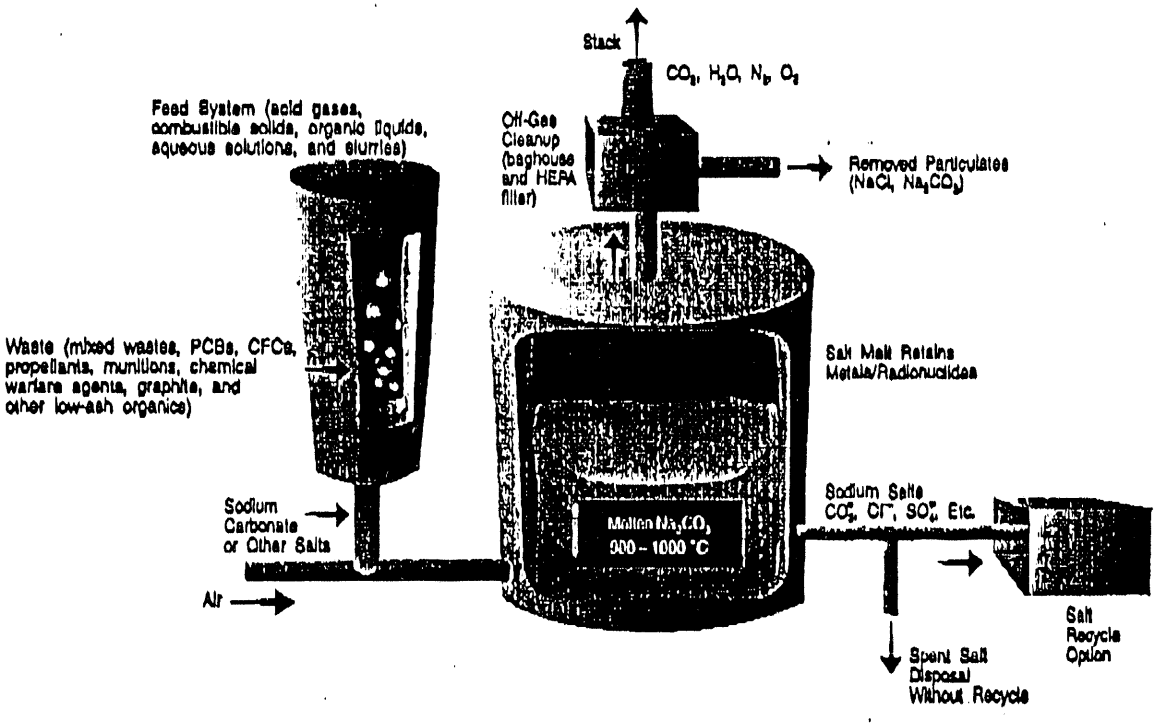

Figure 1. MSO Process

**Molten salt oxidation is not a combustion process in the conventional sense. Combustion usually refers to an oxidation process in which fuel and air are burned at a flame front. The flame front is located at the interface between a fuel-rich region and an oxygen, or oxidizer-rich, region. The flame supports combustion at a flame velocity that is characteristic of each fuel-oxidizer combination. Continued oxidation usually requires a sustained flame. If the flame is extinguished, oxidation of the fuel, even in the presence of the oxidizer, will not continue.

Molten salt oxidation is a combined thermal and chemical treatment process in which the fuel-oxidizer reactions occur in contact with a liquid salt. Because the salt heats the reactants and catalyzes oxidation, the process does not require a flame to initiate or continue the reaction. In the MSO process, the fuel and the oxidizer (usually air) are not separated but are mixed with liquid salt in a turbulent salt bed. Thus, molten salt treatment does not depend on a flame to continue the oxidation process. Moreover, the heat of neutralization is released in the bed. The total heat of reaction is often sufficient to maintain the operating temperature of the molten salt bed without the need for auxiliary fuels.

the ash and other noncombustible material associated with the waste. These characteristics potentially enable (1) superior organic destruction because of enhanced oxidation effects of the salt, a longer residence time, and more intimate contact with caustic molten salt; (2) potential for excellent capture of heavy metals and radionuclides because of wetting, encapsulation, and chemical reaction with the salt melt; (3) reaction and neutralization of acidic products such as HCl, HF, SO_2, and P_2O_5; (4) reduced off-gas flow; and (5) solid, stable, homogeneous residuals. Off-gas treatment systems used with an MSO unit would consist of dry off-gas unit processes that include a baghouse filter and high-efficiency particulate air (HEPA) filter.

Wastes that have been identified as the most appropriate for primary treatment by MSO include high-heating-value organic liquids (e.g., solvents, waste oils), low-heating-value liquids (e.g., chlorinated organic liquids), low-ash combustible solids, chlorofluorocarbons, (e.g., Freon, Halon), organic sludges, explosives, propellants, and chemical warfare agents. These same wastes mixed with radioactive materials also would be appropriate. Particle size reduction may be required for some of these wastes to reduce feed size to one-eighth inch or less. Waste such as soils, asbestos, concrete, grout, and decontamination and decommissioning (D&D) rubble are not practical for MSO treatment because of their high inert content.

