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**Surrogate Formulations for Thermal Treatment of Low-Level Mixed
Waste, Part II: Selected Mixed Waste Treatment
Project Waste Streams**

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MASTER

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ABBREVIATIONS AND ACRONYMS

ASTM	American Society for Testing and Materials
Ce	cerium
CFR	Consolidated Federal Register
CPCF	Central Pollution Control Facility
DOE	U.S. Department of Energy
DRE	Destruction and Removal Efficiency
EPA	U.S. Environmental Protection Agency
FFCA	Federal Facility Compliance Act
INEL	Idaho National Engineering Laboratory
LDR	Land Disposal Restrictions
LLMW	low-level mixed waste
MWIP	Mixed Waste Integrated Program
MWTP	Mixed Waste Treatment Project
NRC	Nuclear Regulatory Commission
PHP	Plasma Hearth Process ⁸
POHCs	Principal Organic Hazardous Constituent
Pu	plutonium
PVC	Polyvinylchloride
RCRA	Resource Conservation and Recovery Act
RDDT&E	Research Development Demonstration Testing and Evaluation
RFP	Rocky Flats Plant
SRP	Savannah River Plant
TRU	transuranic
TSCA	Toxic Substances Control Act
TVA	Tennessee Valley Authority
WHC	Westinghouse Hanford Company

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EXECUTIVE SUMMARY

This report summarizes the formulation of surrogate waste packages, representing the major bulk constituent compositions for 12 waste stream classifications selected by the U.S. Department of Energy (DOE) Mixed Waste Treatment Program. These waste groupings include: neutral aqueous wastes; aqueous halogenated organic liquids; ash; high organic content sludges; adsorbed aqueous and organic liquids; cement sludges, ashes, and solids; chloride; sulfate, and nitrate salts; organic matrix solids; heterogeneous debris; bulk combustibles; lab packs; and lead shapes.

Insofar as possible, formulation of surrogate waste packages are referenced to authentic wastes in inventory within the DOE; however, the surrogate waste packages are intended to represent generic treatability group compositions. The intent is to specify a nonradiological synthetic mixture, with a minimal number of readily available components, that can be used to represent the significant challenges anticipated for treatment of the specified waste class. Performance testing and evaluation with use of a consistent series of surrogate wastes will provide a means for the initial assessment (and intercomparability) of candidate treatment technology applicability and performance. Originally the surrogate wastes were intended for use with emerging thermal treatment systems, but use may be extended to select nonthermal systems as well.

The use of surrogates to represent the fate of radiological constituents greatly alleviates many of the unique transportation, special handling, and regulatory difficulties experienced with the use of authentic mixed wastes. Cerium oxide is selected to simulate the fate of radioactive actinide and transuranium elements, whereas nonradiological (natural) cesium chloride is used to simulate the fate of relatively volatile radioactive fission products. Selected hazardous constituents (as identified by the Resource Conservation and Recovery Act) are added to the surrogate waste packages to assess the fate of these classes of compounds. Naphthalene and 1,2-dichlorobenzene are semivolatile organic compounds selected to represent significant challenges to thermal destruction, whereas chlorobenzene is selected to represent the unique challenges of relatively volatile constituents. Cadmium, chromium, lead, and nickel are selected to represent hazardous metals.

1. INTRODUCTION

1.1 PURPOSE

This report defines surrogate waste formulations for 12 waste stream classifications designated by the Mixed Waste Treatment Project (MWTP) and the Mixed Waste Integrated Program (MWIP). The selected waste streams represent waste streams currently in storage within the Department of Energy (DOE) Complex that must be treated or remediated in compliance with various environmental laws. A variety of thermal treatment technologies are in various stages of development and demonstration (i.e. laboratory scale, pilot scale, full scale) that may provide solutions to the current waste treatment problems. A companion document¹ has developed guidelines for benchmarking the various thermal treatment systems. An integral part of this benchmarking process is the use of surrogate waste formulations. These surrogate formulations will allow consistent methods of development and evaluation of low-level mixed waste (LLMW) thermal treatment technologies.

1.2 SCOPE OF MIXED WASTE PROBLEMS

The DOE-managed facilities are estimated to have a current inventory of 590,000 m³ of mixed wastes.² The total inventory is for transuranic (TRU), high-level, and LLMW. The LLMW represents ~42%, or 247,000 m³, of the current inventory with an additional 298,000 m³ of mixed wastes estimated to be generated during the next 5 years. The total inventory of wastes (590,000 m³) represents 50 sites across the DOE Complex in 22 states, while the LLMW is primarily (~79% or 195,000 m³) being stored at 3 sites, namely, Rocky Flats Plant (RFP), Oak Ridge K-25 Site, and Idaho National Engineering Laboratory (INEL).

The Land Disposal Restrictions (LDR) standards set by the U.S. Environmental Protection Agency (EPA) prohibit land disposal and storage of untreated hazardous wastes. There is insufficient treatment capacity, and in many cases no recognized acceptable treatment technology, to treat DOE's current inventory of mixed wastes to meet the LDR standards. In May 1992, a temporary compliance was granted for mixed waste per Federal Facility Compliance Act (FFCA), based on insufficient treatment capacity. Under the requirements of FFCA, all federal facilities must waive sovereign immunity and come into compliance with applicable federal and state laws and regulations. The FFCA also requires submission of site-specific mixed-waste treatment plans to the appropriate regulatory agency, and includes schedules for developing treatment capability and capacity.

Facing such pressing regulatory compliance requirements, DOE and its contractors are working together expeditiously to upgrade and expand the existing treatment facilities, and many new processes and technologies are being evaluated for the potential applications. The development and implementation of the treatment processes may involve some evolving or emerging technologies and others that have been employed in private industry but may need to be modified for handling mixed waste. Such open-ended all-inclusive cooperative effort will involve contributions of knowledge, experience, and expertise from government, academia, and private sectors. The treatment and disposal needs are generally being addressed through a combination of site-specific and cross-complex technology development activities, and consideration is given to the development of process or technology capable of treating multiple waste streams.

1.3 APPLICATION OF SURROGATE FORMULATIONS AND THEIR LIMITATIONS

The use of the authentic mixed-waste streams in the development of treatment technologies adds considerable difficulties and complexity to the design and overall operation of an experimental facility. To handle the waste containing radioisotopes, the facility operator must obtain Nuclear Regulatory Commission (NRC) license and is legally obligated to the major task of decontamination and decommissioning of the facility after its being shut down. Treatability studies with Resource Conservation and Recovery Act (RCRA) materials have limitations on the amount of materials that can be stored at a single site and the amount of material that can be tested in a single day. These limitations can greatly affect the ability to perform Research Development Demonstration Testing and Evaluation (RDDT&E) on thermal treatment technologies.

In addition to permitting issues for the handling of radioactive and hazardous materials, issues such as health, safety, and environment have to be addressed and adhered to in accordance with DOE orders and various regulatory requirements (see Table 1), all of which can result in substantial increases of both capital and operational costs, not to mention the potential adverse impact on the project schedule. Therefore, it is apparent that there is strong incentive to use surrogate formulations for the mixed-waste streams. The use of surrogate materials for the hazardous and radioactive constituents will allow the expected behavior of the radiological and hazardous constituents to be evaluated, while having less hazardous parameters than the actual waste streams.

The selection of surrogate materials is not an exact science and the selection process is inherently uncertain. First, individual compounds and their respective surrogates may not exhibit the same physical and chemical characteristics when treatment conditions (e.g., temperature, halogen concentration, phase formation) change. Second, waste streams are for the most part inadequately characterized and the formulation of a rigorous surrogate (or simulant) for an entire waste stream will be based upon many assumptions. Thus, trying to model a complex, heterogeneous system that has been loosely defined can only provide a rough level of resemblance to the original definition and may not closely model any specific waste stream. It is not surprising that there is no shortage of researchers who express the limitations and cautions regarding surrogate usage for hazardous waste stream selection and treatment.

Depending on the maturity of a process or technology, a tiered approach to RDDT&E can be adopted. During the initial evaluation of a new technology, a scoping study for example, surrogate materials would substitute radionuclides and select hazardous chemicals in conducting the experiments, followed by phasing out of surrogates and into the total use of authentic ingredients after the experimental work brings more understandings and confidence for the process. The ability to define the composition of a surrogate waste stream also allows multiple facilities to test the "same" waste stream without complex shipping and handling procedures. Therefore at the pilot-scale level, a process under development will be able to be compared as to its performance on treatment of "the same" or at least similar waste feed by the use of surrogate waste stream formulations with common hazardous surrogate or spike constituents (i.e., radiological, organic, and metal constituents). These same comparisons as well as performance on "actual waste" can be made as processes are evaluated at site demonstrations. This will greatly assist in the comparison of various technologies to assess their efficacy in the treatment of a general type of waste stream.

Table 1. Key environmental regulations

Acronym	Title	Regulatory citation	DoE order	Goal/purpose/key elements	Date
CAA	Clean Air Act	40 CFR 50-80	DOE Order 5400.1 and 5400.5	To prevent or control the release into the air of substances that may harm public health or damage natural resources.	1970
CERCLA (Superfund)	Comprehensive Environmental Response, Compensation, and Liability Act	40 CFR 300	DOE Order 5400.4	To promote the cleanup of releases of hazardous materials into air, water, groundwater, and land. Releases covered include both new spills and leakage from waste sites. The law sets up a trust fund (the Superfund) to pay for cleanups and gives EPA the authority to collect cleanup costs from the parties responsible for the contamination.	1980
CWA	Clean Water Act	40 CFR 100-140, 40-CFR 400-470	DOE Order 5400.5	To restore surface waters to good condition and maintain them in good condition. The ultimate goal is for all U.S. waters to be fit for fishing and swimming.	
EPCRA SARA Title III	Emergency Planning and Community Right-to-Know Act	40 CFR 350, 355, 370, 372		To reduce the possibility of a major chemical release disaster. Requirements include reporting chemical inventory information to local emergency planning organizations, providing MSDSs ^a , a and notifying them of releases of hazardous materials.	1986
NEPA	National Environmental Policy Act	40 CFR 1500-1508	DOE Order 5400.1C (under revision 1990)	To encourage harmony between people and the environment, to stop damage to the environment, and to increase understanding of ecological systems and natural resources.	1969
RCRA	Resource Conservation and Recovery Act	40 CFR 240-271	DOE Order 5400.1 and 5820.2A	To control hazardous waste disposal. It sets up a system to identify wastes and track their generation, transport, storage, and ultimate disposal. Amendments ban land disposal of bulk liquid hazardous waste and regulate underground storage tanks.	1976
SARA	Superfund Amendments and Reauthorization Act	40 CFR 300		To set cleanup standards that strongly favor permanent remedies, give EPA more control over cleanup procedures, and involve states and the public in the cleanup decision-making process. SARA sets health and safety standards for workers at hazardous waste cleanup sites.	1986
SDWA	Safe Drinking Water Act	40 CFR 140-149	DOE Order 5400.5	To protect underground water sources from contamination and to set federal drinking water quality standards.	1974
TSCA	Toxic Substances Control Act	40 CFR 700-799		To control exposure to and use of raw materials that are not covered by other environmental laws. To evaluate chemicals before use to make sure that they pose no unnecessary risk to public health or the environment. PCB ^b regulations are found in TSCA.	1976

^aMaterial Safety Data Sheets.

^bPolychlorinated biphenyl.

2. WASTE STREAM CLASSIFICATION SYSTEM

As stated earlier, the DOE prepared the "Interim Mixed Waste Inventory Report"² in response to the 1992 FFCA as a state-by-state summary of the national mixed waste inventory. This report not only provides information about the amount of waste that is currently in storage but also the rate at which new waste is being generated. It should be noted that generation rate is based upon current activities and does not reflect the waste generation that will occur when large-scale environmental remediation and decontamination and decommissioning of the DOE sites begin.

The wastes that are currently in interim storage need to be treated in accordance with RCRA and LDR regulations. In order to facilitate a strategy to develop and establish treatment capacity for mixed waste, as required by regulations, the DOE formed the MWTP.²⁻⁵ MWTP, as part of DOE's Waste Operations, has developed waste stream categories that have been used in defining treatment needs as well as assisting in organizing and tabulating the various waste streams that are present within the DOE complex. Figure 1 shows the flowsheet developed by the MWTP to categorize the mixed wastes in storage throughout the DOE complex.

3. WASTE STREAM SELECTION RATIONALE

In support of facilitating the development of mixed waste treatment options for the DOE, members of the MWTP and the MWIP initially selected 16 waste streams from the full MWTP waste stream flowsheet shown in Fig. 1.⁶ These 16 waste streams were chosen to represent a variety of major DOE waste streams in storage. Figure 2 shows a modified version of the total MWTP waste stream flowsheet with the 16 waste streams highlighted. It was later decided to reduce the number of selected waste streams to 10.⁷ In addition to the 10 general waste streams selected from the MWTP categories, an additional 2 waste streams have been included in this document (MWTP-3200: Organic Matrix Solids; MWTP-5440: Bulk Combustibles); these 2 waste streams were originally selected for testing the Plasma Hearth Process⁸ (PHP), but they were later rejected in favor of the use of two waste streams originally designated in this document. Thus, the formulation for the two new selections for the PHP (MWTP-3122: High Organic Content Sludges and MWTP-5400: Heterogeneous Debris) have been included in both documents and the two replaced surrogate formulations (MWTP-3200, MWTP-5440) have been added to this document. Table 2 lists the final 12 waste streams that were selected and whose surrogate recipes are the focus of this document. This selection of waste streams was decided to best represent waste stream profiles, technical challenges, and support the testing of a wide variety of thermal treatment options. It should be noted that once an actual waste stream is sufficiently characterized it can be assigned to one of the MWTP categories, but specification of a single category only allows a very general description of the major matrix constituents of the waste streams to be formulated. A more detailed description of these waste streams listed in Table 1 is given in Chap. 5 of this document along with the surrogate formulation derived for each waste stream.

Table 2. Twelve MWTP waste stream categories selected for surrogate formulations

MWTP code	Description
1300	Neutral aqueous wastes
2110	Aqueous halogenated organic liquids
3111	Ash
3122	High organic content sludges
3113/3114	Absorbed aqueous and organic liquids
3140	Cement sludges, ashes, and solids
3151/3152	Chloride, sulfate, and nitrate salts
3200*	Organic matrix solids
5400	Heterogenous debris
5440*	Bulk Combustibles
6100	Lab packs
7200	Lead shapes

*Originally selected for PHP testing.

Figure 2. Original sixteen selected waste streams.

