FINAL

BEST DEMONSTRATED AVAILABLE TECHNOLOGY (BDAT) BACKGROUND DOCUMENT FOR INORGANIC CHEMICAL PRODUCTION WASTES — K176, K177, K178

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EXECUTIVE SUMMARY

This background document provides EPA's rationale and technical support for developing Land Disposal Restriction (LDR) treatment standards for K176, K177, and K178. EPA is listing K176, K177, and K178 as hazardous wastes:

- K176: Baghouse filters from the production of antimony oxide, including filters from the production of intermediates (e.g., antimony metal or crude antimony oxide).
- K177: Slag from the production of antimony oxide that is speculatively accumulated or disposed, including slag from the production of intermediates (e.g., antimony metal or crude antimony oxide).
- K178: Residues from manufacturing and manufacturing-site storage of ferric chloride from acids formed during the production of titanium dioxide using the chloride-ilmenite process.

EPA is prohibiting the land disposal of both nonwastewater and wastewater forms of Hazardous Waste Nos. K176, K177, and K178 and promulgating LDR treatment standards for these wastes as proposed in September 2000.[1] Specifically, EPA is applying existing numerical Universal Treatment Standards found at 40 CFR 268.48 to certain constituents present in the wastes listed as K176, K177, and K178. One of the constituents proposed as a basis for listing K178, manganese, is not on the list of universal treatment standards; EPA is deferring final action on treatment standards for manganese in K178. EPA also proposed to add manganese to the UTS table (40 CFR 268.48) and to the constituents regulated by F039 (40 CFR 268.40). In the final rule, EPA is deferring final action on the application of the manganese treatment requirements to F039 leachate, and on the addition of manganese to the UTS. See section IV.b. of the preamble to the final rule for a discussion of EPA's decision to defer final action on manganese-related elements of the proposed rule.

For K178, EPA also extends the option of complying with the technology standard of combustion (CMBST) for the chlorinated dibenzo-p-dioxin and dibenzofuran (dioxins and furans).

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[1] Hazardous Waste Management System; Identification and Listing of Hazardous Waste; Inorganic Chemical Manufacturing Wastes; Land Disposal Restrictions for Newly Identified Wastes; and CERCLA Hazardous Substance Designation and Reportable Quantities; Proposed Rule. September 14, 2000.

Handlers that choose to use combustion to treat K178 wastes are not required to test for the dioxins and furans, but the waste must still comply with numerical standards for metals.

Characterization of Wastes

Information for this BDAT analysis was derived from answers received from a questionnaire under the authority of RCRA 3007 and record sampling. After collecting this information, EPA studied the specific characteristics of the waste and how these wastes will be categorized in LDR treatment standards.

K176 and K177 are both wastes from antimony oxide production. K176 represents baghouse filters and K177 represents slag. Both wastes will typically be designated as nonwastewaters due to their significant solids content. K178 is waste residues from titanium dioxide production, which would also be classified as a nonwastewater.

Development of BDAT Treatment Standards

In developing the LDR treatment standards finalized today, EPA adhered to the following methodology. EPA identified the constituents that would become the basis for listing for these wastes. Additionally, EPA used the record sampling data collected during the visits to some of the facilities. EPA compared these waste concentrations to previously investigated performance data for many of these constituents, obtained through its development of universal treatment standards (UTS) at 40 CFR 268.48 as well as its development of treatment standards for "U and P" listed wastes at 40 CFR 268.40.

For K176 and K177, EPA identified only metal constituents as hazardous constituents present in the waste. In K176, 14 metals from the UTS table at 40 CFR 268.48 were identified in the waste, five of which were found above the treatment levels: antimony, arsenic, cadmium, lead, and mercury. EPA selected treatment standards for these five constituents in K176 equivalent to the UTS levels. Fourteen metals were from the UTS table were also identified in K177, however only antimony and lead were above the UTS levels. In addition, arsenic was found at concentrations near its UTS.

Therefore, EPA selected treatment standards for these three constituents in K177 equivalent to the UTS levels.

For K178, dioxins, furans, organics, and metals were found in the waste stream. Of the metals on the UTS table, only thallium was found at concentrations above the treatment levels. Dioxin and furan congeners were also found in K178 above UTS limits and are included in the list of constituents with treatment standards.

Please see Table ES–1 for a full listing of the treatment standards in K176, K177, and K178.

All of the treatment standards for wastewater and nonwastewater forms of K176, K177, and K178 are consistent with the development of the UTS limits published in the Land Disposal Restrictions Phase II final rulemaking (September 19, 1994; 59 FR 47980), the LDR Phase IV rulemaking (May 28, 1998; 63 FR 28556), the chlorinated aliphatics production wastes rulemaking (November 8, 2000; 65 FR 67067 for certain dioxin and furan congeners), and their associated background documents. However, for the antimony constituent found in K176 and K177 wastes, EPA found that the technology used to develop the UTS standard (stabilization) was not necessarily demonstrated for the high concentration of antimony found in untreated K176 and K177. EPA received no public comments, however, to suggest that the antimony treatment standard for K176 and K177 could not be met using existing available technology.

Table ES–1. Summary of Treatment Standards for Constituents in Inorganic Chemicals Production Wastes K176, K177, and K178

Regulated Hazardous Constituent	CAS [1] Number	Wastewater Treatment Standard, Concentration in mg/L [2], or Technology Code [3]	Nonwastewater Treatment Standard
K176			
Antimony	7440-36-0	1.9	1.15 mg/L TCLP
Arsenic	7440-38-2	1.4	5.0 mg/L TCLP
Cadmium	7440-43-9	0.69	0.11 mg/L TCLP
Lead	7439-92-1	0.69	0.75 mg/L TCLP
Mercury	7439-97-6	0.15	0.025 mg/L TCLP
K177			
Antimony	7440-36-0	1.9	1.15 mg/L TCLP
Arsenic	7440-38-2	1.4	5.0 mg/L TCLP
Lead	7439-92-1	0.69	0.75 mg/L TCLP
K178 [5]			
1,2,3,4,6,7,8-Heptachlorodibenzo-*p*-dioxin	35822-39-4	0.000035 or CMBST[4]	0.0025 mg/kg or CMBST[4]
1,2,3,4,6,7,8-Heptachlorodibenzofuran	67562-39-4	0.000035 or CMBST[4]	0.0025 mg/kg or CMBST[4]
1,2,3,4,7,8,9- Heptachlorodibenzofuran	55673-89-7	0.000035 or CMBST[4]	0.0025 mg/kg or CMBST[4]
HxCDDs (All Hexachlorodibenzo-*p*-dioxins)	34465-46-8	0.000063 or CMBST[4]	0.001 mg/kg or CMBST[4]
HxCDFs (All Hexachlorodibenzofurans)	55684-94-1	0.000063 or CMBST[4]	0.001 mg/kg or CMBST[4]
1,2,3,4,6,7,8,9-Octachlorodibenzo-*p*-dioxin (OCDD)	3268-87-9	0.000063 or CMBST[4]	0.005 mg/kg or CMBST[4]
1,2,3,4,6,7,8,9-Octachlorodibenzofuran (OCDF)	39001-02-0	0.000063 or CMBST[4]	0.005 mg/kg or CMBST[4]
PeCDDs (All Pentachlorodibenzo-*p*-dioxins)	36088-22-9	0.000063 or CMBST[4]	0.001 mg/kg or CMBST[4]
PeCDFs (All Pentachlorodibenzofurans)	30402-15-4	0.000035 or CMBST[4]	0.001 mg/kg or CMBST[4]
TCDDs (All tetrachlorodi-benzo-*p*-dioxins)	41903-57-5	0.000063 or CMBST[4]	0.001 mg/kg or CMBST[4]
TCDFs (All tetrachlorodibenzofurans)	55722-27-5	0.000063 or CMBST[4]	0.001 mg/kg or CMBST[4]
Thallium	7440-28-0	1.4	0.20 mg/L TCLP

1 CAS means Chemical Abstract Services.

2 Concentration standards for wastewaters are expressed in mg/L and are based on analysis of composite samples.

3 All treatment standards expressed as a Technology Code or combination of Technology Codes are explained in detail in 40 CFR 268.42 Table 1-Technology Codes and Descriptions of Technology-Based Standards.

4 For these wastes, the definition of CMBST is limited to: (1) combustion units operating under 40 CFR 266, (2) combustion units permitted under 40 CFR Part 264, Subpart O, or (3) combustion units operating under 40 CFR 265, Subpart O, which have obtained a determination of equivalent treatment under 268.42(b).

5 EPA has decided to defer action in finalizing treatment standards for manganese at this time.

1.0 INTRODUCTION

RCRA Section 3004(m) specifies that treatment standards must minimize long- and short- term threats to human health and the environment arising from land disposal of hazardous wastes. EPA's general approach for complying with this requirement was promulgated as part of the November 7, 1986 Solvents and Dioxins rule. EPA has presented its guidance in establishing treatment standards in the Final Best Demonstrated Available Technology (BDAT) Background Document for Quality Assurance/Quality Control Procedures and Methodology, October 1991 (EPA, 1991).

EPA's treatment standards for individual wastes are presented at 40 CFR 268.40. For a given waste, a treatment standard specifies (1) the concentration of each constituent in total or TCLP analysis, or (2) a technology which must be used for treating the waste. EPA establishes treatment standards for wastewaters and nonwastewaters, as well as any subgroups which may be appropriate (e.g., "high mercury" or "low mercury" categories for D009 wastes). EPA has also established universal treatment standards for underlying hazardous constituents; these are listed at 40 CFR 268.48.

EPA finalized Land Disposal Restriction (LDR) treatment standards based on the Best Demonstrated Available Technology (BDAT) for the regulation of listed hazardous wastes identified in 40 CFR 261.32 as K176, K177, and K178. These BDAT treatment standards are in accordance with the amendments to the Resource Conservation and Recovery Act (RCRA) of 1976 enacted by the Hazardous and Solid Waste Amendments (HSWA) of November 8, 1984. HSWA amended RCRA to require EPA to promulgate treatment standards for a waste within 6 months after determining it is hazardous [Section 3004(g)(4)].

Compliance with the treatment standards is a prerequisite for land disposal, as defined in 40 CFR Part 268. In 40 CFR 268.44, EPA supplies provisions, that, if met, may justify granting a variance from the applicable treatment standards. In 40 CFR 268.6, EPA supplies provisions, that, if met, may justify granting waste- and site-specific waivers from the applicable treatment standards in 268.40.

The hazardous wastes K176, K177, and K178 are generated during production of inorganic chemicals. These hazardous wastes are defined as follows:

- K176 — Baghouse filters from the production of antimony oxide, including filters from the production of intermediates (e.g., antimony metal or crude antimony oxide).
- K177 — Slag from the production of antimony oxide that is speculatively accumulated or disposed, including slag from the production of intermediates (e.g., antimony metal or crude antimony oxide).
- K178 — Residues from manufacturing and manufacturing-site storage of ferric chloride from acids formed during the production of titanium dioxide using the chloride-ilmenite process.

This background document provides EPA's rationale and technical support for developing LDR treatment standards for hazardous wastes K176, K177, and K178.