PURPOSE

An important concern for any treatment technology is the amount and disposition of secondary waste that is generated through the treatment process. A recent report, *Mixed-Waste Treatment—What About the Residuals? A Comparative Analysis of Molten Salt Oxidation and Incineration* prepared by Chem-Nuclear Geotech, Inc., and Martin Marietta Energy Systems, examines the issues concerning the final waste forms, or residuals, that result from the treatment of mixed waste in MSO systems and incineration units. Final waste form is an important issue for the ultimate implementation of MSO because there has been concern that the MSO residuals present unique disposal difficulties. Development of mass balances and analyses of regulatory and final disposal issues, particularly the feasibility of delisting, address this concern.

Residual waste comparisons are made between MSO and incineration because DOE plans to use incineration to treat many of its mixed wastes and because sufficient information about incineration is available in the literature to perform mass balance calculations. The intent of this comparative analysis is *not* to rate one technology as better than another. Rating requires far more information on a large number of technical and nontechnical factors and is inherently site and waste specific. Instead, this analysis attempts to provide a comparison of the two technologies and describe the strengths and weaknesses of each from a technical (e.g., mass balance) and nontechnical (e.g., regulatory) perspective. Other technologies also may be appropriate for mixed-waste treatment but are not evaluated because process details are not sufficient to perform mass balance calculations comparable to those provided for MSO and incineration. However, from a nontechnical, regulatory perspective, it is anticipated that

final waste forms resulting from all mixed-waste treatment technologies will face the same types of regulatory and disposal constraints.

This analysis focuses on treatment of mixed-waste because it presents the most significant obstacles in terms of final waste disposal for DOE. Issues concerning the treatment of organic hazardous waste (with no radioactive contamination), which is an important and appropriate waste stream for MSO and incineration treatment, are a subset of mixed-waste treatment and, therefore, are addressed to a lesser degree.

To ensure that the conclusions drawn are valid, the report [2] was reviewed by experts in the thermal treatment field and by individuals responsible for existing or proposed incineration facilities at DOE sites.

APPROACH

Several critical areas such as regulatory issues, inventories, and mass balance calculations were examined to determine their impact on residual production and disposal.

Regulatory Issues Regarding Acceptability of Final Waste Forms—The Resource Conservation and Recovery Act (RCRA) has the most significant impact on the acceptability of final waste forms. Wastes can be deemed hazardous under RCRA if they are either characteristic or listed. Characteristic waste can be considered nonhazardous under RCRA if the characteristic (ignitability, corrosivity, reactivity, or toxicity) is removed. In the case of a listed waste, residuals under the "derived-from" rule are still considered a hazardous waste even after treatment and must be disposed of in a RCRA-permitted hazardous waste disposal unit. A delisting procedure is available to allow a listed hazardous waste to be designated nonhazardous. However, delisting of waste treatment residuals is difficult because it normally requires very explicit knowledge of processes by which waste streams are generated and subsequently treated or it requires that the composition of a waste stream undergoing treatment be well known.

Typically, DOE wastes will not be good candidates for delisting (DOE has never delisted a mixed waste). The regulations governing management of treatment residuals are more dependent on the waste feed rather than the type of treatment technology used. Consequently, nearly all listed wastes, mixtures of listed wastes, and residuals derived from listed wastes require management as hazardous wastes. This is the case regardless of how the wastes are treated and what treatment levels are achieved. Therefore, from a regulatory perspective, all treatment technologies, including the BDAT for a given listed waste, will result in treatment residuals that are still deemed hazardous. For example, a tetrachloroethylene solvent waste used in degreasing (an F-listed waste) that was treated either by incineration or MSO would yield NaCl as the only residual waste, yet this benign residual would be considered a listed hazardous waste under the "derived-from" rule. Figure 2 provides an overview of how the residuals from both incineration (BDAT for organic-contaminated mixed wastes) and MSO would be considered under current RCRA regulations.