4. SURROGATE SELECTION RATIONALE

4.1 RADIOLOGICAL WASTES

The use of actual radioactive material imposes considerable restrictions on material handling, transportation, and performance testing. In addition to obtaining the requisite NRC licenses to handle the appropriate radioisotopes, there are additional stringent requirements for radiological work, including personnel training, protective clothing, criticality safety review, emissions monitoring and reporting, and so forth. There is also a major investment in equipment that may require extensive decontamination after use. For these and other considerations, it may be desirable to use simulated waste formulations that use surrogate materials to represent the expected behavior of the radiological constituents. In selecting a metal surrogate, the object is to mimic as closely as possible, but in a conservative manner, the behavior of the actual metal as incorporated into both the raw waste and the anticipated treatment residues. A companion document⁹ reviews the selection of surrogate materials for radiological components for testing in thermal treatment systems. Recommendations are summarized in Table 3; some of the recommendations for non-thermal systems are taken from Ref. 10. For example, the lanthanide series of elements are formed by successive filling of the inner 4f electron orbitals, whereas the actinides are formed by filling the 5f orbitals; thus, cerium compounds (rare earth lanthanide series) serve as reasonably good chemical and thermal surrogates for both uranium (actinide series) and plutonium (transuranic series). However, there are always limitations to the use of surrogates; as Shapiro and coworkers¹¹ report on the selection of cerium (Ce) as a surrogate for plutonium (Pu): (1) Ce exhibits a similar chemistry in that much of its aqueous solution chemistry is similar to that of Pu. (2) Ce exhibits a different oxidation state than Pu so that it is not directly analogous. (3) Ce has the potential to form the strongly oxidizing ceric ion, which can enhance corrosion. (4) But they conclude that although some of cerium's atomic characteristics do not perfectly match those of Pu, they are closer than other available surrogates.

Similarly Bates¹² has discussed possible surrogates for uranium, plutonium, and americium, concluding that "While there are no perfect surrogates for these radionuclides, cerium is generally the most conservative (best simulates their behavior). Other less conservative surrogates of plutonium, in degree of similarity are: neodymium > lanthanum > praseodymium > gadolinium > ytterbium > dysprosium > erbium > europium > terbium > lutetium > samarium."

From the arguments presented in this section, it would appear that cerium compounds represent conservative surrogates for both U and Pu which are the two major radiological contaminants expected in the DOE waste streams. Bates¹² has recommended the use of ~0.5 wt% Ce₂O₃ to ensure an adequate level of surrogate for easy detectability in the waste form or residues. A companion document⁹ has shown that the thermal behavior of CeO₂ and Ce₂O₃ are very similar and that their solubilities are similar, and hence due to economic consideration (see Appendix) the use of CeO₂ is being suggested for use in the surrogate formulations. For nonthermal applications the more soluble CeCl₃ salt is recommended (to challenge leachability testing criterion).

In addition to the major fuel and defense isotopes (i.e., U, Pu) the major nuclear fuel fission products (e.g., Cs-137, Tc-99, Sr-90) have to also be addressed. The fission products tend to have greater volatility than the parent actinide⁹ and hence require an additional surrogate material to ensure that the lower volatility radiological materials can be tested. Of the three fission products listed, technetium does not have any stable isotopes and hence is not a candidate material for the

surrogate waste stream formulations. Both cesium and strontium have stable isotopes and could be used in the surrogate waste stream formulations. Natural Cs is a good nonradioactive marker that is suggested for use for the relatively volatile fission products.

Table 3. Suggested surrogates for selected radioisotopes [from Ref. 9]

Radioisotope	Thermal system	Non-thermal system
U-238/U-235	Ce, RE*	Ce, RE, Zr, Mo
Pu-239/TRU	Ce, RE	Ce, RE, Zr
Tc-99, Ru-103	Ru	Ru, Re, Mo, Mn
Cs-137	Natural Cs	Natural Cs
Sr-90	Natural Sr	Natural Sr

*RE = rare earth element (lanthanide series).

4.2 RCRA ORGANIC WASTES

Many of DOE's radiological wastes are contaminated with hazardous organic residues, especially waste water treatment sludges and spent sorbent materials. Typical residues include degreasing solvents (e.g., as tri- and tetrachloroethylene, methyl ethyl ketone, acetone), waste oils, and material contaminated with PCBs. Table 4 lists several of the hazardous organic compounds regulated under the EPA [RCRA; 40 Consolidated Federal Register (CFR), Part 261, Appendix VIII] and the Toxic Substances Control Act (TSCA). The table also lists an incineration ranking designation¹³ for several of the organic compounds of regulatory concern. The Incineration Index is a relative measure of the degree of difficulty for a waste constituent to be thermally destroyed; a low value for the index ranking indicates that the compound is relatively refractory (i.e., stable) toward thermal destruction. Table 5 describes the seven classes that have been identified for thermal stability ranges; the designation T₉₉₍₂₎ indicates that 99% destruction will be achieved within a 2-sec residence time in the indicated temperature range.

Under EPA protocol, an incinerator facility must achieve a Destruction and Removal Efficiency (DRE) of 99.99% for each Principal Organic Hazardous Constituent (POHCs) designated for each waste feed. The selection of POHCs for trial burn evaluation is based upon the relative difficulty to incinerate the waste; the premise is that if the DRE requirement is met for the most difficult to incinerate compounds during a trial burn, then other compounds should be successfully destroyed in subsequent routine operation.¹³

Table 4. Hazardous organics and potential surrogates

Compound	EPA waste code	Incinerability ranking ^a	Vapor pressure (mm Hg @25°C)
Benzene	D018	3	94.2
Naphthalene		5	0.05
Chlorobenzene	D021	18	11.5
1,4-Dichlorobenzene	D027/F002	21-22	1.9
1,2-Dichlorobenzene	D028/F002	23-25	1.4
1,2,4-trichlorobenzene		27-28	0.43
Hexachlorobenzene	D032	31	0.07
2,3,7,8-TCDD ^b		34	
Toluene	F005	35	28.0
Tetrachloroethylene	D039/F001,2	36	8.5
Trichloroethylene	D040/F001,2	41	62.5
Vinyl Chloride	D043	60-64	(760.)
Phenol		101-102	0.21
Cresol(s)	D026/F004	103-105	0.1-0.4
2,4-Dimethylphenol	F003	108-111	0.15
Methyl ethyl ketone	D035/F003,5	108-111	113.
2,4,5-Trichlorophenol	D041	121-125	0.04
2,4,6-Trichlorophenol	D042	121-125	0.03
Carbon Tetrachloride	D019/F001	136-140	109.
Pentachlorophenol	D037	151-153	0.001
Heptachlor	D031	179-180	
Chloroform	D022	194-196	192.
1,1,1-Trichloroethane	F001,2	201	123.
Chlordane	D020	221	
Cyclohexanone	F003	NR	4.5
Ethyl acetate	F003	NR	90.
Methanol	F003	NR	121.
Ethyl benzene	F003	NR	9.5
2-Ethoxyethanol	F005	NR	
Isobutanol	F005	NR	12.3
Xylene(s)	F003	NR	6.6-8.7
2-Nitropropane	F005	NR	16.6
PCB (Aroclor 1254)	(TSCA)	NR	0.0002
Methyl isobutyl ketone	F003	NR	7.1

^aC. C. Lee et al., "Incinerability Ranking Systems for RCRA Hazardous Constituents," *Hazardous Waste and Hazardous Materials*, 7(4) 1990. [Note: the lower the numerical rating, the more refractory the compound is towards thermal destruction]. Designation of "NR" have not been ranked.

^b 2,3,7,8-TCDD = 2,3,7,8-Tetrachlorodibenzo-p-dioxin.

**Table 5. EPA 40 CFR, Part 261, Appendix VIII
Thermal Stability Classes**

Class ^a	Compound ranking	T _{99(b)} temperature range, °C
1	1-34	1590-900
2	35-77	985-800
3	78-119	790-705
4	120-193	695-604
5	194-252	600-425
6	253-271	415-360
7	272-320	320-100

^aC. C. Lee et al., "Incinerability Ranking Systems for RCRA Hazardous Constituents," *Hazardous Waste and Hazardous Materials*, 7(4) 1990.

^bThe designation T₉₉₍₂₎ indicates that 99% destruction will be achieved within a 2-sec. residence time in the indicated temperature range.

For selection of a POHC for addition to a surrogate waste package for thermal treatment testing, desirable properties include a relatively low incinerability index (e.g., Class 1 in Table 5) to provide some assurance that other compounds of concern will also have high DREs, and low ambient temperature vapor pressure to minimize loss of POHC by fugitive emission during surrogate formulation and handling.¹⁴ Since there is no basis for choosing a nonhazardous surrogate material for the hazardous organic constituent, a selection has to be made that both challenges the thermal system (for both volatile and semi-volatile species) and does not create excessive risks and secondary waste stream generation burdens during the preparation of the surrogate waste stream formulation.

To meet all of these criteria, three RCRA organics have been chosen to formulate the RCRA hazardous component of the surrogate waste stream formulations. Naphthalene, a semi-volatile organic, (incinerability ranking 5) is a good choice by these criteria; naphthalene has been used as a destruction testing surrogate for the more toxic and carcinogenic polyaromatic hydrocarbon compounds.¹⁵ Other suitable choices include 1,2,4,5-tetrachlorobenzene (incinerability ranking 27-28) and 1,2-dichlorobenzene (incinerability ranking 23-25), which were recommended as principal surrogates for PCBs in wastes for incinerability testing.¹⁶ [Note in Table 4 that many compounds of concern, including PCBs, have not yet been assigned an Incinerability Ranking in the referenced text.]

Performance testing for thermal destruction of hazardous organic compounds can be addressed by the selection of "Class 1" POHCs from Table 5. We recommend the selection of naphthalene, 1,2-dichlorobenzene, and chlorobenzene to represent refractory compounds with a range of volatilities. Chlorobenzene, the most volatile compound in this selection, may be used to test for possible "thermal channeling"—in some systems, dependent upon combustor thermal profile and gas flow turbulence, relatively volatile compounds can be desorbed from the waste and pass rapidly through the system without being exposed to conditions sufficient to effect total destruction. Refer to the companion report on "benchmarking"¹⁷ for more detailed discussion on the selection of assessment POHCs and the sampling and analysis of these compounds and their products of incomplete combustion.

4.3 RCRA METAL WASTES

The EPA has determined that risks from burning of metal-bearing hazardous wastes in incinerators can be unacceptable under reasonable worst-case circumstances, as defined by concentrations of metals in the incinerated waste, incinerator capacity or feed rate, partitioning of metal to bottom ash, collection efficiency of emission control equipment, and local terrain and meteorological conditions.

At present, toxic metal emissions from incinerators are controlled indirectly by a limitation on particulate matter. Risk-based emission limits for individual toxic metals in addition to the existing particulate standard are proposed. The EPA has identified 12 toxic metals in Appendix VIII of 40 CFR, Part 261, that pose a potential hazard to human health and the environment; these metals are: arsenic, beryllium, cadmium, hexavalent chromium, nickel, antimony, barium, lead, mercury, selenium, silver, and thallium. The EPA has concluded that emissions of these metals from hazardous waste incinerators can pose an unreasonable risk, and control of these emissions is mandated under current and pending regulations [see, e.g., Section 3005(c)(3) and Part 264, Subpart O, of the RCRA regulations]. To assess the performance of candidate treatment technologies against the applicable regulatory requirements, the regulated metals will then have to be spiked into the waste feed to enable the determination of their partitioning to various exit pathways (e.g., combustion chamber bottom ash and residual slag, air pollution control system residues, stack emissions).^{18,19} A "Trial Burn Manual for the Testing of Metals" is currently being drafted to provide guidance to operating hazardous waste incineration facilities preparing to perform trial burn testing for facility permitting.¹⁹

For cost and regulatory considerations, some relatively innocuous metals may be substituted for toxic constituents in initial performance assessments as suggested in a recent report,²⁰ in which it states, "Because metals volatility dominates partitioning, surrogates can be used and the choice of surrogates is simplified... These results show that surrogates partition in the same manner as selected hazardous constituent metals. Thus, the use of surrogates deserves consideration, if not in actual trial burns, then at least in scoping tests used to guide the formal trial burn." The cited report concluded that bismuth behavior in an incineration process is quite similar to that of cadmium; that magnesium or strontium is similar to that of chromium; and that copper is similar to that of arsenic, barium, and lead. It further suggested that other potential surrogates can be similarly identified based on equilibrium vapor pressure and temperature calculations. It should be noted that not only do the thermal properties of the nonhazardous metal need to model those of its hazardous counterpart but also the chemical nature as well. This is particularly true for comparison of leachability parameters (i.e., Toxicity Characteristic Leaching Procedure). Until the use of nonhazardous metals, as thermal and chemical surrogates for hazardous metals, has been researched in more detail it is recommended that the RCRA metals be used in the surrogate formulations

An ideal time to utilize a combination of nonhazardous and RCRA hazardous metals is during the treatment of surrogate formulations. Although this imposes additional research onto development and design, it can be of great benefit to the thermal treatment community to document the behavior of candidate nonhazardous (e.g., Bi, Cu, Mn) metals directly against RCRA hazardous metals that are either present in the waste being treated or have been added as part of the surrogate formulation. The sampling and analysis costs should not be greatly affected, since the methods used for the analysis of the RCRA metals normally provide information on many of the nonhazardous metals simultaneously. Thus, if it is within the scope of making up the surrogates, the addition of nonhazardous materials could be documented and hence provide information to lead to possible surrogates for RCRA metals. This would help to alleviate

treatability and permitting requirements for the treatment of RCRA wastes and may help provide additional credibility for the use of radiological surrogates.

4.4 BULK CONSTITUENTS

The bulk compositions of the surrogate formulations (Chap. 5) as listed are determined by "round-up" of the major innocuous constituents likely to be present in various mixed sludge wastes, real as well as simulated. The bulk ingredients are presumably all nonregulated chemicals that are assembled in an attempt to maximize the resemblance to the nonhazardous components of a typical waste stream. Selection rationales for bulk components of each of the simulated waste streams are presented separately in Chap. 5. Information such as cost and vendor data for the materials are provided in the Appendix.

4.5 MIXING LOGISTICS

A proposed set of mixing instructions is provided with each surrogate recipe. Use of the instructions is one possible method for preparing the surrogate mixture. The mixing instructions take into consideration homogeneity and loss of materials. The basic requirements for this procedure are a drum, a mixing container, and a drum mixer/roller/stirrer. It should be noted that the mixing containers can be reused since the preparation methods that they are used for (metals and organics) are identical for each of the waste streams presented in this document. Note, all measurements (weight or volume) of the individual components should be documented as the surrogate is being made. The exact method of preparing the surrogate should also be documented.

Suggestions are given for mixing the constituents to achieve a degree of uniformity in the waste stream formulation. Additional mixing baffles or components can be added to the drum to ensure adequate mixing, but it is unclear whether this level of mixing is needed. It is noted that the physical strength of the drums for the surrogates should be consistent with the weight loading of the surrogate materials.