1.1 Regulatory Background of Hazardous Wastes from Inorganic Chemicals Industry

Section 3001(e)(2) of RCRA requires EPA to determine whether to list as hazardous 'inorganic chemical industry wastes' (among other wastes unrelated to the inorganic chemical industry). In 1989, the Environmental Defense Fund (EDF) sued EPA (EDF v. Reilly, Civ. No. 89-0598 D.D.C.) in part for failing to meet these statutory deadlines. EPA and EDF entered into a consent decree, which has been amended several times to revise dates. The consent decree sets out a series of deadlines for promulgating RCRA listing decisions, including a requirement to propose a hazardous waste listing determination for inorganic chemical industry wastes. The wastes specified in the consent decree relevant to inorganic chemicals production are as follows:

- Sodium dichromate production wastes
- Wastes from the dry process for manufacturing phosphoric acid
- Phosphorous trichloride production wastes
- Phosphorous pentasulfide production wastes
- Wastes from the production of sodium phosphate from wet process phosphoric acid
- Sodium chlorate production wastes
- Antimony oxide production wastes
- Cadmium pigments production wastes
- Barium carbonate production wastes
- Potassium dichromate production wastes
- Phenyl mercuric acetate production wastes

- Boric acid production wastes
- Inorganic hydrogen cyanide production wastes
- Titanium dioxide production wastes (except for chloride process waste solids).

The consent decree stipulates that listing decisions are not required for wastes already excluded from hazardous waste regulation under RCRA Section 3001(b)(3)(A)(ii). This section of RCRA exempts solid waste from the extraction, beneficiation, and processing of ores and minerals, as further defined by EPA in 40 CFR 261.4(b)(7).

In the past, EPA promulgated listings for ten different wastes from the production of inorganic chemicals and inorganic pigments and established land disposal restrictions for these wastes. This background document does not concern such wastes.

EPA's investigation of the wastes generated by the inorganic chemical industry included two major information collection efforts: field investigations and survey evaluation. EPA's field investigations included engineering site visits, "familiarization sampling" (sample collection and analysis to gain a preliminary understanding of the nature and concentration of constituents in the wastes), and "record sampling" (sample collection and analysis to provide data to use in assessing the potential risks posed by the wastes). The survey effort included (1) the identification of facilities potentially generating the wastes, and (2) the development, distribution, and assessment of an extensive industry-wide RCRA Section 3007 survey. The bulk of the field investigation and survey evaluation were conducted in 1999.

1.2 Approach Used for BDAT Standard Development

The LDR program is designed to protect human health and the environment by prohibiting the land disposal of RCRA hazardous wastes unless specific treatment standards are met. In RCRA Section 3004(m), Congress directed EPA to: ". . . promulgate . . . levels or methods of treatment . . . which substantially diminish the toxicity of the waste or . . . the likelihood of migration of hazardous constituents . . . so that short-term and long-term threats to human health and the environment are minimized." Key provisions of the LDR program require that: (1) treatment standards are met prior to land disposal, (2) treatment is not evaded by long-term storage, (3) actual treatment occurs rather than dilution, (4) record keeping and tracking follow a waste from "cradle to grave" (i.e., generation to disposal), and (5) certification verifies that the specified treatment standards have been met.

In developing the LDR treatment standards for these wastes, EPA adhered to the following methodology. EPA first identified the hazardous constituents present in the wastes. In identifying hazardous constituents, EPA considered the constituents that comprise the basis of the listings and also identified the presence of those other constituents near or in excess of current numerical universal treatment standards. EPA previously investigated performance data for many of these constituents through its development of universal treatment standards (UTS) at 40 CFR 268.48. EPA then identified the Best Demonstrated Available Technology (BDAT) for the hazardous constituents present in the listed wastes.

A universal treatment standard is a single concentration limit established for a specific constituent regardless of the waste matrix in which it is present (i.e., the same treatment standard applies to a particular constituent in each waste code in which it is regulated). Universal treatment standards represent a significant improvement in the LDR program. In the past, different listed hazardous wastes may have had different concentration standards for the same constituent, which raised significant compliance problems when wastes with different standards for the same chemical were comanaged. With the universal treatment standards, the variability in constituent concentrations across listed hazardous waste treatment standards was eliminated. Now, when a mixture of listed hazardous wastes is treated, the constituents must be treated to the same constituent concentration standard regardless of the waste codes contained in the mixture.

EPA established two different sets of universal treatment standards: one for nonwastewater forms of waste and one for wastewater forms of waste. These two sets differ in the population of regulated constituents and the individual universal treatment standards. EPA initially developed universal treatment standards in 1994 for many inorganic and organic contaminants. Treatment standards for some of these metal contaminants were subsequently revised (based on additional data) as part of the Phase IV final rule (63 FR 28556, May 26, 1998).

1.3 Contents of This Document

Section 2.0 of this document describes the industry and processes generating Hazardous Waste Nos. K176, K177, and K178, the basis for listing these inorganic chemical production wastes as hazardous, and waste stream characteristics. Section 3.0 presents the constituents selected for treatment standard development for these wastes. Sections 4.0, 5.0, and 6.0 discuss development of the treatment standards for wastes K176, K177, and K178, respectively. Each section discusses the treatment technologies EPA has designated as "applicable" and "demonstrated" for the waste, identifies BDAT for wastewater and nonwastewater forms of these wastes, and presents the treatment standards. References are listed in Section 7.0. Appendix A presents additional discussion on treatment alternatives considered for K178.

2.0 DESCRIPTION OF LISTED INORGANIC CHEMICAL PRODUCTION WASTES

2.1 Overview of Activities

The inorganic chemical production industry is not a single industry sector, but a collection of dissimilar facilities producing a wide array of products. For the listing determination, EPA considered only those facilities producing the inorganic chemicals identified in the introduction (i.e., resulting from the 14 processes identified in the consent decree), which is a small subset of the many facilities comprising the 'inorganic chemicals' industry. A typical facility studied during the listing determination uses just one of the 14 processes identified in the consent decree and may also produce chemicals outside the scope of the consent decree.

Following evaluation of the data, EPA is listing three wastes generated from two of these sectors. Therefore, this section will only discuss wastes generated from the following two sectors:

- Antimony oxide production wastes (discussed in Section 2.2)
- Titanium dioxide production wastes (discussed in Section 2.3)

EPA is not listing any wastes from the remaining sectors identified in Section 1. They will not be discussed further in this report.

EPA's principal data sources in collecting information regarding the industry, their products and wastes, waste characteristics, and waste generation and management are as follows:

- A questionnaire developed under the authority of RCRA 3007 for distribution to the inorganic chemicals production industry (for those facilities producing the products described in the consent decree). EPA distributed the survey in Spring of 1999 to collect data characterizing operations in 1998.

- EPA conducted engineering site visits at some of these facilities (from zero to two facilities in each of the 14 sectors) to obtain more detailed information regarding waste generation and management. EPA also collected familiarization samples at some of these facilities to assess the effectiveness of the laboratory analytical methods for the consent decree wastes. None of the familiarization sampling data are presented in this report, for use either in treatment standard development or selecting constituents for regulation, because the purpose of the data was not intended to quantitatively characterize the wastes.

- EPA conducted record sampling activity at one to five facilities in each of five sectors, including antimony oxide production and titanium dioxide production. The record sampling results are the primary means EPA uses to evaluate the wastes for its listing determinations and for characterizing constituents for its development of land disposal restrictions.

In evaluating the wastes in Sections 2.2 and 2.3, analytical data relevant to the waste groupings used in the listing decision process are presented. The sample results are summarized according to the maximum concentrations found in a total analysis, TCLP analysis, and SPLP analysis. This refers to the highest detected level. If a constituent was not detected, then the highest detection limit is presented. Therefore, the highest result from a total analysis may not necessarily result from the same sample as the highest TCLP analysis.

2.2 Antimony Oxide Production Wastes

The most significant use of antimony oxide is as a flame retardant component in plastics, paints, textiles, and rubber (Kirk-Othmer, 1992). The U.S. antimony oxide production industry is comprised of four facilities. EPA evaluated the wastes generated and listed as hazardous two of the wastes: K176 (‘baghouse filters’) and K177 (‘slag’). The basis for listing these wastes relies on the hazardous nature of the constituents in these wastes and further evaluation of the current waste management practices. A short description of the processes generating the wastes is presented in Section 2.2.1. Management methods for these wastes are presented in Section 2.2.2. Waste characterization data are presented in Section 2.2.3.

2.2.1 Generation of Wastes from Antimony Oxide Production

Antimony oxide (Sb_2O_3) is a white solid and typically produced and sold in this form as a flame retardant. It is prepared using one of two techniques: the direct combustion of metallic antimony with oxygen, and the indirect process.

The direct method involves the roasting of antimony oxide or sulfide ore in the presence of air (or oxygen). The chemical reaction is as follows:

$$2Sb_2S_3 + 9O_2 \rightarrow 2Sb_2O_3 + 6SO_2$$

The antimony oxide is formed as a fume and cools and is condensed in a baghouse or similar dry collection device (Kirk-Othmer, 1992). Waste baghouse filters can be generated intermittently as part of maintenance requirements.

In the indirect process, antimony metal is first produced in a reduction process from slags, crude (low grade) antimony oxide, and similar feed material. The metal is volatilized and reacted with oxygen in the vapor phase to produce the product. The antimony oxide cools, condenses and is collected in a dry collection device such as baghouse filters. The reaction is as follows:

$$4Sb + 3O_2 \rightarrow 2Sb_2O_3.$$

2.2.2 Existing Waste Management Methods

The different management methods used for the two wastes are listed in Table 2–1. This information was gathered from the 1999 surveys, from visits conducted at the two facilities, and from telephone conversations with the additional facilities where record sampling was not conducted.

Table 2–1. Reported Management Methods for Antimony Oxide Production Wastes

Waste: Baghouse Filters (K176)
Off-site non-hazardous waste incineration
Subtitle D landfill
Offsite antimony recovery
Recycled (re-inserted) to on-site furnace for antimony recovery
Waste: Slag (K177)
Lead or antimony recovery
On-site drum storage accumulation prior to planned onsite land based storage

2.2.3 Waste Characterization

Data Collection

EPA collected record samples of baghouse filters at Laurel Industries (La Porte, TX) and U.S. Antimony (Thompson Falls, MT). Waste characterization data for baghouse filters (K176) are presented in Tables 2–2 and 2–3. Waste characterization data for slag (K177) are presented in Tables 2–4 and 2–5. These tables were constructed based on analysis of the following data:

- Laurel Industries, LaPorte, TX — EPA collected one record sample of baghouse filters (K176). EPA collected one sample of slag (K177), and a field duplicate.

- U.S. Antimony, Thompson Falls, MT — EPA collected two record samples of baghouse filters (K176). One of the filters was associated with the oxidation furnace and the other filter was associated with the reduction furnace. EPA collected three samples of reduction furnace slag. A sample of slag containing less than about five percent antimony (as categorized by the facility) was collected; a field duplicate of this sample; and a sample of slag containing between 5 and 10 percent antimony (as categorized by the facility).