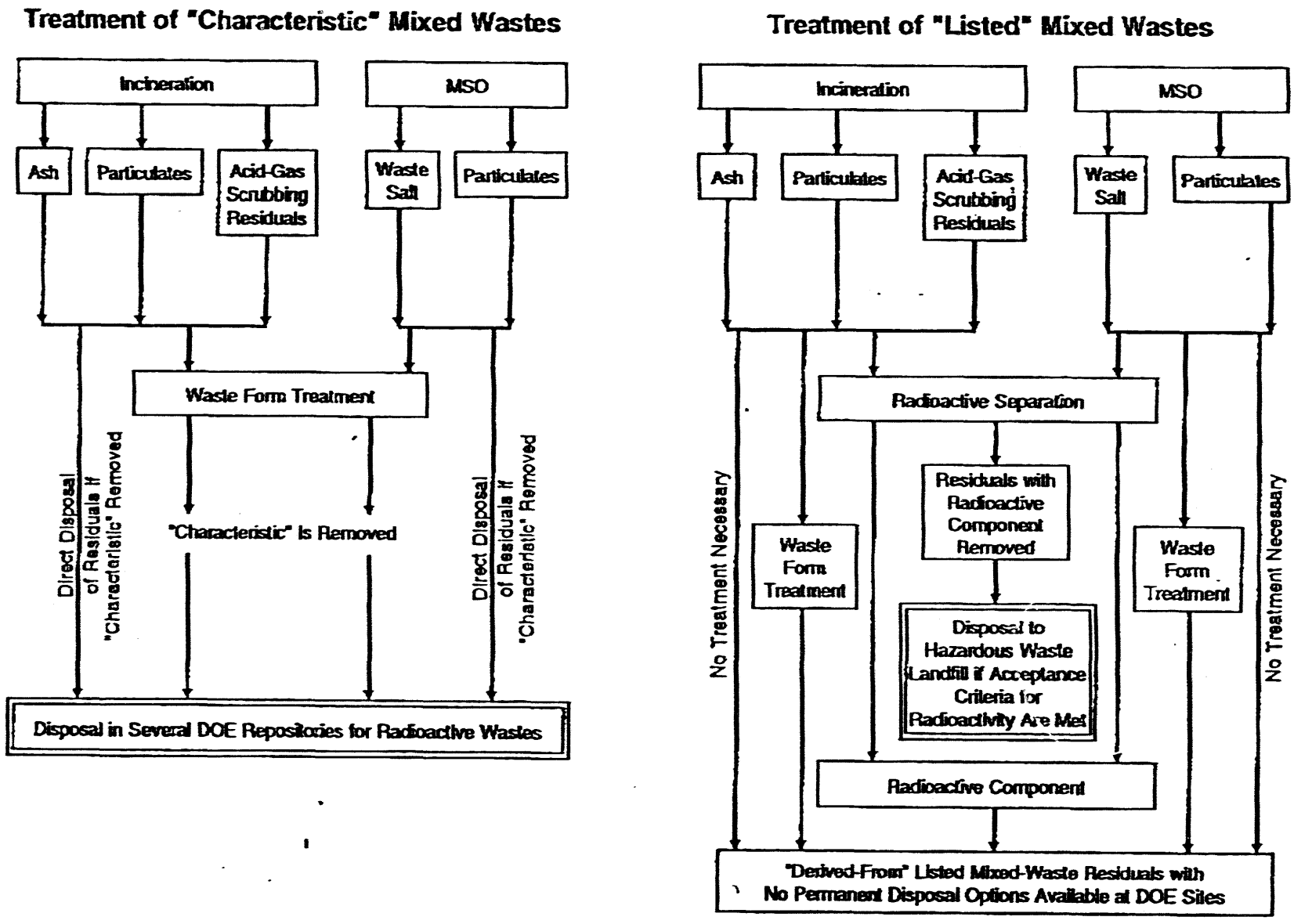

Figure 2. Residual Disposal Options for Characteristic and Listed Mixed Wastes

Mixed-Waste Regulations/Policies—Aside from RCRA, the law having the greatest impact on DOE mixed waste is the Federal Facility Compliance Act (FFCA). The FFCA requires that DOE have approved (by the States and/or U.S. Environmental Protection Agency [EPA] that have jurisdiction over DOE sites) site-specific plans for developing treatment capacities and technologies to treat all mixed wastes to the land disposal restriction (LDR) treatment standards by October 1995. The outcome of the FFCA is to force site personnel to address the mixed-waste issue aggressively and to search for mixed-waste treatment and disposal capacity.

DOE Office of Waste Management (EM-30) Waste Inventories—To determine the number of DOE waste streams that EM-30 has responsibility for and which may be appropriate for treatment by MSO and/or incineration, the entire *Waste Management Information System—Waste Profile Report* [3] was reviewed using "best professional judgment." Although this type of review yields results of limited accuracy (matching treatment technologies to waste streams can only be done on a case-by-case basis after consultation with site personnel), it does provide a general indication of the number of potentially applicable waste streams. MSO may be able to treat approximately 880 DOE EM-30 waste streams; incineration has potential application to a slightly larger number of streams (920) because of its ability to handle soil and other inert material.

DOE Office of Environmental Restoration (EM-40) Waste Inventories—A review of the *Technology Needs Crosswalk* 1993 data base [4] indicated that 198 EM-40 problem units have organic contaminants. Of this amount, 119 problem units or 60 percent are potential candidates for treatment by MSO or incineration. These wastes are typically soil, water, or other media that would first undergo pretreatment (e.g., thermal desorption, solvent extraction, and vapor vacuum extraction onto activated charcoal) to treat the contaminant of concern. Those problem units that would not be appropriate candidates for treatment by MSO are predominantly groundwater problems with very low concentrations of organics. For these problem units, technologies such as hydrogen peroxide/ozone/ultraviolet treatment are more appropriate.

Mass Balance Calculations—Mass balance calculations were completed for 10 specific DOE waste streams that are potential treatment candidates for five existing or planned DOE incinerators and an MSO treatment system. The waste streams were matched with incinerators that would most likely treat the waste (e.g., waste at the Oak Ridge site was assumed to be treated by the Oak Ridge incinerator). The five incinerators considered are the Oak Ridge Reservation rotary-kiln incinerator (OR TSCA), Savannah River Site rotary-kiln incinerator (SR CIF), Los Alamos National Laboratory controlled-air incinerator (LANL CAI), Idaho National Engineering Laboratory controlled-air combustor (INEL WERF), and Rocky Flats Plant fluidized-bed combustion unit (RF FBU/PROD). The characteristics of the individual incinerators are described in Table 1.