The basic surrogate formulation is broken into four parts: bulk ingredients, RCRA metals, RCRA organics, and radiological surrogates. The mixing procedure for each of the formulations is essentially the same to help ensure a consistent waste stream formulation can be made. The dry ingredients are placed into the drum and mixed. In a separate container the liquid RCRA organics (i.e., 1,2-dichlorobenzene, chlorobenzene) are combined with activated carbon and are then added to the drum. The water portion of the formulation is added last and the drum mixed and sealed. Step-by-step detail is given with each surrogate formulation.

The three RCRA organic components are the same for all surrogate formulations. In general, these three components represent a total of 1 wt% of the overall formulation. Thus, for every 100 lb of surrogate formulation, 1 lb (454g) of the hazardous organic component will be added. In order to (1) reduce the loss of the organic contaminant due to volatility, (2) reduce worker exposure risks, (3) increase the overall bulk volume of the hazardous organic component, and (4) assist in the mixing and uniform distribution of the hazardous organic component in the surrogate formulation, activated carbon is used in the surrogate formulation. Naphthalene is a solid at room temperature and is mixed in with the other dry solid components of the formulation. The 1,2-dichlorobenzene and chlorobenzene are liquids. In order to maximize the volume of the liquid fraction of the hazardous organic component, the two ingredients are added to the activated carbon. This will absorb the liquid phase present and allow the resultant solid phase mixture to

be dispersed with the other dry solids and help reduce the loss of fugitive emissions. This provides a consistent means of hazardous organic addition that can be easily repeated for any of the surrogate formulations.

The presence of nitrate salts and organic constituents in the same waste packages, although representative of some mixed wastes, is not inherently thermodynamically stable, and energetic or oxidative reactions may occur during high-temperature melting of the packages. However, no significant quantities of nitrates are present in any of the surrogate formulations [Waste code 3151/3152: Chloride, Sulfate, and Nitrate Salts has 5% of NaNO_3 but has minimal amount (1%) of organics] and should pose no inordinate risk. If long storage time of the wastes is anticipated, the drums can be fitted with a pressure relief cap to ensure that no organics can readily escape and that over-pressurization of the drum does not occur.

The recommended RCRA-hazardous metals spike composition is selected as a compromise between appreciable metal solubility (desirable to challenge the abatement of leachability in the final waste form) and the oxidizing potential of the salt (which may cause unintentional decomposition of the organic constituents); this is especially true for the metals cerium and chromium, where the more soluble higher valence state salts are also strong oxidants. In the surrogate formulations, RCRA-hazardous metals are added as soluble chloride or nitrate salts (for mixtures that contain some water), or as oxides (for simulated "ash" solid material); chloride salts are generally the more volatile form, and thus may represent the greatest challenge to off-gas treatment.⁹ An alternate approach for metal spikes to combustible material is dispersion of finely ground (e.g., 0.1-5 μm colloid salt or oxide particulate into a liquid host (e.g., mineral oil/surfactant, similar to the preparation of a conventional paint pigment).

The surrogate formulations described in the text are proposed for intercomparison and evaluation purposes. However, the concentrations of constituents that are of regulatory concern or that may limit the applicability of a candidate treatment technology may be varied during initial testing to help determine the "ruggedness" of the technology [e.g., one may wish to vary the carbon content of the "ash" surrogate (MWTP-3111) between the limits of <5 to >12% to determine the sensitivity of this residual on treatability].

5. SURROGATE RECIPES

This chapter provides the formulations and suggested mixing protocols for making the waste stream mixture. Each formulation contains information about (1) how the waste stream has been defined by the MWTP and, where possible, references to actual waste streams; (2) the surrogate formulation; and (3) a suggested mixing procedure. This information should allow a consistent waste stream to be formulated and hence, allow a more consistent means of evaluating thermal treatment processes.

5.1 MWTP-1300: NEUTRAL AQUEOUS WASTES

5.1.1 Waste Stream Definition

This waste stream can be aqueous solutions or slurries with pH values between 2 and 12.5 (i.e., not characteristically corrosive by the EPA pH criterion).⁶ The EPA hazardous waste codes that may be associated with this waste stream include: F001 (halogenated degreasing solvents), F003 (spent nonhalogenated solvents), F006 (plating operations waste water treatment sludges), and toxic metal constituents [D004-D011].⁶

Source examples cited by the MWTP working group include secondary wastes such as evaporator condensate [which may contain volatile and semi-volatile organic compounds (e.g., alcohols, creosols and other phenolics) concentrated by steam stripping; volatile forms of radionuclides (e.g., HTcO_4)], and incinerator aqueous scrubber blowdown (which may contain entrained fly ash, hard-water scale, and 1–10% soluble chloride ion from stripping acid gases). Other examples include free liquids isolated from treatment sludges [containing trace toxic metals, soluble anions (e.g., sulfates, nitrates)], and other waste waters that exhibit the characteristics of toxicity for one or more metals [D004-D0011].

In the surrogate formulation presented in Sect. 5.1.2 (Table 6), insoluble calcium (sulfate, phosphate) and magnesium (phosphate) salts (and partially soluble carbonates) will contribute to the solids in the slurry (simulating boiler scale). Fly ash and chloride simulate incineration blowdown. As discussed in Sect. 4.2, naphthalene and 1,2-dichlorobenzene represent semi-volatile organic compounds that are relatively refractory to thermal destruction. The mixing suggestion for this waste stream is given in Table 7.

5.1.2 Surrogate Formulation

Table 6. MWTP 1300: Neutral aqueous wastes

No.	Component name	Wt %
Bulk ingredient		
1	Activated carbon	10
2	Water	75
3	CaCl ₂	3
4	NaHCO ₃	3
5	MgSO ₄ *7H ₂ O	3
6	Na ₂ HPO ₄ *7H ₂ O	2.5
7	Fly ash (ASTM Class F)	1
	Total	97.5
RCRA metals		
8	Cr(NO ₃) ₃ *9H ₂ O	0.25
9	Ni(NO ₃) ₂ *6H ₂ O	0.25
10	Pb(NO ₃) ₂	0.25
11	Cd(NO ₃) ₂ *4H ₂ O	0.25
	Total	1.0
RCRA organics		
12	Naphthalene (C ₁₀ H ₈)	0.4
13	1,2-Dichlorobenzene (C ₆ H ₄ Cl ₂)	0.3
14	Chlorobenzene (C ₆ H ₅ Cl)	0.3
	Total	1.0
Radionuclide surrogate		
15	CeCl ₃	0.25
16	CsCl	0.25
	Total	0.5

5.1.3 Mixing Suggestion

Table 7. MWTP 1300: Neutral aqueous wastes

Step no.	Sequence/instructions
1	Weigh drum and lid and record.
2	To the drum add (in an alternating manner as to ensure better mixing) all of the following dry constituents: 3-12,15,16.
3	Stir/roll drum for ≥ 5 min.
4	Weigh drum, lid, and mixture and record.
5	Add the activated carbon (1) to a separate mixing container. Slowly add the liquid RCRA organics (13,14) and mix the two components until the liquids are absorbed.
6	Add the activated carbon/RCRA organic mixture (see step 5) into the drum.
7	Stir/roll drum for ≥ 5 min.
8	Slowly add the water (2) to the mixed solids in the drum.
9	Stir/roll the drum for ≥ 15 min. Seal the drum.
10	Weigh drum, lid, and surrogate waste stream mixture and record.

5.2 MWTP-2110: AQUEOUS HALOGENATED ORGANIC LIQUIDS

5.2.1 Waste Stream Definition

This waste stream consists of a mixture of aqueous and halogenated organic liquids with contents of 1% or more of organic liquids but $< 99\%$ organic.⁶ The EPA waste codes of concern for treatment are F001, F002, F005, D004, D006, D007, D008, D009, and D010.

This waste stream description can result from many different industrial processes. The surrogate definition selected is a combination of common halogenated and non-halogenated organic components that have favorable vapor pressures and challenging incinerability indexes.^{13,14} Due to the possible energetic reactions with the high organic content of the surrogate, nitrate salts are omitted and metal oxides are used. The use of vermiculite will help in the retention of some of the material and is representative of spill control materials that may be present in the waste stream. It is recognized that not all of these materials will be wholly miscible in a homogeneous mixture, but this is true for many waste streams.

5.2.2 Surrogate Formulation

**Table 8. MWTP 2110 : Aqueous halogenated
organic liquids**

No.	Component name	Wt %
Bulk ingredient		
1	Activated carbon	10
2	Water	12
3	Toluene	10
4	Tetrachloroethylene	10
5	Mineral oil	10
6	Ethylene glycol	10
7	Vermiculite	21.5
	Total	83.5
RCRA metals		
8	$\text{CrCl}_3 \cdot 6\text{H}_2\text{O}$	0.25
9	$\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$	0.25
10	PbCl_2	0.25
11	$\text{CdCl}_2 \cdot 2\frac{1}{2}\text{H}_2\text{O}$	0.25
	Total	1.0
RCRA organics		
12	Naphthalene (C_{10}H_8)	5
13	1,2-Dichlorobenzene ($\text{C}_6\text{H}_4\text{Cl}_2$)	5
14	Chlorobenzene ($\text{C}_6\text{H}_5\text{Cl}$)	5
	Total	15.0
Radionuclide Surrogate		
15	CeCl_3	0.25
16	CsCl	0.25
	Total	0.5

5.2.3 Mixing Suggestion

Table 9. MWTP 2110: Aqueous halogenated organic liquids

Step no.	Sequence/instructions
1	Weigh drum and lid and record.
2	To the drum add (in an alternating manner as to ensure better mixing) all of the following dry constituents: 1,7-12,15,16.
3	Stir/roll drum for ≥ 5 min.
4	Weigh drum, lid, and mixture and record.
5	Slowly add the liquid RCRA organics (13,14) to the drum and mix the components until the liquids are absorbed.
6	Add the liquid bulk components (2-6) to the drum.
7	Stir/roll the drum for ≥ 15 minutes. Seal the drum.
8	Weigh drum, lid, and surrogate waste stream mixture and record.

5.3 MWTP-3111: ASH

5.3.1 Waste Stream Definition

This waste stream contains materials generated from incineration of radioactive and nonradioactive materials. It includes bottom ash, fly ash, and other solid residues.⁶ EPA waste codes associated with this waste stream include F001-F003, F005 (solvent residue codes, from the "derived-from" rule), and toxic metal constituents [D004-D011].⁶ Due to the effect of concentration in the ash, these materials may have significant radiological concerns (including, possibly, criticality safety concerns). Other significant solid residuals include slag materials (predominantly solidified vitreous aluminosilicates).

Table 10 summarizes historic data for bottom ash residues from selected DOE incinerators, as reported by Bryan;²¹ compositions are variable, depending upon the feed to the units, but oxides of aluminum and silicon predominate (oxides of inorganic constituents are the assumed form of these components in thermal treatment residuals). Table 10a summarizes some historic data for fly ash from various DOE steam plant utilities and for a Tennessee Valley Authority (TVA) utility; again, oxides of aluminum and silicon predominate. Note in Tables 10 and 10a that some historic DOE thermal treatment operations may have been relatively inefficient, as evidenced by appreciable residual carbon. Residual carbon may represent a significant challenge to reprocessing these materials; for this reason, we specify a relatively high value (i.e., 12%) of carbon in the surrogate material. Also, as suggested by the Cr values in Table 10, regulatory metals are expected to be concentrated in the "ash" residuals; for this reason, the concentrations of metal oxide "markers" are higher than in the other surrogate wastes.

Table 10. Residue compositions from selected DOE incinerators (wt%)

Constituent	RFP Fluid Bed Incinerator	Mound Cyclone Incinerator	SRP ^a	LANL ^b Controlled Air Incinerator	PNL ^c Incinerator
Al ₂ O ₃	35	33	15	28	17
C	5	d	3	6	14
CaCl	d	d	d	2	4
CaO	d	6	24	2	6
Cr ₂ O ₃	10	3	d	d	d
Fe ₂ O ₃	1	5	11	1	d
MgO	d	8	6	d	d
NaCl	5	d	d	d	2
Na ₂ CO ₃	30	d	d	d	d
SiO ₂	10	31	16	35	34
TiO ₂	d	6	18	23	17
ZnO	d	3	6	d	d
Total	96	95	99	97	94

Source: G. H. Bryan, "Characterization of Transuranium-Contaminated Solid Waste Residues," Report PNL-3776, Pacific Northwest Laboratory, April 1981.

^aSavannah River Plant.

^bLos Alamos National Laboratory.

^cPacific Northwest Laboratory.

^dValue not recorded.

Table 10a. Steam plant fly ash composition (wt %)

Element	Kingston (TVA)	ORNL ^a (DOE)	Y-12 Plant ^b (DOE)	K-25 Site ^c (DOE)
Ag	<0.0001	<0.0001	<0.0001	<0.0001
Al	5.3	3.6	3.0	2.9
As	<0.01	<0.01	<0.01	<0.01
B	0.01	0.02	0.01	0.01
Ba	0.05	0.05	0.05	0.05
Be	0.0002	0.0005	0.0002	0.0005
C	3.67	31.2	12.2	29.7
Ca	0.23	0.37	0.06	0.23
Cd	<0.05	<0.05	<0.05	<0.05
Cr	0.006	0.001	0.002	0.005
Cu	0.01	0.01	0.004	0.01
Fe	3.8	8.4	4.6	13.7
K	1.1	0.31	0.90	0.24
Mg	0.37	0.24	0.21	0.20
Mn	0.01	0.04	<0.001	0.03
Ni	0.09	0.01	0.004	0.01
P	0.05	0.05	0.05	0.05
Pb	0.1	0.02	0.01	0.01
Si	Strong	5	15	0.4
Sr	0.01	0.03	0.01	0.01
Ti	1	0.5	0.5	0.5
V	0.05	0.1	0.05	0.05

Source: J. L. Shoemaker, *Testing Fly Ash from the Steam Plants at Kingston, K-25, X-10, and Y-12 for Effect on Concrete Strength*, Martin Marietta Energy Systems, Inc., Internal Correspondence, August 1984 (to B. E. Vaughn).

^aOak Ridge National Laboratory (also known as X-10).

^bOak Ridge Y-12 Plant.

In the surrogate formulation presented in Sect. 5.3.2 (Table 11), readily-assessable coal ash is used to simulate incinerator ash, supplemented with oxides of selected RCRA metals and radioactive surrogate (CeO₂). American Society for Testing and Materials (ASTM) Class F fly ash is recommended; ASTM Class C fly ash (from burning lignite or subbituminous coal) (if exposed to water) would have both pozzolonic and cementitious properties (i.e., may promote exothermic reactions to form a solidified mass). Vermiculite [nominal composition: SiO₂ (39%), MgO (23%), Al₂O₃ (15%), Fe₂O₃ (9%), K₂O (8%), CaO (1%), trace Cr₂O₃, Mn₂O₄, Cl] is added as a surrogate slugging agent. The mixing suggestion for this waste stream is provided in Table 12.