All of the wastes were analyzed for the following constituents and properties:

- Metals. A total of 23 metals were analyzed, including all 14 metals on the list of universal treatment standards.
- Hexavalent chromium.
- pH.
- Percent solids.
- Specific gravity.
- Toxicity Characteristic Leaching Procedure (TCLP), Method 1311 analyses for metals.
- Synthetic Precipitation Leaching Procedure (SPLP), Method 1312 analyses for metals.

Waste characterization data for K176 and K177 are available only for metals. Therefore, complete characterization of all UTS constituents in this waste (i.e., organics) is not available. Based on the inorganic raw materials and the high temperatures of the waste generation process, however, no additional constituents are expected to be present above nonwastewater UTS.

The specific gravity of the baghouse filters ranged from 0.4 to 1.3 and the solids content ranged from 76 to 94 percent. The specific gravity of the slag ranged from 2.6 to 4.8; its solids content was close to 100 percent.

Data Evaluation

Because the wastes are solids, evaluation of each waste was conducted using the nonwastewater UTS values. Evaluation of the baghouse filters (K176) data in Table 2–2 shows the following:

- Arsenic and lead are present in the waste above their toxicity characteristic (TC) limit when analyzed using the TCLP. The TC limits for arsenic and lead are 5 mg/L.
- Antimony, arsenic, cadmium, lead, and mercury exceed their nonwastewater UTS. No other constituents were detected in TCLP analysis.

A detailed, site-by-site evaluation for the above metals in K176 at each of the two sites sampled are presented in Table 2–3 (i.e., Table 2–3 presents results for antimony, arsenic, cadmium, lead, and mercury at each site). Table 2–3 shows that each site generates waste which exceeds UTS for at least three metals.

Evaluation of the slag data (K177) in Table 2–4 shows the following:

- Lead is present in the waste above its toxicity characteristic (TC) limit when analyzed using the TCLP. The TC limit for lead is 5 mg/L.
- Antimony and lead exceed their nonwastewater UTS.
- The maximum TCLP concentrations for arsenic and vanadium are within ½ of their respective UTS values (i.e., the maximum TCLP concentration for arsenic is 3.1 mg/L TCLP compared to its UTS of 5.0 mg/L TCLP; the maximum TCLP concentration for vanadium is 1.4 mg/L TCLP compared to its UTS of 1.6 mg/L TCLP). All other constituents were well below their UTS or were not detected in TCLP analysis.

A detailed, site-by-site evaluation for the above metals in K177 is presented in Table 2–5. This table shows that both facilities generate waste with high levels of antimony (such that they exceed UTS), but only one of the facilities generates waste with lead levels above UTS.

All data in Tables 2–2 to 2–5 are presented as wet weight. Because wet and dry weight designations affect only total concentrations, and the nonwastewater UTS for metals are expressed as mg/L TCLP, the presentation of data on a wet or dry basis is not significant for evaluating LDR treatment standards for these wastes.

Table 2–2. EPA Record Sampling Results for K176

Constituent	UTS WW (mg/L)	UTS NWW (mg/L TCLP)	Maximum Concentration (mg/kg Total)	Maximum Concentration (mg/L TCLP)	Maximum Concentration (mg/L SPLP)
Constituents with UTS					
Antimony	1.9	1.15	150,000	68.7	287
Arsenic	1.4	5.0	114	6.9	6.87
Barium	1.2	21	<250	<2	<2
Beryllium	0.82	1.22	<100	<0.02	<0.02
Cadmium	0.69	0.11	411	0.3	0.87
Chromium	2.77	0.60	<250	<0.05	<0.05
Chromium $^{6+}$	—	—	<0.02	0.2	<0.02
Lead	0.69	0.75	3.1 [A]	8.5 [A]	16.9 [A]
Mercury	0.15	0.025	95.2	0.026	0.37
Nickel	3.98	11	<250	<0.2	0.0114
Selenium	0.82	5.7	1.3	<0.5	0.144
Silver	0.43	0.14	61	<0.1	0.077
Thallium	1.4	0.20	<1000	<2	0.097
Vanadium	4.3	1.6	0.5	<0.05	<0.05
Zinc	2.61	4.3	3,440	<2	0.624
Constituents without UTS					
Boron	—	—	24	6.5	1.01
Calcium	—	—	6,880	<2	2.21
Cobalt	—	—	0.8	<0.05	<0.05
Copper	—	—	270	<0.25	0.194
Iron	—	—	11.6	<1	0.081
Manganese	—	—	2.9	0.06	0.025
Potassium	—	—	216	<10	5.1

Constituent	UTS WW (mg/L)	UTS NWW (mg/L TCLP)	Maximum Concentration (mg/kg Total)	Maximum Concentration (mg/L TCLP)	Maximum Concentration (mg/L SPLP)
Sodium	—	—	7,110	NA	244
Titanium	—	—	<250	<0.05	<0.05

Maximum of samples from Laurel Industries La Porte, TX (L1-1-AO-03) and U.S. Antimony Thompson Falls, MT (AC-1-AO-03 and AC-1-AO-07).

The sample results in this table are summarized according to the maximum concentrations found in a total analysis, TCLP analysis, and SPLP analysis. When possible, the highest detected level is shown. If a constituent was not detected in any samples, then the highest detection limit is presented. Therefore, the highest result from a total analysis may not necessarily result from the same sample as the highest TCLP analysis.

A. As shown in Table 2–3, these data points are all from a single site and is how the data were reported by the laboratory.

NA: Not analyzed.

Shading indicates the TCLP concentration exceeds nonwastewater UTS.

Table 2–3. Characterization Data for Metals Exceeding UTS in K176

Constituent	UTS WW (mg/L)	UTS NWW (mg/L TCLP)	Maximum Concentration (mg/kg Total)	Maximum Concentration (mg/L TCLP)	Maximum Concentration (mg/L SPLP)
Facility: U.S. Antimony. Maximum of two samples					
Antimony	1.9	1.15	150,000	68.7	287
Arsenic	1.4	5.0	<250	6.9	6.87
Cadmium	0.69	0.11	411	0.3	0.87
Lead	0.69	0.75	<2500	2.8	0.98
Mercury	0.15	0.025	95.2	0.026	0.37
Facility: Laurel Industries. Single sample					
Antimony	1.9	1.15	91,400	9.3	6.24
Arsenic	1.4	5.0	114	<0.5	0.58
Cadmium	0.69	0.11	5.3	0.3	0.47
Lead	0.69	0.75	3.1 [A]	8.5 [A]	16.9 [A]
Mercury	0.15	0.025	0.9	<0.002	0.0011

Samples from Laurel Industries La Porte, TX (L1-1-AO-03) and U.S. Antimony Thompson Falls, MT (AC-1-AO-03 and AC-1-AO-07).

Shading indicates the TCLP concentration exceeds UTS.

A. The data were reported by the laboratory in this manner, without qualification.

Table 2–4. EPA Record Sampling Results for K177

Constituent	UTS WW (mg/L)	UTS NWW (mg/L TCLP)	Maximum Concentration (mg/kg Total)	Maximum Concentration (mg/L TCLP)	Maximum Concentration (mg/L SPLP)
Constituents with UTS					
Antimony	1.9	1.15	127,000	110	211
Arsenic	1.4	5.0	478	3.1	3.8
Barium	1.2	21	311	<2	0.14
Beryllium	0.82	1.22	0.6	<0.02	0.0034
Cadmium	0.69	0.11	15.7	<0.05	<0.005
Chromium	2.77	0.60	37.2	<0.05	<0.005
Chromium $^{6+}$	—	—	<0.02	0.04	<0.5
Lead	0.69	0.75	39,500	22.3	2.36
Mercury	0.15	0.025	<0.1	<0.002	0.0003
Nickel	3.98	11	488	0.5	0.027
Selenium	0.82	5.7	<250	0.8	0.55
Silver	0.43	0.14	465	<0.1	0.025
Thallium	1.4	0.20	3.8	<2	<0.005
Vanadium	4.3	1.6	10.8	1.4	1.2
Zinc	2.61	4.3	1,780	<3	0.056
Constituents without UTS					
Boron	—	—	184	15.1	9.7
Calcium	—	—	9,000	20.1	4.5
Cobalt	—	—	55	<0.05	0.0072
Copper	—	—	4,610	6.3	0.29
Iron	—	—	14,800	8.8	2.9
Manganese	—	—	572	0.1	0.030
Potassium	—	—	2,310	90.5	87.6
Sodium	—	—	329,000	NA	13,800
Titanium	—	—	2,650	0.2	0.0063

Maximum of samples from Laurel Industries La Porte, TX (L1-1-AO-01 and L1-1-AO-07) and U.S. Antimony Thompson Falls, MT (AC-1-AO-01, AC-1-AO-05, and AC-1-AO-06).

The sample results in this table are summarized according to the maximum concentrations found in a total analysis, TCLP analysis, and SPLP analysis. When possible, the highest detected level is shown. If a constituent was not detected in any samples, then the highest detection limit is presented. Therefore, the highest result from a total analysis may not necessarily result from the same sample as the highest TCLP analysis.

NA: Not analyzed.

Shading indicates the TCLP concentration exceeds nonwastewater UTS.

Table 2–5. Characterization Data for Metals Exceeding UTS (or Comparable to UTS) for K177

Constituent	UTS WW (mg/L)	UTS NWW (mg/L TCLP)	Maximum Concentration (mg/kg Total)	Maximum Concentration (mg/L TCLP)	Maximum Concentration (mg/L SPLP)
Facility: U.S. Antimony. Maximum of two samples of 'low antimony' (<5 %) slag					
Antimony	1.9	1.15	19,600	88.4	114
Arsenic	1.4	5.0	349	2.3	2.93
Lead	0.69	0.75	219	<0.5	<0.005
Vanadium	4.3	1.6	<50	1.4	1.2
Facility: U.S. Antimony. Single record sample of 'mid-antimony' (5-10 %) slag					
Antimony	1.9	1.15	127,000	110	211
Arsenic	1.4	5.0	478	3.1	3.8
Lead	0.69	0.75	491	<0.5	<0.005
Vanadium	4.3	1.6	<250	0.6	1.0
Facility: Laurel Industries. Maximum of two samples					
Antimony	1.9	1.15	87,200	28.1	26.5
Arsenic	1.4	5.0	74.3	<0.5	0.028
Lead	0.69	0.75	39,500	22.3	2.36
Vanadium	4.3	1.6	10.8	<0.05	0.056

Samples from Laurel Industries La Porte, TX (L1-1-AO-01 and L1-1-AO-07) and U.S. Antimony Thompson Falls, MT (AC-1-AO-01 and AC-1-AO-05 representing 'slag with <5% antimony,' and AC-1-AO-06 representing 'slag with 5-10% antimony').
Shading indicates the TCLP concentration exceeds nonwastewater UTS.

2.3 Titanium Dioxide Production Wastes

EPA analyzed data collected from titanium dioxide production facilities providing responses to RCRA 3007 surveys and evaluated data from five such facilities where record sampling was conducted. EPA listed as hazardous one waste: Residues from manufacturing of ferric chloride from acids formed during the production of titanium dioxide using the chloride-ilmenite process (K178).