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Table 1. Site-Specific Thermal Treatment Units [references 5–14]

Unit Description	Thermal Treatment Unit Characteristics					
Location	Oak Ridge (OR)	Los Alamos National Lab (LANL)	Idaho National Engineering Lab (INEL)	Savannah River Site (SR)	Rocky Flats (RF)	Energy Technology Engineering Center (ETEC)
Thermal Unit Location	OR TSCA	LANL CAI	INEL WERF	SR CIF	RF FBU/PROD	MSO
Type of Unit	Rotary-Kiln Incineration	Controlled-Air Incineration	Controlled-Air Incineration	Rotary-Kiln Incineration	Fluidized-Bed Combustion Unit	MSO
Combustion Capacity (kW)	2,900	450	600	3,000	440	—
Waste for Comparison (see text)	6,7,8,9,10	4	2,5	3	1	All
Comments or Status	In Operation	Standby	Standby	Planned 1993 Construction	Standby	Undergoing Demonstration
Off-Gas Treatments for Acids	Packed-Bed Scrubber	Packed-Bed Scrubber	Proposed: Spray Cooler Using Caustic	Steam-Jet Scrubber	Na_2CO_3 Solids	Molten Na_2CO_3
Off-Gas Treatments for Solids	Venturi Scrubber, Ionizing Wet Scrubber	Venturi Scrubber, HEPA, Carbon Absorption	Cooler Bag Filters, HEPA	Cyclone, HEPA	Cyclones, Sintered Metal Filters, HEPA	Pre-Cool Bag Filters, HEPA
Caustic Used To Neutralize Acids	NaOH	NaOH	NaOH (proposed)	NaOH	Na_2CO_3	Na_2CO_3
Saturation Efficiency of Caustic (%)	95	90	90[a]	90	30	90
Weight of H_2O to Weight of Caustic in Scrubber Solution	20:1[a]	30:1[a]	20:1[b]	20:1[b]	-0-	-0-
Water Removed (%)	95	95	95	85	-0-	-0-
Residual Waste						
Ash/Metals/Rads	Ash Slurry, Caustic Solutions	Dry Ash and Scrubber Solutions	Dry Ash, Bag Filter Solids, and Caustic Solutions (proposed)	Dry Ash, Cyclone Solids, and Scrubber Solutions	Dry Ash, Filter Solids, and Na Salts	Waste Salt Melt and Bag Filter Solids
Chlorine/Fluorine/ Sulfur	Caustic Scrubber Solutions	Caustic Scrubber Solutions	Caustic Scrubber Solutions (proposed)	Caustic Scrubber Solutions	Dry Na Salts with Ash	Waste Salt Melt and Bag Filter Solids

[a]Estimated values based on other waste streams.

[b]Assumed values based on OR TSCA experience.

Ten specific wastes were identified that are typical to DOE sites. They include large-volume wastes, easily treated wastes, halogenated wastes, and/or difficult-to-treat wastes.

Waste 1: This waste at Rocky Flats consists of approximately 29,000 gallons of low-level waste (LLW) oil with a low percentage of halogenated solvents (1,1,1-trichloroethane, carbon tetrachloride, toluene, ethylbenzene). This waste contains low levels of uranium, plutonium, lead, beryllium, and zinc and could be treated by the RF FBU/PROD facility.

Waste 2: Twenty-one 55-gallon drums of waste oil at INEL contain approximately 6-percent solvents in the form of trichloroethylene (TCE). Radioactive constituents include cesium-137, americium-241/plutonium-238, cobalt-60, and strontium-90. Heavy metals include lead, mercury, silver, and chromium, each being under 15 parts per million (ppm). The WERF incinerator is assumed to be modified with acid-gas scrubbing equipment to handle this waste.

Waste 3: This is a waste stream that is expected to be generated in the future. Approximately 50,000 gallons per year of benzene is expected to be generated from the Defense Waste Processing Facility (DWPF) at the Savannah River Site. No radioactive or other contaminant values are known for this future waste. Ash content is assumed to be zero. This waste was selected to represent an essentially pure-product, nonhalogenated organic. Current plans for treating this waste will be at the future SRS CIF.

Waste 4: This waste is composed of LLW scintillation fluids that are common throughout DOE. Although these wastes are from the Lawrence Berkeley Laboratory (LBL), LANL CAI was identified for treatment because the sample analysis was more complete than similar wastes at LANL. The tritium component of this waste would require a condensation loop for both the incinerator or MSO treatment systems if concentrations exceed air emission discharge standards.

Waste 5: Waste 5 comprises graphite molds and crucibles stored at the Idaho National Engineering Laboratory. This is certified transuranic (TRU) graphite waste. The planned action for this waste is thermal treatment.

Waste 6: This is a waste lubricating and hydraulic oil that is stored at the Bettis Atomic Power Laboratory in Pennsylvania. The radioactive category for this waste oil is LLW. There is the possibility that this waste will be shipped from Pennsylvania to Oak Ridge for treatment at the OR TSCA facility.

Wastes 7, 8, 9, and 10: All four of these wastes are located at the Oak Ridge facility, and all are assumed to be treated at the OR TSCA facility. Waste 7 is perfluorodimethylcyclohexane (C_8F_{16}), and Waste 8 is trichloroheptafluorobutane ($C_4Cl_3F_7$). Waste 9 is waste oil mixed with low-level radioactive components and hazardous constituents such as thorium and beryllium. Waste 10 is two-thirds waste oil and one-fifth tetrachloroethane contaminated with beryllium and uranium and includes Freon and 1,1,1-trichloroethane.