5.3.2 Surrogate Formulation

Table 11. MWTP 3111: Ash

No.	Component name	Wt %
Bulk ingredient		
1	Activated carbon	12
2	Vermiculite	18
3	Fly ash (ASTM Class F)	33
4	Coal bottom ash cinders	33
	Total	96
RCRA metals		
5	Cr ₂ O ₃	0.5
6	NiO	0.5
7	PbO	0.5
8	CdO	0.5
	Total	2.0
RCRA organics		
9	Naphthalene (C ₁₀ H ₈)	0.4
10	1,2-Dichlorobenzene (C ₆ H ₄ Cl ₂)	0.3
11	Chlorobenzene (C ₆ H ₅ Cl)	0.3
	Total	1.0
Radionuclide surrogate		
12	CeO ₂	0.5
13	CsCl	0.5
	Total	1.0

5.3.3 Mixing Suggestion

Table 12. MWTP 3111: Ash

Step no.	Sequence/instructions
1	Weigh drum and lid and record.
2	To the drum add (in an alternating manner as to ensure better mixing) all of the following dry constituents: 2-9,12,13
3	Stir/roll drum for ≥ 5 min.
4	Weigh drum, lid, and mixture and record.
5	Add the activated carbon (1) to a separate mixing container. Slowly add the liquid RCRA organics (10,11) and mix the two components until the liquids are absorbed.
6	Add the activated carbon/RCRA organic mixture (see step 5) into the drum.
7	Stir/roll the drum for ≥ 15 min. Seal the drum.
8	Weigh drum, lid, and surrogate waste stream mixture and record.

5.4 MWTP-3113/3114: ABSORBED AQUEOUS AND ORGANIC LIQUIDS

5.4.1 Waste Stream Definition

No appropriate documented reference formulation, either real or simulated, could be found for this waste stream; however, this waste is presumed to constitute inorganic-based materials such as clay, vermiculite, or diatomaceous earth that have been used to absorb either aqueous or organic liquids contaminated with hazardous materials. These sorbents, inexpensive and available in bulk quantities, are chemically inert and have high absorption efficiencies, and therefore are generally employed in "sop-up" of spills or leakages that may occur in plant operations and maintenance. The EPA waste stream codes that are of concern for treatment are F001, F002, F003, F005, D004, D005, D007, D008, D009, and D011.⁶

The absorbed organic and inorganic liquids could have been generated when containers leaked or broke and the liquid was safely absorbed by sorbents customarily placed outside the container to prevent the release of hazardous materials to the environment. Another example might exist in the sorbents used to remove accidental release of contaminated lubricant and coolant from vacuum pumps, or machines installed to fabricate metal parts composed of nuclear materials.

The recommended surrogate waste composition for the waste stream is presented in Table 13. The surrogate composition was formulated based on the rationale stated in this section. The mixing suggestion is provided in Table 14.

5.4.2 Surrogate Formulation

**Table 13. MWTP 3113/3114:
Absorbed aqueous and organic liquids**

No.	Component name	Wt %
Bulk ingredient		
1	Activated carbon	10
2	Water	19
3	Perlite (SiO ₂)	25
4	Vermiculite	25
5	Ethylene glycol	8.5
	Total	87.5
RCRA metals		
6	CrCl ₃ *6H ₂ O	0.25
7	NiCl ₂ *6H ₂ O	0.25
8	PbCl ₂	0.25
9	CdCl ₂ *2½H ₂ O	0.25
	Total	2
RCRA organics		
10	Naphthalene (C ₁₀ H ₈)	4
11	1,2-Dichlorobenzene (C ₆ H ₄ Cl ₂)	3
12	Chlorobenzene (C ₆ H ₅ Cl)	3
	Total	10
Radionuclide surrogate		
13	CeCl ₃	0.25
14	CsCl	0.25
	Total	0.5

5.4.3 Mixing Suggestion

Table 14. MWTP 3113/3114: Absorbed aqueous and organic liquids

Step no.	Sequence/instructions
1	Weigh drum and lid and record.
2	To the drum add (in an alternating manner as to ensure better mixing) all of the following dry constituents: 3,4,6-10,13,14.
3	Stir/roll drum for ≥ 5 min.
4	Weigh drum, lid, and mixture and record.
5	Add the activated carbon (1) to a separate mixing container. Slowly add the liquid RCRA organics (11,12) and mix the two components until the liquids are absorbed.
6	Add the activated carbon/RCRA organic mixture (see step 5) into the drum.
7	Stir/roll drum for ≥ 5 min.
8	Slowly add the remaining liquid ingredients (2,5) to the mixed solids in the drum.
9	Stir/roll the drum for ≥ 15 minutes. Seal the drum.
10	Weigh drum, lid, and surrogate waste stream mixture and record.

5.5 MWTP-3122: HIGH ORGANIC CONTENT SLUDGES

5.5.1 Waste Stream Definition

This waste stream includes sludges with $>1\%$ hazardous organic (halogenated or nonhalogenated) material.⁶ The EPA hazardous waste codes of concern for treatment are F001-4 (solvent residuals), and toxic metal constituents [D004-D011].⁶

An example of a waste water sludge containing relatively high organic residue is the historic Central Pollution Control Facility (CPCF) sludge, originating from treatment of waste from the Y-12 Plant; this material contained ~ 23 wt% ill-defined "oil and grease" component in an inorganic oxyhydroxide sludge matrix (high Ca, Fe, Al, with moderate amounts of P).²² The hazardous organics in the CPCF sludge included various phenolic compounds. The CPCF sludge, and the general compositions of various waste water treatment sludges,²³ serve to model the bulk constituents in the surrogate presented in Sect. 5.4.2 (Table 15). The mixing suggestion is given in Table 16.

5.5.2 Surrogate Formulation

Table 15. MWTP 3122: High organic content sludges

No.	Component name	Wt %
Bulk ingredient		
1	Activated carbon	10
2	Water	20
3	Perlite	10
4	Fe ₂ O ₃	10
5	CaSO ₄ *2H ₂ O	10
6	Al ₂ O ₃	5
7	Ethylene glycol	14.5
8	Mineral oil	12.0
	Total	91.5
RCRA metals		
9	CrCl ₃ *6H ₂ O	0.25
10	NiCl ₂ *6H ₂ O	0.25
11	PbCl ₂	0.25
13	CdCl ₂ *2½H ₂ O	0.25
	Total	1
RCRA organics		
13	Naphthalene (C ₁₀ H ₈)	3
14	1,2-Dichlorobenzene (C ₆ H ₄ Cl ₂)	2
15	Chlorobenzene (C ₆ H ₅ Cl)	2
	Total	7
Radionuclide surrogate		
16	CeCl ₃	0.25
17	CsCl	0.25
	Total	0.5

5.5.3 Mixing Suggestion

Table 16. MWTP 3122: High organic content sludges

Step no.	Sequence/instructions
1	Weigh drum and lid and record.
2	To the drum add (in an alternating manner as to ensure better mixing) all of the following dry constituents: 3-6,9-13,16,17.
3	Stir/roll drum for ≥ 5 min.
4	Weigh drum, lid, and mixture and record.
5	Add the activated carbon (1) to a separate mixing container. Slowly add the liquid RCRA organics (14,15) and mix the two components until the liquids are absorbed.
6	Add the activated carbon/RCRA organic mixture (see step 5) into the drum.
7	Stir/roll drum for ≥ 5 min.
8	Slowly add the remaining liquid ingredients (2,7,8) to the mixed solids in the drum.
9	Stir/roll the drum for ≥ 15 min. Seal the drum.
10	Weigh drum, lid, and surrogate waste stream mixture and record.

5.6 MWTP-3140: CEMENT SLUDGES, ASHES, AND SOLIDS

5.6.1 Waste Stream Definition

This waste stream contains sludges or solids that contain cement or other solidifying agents either to control free water or to produce a waste form, but do not yet meet disposal requirements.⁶ The EPA hazardous waste codes of concern for treatment are F001-4 (solvent residuals), and toxic metal constituents [D004-D011], and the EPA LDR requirements for no free water in waste for disposal.⁶ [Because of the alkaline nature of cement, excess (free) water associated with this material can have a pH value high enough (≥ 12.5) to be characterized as RCRA hazardous.]

Currently, cement-based solidification/stabilization is the most widely used technology for the treatment of mixed waste sludges; however, problems in the management of raw and improperly stabilized sludge are not uncommon within the DOE community.²⁴ Problems include underestimating the requirements of the waste form and package (e.g., deterioration of product and package over time to cause leakage/spillage); treatment formulations that are not sufficiently "forgiving" to accommodate the full range of variability within the waste stream composition (sometimes abetted by inadequate waste stream characterization prior to formulation); and operational difficulties that produce waste forms that do not meet product specifications.

In addition to portland cement, other common solidification agents and admixtures include coal combustion fly ash, blast furnace slag (e.g., SRP "Saltstone" product), calcium sulfate (LANL "Envirostone" product), and various other silicate-based pozzolonic and sorptive agents.

In formulating a surrogate for this material, it was considered to be preferable to use crushed, cured cement [screened to remove large (>1-in.) aggregate] rather than portland cement (which reacts exothermally with water to promote gel formation; this could cause loss of volatile organic compounds in the waste form).¹⁴ The recommended surrogate waste composition for the waste stream is presented in Table 17. The mixing suggestion is provided in Table 18.

5.6.2 Surrogate Formulation

**Table 17. MWTP 3140:
Cement, sludges, ashes, and solids**

No.	Component name	Wt %
Bulk ingredient		
1	Activated carbon	10
2	Water	50
3	Perlite	10
4	Fly ash (ASTM Class F)	10
5	Concrete (cured, crushed, screened)	10
6	CaSO ₄ *0.5H ₂ O ("Plaster of Paris")	3
7	Fe ₂ O ₃ (hematite)	3
8	Al ₂ O ₃	1.5
	Total	97.5
RCRA metals		
9	Cr ₂ O ₃	0.25
10	NiO	0.25
11	PbO	0.25
12	CdO	0.25
	Total	1
RCRA organics		
13	Naphthalene (C ₁₀ H ₈)	0.4
14	1,2-Dichlorobenzene (C ₆ H ₄ Cl ₂)	0.3
15	Chlorobenzene (C ₆ H ₅ Cl)	0.3
	Total	1
Radionuclide surrogate		
16	CeO ₂	0.25
17	CsCl	0.25
	Total	0.5

5.6.3 Mixing Suggestion

Table 18. MWTP 3140: Cement, sludges, ashes, and solids

Step no.	Sequence/instructions
1	Weigh drum and lid and record.
2	To the drum add (in an alternating manner as to ensure better mixing) all of the following dry constituents: 3-13,16,17.
3	Stir/roll drum for ≥5 min.
4	Weigh drum, lid, and mixture and record.
5	Add the activated carbon (1) to a separate mixing container. Slowly add the liquid RCRA organics (14,15) and mix the two components until the liquids are absorbed.
6	Add the activated carbon/RCRA organic mixture (see step 5) into the drum.
7	Stir/roll drum for ≥5 min.
8	Slowly add the water (2) to the mixed solids in the drum.
9	Stir/roll the drum for ≥15 min. Seal the drum.
10	Weigh drum, lid, and surrogate waste stream mixture and record.

5.7 MWTP-3151/3152: CHLORIDE, SULFATE, AND NITRATE SALTS

5.7.1 Waste Stream Definition

This waste stream is from the evaporated or process salt that may contain more than trace concentrations of sulfate or chlorides or are predominantly nitrate salts.⁶ The EPA waste codes that are of concern for treatment are D005, D006, D007, and D008. Additional concerns in the treatment of this waste classification include corrosion potential, limited solubility of salts in final glass forms, and the destruction of NO_x.

The surrogate formulation for this waste stream is specified in Table 19. The mixing suggestion is given in Table 20. References²⁵⁻²⁹ were reviewed in establishing the major constituents and concentrations. Expected salt components from the Molten Salt Oxidation Process are also considered. The waste streams described in the cited references are as follows:

- Savannah River Plant (SRP) simulated effluent treatment facility feed (Ref. 25, Table 1);
- Westinghouse Hanford Company (WHC) treatability surrogate formulations for eight waste feed streams to the waste receiving and processing module 2A (Ref. 26, Tables 1 and 2);
- SRP Solids forms of rad waste—composition data (Ref. 27, Tables I and II);
- WHC Salt cake and SRP waste calcines composition data (Ref. 28, Tables 3 and 4); and
- INEL simulated sludge composition data (Ref. 29, Table 3.1).

Due to the high concentration of nitrate salts, RCRA organic compounds are omitted from the formulation (see also Sect. 4.5).

5.7.2 Surrogate Formulation

**Table 19. MWTP 3151/3152:
Chloride, sulfate, and nitrate salts**

No.	Component name	Wt %
Bulk ingredient		
1	Activated carbon	5
2	Water	18.5
3	NaCl	15
4	Na ₂ SO ₄	15
5	NaCO ₃	15
6	NaNO ₃	15
7	Na ₃ PO ₄	5
8	KF	10
	Total	98.5
RCRA metals		
9	Cr(NO ₃) ₃ *9H ₂ O	0.25
10	Ni(NO ₃) ₂ *6H ₂ O	0.25
11	Pb(NO ₃) ₂	0.25
12	Cd(NO ₃) ₂ *4H ₂ O	0.25
	Total	1
Radionuclide surrogate		
13	CeO ₂	0.25
14	CsCl	0.25
	Total	0.5

5.7.3 Mixing Suggestion

Table 20. MWTP 3151/3152: Chloride, sulfate, and nitrate salts

Step no.	Sequence/instructions
1	Weigh drum and lid and record.
2	To the drum add (in an alternating manner as to ensure better mixing) all of the following dry constituents: 1,3-14.
3	Stir/roll drum for ≥ 5 min.
4	Weigh drum, lid, and mixture and record.
5	Stir/roll drum for ≥ 5 min.
6	Slowly add the water (2) to the mixed solids in the drum.
7	Stir/roll the drum for ≥ 15 min. Seal the drum.
8	Weigh drum, lid, and surrogate waste stream mixture and record.

5.8 MWTP-3200: ORGANIC MATRIX SOLIDS

5.8.1 Waste Stream Definition

Organic matrix solids, Waste Code 3200, are materials that are primarily organic in composition, and as such would leave only moderate ash residue by conventional incineration treatment. The primary treatment concern is destruction of the organic constituents. Subcategories in the 3200 series include spent ion exchange media (3210) and other resins (3212), activated carbon (3211), liquids sorbed on organic material (3213), organic sludges (3220), and so forth.

No well-characterized authentic or simulated waste stream was found to well represent this waste category; therefore, an effort was made to assemble a composition as shown in Sect. 5.8.2 (Table 21). Activated carbon, cellulose, and organic resin are selected based on information from a MWTP document.⁶ These organic materials have been accumulated as wastes at DOE sites arising from their usages in operational activities such as waste water treatment, removal of contaminants from off gases discharged through packed columns, and general absorptions of liquids. The mixing suggestion for organic matrix solids is given in Table 22.