A short description of the process generating the listed waste is presented in Section 2.3.1. Waste characterization data are presented in Section 2.3.2.

2.3.1 Generation of Wastes from Titanium Dioxide Production

Titanium dioxide (TiO_2) is a bright-white powder used predominately as a pigment for paints, rubber, paper, and plastics. Titanium dioxide is manufactured through either the sulfate, chloride, or chloride-ilmenite process. Only one facility (the Edgemoor Delaware facility of E.I. DuPont de Nemours and Company (DuPont)) using the chloride-ilmenite process generates K178.

The chloride-ilmenite process utilizes several steps to convert a low-grade ilmenite to TiO_2. First, the ilmenite ore is reacted with chlorine in the presence of coke as a reducing agent; the chlorine reacts with the iron oxide and other metals in the ilmenite ore to produce gaseous metal chloride intermediates. The gas, comprised of $TiCl_4$ and other volatile metal compounds, is purified to remove ore/coke solids, ferric chloride acid, and vanadium impurities. The purified titanium tetrachloride is oxidized to form titanium dioxide, for sale as a dry solid or water-based slurry.

At the Delaware facility, ferric chloride acid is sold as a byproduct. Prior to sales, the facility adds chlorine to the acid stream, filters the acid to remove solids, and stores the ferric chloride acid in a surface impoundment. The generated solids are discharged to the facility's wastewater treatment plant. Additionally, the titanium dioxide production process generates various other wastewaters and wastestreams which are managed at the wastewater treatment plant. Sludge generated from the treatment plant would be classified as K178 based on the facility's current process configuration.

2.3.2 Waste Characterization

Data Collection

EPA collected one record sample from the Edgemoor facility to characterize the wastewater treatment plant solids (which contain residues from the manufacture of ferric chloride). EPA's record sample was analyzed for the following constituents and properties:

- Metals. A total of 27 metals were analyzed, including all 14 metals on the list of universal treatment standards.
- Hexavalent chromium.
- pH.
- Percent solids.
- Specific gravity.
- Toxicity Characteristic Leaching Procedure (TCLP), SW-846 Method 1311 analyses for metals.
- Synthetic Precipitation Leaching Procedure (SPLP), SW-846 Method 1312 analyses for metals.
- Dioxins/Furans, Method 1613B. Total and SPLP analysis.
- Semivolatile organic compounds.

Data for most underlying hazardous constituents were available. Tables 2–6 to 2–8 summarize the EPA record sampling data.

Data Evaluation

Metals data are presented in Table 2–6. As shown, thallium exceeds UTS in the Edgemoor sample. Table 2–7 summarizes the available organics data (for non-dioxin and furan constituents). Almost all organic analytes were reported as not detected; the remaining were detected at levels below nonwastewater UTS.

Table 2–8 shows that one dioxin/furan congener exceeds UTS at the Edgemoor facility. Comparisons are made on a dry basis to address commenter concerns from the chlorinated aliphatics proposed rule that comparisons between waste concentrations and UTS be shown on a dry basis.

Table 2–6. Record Sampling Data for K178: Metals

Constituent	UTS WW (mg/L)	UTS NWW (mg/L TCLP)	Concentration (mg/kg Total)	Concentration (mg/L TCLP)	Concentration (mg/L SPLP)
Constituents with UTS					
Antimony	1.9	1.15	0.9	<0.021	0.02
Arsenic	1.4	5.0	2.2	<0.0035	0.001
Barium	1.2	21	178	2.4	0.92
Beryllium	0.82	1.22	1.2	<0.00024	<0.002

Table 2–6. Record Sampling Data for K178: Metals

Constituent	UTS WW (mg/L)	UTS NWW (mg/L TCLP)	Concentration (mg/kg Total)	Concentration (mg/L TCLP)	Concentration (mg/L SPLP)
Cadmium	0.69	0.11	0.6	<0.0013	<0.005
Chromium	2.77	0.60	777	<0.05	0.002
Chromium $^{6+}$	—	—	<0.40	Not Analyzed	<0.02
Lead	0.69	0.75	309	0.03	0.003
Mercury	0.15	0.025	<0.1	<0.002	<0.0002
Nickel	3.98	11	91.8	0.5	<0.005
Selenium	0.82	5.7	<0.5	<0.5	<0.005
Silver	0.43	0.14	<0.1	<0.1	<0.001
Thallium	1.4	0.20	3.7	0.28	0.012
Vanadium	4.3	1.6	240	0.0003	<0.005
Zinc	2.61	4.3	122	1.1	0.03
Constituents without UTS					
Aluminum	—	—	10,100	<1	<0.1
Boron	—	—	30.0	1.7	0.61
Calcium	—	—	28,500	1,330	1,230
Cobalt	—	—	44.5	0.43	<0.005
Copper	—	—	28.5	0.014	0.003
Iron	—	—	91,600	348	0.18
Magnesium	—	—	3,140	61.3	33.4
Manganese	—	—	10,600	252	16.3
Molybdenum	—	—	7.4	0.026	0.005
Tin	—	—	53.2	0.025	<0.01
Titanium	—	—	6,380	<0.05	<0.005

EPA record sample DPE-SO-01 from DuPont (Edgemoor, DE).
Source: EPA, Titanium Dioxide Listing Background Document for the Inorganic Chemical Listing Determination. August 2000.
Shading indicates the TCLP concentration exceeds nonwastewater UTS.

Table 2–7. Organics Data (non-Dioxin/Furan) Available for K178

Data Source	Organic Analyses Conducted	Analyte	Result	Nonwastewater UTS
DPE-SO-01 EPA record sample: Edgemoor Iron-Rich	EPA SW-846 Method 8270C semivolatiles, total	Hexachlorobenzene	1.7 mg/kg	10 mg/kg
		Hexachlorobutadiene	0.53 mg/kg (J)	5.6 mg/kg

All constituents are reported on a wet basis. The solids content of the Edgemoor sample is 42 percent. Even if the above data were expressed on a dry basis (i.e., dry concentrations 2 to 3 times greater than wet concentrations in this case), none of the constituents would exceed UTS.
(J) Concentration estimated.

Table 2–8. Record Sampling Data for K178: Dioxins and Furans

Constituent	UTS WW (ng/L)	UTS NWW (ng/kg)	Maximum Concentration, Dry Basis	
			(ng/kg Total)	(ng/L SPLP)
Total Tetra CDDs	63	1,000	<0.95	<0.010
Total Tetra CDFs	63	1,000	211	<0.010
Total Penta CDDs	63	1,000	<4.3	<0.051
Total Penta CDFs	35	1,000	336	<0.051
Total Hexa CDDs	63	1,000	<4.3	<0.051
Total Hexa CDFs	63	1,000	688	<0.051
1,2,3,4,6,7,8-Hepta CDD	35	2,500	<4.3	<0.051
1,2,3,4,6,7,8-Hepta CDF	35	2,500	450	<0.051
1,2,3,4,7,8,9-Hepta CDF	35	2,500	300	<0.051
Octa CDD	63	5,000	53	<0.100
Octa CDF	63	5,000	58,100	<0.100

Sample DPE-SO-01 from DuPont (Edgemoor, DE). Dry basis. EPA data were converted from wet basis by dividing by the percent solids (42 percent).
Shading indicates the total concentration exceeds nonwastewater UTS.

3.0 SELECTION OF CONSTITUENTS FOR REGULATION

This section presents the methodology and rationale for selecting constituents for regulation in nonwastewater and wastewater forms of K176, K177, and K178. EPA has identified certain constituents for regulation in 40 CFR 268.40 for these wastes; establishing treatment standards for these particular constituents will best ensure that risks from these wastes are minimized, as required by RCRA Section 3004(m). Constituents were selected for regulation because they are present in the wastes at high levels, relative to either of the following: (1) concentrations which would cause the waste to exhibit risks exceeding EPA risk criteria (i.e., they are present as the basis for listing), or (2) they are underlying hazardous constituents[2] in concentrations above those known to be achievable by available, well-operated technologies for reducing the toxicity of the waste (i.e., they are present in the wastes above UTS). While many other constituents may be present in the wastes, EPA did not develop treatment standards due to the following reasons:

- They are expected to be present in the wastes at levels below those anticipated to be achievable in a well-designed and applicable waste treatment unit. Development of numerical treatment standards for such constituents would not result in reduced toxicity of the waste, because the waste would likely meet the treatment standards even without waste treatment.

- They are expected to be treated concurrently with other constituents. It is common for a single treatment technology to reduce the toxicity or mobility of many constituents. Therefore, treatment standards promulgated for a small number of constituents would necessarily result in the waste being effectively treated for other constituents not targeted for regulation.

This section identifies those constituents in K176, K177, and K178 wastes for which treatment standards are being developed. Sections 4, 5, and 6 (respectively) of this report describe applicable and demonstrated technologies for effectively treating wastes for such constituents, and develops appropriate numerical or technology-specific treatment standards for each of the wastes.

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[2] In 40 CFR 268.2(i), EPA defines an underlying hazardous constituent as “any constituent listed in 40 CFR 268.48, Table UTS-Universal Treatment Standards, except fluoride, selenium, sulfides, vanadium, and zinc, which can reasonably be expected to be present at the point of generation of the hazardous waste, at a concentration above the constituent-specific UTS treatment standards.”

Table 3–1 identifies constituents evaluated in this Section, for which treatment standards are being finalized for K176, K177, and K78. The reasons for their selection are presented in Sections 3.1 and 3.2.

3.1 Constituents Identified as the Bases for Listing

EPA selected K176 for regulation because these wastes routinely exhibit one or more of the characteristics of hazardous waste for arsenic and lead. EPA selected K177 and K178 for regulation because, in its risk assessment, EPA found that certain constituents pose unacceptable risks to human health and the environment. The following constituents are included as the basis for listing these wastes (i.e., included in 40 CFR Part 261 Appendix VII):

- K176: exhibits a hazardous waste characteristic (i.e., toxicity characteristic (TC) for arsenic and/or lead).
- K177: constituent identified as a basis for listing is antimony.
- K178: constituent identified as basis for listing is thallium.

EPA is finalizing treatment standards for each of these constituents in the respective wastes equivalent to UTS.

3.2 Other Constituents Present in Wastes

EPA identified other underlying hazardous constituents in the wastes and identified those present at levels higher than (or comparable to) universal treatment standards. As discussed in Section 1, universal treatment standards were developed from waste treatment data representing BDAT. Therefore, wastes with high concentrations (relative to UTS) of hazardous constituents should be capable of being treated to lower contaminant levels. The results of this analysis are as follows:

- For K176, waste concentrations of the following constituents exceed nonwastewater UTS: antimony, arsenic, cadmium, lead, and mercury. All are underlying hazardous constituents as defined in 40 CFR 268.2(i). EPA is finalizing numerical treatment standards for each of these constituents.
- For K177, waste concentrations of antimony and lead exceed nonwastewater UTS. Concentrations of arsenic and vanadium are within ½ of their UTS. EPA is finalizing

treatment standards for antimony, lead, and arsenic because the three constituents are underlying hazardous constituents as defined in 40 CFR 268.2(i).