Results of the mass balance calculations (presented in Tables 2 and 3 and in Figures 3, 4, and 5) indicate that (1) similar mass quantities (dry) of residuals are produced by MSO and incineration, and (2) the residuals comprise nearly identical constituents (mostly ash and salts). Overall, ancillary systems for incineration (e.g., acid-gas treatment systems) have a greater impact on the quantities of residuals produced than the primary treatment unit.

Waste Form Treatment—In some cases, the residuals produced from MSO and/or incineration may require further treatment to immobilize contaminants or improve handling characteristics. The treatment options evaluated were glass, hydraulic cement, sulfur polymer cement, ceramics, and organic binders [15]. The way that a residual is treated, either from MSO or incineration, will depend on the original waste feed. Nevertheless, some generic conclusions can be developed from the appropriate waste-form treatment options. Figure 6 presents an overview of the appropriateness of treatment options for residuals generated by MSO or incineration. This figure also shows that some waste forms are common to both MSO and incineration (waste salt and particulates from MSO and dry ash, which has a high salt content, from the incinerator acid-collection system). Although numerous treatment options are available, most have not been adequately tested to determine if they are appropriate for any of the residual wastes, even on a generic basis. Because of the variability in the residuals resulting from different waste feeds, it is clear that treatability studies will be needed to match waste forms to treatment options.

Table 2. Mass Balance Results for Treatment of 1.000 kg of Selected Waste by Site-Specific Thermal Systems

Description	Mass Balance Results for Treatment by Site-Specific Thermal Treatment Systems Basis: 1.000 kg of Waste Feed (See Table 4-2 for compositions). All Amounts in kg Unless Otherwise Stated									
Waste Number	1	2	3	4	5	6	7	8	9	10
Waste Name or Description	Oil/Solvent	Decontamination Solvent	DWPF Benzene	LBL Scintillation Fluid	TRU Graphite	Bettis OIMSF-008,010	Perfluoro-dimethylcyclohexane (C_4F_{10})	Trichloro-heptafluoro-butane ($C_4Cl_3F_7$)	ORNL Waste Oil	2/3 oil;1/5 tetra-chloroethane ($C_2H_2Cl_4$)
Thermal Treatment Systems	RF FBU/ PROD	INEL WERF	SRS CIF	LANL CAI	INEL WERF	OR TSCA	OR TSCA	OR TSCA	OR TSCA	OR TSCA
Caustic	Na_2CO_3	NaOH	NaOH	NaOH	NaOH	NaOH	NaOH	NaOH	NaOH	NaOH
Stoichiometric Reactants										
O_2 Reacted	3.440	3.254	3.078	3.414	2.587	3.440	0.320	0.186	3.251	2.406
Na_2CO_3 or NaOH for Cl	0.0033	0.056		0.011	<0.015		-0-	0.417	0.055	0.273
Na_2CO_3 or NaOH for F	0.003				0.028		1.600	0.975	≤0.002	0.013
Na_2CO_3 or NaOH for P_2O_5									0.058	
Total Reactants	4.446	4.310	4.078	4.425	5.630	4.440	2.920	2.558	4.368	3.692
Stoichiometric Products										
CO_2	3.081	2.934	3.385	3.044	3.557	3.080	0.880	0.612	2.912	2.244
H_2O from H	1.350	1.260	0.692	1.350	Small	1.350	-0-	-0-	1.268	0.936
H_2O from NaOH	-0-	0.013	-0-	0.002	<0.007	-0-	0.360	0.313	0.026	0.064
NaCl	0.0037	0.082		0.016	≤0.016		-0-	0.610	0.083	0.399
NaF	<0.002	-0-			≤0.020		1.680	1.323	-0-	0.013
Na_3PO_4									0.079	
Other (feed amounts)	≤0.010	≤0.010	-0-	≤0.010	≤0.030	≤0.010	-0-	-0-	-0-	0.036
Total Stoichiometric Products	4.447	4.311	4.077	4.422	3.630	4.440	2.920	2.558	4.368	3.692
Excess Reactants Required to Maintain Treatment Efficiency										
Saturation Efficiency of Caustic	30%	90%	90%	90%	90%	95%	95%	95%	95%	95%
Excess NaOH or Na_2CO_3	0.0133	0.009	-0-	0.0018	0.004	-0-	0.088	0.086	0.009	0.022
Total Dry Product	0.029	0.10	-0-	0.028	0.070	0.010	1.768	1.719	0.171	0.470
Water in Residual Wastes*	-0-	0.091	-0-	0.018	0.040	-0-	1.768	1.719	0.171	0.434

*To represent this waste in a slurry form, the salts and excess caustic collected in the blowdown are assumed to contain an equal amount of water by mass.