The inclusion of sodium sulfate, carbon carbonate, and water is to represent the relatively minor presence of inorganic salts and moisture in a typical organic sludge. Other materials, such as lubricating oils,¹³ organic chemicals, and solvents^{30,31} generally used for cleaning and other applications, are excluded in the formulation as they would all be represented appropriately by the surrogate organics that were selected (as described in Sect. 4.2) due to their low incinerability ranking (i.e., relatively high resistance to thermal destruction) and low ambient vapor pressure.

5.8.2 Surrogate Formulation

Table 21. MWTP 3200: Organic matrix solids

No.	Component name	Wt %
Bulk ingredient		
1	Activated carbon	30
2	Water	10
3	Cation exchange resin	30
4	Cellulose (cob dry)	18
5	Na ₂ SO ₄	5
6	CaCO ₃	4.5
	Total	97.5
RCRA metals		
7	CrCl ₃ *6H ₂ O	0.25
8	NiCl ₂ *6H ₂ O	0.25
9	PbCl ₂	0.25
10	CdCl ₂ *2½H ₂ O	0.25
	Total	1
RCRA organics		
11	Naphthalene (C ₁₀ H ₈)	0.4
12	1,2-Dichlorobenzene (C ₆ H ₄ Cl ₂)	0.3
13	Chlorobenzene (C ₆ H ₅ Cl)	0.3
	Total	1
Radionuclide surrogate		
14	CeCl ₃	0.25
15	CsCl	0.25
	Total	0.5

5.8.3 Mixing Suggestion

Table 22. MWTP 3200: Organic matrix solids

Step no.	Sequence/instructions
1	Weigh drum and lid and record.
2	To the drum add (in an alternating manner as to ensure better mixing) all of the following dry constituents: 3-11,14,15
3	Stir/roll drum for ≥ 5 min.
4	Weigh drum, lid, and mixture and record.
5	Add the activated carbon (1) to a separate mixing container. Slowly add the liquid RCRA organics (12,13) and mix the two components until the liquids are absorbed.
6	Add the activated carbon/RCRA organic mixture (see step 5) into the drum.
7	Stir/roll drum for ≥ 5 min.
8	Slowly add the water (2) to the mixed solids in the drum.
9	Stir/roll the drum for ≥ 15 min. Seal the drum.
10	Weigh drum, lid, and surrogate waste stream mixture and record.

5.9 MWTP-5400: HETEROGENEOUS DEBRIS

5.9.1 Waste Stream Definition

The waste stream comprises debris materials that contain ~50% combustible materials intermingled with noncombustible debris. As heterogeneous debris, these materials may be associated with a variety of EPA waste codes (e.g., F001-05, D004-11).⁶

Previous waste stream characterization^{32,33} was used in part in establishing the major combustible constituents and associated concentrations, whereas values reported in Refs. 34 and 35 were used to establish the major noncombustible constituents and their associated concentrations.

The specifications of the combustible species/fractions were done in conjunction with reviewing the MWTP waste code 5440, which was patterned after buried wastes originally generated at the RFP and currently buried at INEL.³⁶ The specifications of the non-combustible species were done in conjunction with reviewing the appropriate proposed rules published in 1992 in the Federal Register.³⁷ The May 26, 1992³⁷ Federal Register defines treatability group 13 as relevant for solid debris wastes that exhibit the characteristics of toxicity due to metals (D004-D011) with matrices that are nonfriable; inorganic solids, glass, concrete, refractory bricks, slags, and metal industrial equipment are included therein.

Table 23, which lists some attributes of bulk combustibles and simulated heterogenous debris that have been used previously in testing incinerator performance, was also considered in the selection of surrogate materials.

The surrogate formulation for heterogeneous debris is provided in Table 24, and the mixing suggestion for this waste stream is in Table 25.

Table 23. Simulated heterogeneous, predominantly combustible waste compositions

Reference	Simulant Composition (Weight %)			Comments
	Plastics/polymers	Cellulosics	Noncombustible	
Pattengill et al. (1982)	Polyethylene (9%) PVC ^a (6%)	Cloth (7%)	Shredded steel (33%)	Incineration of simulated TRU wastes from INEL: Combustible-filled drum. Data on ash composition, particle size, distribution, etc.
Tenaglia and McCall (1983)	Polyethylene (73%) PVC (8%)	Wood (5%) Paper (5%) Cloth (9%)	[Various noncombustibles, e.g. soil, glass, firebrick, cryolite, sludge, and cement were blended with combustible mix.]	Induction melting of simulated TRU waste. Characterization data for all products and residuals.
Ford and Jenkins (1984)	PVC (49.4%) Polyethylene (10.4%) Polypropylene (11.7%) Hypalon (19.9%)	Tissues (8.6%)	N/A	Incineration of simulated TRU waste from BNFL. ^b
Ford and Jenkins (1984)	PVC (8.8%) Polyethylene (30%) Neoprene (20.3%) Hypalon (5.4%) Polyurethane (8.8%)	Tissues (15%)	N/A	Incineration of simulated TRU waste from DNE.
Brunel et al. (1992)	PVC (50%) Neoprene (27%) Latex (15%)	Cotton (4%) Tissues (4%)	N/A	Incineration of simulated waste from French mixed oxide fuel facility. Characterized ash, tested ash stabilization.
Gilmore (ed) (1977)	Rubber tubing (15%) Neoprene (15%) PVC (20%) Tygon (10%) Polyethylene (10%)	Tissues (15%) Rags (15%)	N/A	Pyrolysis/incineration of simulated alpha-waste at Battelle Northwest Laboratories. Ash products characterized.

Sources: M. G. Pattengill et al., Report EGG-2223 (1982); R. D. Tenaglia and J. L. McCall, Report EGG-2263 (1983); L. H. Ford and M. J. Jenkins, Report EUR-9219-EN (1984); G. R. Brunel, C. J. Kertesz, and L. M. Auffret, in *Waste Management '92* (1992), p. 1459; W. R. Gilmore (ed), *Radioactive Waste Disposal (Low and High Level)*, Noyes Data Corporation (1977), p. 153.

^apolyvinylchloride

^bBritish Nuclear Fuels, Ltd.

5.9.2 Surrogate Formulation

Table 24. MWTP 5400: Heterogeneous debris

No.	Component name	Wt %
Bulk ingredient		
1	Activated carbon	5
2	Water	14.5
3	Wood	10
4	Polyvinylchloride (PVC)	10
5	Neoprene	10
6	Mild steel	10
7	Glass beads	10
8	Concrete (cured, crushed)	8
9	Alumina crucibles	10
10	Diatomaceous earth	10
	Total	97.5
RCRA metals		
11	$\text{CrCl}_3 \cdot 6\text{H}_2\text{O}$	0.25
12	$\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$	0.25
13	PbCl_2	0.25
14	$\text{CdCl}_2 \cdot 2\frac{1}{2}\text{H}_2\text{O}$	0.25
	Total	1
RCRA organics		
15	Naphthalene (C_{10}H_8)	0.4
16	1,2-Dichlorobenzene ($\text{C}_6\text{H}_4\text{Cl}_2$)	0.3
17	Chlorobenzene ($\text{C}_6\text{H}_5\text{Cl}$)	0.3
	Total	1
Radionuclide surrogate		
18	CeCl_3	0.25
19	CsCl	0.25
	Total	0.5

5.9.3 Mixing Suggestion

Table 25. MWTP 5400: Heterogeneous debris

Step no.	Sequence/instructions
1	Weigh drum and lid and record.
2	To the drum add (in an alternating manner as to ensure better mixing) all of the following dry constituents: 3-15,18,19.
3	Stir/roll drum for ≥ 5 min.
4	Weigh drum, lid, and mixture and record.
5	Add the activated carbon (1) to a separate mixing container. Slowly add the liquid RCRA organics (16,17) and mix the two components until the liquids are absorbed.
6	Add the activated carbon/RCRA organic mixture (see step 5) into the drum.
7	Stir/roll drum for ≥ 5 min.
8	Slowly add the water (2) to the mixed solids in the drum.
9	Stir/roll the drum for ≥ 15 min. Seal the drum.
10	Weigh drum, lid, and surrogate waste stream mixture and record.

5.10 MWTP-5440: BULK COMBUSTIBLES

5.10.1 Waste Stream Definition

Waste Code 5440 comprises debris materials that contain ~50% to 95% combustible material intermingled with noncombustible debris. As a heterogeneous debris, these materials may be associated with a variety of EPA waste codes (e.g., F001, F002, F003, F005, D004, D006, D007, D008, D009, D010, D011).

Table 26 shows the bulk components for the combustible solid waste stream (Waste Code 5440) that are generally patterned after the composition of the combustible wastes in pit 9 of INEL. Table 27 gives the mixing suggestion. These buried wastes were originally generated at the RFP and are composed of cardboard, wood scrap, paper, rags, rubber, plastic, asphalt, and oil.¹³ References were also made to various simulated heterogeneous, combustible wastes;³² see also Table 23, which lists some attributes of bulk combustibles and simulated heterogeneous debris that have been used in testing incinerator performance.

5.10.2 Surrogate Formulation

Table 26. MWTP 5440: Bulk combustible

No.	Component name	Wt %
Bulk ingredient		
1	Activated carbon	10
2	Water	15
3	Cellulose (cob dry)	10
4	Wood chips	15
5	Paper	10
6	Cloth (shredded)	5
7	Polyvinylchloride (PVC)	8
8	Polyethylene	15
9	Rubber (neoprene)	9.5
	Total	97.5
RCRA metals		
10	$\text{CrCl}_3 \cdot 6\text{H}_2\text{O}$	0.25
11	$\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$	0.25
12	PbCl_2	0.25
13	$\text{CdCl}_2 \cdot 2\frac{1}{2}\text{H}_2\text{O}$	0.25
	Total	1
RCRA organics		
14	Naphthalene (C_{10}H_8)	0.4
15	1,2-Dichlorobenzene ($\text{C}_6\text{H}_4\text{Cl}_2$)	0.3
16	Chlorobenzene ($\text{C}_6\text{H}_5\text{Cl}$)	0.3
	Total	1
Radionuclide surrogate		
17	CeCl_3	0.25
18	CsCl	0.25
	Total	0.5

5.10.3 Mixing Suggestion

Table 27. MWTP 5440: Bulk combustible

Step no.	Sequence/instructions
1	Weigh drum and lid and record.
2	To the drum add (in an alternating manner as to ensure better mixing) all of the following dry constituents: 3-14,17,18.
3	Stir/roll drum for ≥ 5 min.
4	Weigh drum, lid, and mixture and record.
5	Add the activated carbon (1) to a separate mixing container. Slowly add the liquid RCRA organics (15,16) and mix the two components until the liquids are absorbed.
6	Add the activated carbon/RCRA organic mixture (see step 5) into the drum.
7	Stir/roll drum for ≥ 5 min.
8	Slowly add the water (2) to the mixed solids in the drum.
9	Stir/roll the drum for ≥ 15 min. Seal the drum.
10	Weigh drum, lid, and surrogate waste stream mixture and record.

5.11 MWTP-6100: LAB PACKS

5.11.1 Waste Stream Definition

Lab packs arise from two categories specified in appendices IV and V of 40 CFR, Part 268.³⁷ Regulated LDR Appendix IV and V lab packs may contain numerous P, U, F, and K listed wastes, exhibiting the characteristics of ignitability (D001) and toxicity due to pesticides (D012-D017). Appendix IV lab packs may additionally exhibit the characteristics of corrosivity (D002), reactivity (D003), and toxicity due to metals except mercury (D004-D008, D010, D011). Discarded laboratory chemicals and unused portions of samples may be particular constituents. Unregulated wastes may be commingled within lab packs. The waste container can contain liquids in smaller containers surrounded with packing materials such as vermiculite. Treatment concerns may require unpacking and sorting, characterization, and behavior of chemicals in small, sealed containers.

It should be noted that glass vials and metal cans can contain priority chemical wastes (such as trichloroethylene), which are too volatile to add to (and retain in) other waste packages. The mass for these filled containers can be subtracted from the mass of the vermiculite packing material to maintain the total mass of the waste package.

The surrogate formulation for MWTP 6100 lab packs is provided in Table 28, and the mixing suggestion in Table 29.

5.11.2 Surrogate Formulation

Table 28. MWTP 6100: Lab packs

No.	Component name	Wt%
Bulk ingredient		
1	Activated carbon	5
2	Water	10
3	Vermiculite	53.5
4	Glass jars w/lids	10
5	Metal cans	5
6	Polyethylene	5
	Total	88.5
RCRA metals		
7	$\text{CrCl}_3 \cdot 6\text{H}_2\text{O}$	0.25
8	$\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$	0.25
9	PbCl_2	0.25
10	$\text{CdCl}_2 \cdot 2\frac{1}{2}\text{H}_2\text{O}$	0.25
	Total	1
RCRA organics		
11	Naphthalene (C_{10}H_8)	4
12	1,2-Dichlorobenzene ($\text{C}_6\text{H}_4\text{Cl}_2$)	3
13	Chlorobenzene ($\text{C}_6\text{H}_5\text{Cl}$)	3
	Total	10
Radionuclide surrogate		
14	CeCl_3	0.25
15	CsCl	0.25
	Total	0.5

5.11.3 Mixing Suggestion

Table 29. MWTP 6100: Lab packs

Step no.	Sequence/instructions
1	Weigh drum and lid and record.
2	To the drum add (in an alternating manner as to ensure better mixing) all of the following dry constituents: 3-11,14,15. Reserve enough of the glass jars and lids (item 4) for step 5.
3	Stir/roll drum for ≥ 5 min.
4	Weigh drum, lid, and mixture and record.
5	Add the activated carbon (1) to a mixing container with sufficient capacity to contain Items 12 and 13. Slowly add the liquid RCRA organics (12,13) to the glass jar (4), seal and mix the two components until the liquids are absorbed.
6	Add the activated carbon/RCRA organic container (see step 5) into the drum.
7	Stir/roll drum for ≥ 5 min.
8	Slowly add the water (2) to the mixed solids in the drum.
9	Stir/roll the drum for ≥ 15 min. Seal the drum.
10	Weigh drum, lid, and surrogate waste stream mixture and record.

5.12 MWTP-7200: LEAD SHAPES

5.12.1 Waste Stream Definition

This waste stream is made of bulk lead materials that are separable from other wastes (i.e., bricks, sheets, unique components).⁶ The bulk lead may or may not be radioactive (i.e., activated) or it may or may not have been "coated" with additional waste materials. The EPA defines LLMW radioactive lead solids³⁷ as lead shapes (bricks or sheets) that may or may not need to be decontaminated prior to treatment. Although thermal treatment is not the preferred treatment for this waste stream, there may be cases where the lead shapes are not totally retrievable from the waste stream to be processed, and hence the ability of thermal treatment system to treat high levels of lead-based waste may be important. The waste stream described is simply made from lead bricks or shapes and has been coated with a RCRA metal, RCRA organic, and radiological surrogate mixture. This addition to the waste stream allows the effects of high lead concentrations on the "other" waste components to be documented. The surrogate formulation for this waste stream is given in Table 30, and the mixing suggestion in Table 31.