Although concentrations of vanadium are also within ½ of its UTS value, vanadium is not an underlying hazardous constituents as defined in 40 CFR 268.2(i). For this reason EPA's treatment standards for K177 do not include vanadium.

- For K178, waste concentrations of octachlorodibenzofuran exceed nonwastewater UTS standards. EPA is finalizing numerical treatment standards for all dioxin and furan congeners (i.e., tetra through octa) for which UTS are currently promulgated.

  EPA is finalizing numerical treatment standards for thallium because it is the basis for listing K178 and reduction of its mobility is required to meet RCRA Section 3004(m)(1). Thallium is also present above its UTS.

Table 3–1. Constituents in K176, K177, and K178 Evaluated for Treatment Standards

Waste and Typical Form	Constituent	Maximum Waste Concentration	UTS for Form of Waste	Comment
K176 baghouse filters (nonwastewater)	antimony	68.7 mg/L TCLP	1.15 mg/L TCLP	constituent is a UHC that exceeds UTS
	arsenic	6.9 mg/L TCLP	5.0 mg/L TCLP	constituent is a UHC that exceeds UTS
	cadmium	0.3 mg/L TCLP	0.11 mg/L TCLP	constituent is a UHC that exceeds UTS
	lead	8.5 mg/L TCLP	0.75 mg/L TCLP	constituent is a UHC that exceeds UTS
	mercury	0.026 mg/L TCLP [A]	0.025 mg/L TCLP	constituent is a UHC that exceeds UTS
K177 slag (nonwastewater)	antimony	110 mg/L TCLP	1.15 mg/L TCLP	constituent is a basis for listing and is a UHC that exceeds UTS
	arsenic	3.1 mg/L TCLP	5.0 mg/L TCLP	constituent is a UHC that approaches UTS
	lead	22.3 mg/L TCLP	0.75 mg/L TCLP	constituent is a UHC that exceeds UTS
K178 Titanium dioxide residues (nonwastewater)	manganese	252 mg/L TCLP	—	constituent was proposed as basis for listing; it is not a UHC. EPA is deferring action in finalizing treatment standards for manganese.
	thallium	0.28 mg/L TCLP	0.20 mg/L TCLP	constituent is a basis for listing and is a UHC that exceeds UTS
	dioxins and furans	UTS is exceeded for octachlorodibenzofuran.		This congener is a UHC that exceeds UTS. Treatment standards were promulgated for all dioxin congeners because dioxins and furans are frequently found together.[B]

A. This waste has less than 260 mg/kg total mercury and would meet the 'low mercury' subcategory.
B. As discussed in Section 6, an alternative technology-specific treatment standard of combustion also is being promulgated for this waste.

4.0 TREATMENT STANDARD DEVELOPMENT FOR K176

EPA is required to set as treatment standards "... levels or methods of treatment, if any, which substantially diminish the toxicity of the waste or substantially reduce the likelihood of migration of hazardous constituents from the waste so that short-term and long-term threats to human health and the environment are minimized." [RCRA Section 3004(m)(1)]. The constituents identified by EPA as present in K176 wastes and requiring toxicity reduction were identified in Section 3.

To meet the requirements of the statute, EPA can set either technology-specific or numerical treatment standards. This section develops the treatment standards for these constituents in wastewater and nonwastewater forms of K176 to best meet the requirements of RCRA Section 3004(m). The section is organized in the following manner:

- Section 4.1 summarizes the results of Section 3 and provides an overview of the treatment needs of the waste.
- Section 4.2 discusses wastewater forms of K176. Specifically, technologies applicable for treating the constituents identified in the waste are discussed in Section 4.2.1. The technology or technologies identified as BDAT, and the treatment standards, are then presented in Section 4.2.2.
- Section 4.3 discusses nonwastewater forms of K176. The format of the discussion is similar to that for wastewater forms of K176.

<u>4.1 Summary of Constituents Selected for Regulation</u>

As presented in Section 3, the following constituents were identified for treatment standards in K176 wastes:

- Antimony
- Arsenic
- Cadmium
- Lead
- Mercury.

This section identifies technologies appropriate for reducing the toxicity of these metal contaminants in K176 wastes.

4.2 Wastewater Forms of K176

As discussed in Section 2, the K176 waste, baghouse filters, is a cloth (solid) material with inorganic contaminants. The technologies listed here are expected to be applicable to wastewater forms of K176, in the event that such wastes are generated.

4.2.1 Applicable and Demonstrated Technologies for Treating Metals

To be applicable, a technology must theoretically be usable to treat the waste in question or a waste that is similar, in terms of parameters that affect treatment selection (EPA, 1994b). Applicable technologies for treating metals are those that remove, or transfer, metals from the wastewater to a nonwastewater media, such as a sludge. The technologies listed in this section are applicable and have been demonstrated to treat metal constituents in wastewater forms of other hazardous wastes. EPA (1994b) presents a thorough discussion of these technologies. The technologies applicable to wastewater forms of K176 include:

- Biological treatment (including activated sludge, aerobic lagoon, rotating biological contactor, and trickling filter technologies)
- Chemically assisted clarification treatment (including chemical precipitation technology)
- Chemical oxidation
- PACT® treatment
- Chemical reduction treatment (including chemical reduction or precipitation followed by sedimentation and filtration technologies)
- Electrochemical treatment
- Lime, sedimentation, and filtration treatment.

Biological Treatment

Biological treatment is a destruction technology that biodegrades hazardous organic constituents in wastewaters. This technology is applicable to wastewaters that contain metals in low concentrations, where the contaminant becomes bound in the biosludge. This technology generates two treatment residuals: a treated effluent and a waste biosludge.

Chemically Assisted Clarification Treatment

Chemically assisted clarification, including chemical precipitation, is a separation technology that removes organic and inorganic constituents from wastewater by the addition of chemicals that cause the formation of precipitates. The solids formed are then separated from the wastewater by settling, clarification, and/or polishing filtration. This technology generates two treatment residuals: treated wastewater effluent and separated solid precipitate.

Chemical Oxidation

Chemical oxidation is a destruction technology that oxidizes inorganic cyanide, some dissolved organic compounds, and sulfides to yield carbon dioxide, water, salts, simple organic acids, and sulfates. This technology generates one treatment residual; treated effluent. Metals can be removed through subsequent precipitation.

PACT® Treatment

PACT® treatment combines carbon adsorption and biological treatment to biodegrade hazardous organic constituents and selectively adsorb them onto powdered activated carbon. This technology generates two treatment residuals: a treated effluent and spent carbon/biosludge. The spent carbon is often regenerated and recycled to the process or incinerated. Metal constituents may also adsorb on the carbon/biosludge.

Chemical Reduction Treatment

Chemical reduction treatment reduces metal constituents from a higher oxidation state to a lower oxidation state, and subsequently removes the contaminants from the wastewater using chemical precipitation and subsequent sedimentation and/or filtration. This technology generates two treatment residuals: a treated effluent and a settled or filtered solid containing the precipitated metal.

Electrochemical Treatment

Electrochemical treatment is a technology in which direct current is applied to iron electrodes submerged in the wastewater, generating ferrous ions. Metal constituents are removed by adsorbing and coprecipitating within insoluble ferrous ion matrices. These matrices settle out of solution using chemically assisted clarification (described above). This technology produces two treatment residuals: a treated effluent and a settled solid containing the precipitated metal.

Lime, Sedimentation and Filtration Treatment

As a separation technology, this treatment mixes wastewaters with lime (primarily calcium oxide) which produces an insoluble metal oxide which settles out of solution. The wastewater is filtered to remove the precipitated material. This treatment technology produces two residuals: a treated effluent and a filter cake containing lime and metals oxides.

4.2.2 Identification of BDAT and Treatment Standards for Wastewater Forms of K176

EPA determines BDAT for individual constituents, and wastes, upon review of all available performance data for wastes identical or similar to the waste of concern (EPA, 1994b). Once the applicable and demonstrated treatment technologies are identified for the particular waste, performance data are examined to identify the "best" performing technologies. These criteria include:

- Whether the data represent the operation of a well-designed and well-operated treatment system;
- Whether sufficient analytical quality assurance/quality control measures were used to ensure the accuracy of the data; and

- Whether the appropriate measure of performance was used to assess the performance of the particular treatment technology.

Once this is determined, EPA decides where the best demonstrated technology is “available.” EPA defines an available technology as one that (EPA, 1994b):

- Is not a proprietary or patented process and can be purchased or licensed from the proprietor, and

- Substantially diminishes the waste’s toxicity or substantially reduces the likelihood that hazardous contaminants will migrate from the waste.

BDAT for Metals

EPA determined the BDAT for the five metal constituents requiring treatment in wastewater forms of K176 in its development of UTS. In developing UTS for antimony, arsenic, and mercury, EPA identified the appropriate BDAT as lime addition followed by sedimentation followed by filtration. In developing UTS for cadmium and lead, EPA identified the appropriate BDAT as chemical precipitation followed by sedimentation (EPA, 1994b).

BDAT for Wastewater Forms of K176: Conclusion

Two technologies were identified as BDAT in treating individual components present in K176 wastes. These technologies included the treatment train consisting of lime addition followed by sedimentation followed by filtration; and the treatment train consisting of chemical precipitation followed by sedimentation. These technologies are similar, however, because each involves the formation of a relatively insoluble metal compound as a precipitate (in the case of lime addition, the metals precipitate as oxides or hydroxides in a calcium matrix).

EPA (1994b) presents treatment data using various technologies for the five metals discussed in this section, including the two technologies listed above. These technologies can be used in achieving levels of treated effluent below the UTS for the specified metal. A summary of these data are presented in Table 4–1. While data are not available for each metal in each treatment train, the data show that, in several cases, different types of treatment can achieve levels of treated effluent below UTS.

Table 4–1. Treatment Technologies Appropriate for Metals in K176 Wastewaters

Metal	**Technology**	**Maximum Influent Concentration, mg/L**	**Effluent Concentration, mg/L**	**UTS (Wastewater), mg/L**
Antimony	L+Sed+Fil	8.5	0.47	1.9
	ChPt+Sed	Data not available		
Arsenic	L+Sed+Fil	4.2	0.34	1.4
	Chred/Pt+Sed+Fil	3.0	0.18	
Cadmium	L+Sed+Fil	2.3	0.049	0.69
	ChPt+Sed	Data not available	0.13	
Lead	L+Sed+Fil	29.2	0.08	0.69
	ChPt+Sed	Data not available	0.20	
Mercury	L+Sed+Fil	Data not available	0.036	0.15
	ChPt+Sed	Data not available		

Source: EPA, 1994b.
L+Sed+Fil: lime addition followed by sedimentation followed by filtration
ChPt+Sed: chemical precipitation followed by sedimentation
Chred/Pt+F+Sed: Chemical reduction/precipitation followed by sedimentation and filtration.