Table 3. Mass Balance Results for Treatment of 1.000 kg of Selected Waste by MSO

Description	Mass Balance Results for Treatment by MSO [illegible]									
Waste Number	1	2	3	4	5	6	7	8	9	10
Waste Name or Description	Oil/Solvent	Decontamination Solvent	DWPF Benzene	LBL Scintillation Fluid	TRU Graphite	Bettis Oil/MSF-003,018	Perfluorodimethylcyclohexane (C_8F_{16})	Trichloroheptafluorobutane ($C_4Cl_3F_7$)	ORNL Waste Oil	2/3 oil;1/6 tetrachloroethane ($C_2H_2Cl_4$)
Stoichiometric Reactants										
O_2 Reacted	3.440	3.254	3.078	3.414	2.587	3.440	0.328	0.166	3.251	2.406
Na_2CO_3 for Cl	0.0033	0.075		0.015	<0.015		0	0.553	0.075	0.362
Na_2CO_3 for F	0.003				0.028		2.120	1.292	0	0.017
Na_2CO_3 for P_2O_5									0.077	
Total Reactants	4.446	4.329	4.078	4.429	3.630	4.440	3.440	3.011	4.403	3.785
Stoichiometric Products										
CO_2	3.081	2.965	3.385	3.050	3.563	3.080	1.760	1.376	2.975	2.410
H_2O from H	1.350	1.260	0.692	1.350	Small	1.350	0	0	1.268	0.936
NaCl	0.0037	0.082		0.016	≤0.016		0	0.610	0.083	0.399
NaF	<0.002				≤0.020		1.680	1.023	0	0.013
Na_3PO_4									0.074	
Other (feed amounts-ash)	≤0.01	≤0.01	-0-	≤0.01	≤0.03	≤0.01	0	0	0	0.036
Total Stoichiometric Products	4.448	4.328	4.077	4.428	3.631	4.440	3.440	3.009	4.400	3.785
Excess Reactants Required to Maintain Treatment Efficiency										
Saturation Efficiency of Caustic	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%
Excess Na_2CO_3	0.0006	0.009	0	0.0018	0.004	0	0.187	0.181	0.017	0.046
Saturation Efficiency of Ash	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
Excess Salts for Ash	0.04	0.04	-0-	0.04	0.12	0.04	-0-	-0-	-0-	0.144
Melt Chemistry Controlling Discharge of Waste Melt	Ash	NaCl		Ash	Ash	Ash	NaF	NaCl + NaF	NaCl + Na_3PO_4	NaCl + NaF
Total Waste Melt (as discharged)	0.05	0.101	-0-	0.05	0.15	0.05	1.867	1.814	0.174	0.484

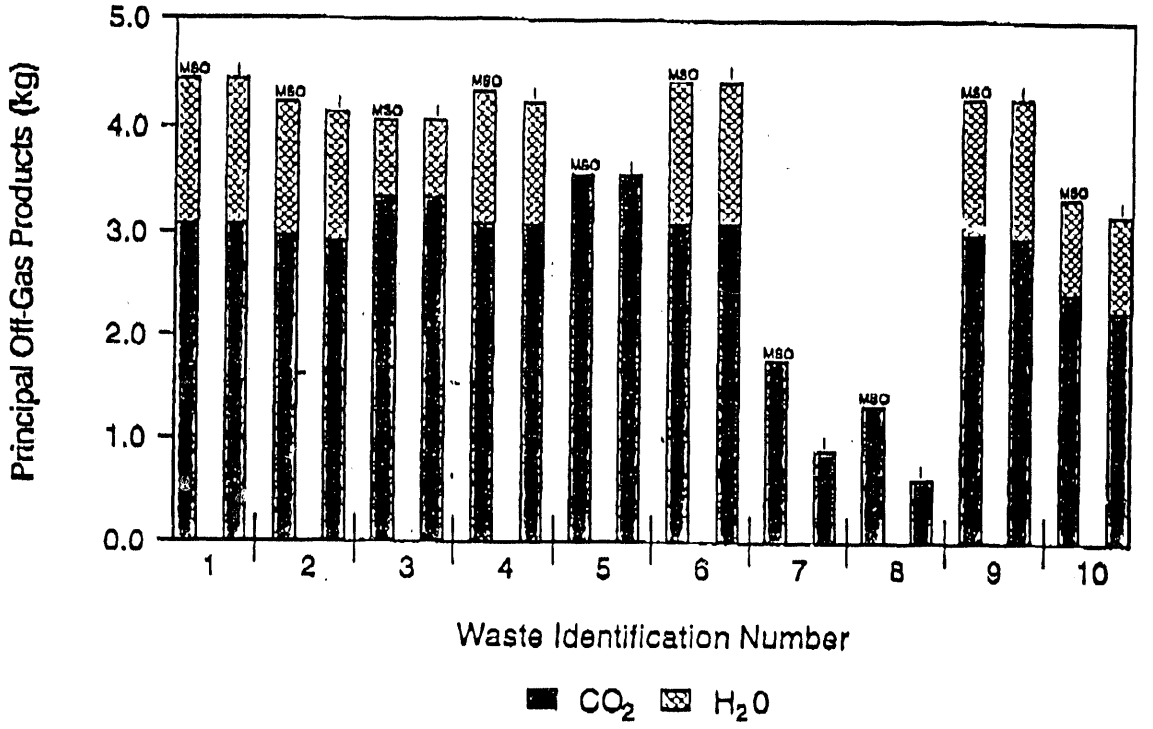

Figure 3. Principal Off-Gas Products (CO_2 and H_2O) From Treatment of 1.0 kg of Waste by MSO and Site-Specific Thermal Treatment Units