5.12.2 Surrogate Formulation

Table 30. MWTP 7200: Lead shapes

No.	Component name	Wt %
Bulk ingredient		
1	Activated carbon	5
2	Water	9.5
3	Lead shapes (bricks and sheets)	83
	Total	97.5
RCRA metals		
4	$\text{CrCl}_3 \cdot 6\text{H}_2\text{O}$	0.25
5	$\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$	0.25
6	PbCl_2	0.25
7	$\text{CdCl}_2 \cdot 2\frac{1}{2}\text{H}_2\text{O}$	0.25
	Total	1
RCRA organics		
8	Naphthalene (C_{10}H_8)	0.4
9	1,2-Dichlorobenzene ($\text{C}_6\text{H}_4\text{Cl}_2$)	0.3
10	Chlorobenzene ($\text{C}_6\text{H}_5\text{Cl}$)	0.3
	Total	1
Radionuclide surrogate		
11	CeCl_3	0.25
12	CsCl	0.25
	Total	0.5

5.12.3 Mixing Suggestion**Table 31. MWTP 7200: Lead shapes**

Step no.	Sequence/Instructions
1	Weigh drum and lid and record.
2	To the drum add (in an alternating manner as to ensure better mixing) all of the following dry constituents: 3-8,11,12.
3	Stir/roll drum for ≥ 5 min.
4	Weigh drum, lid, and mixture and record.
5	Add the activated carbon (1) to a separate mixing container. Slowly add the liquid RCRA organics (9,10) and mix the two components until the liquids are absorbed.
6	Add the activated carbon/RCRA organic mixture (see step 5) into the drum.
7	Stir/roll drum for ≥ 5 min.
8	Slowly add the water (2) to the mixed solids in the drum.
9	Stir/roll the drum for ≥ 15 min. Seal the drum.
10	Weigh drum, lid, and surrogate waste stream mixture and record.

6. SUMMARY

The twelve surrogate waste formulations described in the text are generic representations for categories of actual mixed waste residing within the DOE complex. The matrix compositions for these surrogate waste packages are intended to present a variety of handling and treatment challenges, and are proposed for use in the preliminary evaluation of candidate technologies. The surrogate waste compositions are formulated based upon bulk materials that are readily available from a variety of sources, and a limited number of "markers," representing hazardous organic compounds and metals of regulatory concern. The Appendix lists suggested material sources, information on relative costs for materials, and selected physical data and hazard cautions from the corresponding Material Safety Data Sheets.

Use of well-defined synthetic mixtures, with credible surrogates to allow prediction of the behavior of the principal radiological contaminants in authentic wastes, will allow more facile testing and will permit more direct performance evaluation among potentially competing candidate treatment technologies. It is anticipated that testing may occur in several stages, depending upon the maturity of the candidate technology, the operational experience of the investigators, and the engineering controls and permits held by the testing facility. A tiered approach may proceed from parametric studies based upon the use of generalized surrogates to the use of authentic mixed waste materials (as justified and permitted).

Companion reports in this series support the rationale for the use of surrogates for radionuclides, provide the framework for consistent methods to measure and document the system performance evaluation for thermal treatment processes (i.e., "benchmarking"), and provide the framework for complete and consistent collection and measurement of relevant data (i.e., "data quality objectives").

7. REFERENCES

1. D. P. Hoffmann, L. V. Gibson, W. H. Hermes, R. E. Bastian, and W. T. Davis, "Guidelines for Benchmarking Thermal Treatment Systems for Low-Level Mixed Waste," Report DOE/MWIP-19, January 1994.
2. "U.S. Department of Energy Interim Mixed Waste Inventory Report: Waste Streams, Treatment Capacities, and Technologies," DOE/NBM-1100, April 1993.
3. J. Coleman, S. Cowan, L. H. Harmon, J. Rhoderick, L. C. Borduin, B. C. Musgrave, W. A. Ross, "Mixed Waste Treatment Project—Scope and Status," Waste Management 92, Vol. 2, Tucson, Ariz., March 1-5 1992, pp. 1123-1125.
4. W. A. Ross, M. R. Elmore, C. L. Warner, L. J. Wachter, W. L. Carlson, R. L. Devries, "Locations, Volumes, and Characteristics of DOE's Mixed Low-Level Wastes," Waste Management 92, Vol. 2, Tucson, Ariz., March 1-5 1992, pp. 1127-1135.
5. L. H. Harmon, J. E. Rhoderick, L. C. Borduin, B. C. Musgrave, W. A. Ross, "Technology needs for Treatment of DOE's Low-Level Mixed Wastes," Waste Management 92, Vol. 2, Tucson, Ariz., March 1-5 1992, pp. 1137-1142.
6. Memo from J. Mayberry to L. Borduin et al., "Waste Stream Definition," February 5, 1993.
7. Private communication, J. Mayberry to W. D. Bostick, August 1993.
8. J. M. Chiang, W. D. Bostick, D. P. Hoffmann, W. H. Hermes, L. V. Gibson, Jr., A. A. Richmond, "Surrogate Formulations for Thermal Treatment of Low-Level Mixed Wastes, Part III: Plasma Hearth Process Testing," Report DOE/MWIP-17, Martin Marietta Energy Systems, Inc., January 1994.
9. J. A. Stockdale, H. T. Lee, W. D. Bostick, and D. P. Hoffmann, "Surrogate Formulations for Thermal Treatment of Low-Level Mixed Wastes, Part I: Radiological Surrogates," Report DOE/MWIP-15, Martin Marietta Energy Systems, Inc., January 1994.
10. W. J. Bjorklund, "Development and Use of Sintered High Level Waste," Report BNNW-2074, Battelle Pacific Northwest Laboratories, Richland, Wash., July 1976.
11. C. Shapiro, K. Garcia, and J. Beller, "Treatment of a Simulated Mixed Waste with Supercritical Water Oxidation," in A. Moghissi et al. (eds), Proceedings of the Second International Symposium on Mixed Waste, Baltimore, Md., August 17-20, 1993, pp. 10.3.1-10.3.16.
12. S. O. Bates, "Definition and Compositions of Standard Waste Streams for Evaluation of Buried Waste Integrated Demonstration Treatment Technologies," Report EGG-WTD-1066 (January 1993).
13. C. C. Lee, G. L. Huffman, and S. M. Sasseville, "Incinerability Ranking Systems for RCRA Hazardous Constituents," Hazardous Waste and Hazardous Materials, 7(4), 1990.
14. R. D. Spence, T. M. Gilliam, I. L. Morgan, S. C. Osborne, "Immobilization of Volatile Organic Compounds in Commercial Cement-Based Waste Forms," Report ORNL/TM-11251, Martin Marietta Energy Systems, Inc., December 1990.
15. M. T. Harris, R. L. Jolley, G. E. Oswald, and J. C. Rose, "Wet Oxidation of Phenol and Naphthalene (as a Surrogate PAH) in Aqueous and Sludge Solution: Application to Coal Conversion Wastewater and Sludge Treatment," Report ORNL/TM-8576, Union Carbide Corp., May 1983.
16. R. W. Anderson, "Recommended Surrogate PCB Waste Feed and Fuel Compositions to Meet Spec. K/D-5552 for Test Burns in the Martin Marietta Energy Systems, Inc. Incinerator," Report K/PS-975, December 1984.

17. P. Sadler, "Understanding Metals Compliance: The Tiered Approach and Dealing With Multiple Sources," in Proceedings of the 1993 Incineration Conference, Knoxville, TN., May 3-7, 1993, p. 405.

18. J. M. Hillary, "Review of the 'Trial Burn Manual for the Testing of Metals': A Product of the Coalition for Responsible Waste Incineration," in Proceedings of the 1993 Incineration Conference, Knoxville, TN., May 3-7, 1993, p. 411.

19. J. R. Waterland and D. J. Fournier, "Potential Surrogate Metals for Incinerator Trial Burns," in Proceedings of the 1993 Incineration Conference, Knoxville, TN., May 3-7, 1993, p. 433.

20. G. H. Bryan, "Characterization of Transuranium-Contaminated Solid Waste Residues, Report PNL-3776, Pacific Northwest Laboratory, April 1981.

21. R. M. Neilson, Jr., and P. Colombo, "Solidification of Simulated Transuranic Contaminated Incinerator Ash Wastes Using Portland Type I Cement," Report BNL-50854, Brookhaven National Laboratory (May 1978).

22. R. L. Fellows, W. D. Bostick, J. L. Shoemaker, and I. L. Morgan, "Extraction of Organics from Sludge: CPCF Sludge Extraction Evaluation - Bench-Scale Chemistry Tests," Report K/QT-406, Martin Marietta Energy Systems, Inc., April 1991.

23. W. D. Bostick, D.P. Hoffmann, R.J. Stevenson, A.A. Richmond, D.F. Bickford, "Surrogate Formulations for Thermal Treatment of Low-Level Mixed Waste, Part IV: Waste Water Treatment Sludges," Report DOE/MWIP-18, Martin Marietta Energy Systems, Inc., January 1994.

24. T. F. Lomenick (editor), "Proceedings of the Workshop on Radioactive, Hazardous, and/or Mixed Waste Sludge Management," Report CONF-901264, Martin Marietta Energy Systems, Inc. (January 1992).

25. G. K. Georgetown, J. L. Shiler "Pilot Scale Studies in Treating a Simulated Low-Level Radioactive Waste," Proceedings AICHE Summer National Meeting, Denver, August 21-24, 1988.

26. D. A. Burbank, K. M. Weingardt, "Mixed Waste Solidification Testing on Thermosetting Polymer and Cement Based Waste Forms in Support of Hanford's WRAP Module 2A Facility," Report, Westinghouse Hanford Company.

27. R. M. Wallace, W. H. Hale, R. F. Bradley, H. L. Hull, J. A. Kelly, J. A. Stone, G. H. Thompson, "Solid Forms for Savannah River Plant Radioactive Wastes," Advances in Chemistry Series, 153, 1976.

28. M. J. Kupfer, "Preparation of Nonradioactive Substitutes for Radioactive Wastes," Report DOE/ET/41900-8, Rockwell Hanford Operations, July 1981.

29. T. M. Bersgman, J. W. Shade, R. K. Farnsworth, "Fifth In Situ Vitrification Engineering-Scale Test of Simulated INEL Buried Waste Sites," Report PNL-8152, Pacific Northwest Laboratory, June 1992.

30. Oak Ridge K-25 Site Technology Logic Diagram, K-2073 (Vol. 3), February 1993.

31. Oak Ridge National Laboratory Mixed Waste Database File, February 1993.

32. W. R. Gilmore (ed.), "Radioactive Waste Disposal (Low and High Level)," Noyes Data Corporation (1977).

33. L. H. Ford and M. J. Jenkins, "Commission of the European Communities, Nuclear Science and Technology, Incineration of Simulated Plutonium-Contaminated Waste," EUR 9219 EN, Directorate-General, Science, Research and Development, United Kingdom Atomic Energy Authority, Springfields Nuclear Power Development Laboratories, Salwick, Preston PR4 0RR, United Kingdom, 1984, Final Report.

34. T. L. Eddy, P. C. Kong, B. D. Ralvo, and G. L. Anderson, "Thermal Processing System Concepts and Considerations for RWMC Buried Waste," EGG-WTD-10058, DE92 018049, Idaho National Engineering Laboratory, EG&G Idaho, Inc., Idaho Falls, Idaho 83415, February 1992.

35. H. E. Martz, G. P. Roberson, D. J. Schneberk, M. F. Skeate, D. Perkins, and S. G. Azevedo, "Computerized Tomography of a Simulated Waste Canister," UCID--21940, DE90 008014, Nondestructive Evaluation Section, Lawrence Livermore National Laboratory, Livermore, Calif. 94551.

36. S. O. Bates, "Definition and Compositions of Standard Waste Streams of Evaluation of Buried Waste Integrated Demonstration Technologies," Report EGG-WTD-1066, January 1993.

37. U.S. EPA, 57 FR 22027, May 26, 1992.

Appendix A
MATERIALS SPECIFICATION

Forms and Sources for Surrogate Formulations		
Property	Chemical or Material	
	Chromium III Chloride Hexahydrate	Chromium Oxide
Chemical Formula Trade Name	$\text{CrCl}_3 \cdot 6\text{H}_2\text{O}$	Cr_2O_3
Physical Form	powder or granules	powder
Suggested Vendors	Bodman Industries (800-459-8036)	Aldrich (800-766-7000) Spectrum (800-772-8786)
1993 Market Price Reagent Grade	25 lbs at \$13.50/lb	\$168.25/5 lbs
Bulk Grade		\$5.50 per lb in 50 lb bags by the car load (hydrated)
Particle Size Range		about 1 micron
Typical Impurities	Sulfate Alkalies and Earths Aluminum Heavy Metals (as Pb)	Iron Chloride Ammonia Sulfate Iron Substances not precipitated by NH_4OH
Purity or Assay	99%	98+%
Specific Gravity		
Bulk Density (lb/ft ³)	60 - 62	180
Health Hazard.	Harmful if inhaled, ingested, or absorbed through the skin; lengthy exposure may result in irreversible damage.	Harmful; Avoid contact with the body; do not inhale vapors; may be irritating to the skin.
Fire Hazard	Not considered a fire hazard.	Not combustible.
Reaction Hazard	Stable under ordinary conditions of use and storage. Toxic fumes on decomposition.	Stable under ordinary conditions of use and storage.

Forms and Sources for Surrogate Formulations		
Property	Chemical or Material	
	1,2-Dichlorobenzene	Activated Carbon
Chemical Formula Trade Name	$C_6H_4Cl_2$ (o-dichlorobenzene)	Filtrisorb 300
Physical Form	liquid	powder
Suggested Vendors	Spectrum Chemical Mfg. Corp. (800-772-8786)	Calgon Carbon Corp. (412-787-6700)
1993 Market Price Reagent Grade	\$169.80/5 gal	
Bulk Grade		\$2/lb in 5 gal bucket or 55 lb bag
Particle Size Range	N.A.	4-100 Mesh; 10-74 microns
Typical Impurities		
Purity or Assay	98% min	
Specific Gravity	1.30	
Bulk Density (lb/ft ³)		20
Health Hazard	2 - May be harmful if inhaled. Aspiration hazard if ingested. For eye and skin contact, wash immediately and call physician.	1 - May be harmful by inhalation, ingestion, or skin adsorption.
Fire Hazard	2 - Combustible. Flash pt. 66°C (151°F)	1 - Flash pt. >300°F. Unusual fire and explosion hazard emits toxic fumes.
Reaction Hazard	0 - Stable under ordinary conditions of use and storage.	0 - Incompatibilities-strong oxidizing agents. Hazardous decomposition products.