EPA (1994b) does not present treatment data for constituents that appear together in the same waste (i.e., it is not possible to identify wastes where antimony, arsenic, cadmium, lead, and mercury are present together). However, the above data indicate that treatment is possible using a single treatment train, consisting of either lime addition followed by sedimentation followed by filtration; or the treatment train consisting of chemical precipitation followed by sedimentation. The effectiveness of treatment is influenced by waste-specific factors such as contaminant concentrations in the waste, and other non-toxic contaminants present (e.g., organic matter). Because EPA has no examples of wastewater forms of K176 that would be generated, the effectiveness of these treatment technologies cannot be further assessed. Nevertheless, EPA anticipates that effective treatment is possible using either of these two treatment trains.

Treatment Standards

EPA is finalizing numerical treatment standards for five constituents in wastewater forms of K176 equivalent to UTS. Universal treatment standards have previously been promulgated for all of these constituents. These standards are identified below:

- Antimony: 1.9 mg/L
- Arsenic: 1.4 mg/L
- Cadmium: 0.69 mg/L
- Lead: 0.69 mg/L
- Mercury: 0.15 mg/L

EPA expects the treatment technologies previously described to result in treated effluent with contaminant concentrations lower than the numerical treatment standards. Since numerical treatment levels are finalized for wastewater forms of K176, the use of any technology (other than impermissible dilution) is allowed in complying with the treatment standards. Therefore, facilities are not required to use the treatment technologies identified in Table 4–1 to manage wastewater forms of K176 and may find they can use an alternative treatment train to meet the numerical treatment standards.

4.3 Nonwastewater Forms of K176

4.3.1 Applicable and Demonstrated Technologies for Treating Metals

Applicable treatment technologies for metals include those that immobilize or reduce the total amount of metal constituents in a waste. The technologies listed in this section are applicable and have been demonstrated to treat metal constituents in nonwastewater forms of other hazardous wastes. These technologies are commonly used to treat wastes which contain the metal constituents regulated by universal treatment standards. EPA (1988a; 1990; 1994a) presents a thorough discussion of these technologies. The technologies applicable to wastes with the physical and chemical characteristics of K176 include:

- Acid Leaching
- Vitrification
- Stabilization
- Pyrometallurgical recovery process (high temperature metals recovery)
- Hydrometallurgical recovery processes
- Recycling

Mercury has been identified as a constituent requiring treatment in this waste. However, its concentration is low (<260 mg/kg) such that mercury recovery is not an applicable technology for this waste.

Acid Leaching

Acid leaching is a process that removes soluble constituents from an insoluble matrix by contact with a strongly acidic solution. The soluble contaminant is more soluble in an acidic solution and will be transferred to the acid phase. The solids are separated from the liquid (e.g., using filtration or equipment design). This treatment process generates two residuals: a treated solid and an acidic, metal-laden liquid which requires additional treatment or recovery.

Vitrification

Glass vitrification and slag vitrification are high temperature stabilization technologies that are applicable for treatment of arsenic-containing wastes. In either type of vitrification process, the waste is blended with lime, soda ash, silica, and other glass making ingredients (such that the ending volume is greater than the initial waste volume). Material is fed to a furnace containing molten glass, so that organics in the waste are vaporized (or destroyed) and metals are dissolved. Volatile metals (such as arsenic compounds) condense within the furnace. The glass is removed and cooled. The process generates a single solid waste treatment residual.

Stabilization

Stabilization is a broad class of treatment technologies that reduces the mobility of metal constituents in a waste; the metals are chemically bound into a solid matrix that resists leaching when water or a mild acid solution comes into contact with the waste material. Organic materials usually are not stabilized effectively and may, in fact, inhibit the stabilization of metals. Hence, stabilization is applicable to nonwastewaters only after the organics have been removed by other treatment.

Pyrometallurgical Recovery Processes (High Temperature Metals Recovery)

Pyrometallurgical recovery processes are those treatment technologies that use physical and chemical reactions at elevated temperatures for extraction/separation of metals, ores, salts, and other materials. For the purposes of the Land Disposal Restrictions Program, pyrometallurgical processes are referred to as High Temperature Metals Recovery (HTMR). Some examples of HTMR systems include rotary kilns, flame reactors, electric furnaces, plasma arc furnaces, slag reactors, and rotary hearth/electric furnaces. These thermal reduction processes use carbon, limestone, and silica (sand) as raw materials. The carbon acts as a reducing agent and reacts with metal oxides in a high temperature processing unit (e.g., kiln, furnace) to produce carbon dioxide and a free metal. This process yields a metal product for reuse and reduces the concentration of metals in the residuals.

Hydrometallurgical Recovery Processes

Hydrometallurgical recovery processes extract and recover materials by using acidic solutions. These processes are most effective with wastes containing high concentrations of metals that are soluble in a strong acid solution or that can be converted by reaction with a strong acid to a soluble form. Some hydrometallurgical processes include chemical precipitation, leaching, ion exchange, solvent extraction, and electrowinning.

EPA is aware that some facilities are using a series of technologies, including chemical precipitation, ion exchange, and electrowinning, to recover metals from various metal-bearing waste streams (i.e., not necessarily K176, K177, or K178 wastes). Some of these facilities claim that these hydrometallurgical processes, unlike other processes, generate no residuals for land disposal.

Recycling

For some metal-bearing wastes, recycling may be an applicable technology. For example, as identified in Section 2, both baghouse filters (K176 waste) and slag (K177 waste) are recycled onsite in the antimony oxide production furnace, or sent offsite for a similar use. Therefore recycling is demonstrated for these wastes. Such practices facilitate the recovery of metals while reducing or eliminating the material designated for land disposal.

4.3.2 Identification of BDAT and Treatment Standards for Nonwastewater Forms of K176

BDAT for Metals

In the development of UTS in 1994 and later as part of the Phase IV final rule in 1998, EPA identified different BDATs for antimony, arsenic, cadmium, lead, and mercury. These technologies are as follows:

- Antimony: Stabilization or high temperature metals reclamation (HTMR) (Phase IV)
- Arsenic: Slag vitrification (EPA, 1994a)
- Cadmium: HTMR (Phase IV)
- Lead: Stabilization (Phase IV)
- Mercury: acid leaching (EPA, 1994a).

BDAT for Nonwastewater Forms of K176: Conclusion

EPA has identified recycling as applicable and demonstrated for K176 wastes, and some K176 wastes are already managed in this manner (see Table 2–1). While in this case EPA encourages the continuation of this practice, EPA recognizes that some wastes (particularly 'derived-from' wastes) may not be amenable to recycling. Therefore EPA is applying the above, previously identified BDAT to the individual metals present in K176 wastes.

It is expected to be difficult and impractical to construct a treatment train incorporating each of the above technologies of acid leaching, vitrification, stabilization, and high temperature metals recovery. For example, during vitrification the arsenic remains in the waste, while during HTMR volatile metals such as arsenic and mercury are removed. Therefore, EPA expects that the actual treatment employed will depend on the concentration of metals present in the generated wastes. For example, if the content of arsenic is relatively low, then it would be unlikely to present treatment difficulties during an alternative treatment process.

Table 4–2 shows available treatment data for these five metals using various treatment technologies. The maximum concentration of the contaminant present in K176 wastes is also shown, for comparison (these data are from Section 2 of this report). These technologies can be used in achieving levels of treated wastes below the UTS for the specified metal. While data are not available for each metal in each treatment train, the data show that, in several cases, a variety of treatment technologies can achieve levels in treated wastes below UTS.

Table 4–2 shows that stabilization can be used to treat wastes to below UTS, for wastes with similar concentrations of arsenic, cadmium, lead, and mercury as found in K176 wastes. In the case of antimony, however, EPA's available treatment performance data (for any technology) do not include any wastes with such high initial levels of antimony. Nevertheless, the physical and chemical characteristics of K176 wastes are similar to other wastes that have successfully been treated with stabilization. In conclusion, EPA anticipates that stabilization is BDAT for this waste, although performance data for wastes with high levels of antimony are not available.

Table 4–2. Treatment Technologies Appropriate for Metals in K176 Nonwastewaters

Metal	**Maximum K176 Waste Concentration**	**Technology**	**Maximum Untreated Concentration, mg/L TCLP**	**Corresponding Treated Concentration, mg/L TCLP**	**UTS (Nonwaste-water), mg/L TCLP**
Antimony	69 mg/L TCLP, 150,000 ppm total	Stabilization [A]	16.1	0.038	1.15
		HTMR [B]	— [B]	0.85	
Arsenic	6.9 mg/L TCLP, 114 ppm total	Vitrification [C]	— [C]	1.8 [C]	5.0
		Stabilization [C]	Significant variability in results [C]		
		Stabilization [A]	33.1	0.32	
Cadmium	0.3 mg/L TCLP, 411 ppm total	Stabilization [A]	1220	0.082	0.11
		HTMR [B]	— [B]	<0.06	
Lead	8.5 mg/L TCLP, 3.1 ppm total	Stabilization [A]	1280	0.65	0.75
Mercury	0.026 mg/L TCLP, 95 ppm total	Stabilization [A]	0.11	<0.05	0.025
		Acid leaching [D]	20	0.002 or less	

Performance data showing effective treatment of constituents with initial concentrations similar to or greater than levels in K176 wastes are highlighted. Shading indicates cases where metals are treated to below UTS, from initial levels comparable to or higher than those found in K176.
Only performance data resulting in treated waste with levels below UTS are presented in this table.
Sources:
A. Phase IV Rule (March 10, 1997 Memorandum from H. Finkel (ICF) to A. Cummings (EPA).
B. Final Best Demonstrated Available Technology (BDAT) Background Document for K061, August1988 (EPA, 1988b). Antimony levels in untreated waste are given as 100 ppm (or less) total. Cadmium levels in untreated waste are given as 860 ppm or less. Leachate data are given as mg/L TCLP.
C. Final Best Demonstrated Available Technology (BDAT) Background Document for K031, K084, K101, K102, Characteristic Arsenic Wastes (D004), Characteristic Selenium Wastes (D010), and P and U Wastes Containing Arsenic and Selenium Listing Constituents. Leachate data are given as mg/L Extraction Procedure (EP). Total arsenic level in treated waste is given as 24 percent.
D. Final Best Demonstrated Available Technology (BDAT) Background Document for K071. August 1988 (EPA, 1988a).

Treatment Standards

EPA is finalizing numerical treatment standards for five constituents in nonwastewater forms of K176 equivalent to UTS. Universal treatment standards have previously been promulgated for all of these constituents, as follows:

- Antimony: 1.15 mg/L TCLP

- Arsenic: 5.0 mg/L TCLP
- Cadmium: 0.11 mg/L TCLP
- Lead: 0.75 mg/L TCLP
- Mercury: 0.025 mg/L TCLP

Since numerical treatment levels are finalized for nonwastewater forms of K176, the use of any technology (other than impermissible dilution) is allowed in complying with the treatment standards. Therefore, facilities are not required to use the treatment technologies identified in Table 4–2 to manage nonwastewater forms of K176, and may find they can use an alternative treatment train to meet the numerical treatment standards.