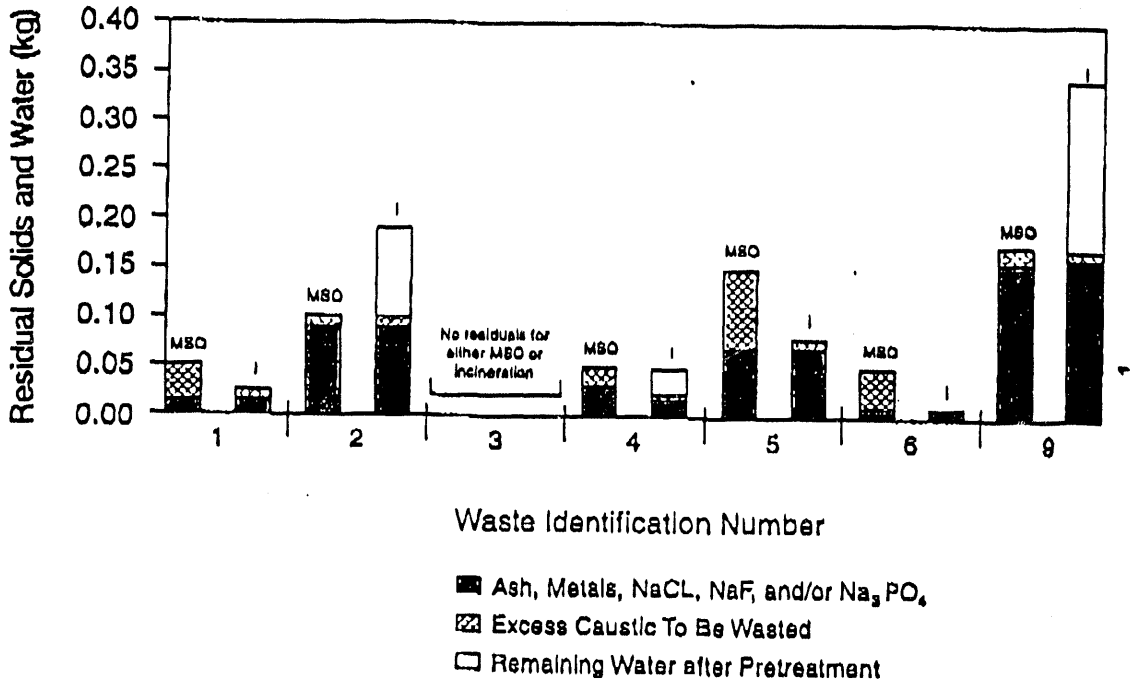

Figure 4. Residual Solids and Water From Treatment of 1.0 kg of Waste by MSO and Site-Specific Thermal Treatment Units

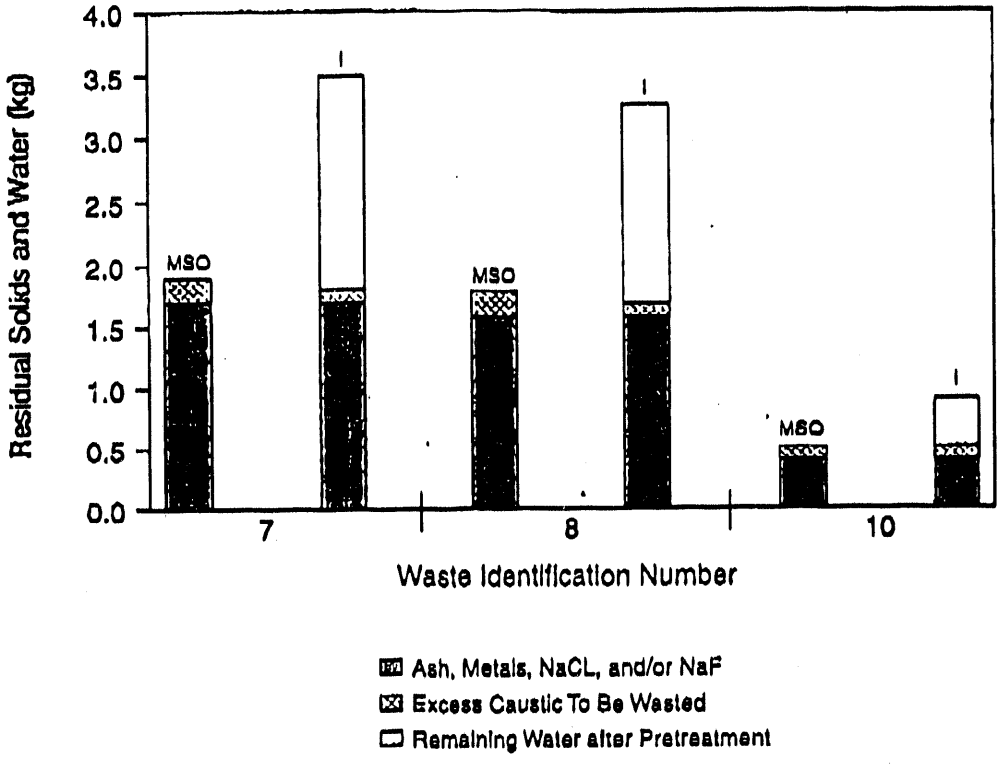

Figure 5. Residual Solids and Water From Treatment of 1.0 kg of Halogenated Wastes by MSO and Site-Specific Thermal Treatment Units

FINDINGS

The major findings of the report are

- Final disposal options are more significantly impacted by the type of waste treated and the existing regulations than by the type of treatment technology.