Forms and Sources for Surrogate Formulations		
Property	Chemical or Material	
	Aluminum Oxide	Alumina Crucibles
Chemical Formula \Trade Name	Al ₂ O ₃ Alumina	Coors Metallurgical Crucibles
Physical Form	powder	
Suggested Vendors	Spectrum Chemical Mfg. Corp (800-772-8786)	Fisher Scientific (800-766-7000)
1993 Market Price Reagent Grade Practical Grade	100 lbs at \$6.85/lb 100 lbs at \$4.65/lb	\$18/each - 10 ml. size \$34/each - 100 ml. size
Particle Size Range		
Typical Impurities	Chloride iron sulfate	
Purity or Assay	99.0% min	
Specific Gravity		
Bulk Density (lb/ft³)	71	
Health Hazard	Low health risk by inhalation. Overexposure - possible lung injury.	1
Fire Hazard	Not combustible	0
Reaction Hazard	Stable under ordinary conditions of use and storage.	0

Forms and Sources for Surrogate Formulations		
Property	Chemical or Material	
	Cadmium II Chloride	Cadmium II Chloride Hydrate
Chemical Formula \Trade Name	CdCl₂	CdCl₂*2.5H₂O
Physical Form	granular or powder	powder
Suggested Vendors	Spectrum Chemical Mfg. Corp. (800-772-8786)	Spectrum Chemical Mfg Corp. (800-772-8786)
1993 Market Price Reagent Grade Bulk Grade	100 lbs at \$27.40/lb	100 lbs at \$24.80/lb
Particle Size Range		
Typical Impurities	Nitrate Sulfate Ammonium Copper Iron	Nitrate Sulfate Ammonium Copper Iron
	Lead Zinc	Lead Zinc
Purity or Assay	95% min	79.5-80.0% as CdCl₂
Specific Gravity		
Bulk Density (lb/ft³)	140	110
Health Hazard	Cancer hazard; ingestion may be fatal; skin irritant and may be harmful if absorbed.	Cancer hazard. Ingestion-toxic. Harmful if absorbed through skin. Eye irritant.
Fire Hazard	Not considered to be a fire or explosion hazard.	Not a fire or explosion hazard.
Reaction Hazard	Stable under ordinary conditions of use and storage.	Stable under ordinary conditions of use and storage. Hazardous decomposition products.

Forms and Sources for Surrogate Formulations		
Property	Chemical or Material	
	Calcium Carbonate	Calcium Chloride
Chemical Formula Trade Name	CaCO ₃	CaCl ₂
Physical Form	powder	granular, powder, flake, or pellet
Suggested Vendors	Spectrum Chemical Mfg. Corp. (800-772-8786)	Spectrum Chemical Mfg Corp. (800-772-8786)
1993 Market Price Reagent Grade	100 lbs at \$7.95/lb	100 lbs at \$2.25/lb
Bulk Grade	\$115-\$200 per ton-fine (0.5 um)	\$325-\$330 per ton per carload (94-97%, flake or pellet)
Particle Size Range		4 - 8 mesh
Typical Impurities	Arsenic Barium Heavy Metals (as Pb) Iron	Magnesium Mecury Magnesium and Alkali Salts (as SO ₄)
Purity or Assay	99.0% min	95-96%
Specific Gravity		
Bulk Density (lb/ft ³)	85	67
Health Hazard	0	Irritant on inhalation or skin contact. May be harmful if swallowed.
Fire Hazard	0	0 - Not considered to be a fire hazard.
Reaction Hazard	0	Stable under ordinary conditions of use and storage. Toxic fumes when heated to decomposition.

Forms and Sources for Surrogate Formulations		
Property	Chemical or Material	
	Calcium Sulfate	Cation Exchange Resin
Chemical Formula (Trade Name)	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ (Calcium Sulfate dihydrate) or Gypsum	Rexyn 101 (H) beads; Purolite C1000
Physical Form	Lump	beads
Suggested Vendors	Spectrum Chemical Mfg. Corp. (800-772-8786)	Fisher Scientific (800-766-7000) Reskem Co. (800-323-1983)
1993 Market Price Reagent Grade		\$34-\$64 per 500 g.
Technical Grade	\$94.25/25 lb	\$60 per ft ³
Particle Size Range		16-50 mesh
Typical Impurities	Carbonate Chloride Iron Magnesium Alkal Salts Heavy Metals (as Pb)	Research grade: Iron Nickel Copper Lead
Purity or Assay		
Specific Gravity		
Bulk Density (lb/ft³)	80	49
Health Hazard	No adverse health effects on ingestion, skin contact, or chronic exposure. Eye irritant. Nuisance dust.	!
Fire Hazard	Not a fire or explosion hazard.	0
Reaction Hazard	Stable under ordinary conditions of use and storage. Toxic decomposition products.	0 - Incompatible with strong reducing agents, NaOH.

Forms and Sources for Surrogate Formulations		
Property	Chemical or Material	
	Cerium III Chloride	Cerium Oxide
Chemical Formula Trade Name	CeCl ₃	CeO ₂ (Cerium (IV) Oxide)
Physical Form	powder	powder
Suggested Vendors	Great Western Inorganics, Inc. (303-423-9770)	Aldrich (800-558-9160)
1993 Market Price Reagent Grade		\$51.00 per 500 g.
Technical Grade	150 lbs at \$38.75/lb	
Particle Size Range		1 micron
Typical Impurities	La ₂ O ₃ Pr ₆ O ₁₁ Nd ₂ O ₃ Fe ₂ O ₃ CaO Na ₂ O	PbO MnO ₂ F SO ₄
Purity or Assay	96%	99.0%
Specific Gravity		
Bulk Density (lb/ft ³)		240
Health Hazard	Irritant, avoid contact with eyes, and skin; do not inhale. Moderately toxic by Ingestion.	May be harmful if inhaled, ingested or absorbed through skin. Irritant to eyes and skin.
Fire Hazard	Not considered a fire hazard.	Noncombustible. Toxic fumes under fire conditions.
Reaction Hazard		Incompatibilities-strong oxidizing agents. Hazardous decomposition products.

Forms and Sources for Surrogate Formulations		
Property	Chemical or Material	
	Cellulose	Cesium Chloride
Chemical Formula Trade Name	Cob Dry	CsCl
Physical Form	granules	powder
Suggested Vendors	Composition Materials Co. (800-262-7763)	CM Chemical Products, Inc. (908-665-8593)
1993 Market Price Reagent Grade		\$1563.75/50 lb drum
Bulk Grade	\$20 per 50 lb. bag (100 lb. min.)	
Particle Size Range	20 microns	
Typical Impurities		Aluminum Barium Calcium Chromium Copper Iron Strontium Lithium Magnesium Manganese Potassium Rubidium Sodium Zinc
Purity or Assay		99.5% min
Specific Gravity	0.50	
Bulk Density (lb/ft ³)		140
Health Hazard	1 - May be harmful if inhaled. May cause eye or skin irritation.	Inhalation or skin contact not expected to be health hazard. Large doses on ingestion may cause disturbances. Eye irritant.
Fire Hazard	1 - Capable of creating a dust explosion. Flash pt. 500°F.	Not considered to be a fire or explosion hazard.
Reaction Hazard	0	Stable under ordinary conditions of use and storage.

Forms and Sources for Surrogate Formulations		
Property	Chemical or Material	
	Chromium II Chloride	Chromium Oxide
Chemical Formula Trade Name	CrCl_2	Cr_2O_3
Physical Form	granular or powder	powder
Suggested Vendors	Great Western Inorganics Inc. (303-423-9770)	Aldrich (800-766-7000) Spectrum (800-772-8786)
1993 Market Price Reagent Grade	25 lbs at \$254.61/lb	\$168.25/5 lb
Bulk Grade		\$5.50 per lb. in 50 lb. bags by the carload (hydrated)
Particle Size Range		1 micron
Typical Impurities	Sulfate Alkalies and Earths Aluminum Heavy Metals (as Pb) Iron	Chloride Ammonia Sulfate Iron Substances not precipitated by NH_4OH
Purity or Assay	95+%	98+%
Specific Gravity		
Bulk Density (lb/ft³)	94	180
Health Hazard	Harmful if inhaled, ingested, or absorbed through the skin; lengthy exposure may result in irreversible damage.	Harmful; Avoid contact with the body; do not inhale vapors; may be irritating to the skin.
Fire Hazard	Not considered a fire hazard.	Not combustible.
Reaction Hazard	Stable under ordinary conditions of use and storage. Toxic fumes on decomposition.	Stable under ordinary conditions of use and storage.

Forms and Sources for Surrogate Formulations		
Property	Chemical or Material	
	Cloth	Coal Bottom Ash Cinders
Chemical Formula Trade Name	cotton	
Physical Form	fabric pieces	Particulate
Suggested Vendors	Kel-san Products Co. (615-525-7132)	
1993 Market Price Reagent Grade Bulk Grade	 \$94.50/50 lb box	
Particle Size Range	NA	
Typical Impurities	NA	
Purity or Assay	clean, washed	
Specific Gravity		0.64-0.72
Bulk Density (lb/ft³)	9.1	
Health Hazard		
Fire Hazard	Combustible.	0
Reaction Hazard	Stable under ordinary conditions of use and storage.	Stable under normal conditions of use and storage.

Forms and Sources for Surrogate Formulations		
Property	Chemical or Material	
	Concrete	Diatomaceous Earth
Chemical Formula Trade Name		Hyflo Super-Cel
Physical Form	granular or powder	Powder
Suggested Vendors	Local Contractor	Celite Corp. (805 735 7791)
1993 Market Price Reagent Grade Bulk Grade		\$25/50 lb bag
Particle Size Range	30 mesh or less	
Typical Impurities	NA	
Purity or Assay	NA	NA
Specific Gravity		0.2
Bulk Density (lb/ft³)	87	12.5
Health Hazard		4
Fire Hazard	Not combustible.	0
Reaction Hazard	Stable under ordinary conditions of use and storage.	0

Forms and Sources for Surrogate Formulations		
Property	Chemical or Material	
	Ethylene Glycol	Fly Ash
Chemical Formula Trade Name	$C_2H_6O_2$	(ASTM Class F)
Physical Form	liquid	powder
Suggested Vendors	Ashland Chemical Company (614-889-3333)	Local Utility Company
1993 Market Price Reagent Grade Bulk Grade	 \$0.76/lb in drums of 519 lbs	
Particle Size Range	NA	
Typical Impurities	Water	
Purity or Assay	99+%	
Specific Gravity	1.11-1.12	
Bulk Density (lb/ft ³)		60
Health Hazard	Dangerous. May be fatal if swallowed or harmful if inhaled. Affects central nervous system.	1
Fire Hazard	Slight to moderate fire hazard when exposed to heat or flame. Flash pt. 110°C (230°F).	0
Reaction Hazard	Stable under ordinary conditions of use and storage. Incompatible with strong oxidizing agents.	0

Forms and Sources for Surrogate Formulations		
Property	Chemical or Material	
	Glass Jars with lids	Glass, borosilicate
Chemical Formula Trade Name	(wide mouth, clear glass) Mason Jars	Spherglass 3000E
Physical Form	solid pieces	powder
Suggested Vendors	Local Supermarket	Potters Industries (201-299-2900)
1993 Market Price Reagent Grade Bulk Grade	\$8 /1 doz. (qt. size)	\$1.25/lb in 50 lb bags
Particle Size Range	NA	30 micron
Typical Impurities	NA	
Purity or Assay	NA	
Specific Gravity		2.3
Bulk Density (lb/ft³)	100 (Approximate)	80
Health Hazard	1	1
Fire Hazard	0	0
Reaction Hazard	0	0

Forms and Sources for Surrogate Formulations		
Property	Chemical or Material	
	Iron Oxide	Lead Shapes
Chemical Formula Trade Name	Fe ₂ O ₃ Ferric Oxide	Lead Shot
Physical Form	Red powder; anhydrous	pellets
Suggested Vendors	Spectrum Chemical Mfg. Corp. (800-772-8786)	Aldrich (800-558-9160)
1993 Market Price Reagent Grade Technical Grade	100 lbs at \$4.85/lb	\$44 per 2 kg.
Particle Size Range	1 micron or less	2 mm or less
Typical Impurities	Nitrate Phosphate Sulfate Arsenic Copper Manganese NH ₄ OH Zinc Substances not precipitated by H ₂ S	
Purity or Assay	99%	99.9%
Specific Gravity		
Bulk Density (lb/ft³)	180	380-390
Health Hazard	Avoid contact with the body including inhalation of vapors.	Ingestion is poisonous.
Fire Hazard	Not combustible.	Not considered to be a fire hazard. Flammable in dust form when exposed flame.
Reaction Hazard	Stable under ordinary conditions of use and storage.	Stable under ordinary conditions. Incompatibilities: NaN ₃ , Zr, disodium acetylide, oxidants.

Forms and Sources for Surrogate Formulations		
Property	Chemical or Material	
	Lead Chloride	Lead Oxide
Chemical Formula Trade Name	PbCl_2 (Lead (II) Chloride)	PbO Lead Oxide Yellow
Physical Form	granular or powder	powder
Suggested Vendors	Spectrum Chemical Mfg. Corp. (800-772-8786)	Spectrum Chemical Mfg. Corp.
1993 Market Price Reagent Grade Bulk Grade	110 lbs at \$14.95/lb	100 lbs at \$3.45/lb
Particle Size Range		
Typical Impurities	Chloride Copper Iron Insoluble Matter Substances not precipitated by H_2S	Chloride Copper Iron Nitrate Silver Substances not precipitated by H_2S Alkalies and Earths Bismuth
Purity or Assay	97% min	95%
Specific Gravity		
Bulk Density (lb/ft³)	200	300
Health Hazard	Harmful if ingested, inhaled, or absorbed through the skin. Lengthy exposure may result in irreversible damage.	Poisonous. May be fatal if swallowed; harmful if inhaled; neurotoxin. Avoid breathing dust. Irritant to skin and eyes.
Fire Hazard	Not combustible.	Not a fire or explosion hazard.
Reaction Hazard	Stable under ordinary conditions of use and storage. Hazardous decomposition products.	Stable under ordinary conditions of use and storage. Incompatible with certain chemicals.