5.0 TREATMENT STANDARD DEVELOPMENT FOR K177

This section is organized in a similar fashion as Chapter 4, as follows:

- Section 5.1 summarizes the results of Section 3 and provides an overview of the treatment needs of the waste.
- Section 5.2 discusses wastewater forms of K177. Specifically, technologies applicable for treating the constituents identified in the waste are discussed in Section 5.2.1. The technology or technologies identified as BDAT and the treatment standards are presented in Section 5.2.2.
- Section 5.3 discusses nonwastewater forms of K177. The format of the discussion is similar to that for wastewater forms of K177.

5.1 Summary of Constituents Selected for Regulation

As presented in Section 3, the following constituents were identified for treatment standards for K177:

- Antimony
- Arsenic
- Lead

This section identifies technologies appropriate for reducing the toxicity of these metal contaminants in K177 wastes.

5.2 Wastewater Forms of K177

As discussed in Section 2, K177 is a solid and would normally be required to meet treatment standards applicable to nonwastewaters. The technologies listed here are expected to be applicable to wastewater forms of K177, in the event that such wastes are generated.

5.2.1 Applicable and Demonstrated Technologies for Treating Metals

The contaminants identified in K177 are a subset of those identified for K176. Therefore, all technologies discussed in Section 4.2.1 as applicable and demonstrated for treating metals in wastewater forms of K176 can be applied to metals treatment in wastewater forms of K177 as well.

5.2.2 Identification of BDAT and Treatment Standards for Wastewater Forms of K177

BDAT for Metals

EPA determined the BDAT for the three metal constituents requiring treatment in wastewater forms of K177 in its development of UTS. In developing UTS for antimony and arsenic, EPA identified the appropriate BDAT as lime addition followed by sedimentation followed by filtration. In developing UTS for lead, EPA identified the appropriate BDAT as chemical precipitation followed by sedimentation (EPA, 1994b).

BDAT for Wastewater Forms of K177: Conclusion

Two technologies were identified as BDAT in treating individual components present in K177 wastes. These technologies included the treatment train consisting of lime addition followed by sedimentation followed by filtration; and the treatment train consisting of chemical precipitation followed by sedimentation. These technologies are similar, however, because each involves the formation of a relatively insoluble metal compound as a precipitate (in the case of lime addition, the metals precipitate as oxides or hydroxides in a calcium matrix).

Section 4.2.2 presented treatment performance data for contaminants in K176 wastes (these contaminants included antimony, arsenic, and lead). These data indicate that treatment is possible using a single treatment train, consisting of either lime addition followed by sedimentation followed by filtration; or the treatment train consisting of chemical precipitation followed by sedimentation. The effectiveness of treatment is influenced by waste-specific factors such as contaminant concentrations in the waste, and other non-toxic contaminants present (e.g., organic matter). Because

EPA has no examples of wastewater forms of K177 that would be generated, the effectiveness of these treatment technologies cannot be further assessed.

Treatment Standards

EPA is finalizing numerical treatment standards for three constituents in wastewater forms of K177 wastes, equivalent to UTS. Universal treatment standards have previously been promulgated for all of these constituents. These standards are identified below:

- Antimony: 1.9 mg/L
- Arsenic: 1.4 mg/L
- Lead: 0.69 mg/L.

EPA expects the treatment train previously described to result in treated effluent with contaminant concentrations lower than the numerical treatment standards. Since numerical treatment levels are finalized for wastewater forms of K177, the use of any technology (other than impermissible dilution) is allowed in complying with the treatment standards. Therefore, facilities are not required to use the treatment technologies discussed above to manage wastewater forms of K177, and may find they can use an alternative treatment train to meet the numerical treatment standards.

5.3 Nonwastewater Forms of K177

5.3.1 Applicable and Demonstrated Technologies for Treating Metals

The contaminants identified in K177 are a subset of those identified for K176. Therefore, all technologies discussed in Section 4.3.1 as applicable and demonstrated for treating metals in nonwastewater forms of K176 can be applied to metals treatment in nonwastewater forms of K177 as well.

5.3.2 Identification of BDAT and Treatment Standards for Nonwastewater Forms of K177

As identified in Section 4.3.2, EPA identified that stabilization or HTMR was capable of meeting UTS for antimony (based on data from the 1998 Phase IV rule); vitrification was BDAT for arsenic, and stabilization was capable of meeting BDAT for lead. Available performance data for these contaminants are shown in Table 5–1 to compare with the respective levels in untreated K177 waste.

Table 5–1. Treatment Technologies Appropriate for Metals in K177 Nonwastewaters

Metal	Maximum K177 Waste Concentration	Technology	Maximum Untreated Concentration, mg/L TCLP	Corresponding Treated Concentration, mg/L TCLP	UTS (Nonwastewater), mg/L TCLP
Antimony	110 mg/L TCLP, 127,000 ppm total	Stabilization [A]	16.1	0.038	1.15
		HTMR [B]	— [B]	0.85	
Arsenic	3.1 mg/L TCLP, 478 ppm total	Vitrification [C]	— [C]	1.8 [C]	5.0
		Stabilization [C]	Significant variability in results [C]		
		Stabilization [A]	33.1	0.32	
Lead	22.3 mg/L TCLP, 39,500 ppm total	Stabilization [A]	1280	0.65	0.75

Only performance data resulting in treated waste with levels below UTS are presented in this table.
Performance data showing effective treatment of constituents with initial concentrations similar to or greater than levels in K176 wastes are highlighted.
Sources:
A. Phase IV Rule (March 10, 1997 Memorandum from H. Finkel (ICF) to A. Cummings (EPA).
B. Final Best Demonstrated Available Technology (BDAT) Background Document for K061, August 1988 (EPA, 1988b). Antimony levels in untreated waste are given as 100 ppm (or less) total. Leachate data are given as mg/L TCLP.
C. Final Best Demonstrated Available Technology (BDAT) Background Document for K031, K084, K101, K102, Characteristic Arsenic Wastes (D004), Characteristic Selenium Wastes (D010), and P and U Wastes Containing Arsenic and Selenium Listing Constituents. Leachate data are given as mg/L Extraction Procedure (EP). Total arsenic level in treated waste is given as 24 percent.

The treatment performance data in Table 5–1 demonstrate that arsenic and lead can be effectively treated using stabilization, based on data for similar wastes with arsenic and lead concentrations higher than those found in K177 wastes. However, there are no similar available performance data for antimony in wastes with comparable levels in untreated wastes. EPA anticipates that stabilization will result in levels of arsenic and lead to below UTS, with uncertainty regarding the performance for antimony.

EPA is finalizing numerical treatment standards for three constituents in nonwastewater forms of K177 equivalent to UTS. Universal treatment standards have previously been promulgated for these constituents, as follows:

- Antimony: 1.15 mg/L TCLP
- Arsenic: 5.0 mg/L TCLP
- Lead: 0.75 mg/L TCLP.

Since numerical treatment levels are finalized for nonwastewater forms of K177, the use of any technology (other than impermissible dilution) is allowed in complying with the treatment standards. Therefore, facilities are not required to use the treatment technologies identified in Table 5–1 to manage nonwastewater forms of K177, and may find they can use an alternative treatment method to meet the numerical treatment standards.

6.0 TREATMENT STANDARD DEVELOPMENT FOR K178

This section is organized in a similar fashion as Chapter 4, as follows:

- Section 6.1 summarizes the results of Section 3 with regard to K178 wastes and provides an overview of the treatment needs of the waste.

- Section 6.2 discusses wastewater forms of K178. Specifically, technologies applicable for treating the metal constituents identified in the waste are discussed in Section 6.2.1. Technologies applicable for treating the dioxin and furan congeners are discussed in Section 6.2.2. The technology or technologies identified as BDAT and the treatment standards are presented in Section 6.2.3.

- Section 6.3 discusses nonwastewater forms of K178. The format of the discussion is similar to that for wastewater forms of K178.

6.1 Summary of Constituents Selected for Regulation

As presented in Section 3, the following constituents were identified for treatment standards in K178 wastes:

- Thallium
- The following chlorinated dibenzo-p-dioxins (CDDs) and dibenzo-p-furans (CDFs):
  - 1,2,3,4,6,7,8-Heptachlorodibenzo-*p*-dioxin
  - 1,2,3,4,6,7,8-Heptachlorodibenzofuran
  - 1,2,3,4,7,8,9- Heptachlorodibenzofuran
  - HxCDDs (All Hexachlorodibenzo-*p*-dioxins)
  - HxCDFs (All Hexachlorodibenzofurans)
  - 1,2,3,4,6,7,8,9-Octachlorodibenzo-*p*-dioxin (OCDD)
  - 1,2,3,4,6,7,8,9-Octachlorodibenzofuran (OCDF)
  - PeCDDs (All Pentachlorodibenzo-*p*-dioxins)
  - PeCDFs (All Pentachlorodibenzofurans)
  - TCDDs (All tetrachlorodi-benzo-*p*-dioxins)
  - TCDFs (All tetrachlorodibenzofurans)

EPA proposed treatment standards for manganese in K178 wastes. EPA is deferring final action on manganese treatment standards. See section IV.b. of the preamble to the final rule for a discussion of EPA's decision to defer final action on manganese-related elements of the proposed rule.

6.2 Wastewater Forms of K178

As discussed in Section 2, K178 is typically generated as a nonwastewater. Wastewater forms of treatment residuals may be generated, requiring additional treatment for compliance with LDR treatment standards. The technologies listed here are expected to be applicable to wastewater forms of K178 (if generated).

6.2.1 Applicable and Demonstrated Technologies for Treating Metals

In general, the technologies described for treating metals in K176 would be applicable to treating metals in wastewater forms of K178. These technologies are described in Section 4.2.1.

6.2.2 Applicable and Demonstrated Technologies for Treating Dioxins and Furans

To be applicable, a technology must theoretically be usable to treat the waste in question or a waste that is similar, in terms of parameters that affect treatment selection (EPA, 1994b). In general, technologies applicable to the treatment of organic compounds are applicable to dioxin/furan compounds. EPA (1994b) presents a thorough discussion of the following technologies which are applicable and have been demonstrated to treat dioxins/furans in wastewater forms of other hazardous wastes:

- Biological treatment (including aerobic fixed film, aerobic lagoon, activated sludge, anaerobic fixed film, rotating biological contactor, sequential batch reactor, and trickling filter technologies)
- Carbon adsorption treatment (including activated carbon and granular activated carbon technologies)
- Chemically assisted clarification treatment (including chemical precipitation technology)
- Chemical oxidation
- PACT® treatment (including powdered activated carbon addition to activated sludge and biological granular activated carbon technologies)
- Reverse osmosis treatment
- Solvent extraction treatment (including liquid/liquid extraction)
- Stripping treatment (including steam stripping and air stripping technologies)
- Wet air oxidation treatment (including supercritical oxidation technology)

- Glycolate dechlorination
- Incineration
- Total recycle or reuse.