- Mixed waste with a characteristic hazardous component can be reclassified as radioactive waste if the waste can be treated to remove the characteristic. However, a mixed waste with a listed hazardous component will remain a mixed waste, regardless of the treatment technology used or treatment levels achieved, unless the residuals can be successfully delisted.

- Typical DOE waste streams are not good candidates for delisting because they were generated through diverse processes and commonly contain a varying mixture of contaminants. In addition, limited records are available describing the wastes.

- The FFCA will force DOE to aggressively develop additional mixed-waste treatment capacity using treatment technologies such as MSO.

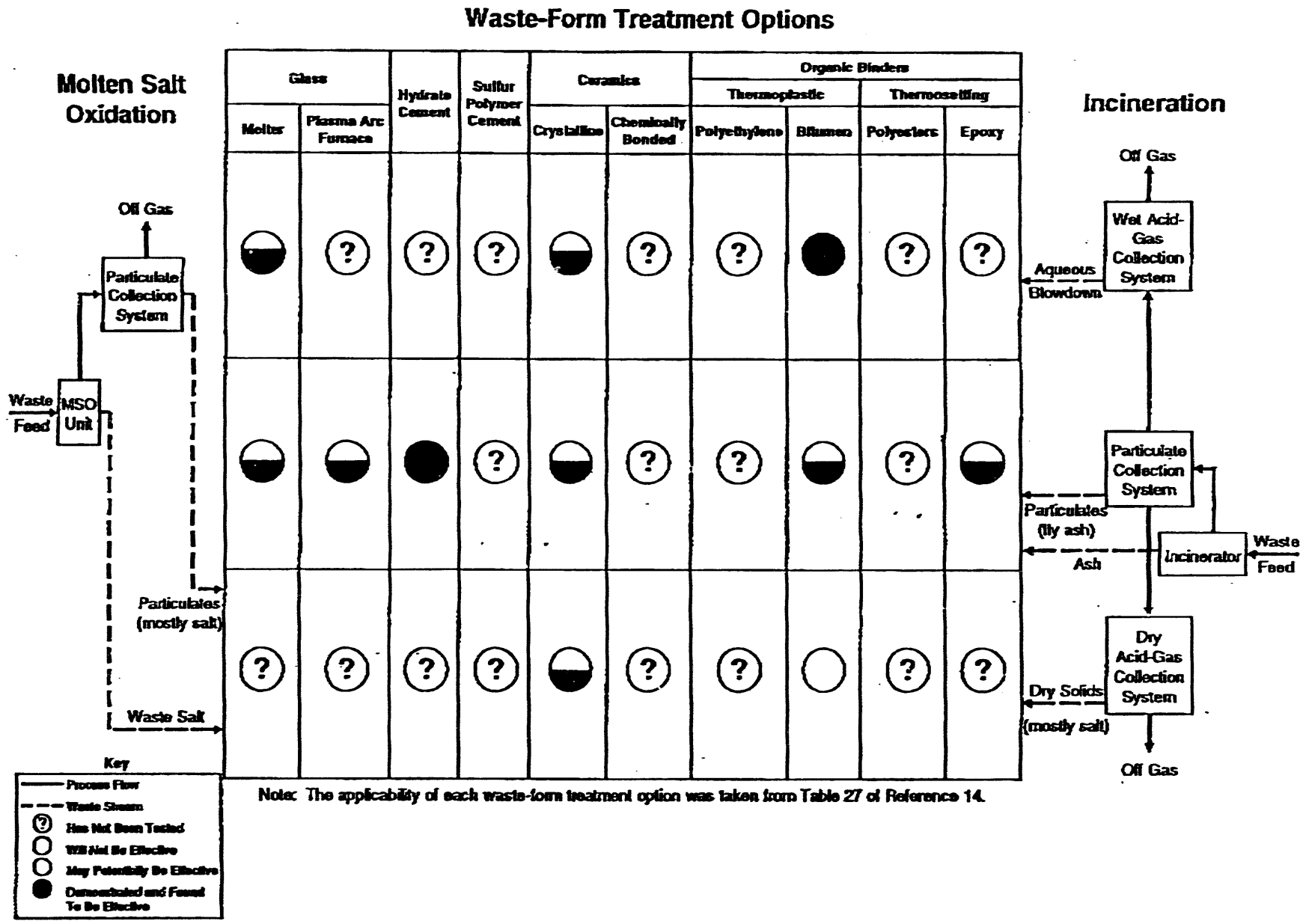

Figure 6. Final Waste Form Treatment Options

- MSO may potentially be able to treat most of the EM-30 waste streams (95 percent) that are candidates for treatment by incineration. Sixty percent of the EM-40 problem units with organic contaminants are potential candidates for treatment by either MSO or incineration as a component of the treatment train.

- Mass balance results indicate that MSO and incineration generate similar quantities (dry) and types of residuals: ash, NaF and/or NaCl, excess caustic, and waste gases. However, the wet off-gas systems employed by incinerators to treat acidic gases also result in excess water in the blowdown residuals (resulting in a slurry waste form).

- If secondary waste treatment is considered an obstacle for MSO, it also exists for every type of thermal treatment technology, including incineration.

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