Forms and Sources for Surrogate Formulations		
Property	Chemical or Material	
	Magnesium Sulfate Heptahydrate	Metal Cans, steel
Chemical Formula Trade Name	MgSO ₄ *7H ₂ O Epsom Salts	
Physical Form	granular or powder	solid pieces
Suggested Vendors	Spectrum Chemical Mfg. Corp. (800-772-8786)	House of Cans, Inc. (312-342-3600)
1993 Market Price Reagent Grade Bulk Grade	100 lbs at \$2.25/lb	 \$81.92/case of 64 (66 oz size)
Particle Size Range	NA	NA
Typical Impurities	Insoluble Matter Chloride Nitrate Ammonium Arsenic Calcium Iron Heavy Metals (as Pb) Potassium Sodium Strontium Manganese	
Purity or Assay	99+%	NA
Specific Gravity		
Bulk Density (lb/ft ³)	57	5.3
Health Hazard	Inhalation - dust may be an irritant. Ingestion may be harmful. Irritant to skin and eyes.	0
Fire Hazard	Not a fire or explosion hazard.	0
Reaction Hazard	Stable under ordinary conditions of use and storage. Hazardous decomposition products.	0

Forms and Sources for Surrogate Formulations		
Property	Chemical or Material	
	Mild Steel	Mineral Oil
Chemical Formula Trade Name	Carbon steel	
Physical Form	Granular	liquid, medium viscosity range
Suggested Vendors	Sandmasters (615-531-3890)	Spectrum Chemical Mfg. Corp. (800-772-8786)
1993 Market Price Reagent Grade Bulk Grade	 50 lb bags at \$0.53/lb	 \$128.50 per 5 gallon can \$735.00 per 55 gallon drum
Particle Size Range	0.6 - 1.0 mm	NA
Typical Impurities	NA	Readily carbonizable substances, polynuclear compounds, solid paraffin, sulfur compounds.
Purity or Assay	NA	NA
Specific Gravity		0.82 - 0.88
Bulk Density (lb/ft³)	270	
Health Hazard		Not thoroughly investigated. May be harmful by inhalation, ingestion or skin adsorption. May cause eye or skin irritation.
Fire Hazard	0	Combustible.
Reaction Hazard	Stable under ordinary conditions of use and storage. Incompatible with strong oxidizing agents.	Incompatible with strong oxidizing agents. Hazardous decomposition products.

Forms and Sources for Surrogate Formulations		
Property	Chemical or Material	
	Napthalene	Neoprene
Chemical Formula Trade Name	$C_{10}H_8$	$(C_2H_2Cl-C_2H_3)_n$
Physical Form	crystalline flakes	granular or powder
Suggested Vendors	Spectrum Chemical Mfg. Corp. (800-772-8786)	DuPont Chemical (800-441-7515)
1993 Market Price Reagent Grade Bulk Grade	 110 lbs at \$3.45/lb	 \$100 per 10 lbs.
Particle Size Range		
Typical Impurities		
Purity of Assay		
Specific Gravity		
Bulk Density (lb/ft ³)	34 (flakes)	49 (granules)
Health Hazard	Harmful if swallowed or inhaled, or absorbed through the skin. May cause eye or skin irritation.	1
Fire Hazard	Flash pt. - 174°F Autoignition temp. - 978°F	0
Reaction Hazard	Incompatible with oxidizing agents. Hazardous decomposition products-CO and CO ₂ .	0

Forms and Sources for Surrogate Formulations		
Property	Chemical or Material	
	Nickel II Chloride Hexahydrate	Nickel Oxide
Chemical Formula Trade Name	$\text{NiCl}_2 \cdot 6\text{H}_2\text{O}$	NiO
Physical Form	granules or flakes	powder
Suggested Vendors	Spectrum Chemical Mfg. Corp. (800-772-8786)	Spectrum Chemical Mfg. Corp. (800-772-8786)
1993 Market Price Reagent Grade Bulk Grade	110 lbs at \$8.75/lb	100 lbs at \$18.50/lb
Particle Size Range		approx. 5 microns
Typical Impurities	Chloride Cobalt Copper Insoluble matter Iron Lead	Sulfate Alkalies and Earth Zinc Substances not precipitated by $(\text{NH}_4)_2\text{S}$ Calcium Chloride Nitrogen compounds Sulfate Lead Copper
Purity or Assay	95% min	
Specific Gravity		
Bulk Density (lb/ft ³)	120	230
Health Hazard	Very toxic; very hazardous when breathed, swallowed or in contact with the skin; can lead to death.	Avoid contact with the body including inhalation of vapors; irritant.
Fire Hazard	0 - Not combustible, but is a strong oxidizer. Heat of rxn. with certain agents may cause ignition.	0
Reaction Hazard	0 - Stable under ordinary conditions.	0

Forms and Sources for Surrogate Formulations		
Property	Chemical or Material	
	Paper	Perlite
Chemical Formula Trade Name	Copier Paper	SiO ₂
Physical Form	solid - sheets	powder
Suggested Vendors	Local Office Supply	World Minerals Inc. (404-840-4500)
1993 Market Price Reagent Grade Bulk Grade	 \$36 to \$60/45 lbs	 No. 200 grade: \$12.20/35 lb bag \$5.30/35 lb bag per truck load
Particle Size Range	NA	
Typical Impurities	NA	NA
Purity or Assay		NA
Specific Gravity		
Bulk Density (lb/ft ³)	40 (in packages)	13
Health Hazard	0	May have irritating effect on skin, eyes, and respiratory organs. Avoid inhalation.
Fire Hazard	1 - Combustible. Flash pt. 500°F.	0
Reaction Hazard	0	Stable under ordinary conditions of use and storage.

Forms and Sources for Surrogate Formulations		
Property	Chemical or Material	
	Plaster of Paris	Polyethylene
Chemical Formula Trade Name	$\text{CaSO}_4 \cdot 0.5\text{H}_2\text{O}$ Calcium Sulfate, 1/2 hydrate	$(\text{CH}_2-\text{CH}_2)_n$
Physical Form	powder	beads
Suggested Vendors	Aldrich (800-558-9160) Spectrum (800-772-8786)	Dow Chemical Co. (800-441-4369)
1993 Market Price Reagent Grade	\$120 per 10 kg.	
Bulk Grade	\$75/25 lb (Technical Grade)	\$250 per 25 lb. bag (high density beads)
Particle Size Range	<44 microns	
Typical Impurities	Chloride Iron	
Purity or Assay	98%	
Specific Gravity		0.90
Bulk Density (lb/ft ³)	80	
Health Hazard		1 - Ingestion low toxicity. Skin contact and inhalation not very harmful. Solid or dust may cause eye irritation.
Fire Hazard	0	1 - Accumulation of fine dust particles could pose an explosion hazard. Flash pt. 930°F.
Reaction Hazard	0	0 - Avoid temp.>572°F - will release combustible gases. Hydralized by strong acids and bases.

Forms and Sources for Surrogate Formulations		
Property	Chemical or Material	
	Polyvinylchloride	Sodium Bicarbonate
Chemical Formula Trade Name	$(\text{CH}_2\text{-CHCl})_n$ PVC	NaHCO_3 (Sodium Hydrogen Carbonate)
Physical Form	Pellets or powder	granular or powder
Suggested Vendors	Aldrich (800-558-9160) DuPont Chemical (800-441-7515)	Spectrum Chemical Mfg. Corp. (800-772-8786)
1993 Market Price Reagent Grade	\$30 per kg.	110 lbs at \$1.85/lb
Bulk Grade	\$200 per 25 lb. bag	\$21 per 100 lbs. per truckload
Particle Size Range		
Typical Impurities		Insoluble matter Chloride Phosphate Sulfur compounds Ammonium Calcium and Magnesium precipitate Iron Potassium Heavy Metals (as Pb)
Purity or Assay		99.7% (Reagent Grade)
Specific Gravity		
Bulk Density (lb/ft ³)	85 - 90	74
Health Hazard	1 - High dust concentration may irritate eyes, nose, or skin.	No hazardous ingredients. Avoid unnecessary exposure. Inhalation or eye contact may cause mild irritation. Ingestion may cause gastrointestinal disturbances.
Fire Hazard	1 - Flash pt. 700°F. Avoid breathing vapors of combustion.	Not a fire or explosion hazard.
Reaction Hazard	0 - Stable. Avoid excessively high temperatures (250°F)	Stable under ordinary conditions. Incompatible with acids. Hazardous decomposition products.

Forms and Sources for Surrogate Formulations		
Property	Chemical or Material	
	Sodium Carbonate, anhydrous	Sodium Chloride
Chemical Formula Trade Name	Na_2CO_3	NaCl (Salt)
Physical Form	granular or powder	granular or powder
Suggested Vendors	Spectrum Chemical Mfg. Corp. (800-772-8786)	Spectrum Chemical Mfg. Corp. (800-772-8786)
1993 Market Price Reagent Grade	100 lbs \$2.95/lb	100 lbs at \$0.95 to \$1.48/lb
Bulk Grade		
Particle Size Range		
Typical Impurities	Chloride Nitrogen compounds (as N) Phosphate Silica Sulfate compounds (as SO_4) Ammonium Hydroxide	Arsenic Calcium and Magnesium precipitates Heavy Metals (as Pb) Iron Potassium Phosphate
		Insoluble matter Iodide Bromide Chlorate and Nitrate Nitrogen compounds (as N) Phosphate Sulfate
		Calcium and Magnesium precipitates Heavy metals (as Pb) Iron Potassium Barium
Purity or Assay	99+% min	99+%
Specific Gravity		
Bulk Density (lb/ft ³)	87	74
Health Hazard	Not thoroughly investigated. May be harmful on inhalation or ingestion, or cause skin irritation.	Irritant to eyes or on inhalation. Ingestion may be harmful in large doses.
Fire Hazard	Noncombustible.	Not a fire or explosion hazard.
Reaction Hazard	Incompatibilities: strong acids, aluminum. Hazardous decomposition products.	Stable under ordinary conditions. Incompatible with lithium or bromide trifluoride.

Forms and Sources for Surrogate Formulations		
Property	Chemical or Material	
	Sodium Nitrate	Sodium Phosphate dibasic, 7-hydrate
Chemical Formula Trade Name	NaNO_3	$\text{Na}_2\text{HPO}_4 \cdot 7\text{H}_2\text{O}$
Physical Form	granular or powder	granular or powder
Suggested Vendors	Ashland Chemical Company (614-889-3333)	Spectrum Chemical Mfg Corp. (800-772-8786)
1993 Market Price Reagent Grade Bulk Grade	 \$0.83/lb in 50 lb bags	 100 lbs at \$2.95/lb
Particle Size Range	1-2 mm (granules)	NA
Typical Impurities	Insoluble matter Chloride Sulfate Calcium, Magnesium, and R_2O_3 precipitate Potassium	Iodate Phosphate Heavy metals (as Pb) Iron
		Insoluble matter Chloride Sulfate Heavy Metals (as Pb) Iron
		Nitrogen compounds Arsenic
Purity or Assay	98.0% min	98.0% min
Specific Gravity		
Bulk Density (lb/ft ³)	78	58
Health Hazard	Harmful if swallowed. Irritant.	May have irritation effect on skin, eyes and respiratory organs.
Fire Hazard	Not combustible, but strong oxidizer. Heat of reaction with certain agents may cause ignition.	
Reaction Hazard	Stable under ordinary conditions of use and storage. Hazardous decomposition products.	

Forms and Sources for Surrogate Formulations		
Property	Chemical or Material	
	Sodium Phosphate tribasic	Sodium Sulfate (anhydrous)
Chemical Formula Trade Name	Na_3PO_4	Na_2SO_4
Physical Form	granular or powder	granular or powder
Suggested Vendors	Spectrum Chemical Mfg. Corp. (800-772-8786)	Spectrum Chemical Mfg. Corp. (800-772-8786)
1993 Market Price Reagent Grade		100 lbs at \$3.06/lb
Bulk Grade	\$94.50/25. lb (Technical)	
Particle Size Range		10-60 Mesh
Typical Impurities	Chloride Nitrogen Compounds (as N) Sulfate Arsenic Heavy Metals (as Pb)	Insoluble matter Chloride Phosphate Calcium, Magnesium, and R_2O_3 precipitate Nitrogen compounds (as N) Arsenic Heavy metals (as Pb) Iron
Purity or Assay		99%
Specific Gravity		
Bulk Density (lb/ft ³)	87	93
Health Hazard	Harmful if swallowed, inhaled, or absorbed through skin. Inhalation could be fatal.	Low to none. Ingestion may cause disturbances.
Fire Hazard	Noncombustible. Unusual fire or explosion hazards emit toxic fumes.	Not a fire or explosion hazard.
Reaction Hazard	Incompatibilities-strong acids. Protect from moisture. Hazardous decomposition products.	Stable under ordinary conditions of use and storage. Hazardous decomposition products.

Forms and Sources for Surrogate Formulations		
Property	Chemical or Material	
	Tetrachloroethylene	Toluene
Chemical Formula Trade Name	C_2Cl_4	$CH_3C_6H_5$
Physical Form	liquid	liquid
Suggested Vendors	Aldrich (800-336-9719) Fisher Scientific (800-766-7000)	Ashland Chemical Company (614-889-3333)
1993 Market Price Reagent Grade Bulk Grade	 \$63/4 liters; \$133.50/18 liters	 \$0.785/lb in 400 lb drums
Particle Size Range	NA	NA
Typical Impurities	Stabilizer (ethanol)	Water Sulfur compounds (as S) Iron Lead Nickel Copper
Purity or Assay	99%	99.8% min
Specific Gravity	1.62	0.86
Bulk Density (lb/ft ³)		
Health Hazard	Toxic when inhaled, swallowed or in contact with the skin; may have an irritating effect on skin, eyes and respiratory organs.	Harmful if swallowed or inhaled. Irritant to skin and eyes. May affect central nervous system, liver or kidneys.
Fire Hazard		Flammable. Flash pt. 4°C (400°F).
Reaction Hazard	Stable under ordinary conditions of storage.	Stable under ordinary conditions. Incompatible with strong oxidizers, acids nitric and sulfuric.

Forms and Sources for Surrogate Formulations		
Property	Chemical or Material	
	Vermiculite	Wood
Chemical Formula		
Physical Form	particulate	chips or pellets
Suggested Vendors	Strong-Lite Products Corp. (800-255-9057)	Composition Materials Co. (800-262-7763)
1993 Market Price	\$75 per 25 lb. bag	\$10 per 40 lb. bag (cube cut - 1/8"x3/16")
Reagent Grade		
Bulk Grade		
Particle Size Range		
Typical Impurities	NA	NA
Purity or Assay		
Specific Gravity		
Bulk Density (lbm³)	4.3	25
Health Hazard	2	1
Fire Hazard	0	1 - Combustible, Flash pt. 500°F.
Reaction Hazard	0	0

Forms and Sources for Surrogate Formulations		
Property	Chemical or Material	
	Rubber	
Chemical Formula \Trade Name	Natural Latex	
Physical Form	Rubber gloves	
Suggested Vendors	Baxter Scientific (800-234-5227)	
1993 Market Price Reagent Grade Bulk Grade	\$14-\$19 /12 ct. pkg.	
Particle Size Range	NA	
Typical Impurities	NA	
Purity	NA	
Specific Gravity		
Bulk Density (lb/ft³)	16	
Health Hazard	1	
Fire Hazard	0 (Normal storage conditions.)	
Reaction Hazard	0	

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