The concentrations and type(s) of constituent present in the waste generally determine which technology is most applicable. Carbon adsorption, for example, is often used as a polishing step following primary treatment by biological treatment, solvent extraction, or wet air oxidation. Typically, carbon adsorption is applicable for treatment of wastewaters containing less than 0.1% total organic constituents. Wet air oxidation, PACT® treatment, biological treatment, and solvent extraction are generally applicable for treatment of wastewaters containing up to 1% total organic constituents. EPA does not have information on the total organic content of wastewater forms of K178 because such wastes are typically generated as nonwastewaters. Therefore, each of these treatment technologies can potentially be used for K178 wastewaters.

Brief descriptions of the above treatment technologies are presented below.

Biological Treatment

Biological treatment is a destruction technology that biodegrades hazardous organic constituents in wastewaters. This technology generates two treatment residuals: a treated effluent and a waste biosludge.

Carbon Adsorption

Carbon adsorption is a separation technology that selectively adsorbs organic constituents in wastewaters onto activated carbon. This technology generates two treatment residuals: a treated effluent and spent activated carbon. The spent activated carbon may be reactivated, recycled, incinerated, or land disposed (in accordance with land disposal restrictions).

Chemically Assisted Clarification Treatment

Chemically assisted clarification, including chemical precipitation, is a separation technology that removes organic and inorganic constituents from wastewater by the addition of chemicals that cause the formation of precipitates. The solids formed are then separated from the wastewater by settling, clarification, and/or polishing filtration. This technology generates two treatment residuals: treated wastewater effluent and separated solid precipitate.

Chemical Oxidation

Chemical oxidation is a destruction technology that oxidizes inorganic cyanide, some dissolved organic compounds, and sulfides to yield carbon dioxide, water, salts, simple organic acids, and sulfates. This technology generates one treatment residual: treated effluent.

PACT® Treatment

PACT® treatment combines carbon adsorption and biological treatment to biodegrade hazardous organic constituents and selectively adsorb them onto powdered activated carbon. This technology generates two treatment residuals: a treated effluent and spent carbon/biosludge. The spent carbon is often regenerated and recycled to the process or incinerated.

Reverse Osmosis

Reverse osmosis is a separation technology that removes dissolved organics (usually salts) from a wastewater by filtering the wastewater through a semipermeable membrane at a pressure greater than the osmotic pressure caused by the dissolved organics in the wastewater. This technology generates two treatment residuals: the treated effluent and the concentrated organic salt materials which do not pass through the membrane.

Solvent Extraction

Solvent extraction is a separation technology that removes organic compounds from a waste due to greater constituent solubility in a solvent phase than in the waste phase. This technology generates two residuals: a treated waste residual and an extract.

Stripping Treatment

Stripping treatment is a separation technology in which volatile organic constituents in a liquid waste are physically transferred to a flowing gas or vapor. In steam stripping, steam contacts the waste, strips the volatile organics, and carries them to a condenser where the mixture of organic vapors and steam is condensed and collected in an accumulator tank. In air stripping, air contacts the waste and strips the volatile organic constituents. Stripping generates two treatment residuals: treated effluent and condensed vapors.

Wet Air Oxidation

Wet air oxidation is a destruction technology that oxidizes hazardous organic constituents in wastes under pressure at elevated temperatures in the presence of dissolved oxygen. This technology is applicable for wastes comprised primarily of water and with up to 10 percent total organic constituents. Wet air oxidation generates one treatment residual: treated effluent. The treated effluent may require further treatment for hazardous organic constituents by carbon adsorption or PACT® treatment. Trapped air emissions from wet air oxidation may also require further treatment.

Glycolate Dechlorination

EPA (1994b) describes a bench-scale process involving dechlorination of toxics (e.g., dioxins) using an alkoxide formed by the reaction of potassium hydroxide with polyethylene glycol (KPEG). The U.S. Navy’s Environmental Restoration Division also provides another description of this process.[3] The KPEG technology is an example of the use of an alkaline polyethylene glycol reagent (APEG), and is considered as an innovative remediation technology applicable to small volume of soils (i.e., nonwastewaters) due to cost constraints. The process involves the mixing and heating of contaminated soils and the reagent in a batch treatment vessel. The reaction between the chlorinated organics and the KPEG causes replacement of a chlorine molecule with polyethylene glycol. The reagent then dehalogenates the pollutant to form a glycol ether and/or a hydroxylated compound and an alkali metal salt, which are water-soluble byproducts. The data from the U.S. Navy's Environmental Restoration Division is primarily for soil. However, data from EPA's National Risk Management Research Laboratory (http://www.epa.gov/tdbnrmrl/intro.htm) shows that this technology has been used for treating dioxins and furans in liquids and in waters.

Incineration

Please see section 6.3.2 for a discussion of incineration.

Total Recycle or Reuse

Total recycle or reuse within the same process or an external process eliminates waste generation. As a result of recycling, however, impurities may require removal from the system on a periodic or continuous basis.

6.2.3 Identification of BDAT and Treatment Standards for Wastewater Forms of K178

BDAT for Metals

In developing UTS for thallium, EPA identified the appropriate BDAT as lime conditioning followed by sedimentation and filtration (EPA, 1994b). The UTS was unchanged since this date.

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[3] http://erb.nfesc.navy.mil/restoration/technologies/remed/phys_chem/phc-12.asp. The date of the report was not provided, but appears to be from 1998.

BDAT for Dioxins/Furans

EPA previously developed UTS for the following dioxin/furan classes, identifying biological treatment as BDAT (EPA, 1994b):

- HxCDDs (All hexachlorodibenzo-*p*-dioxins)
- HxCDFs (All hexachlorodibenzofurans)
- PeCDDs (All pentachlorodibenzo-*p*-dioxins)
- PeCDFs (All pentachlorodibenzofurans)
- TCDDs (All tetrachlorodibenzo-*p*-dioxins)
- TCDFs (All tetrachlorodibenzofurans)

EPA finalized treatment standards for the five hepta- and octa- dioxin and furan congeners (in the final rule to list chlorinated aliphatics wastes as hazardous, November 8, 2000). However, EPA expects that applicable treatment technologies and BDAT for the above congeners are appropriate for the remaining dioxin and furan congeners. Biological treatment is expected to perform equally well for these constituents as it does for the other congeners due to similarity in structure and properties of these compounds.

BDAT for Wastewater Forms of K178: Conclusion

Biological treatment is a demonstrated method for treating wastewaters with low levels of dioxin/furan components. In data submitted by industry prior to promulgation of the Land Disposal Restrictions for the Third Third Scheduled Wastes (55 *FR* 22520), wastewaters including hazardous waste landfill leachate were managed using biological treatment in both batch and full scale processes.[4] However, biological treatment is expected to only slightly decrease the concentration of metals in the waste.

To adequately treat both metals and organics potentially present in wastewater forms of K178, EPA identifies a treatment train consisting of lime treatment followed by sedimentation and filtration (for metals treatment), followed by biological treatment (for organics treatment) as BDAT for the treatment of wastewater forms of K178.

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[4] Letter from Chemical Waste Management Incorporated, F-89-LD12-S0967. Letter from Dow Chemical USA, F-89-LD12-S0968.

Treatment Standards

EPA is finalizing numerical treatment standards as follows. These are equivalent to promulgated UTS for thallium and the dioxin/furan congeners. In the case of manganese, EPA has deferred final action. These standards finalized for K178 are as follows:

- Thallium: 1.4 mg/L
- The following chlorinated dibenzo-p-dioxins (CDDs) and dibenzo-p-furans (CDFs):
  - 1,2,3,4,6,7,8-Heptachlorodibenzo-*p*-dioxin: 0.000035 mg/L
  - 1,2,3,4,6,7,8-Heptachlorodibenzofuran: 0.000035 mg/L
  - 1,2,3,4,7,8,9-Heptachlorodibenzofuran: 0.000035 mg/L
  - HxCDDs (All hexachlorodibenzo-*p*-dioxins): 0.000063 mg/L
  - HxCDFs (All hexachlorodibenzofurans): 0.000063 mg/L
  - 1,2,3,4,6,7,8,9-Octachlorodibenzo-*p*-dioxin (OCDD): 0.000063 mg/L
  - 1,2,3,4,6,7,8,9-Octachlorodibenzofuran (OCDF): 0.000063 mg/L
  - PeCDDs (All pentachlorodibenzo-*p*-dioxins): 0.000063 mg/L
  - PeCDFs (All pentachlorodibenzofurans): 0.000035 mg/L
  - TCDDs (All tetrachlorodi-benzo-*p*-dioxins): 0.000063 mg/L
  - TCDFs (All tetrachlorodibenzofurans): 0.000063 mg/L

EPA also finalized an alternative treatment standard of combustion (CMBST) for the dioxin and furan constituents of K178. Combustion is the basis for the dioxin/furan numerical limits in nonwastewaters, and properly conducted combustion should effectively destroy dioxin/furan constituents. If this method of treatment is used to treat K178 in certain specified combustion devices,[5] there would be no need to monitor compliance with numerical limits established for dioxin/furan constituents. However, the other constituent (i.e., thallium) would require monitoring prior to land disposal.

Since numerical treatment levels are finalized for wastewater forms of K178, the use of any technology (other than impermissible dilution) is allowed in complying with the treatment standards. Therefore, facilities are not required to use the above treatment train to manage wastewater forms of K178, and may find they can use an alternative treatment train to meet the numerical treatment standards.

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[5] The definition of CMBST is limited to: (1) combustion units operating under 40 CFR Part 266, (2) combustion units permitted under 40 CFR Part 264, Subpart O, or (3) combustion units operating under 40 CFR Part 265, Subpart O, which have obtained a determination of equivalent treatment under 40 CFR 268.42(b).

6.3 Nonwastewater Forms of K178

6.3.1 Applicable and Demonstrated Technologies for Treating Metals

In general, the technologies described for treating metals in K176 would be applicable to treating metals in K178. These technologies are described in Section 4.3.1.

6.3.2 Applicable and Demonstrated Technologies for Treating Dioxins/Furans

The technologies listed in this section are applicable and have been demonstrated to treat dioxin and furan congeners (or other organics) in nonwastewater forms of other hazardous wastes. They are expected to be applicable to wastes with physical and chemical forms similar to K178. EPA (1994a) presents a thorough discussion of these technologies. Those technologies deemed applicable to the physical and chemical characteristics of K178 are as follows:

- Incineration
- Solvent extraction
- Critical fluid extraction
- Pressure filtration
- Thermal drying of biological treatment sludge
- Thermal desorption
- Total recycle or reuse

Except for total waste recycle and reuse, all of the treatment methods listed above generate additional wastes in liquid or solid form. Such wastes would require additional management, including additional treatment to meet applicable land disposal restriction treatment standards if necessary. Each technology is described below.

Incineration

Incineration is a destruction technology in which heat is transferred to the waste to destabilize chemical bonds and destroy hazardous organic constituents. Off-gases (following additional combustion in an afterburner) are fed to a scrubber system for cooling and for removal of entrained particles and acid gas. Three incineration technologies are applicable and demonstrated for organics in nonwastewaters: liquid injection, rotary kiln, and fluidized-bed. Incineration potentially may produce two residuals: scrubber water and ash. Waste properties, the type of incineration system used, and the air pollution control devices employed dictate the quantity of each residual generated.

Solvent Extraction

Solvent extraction is a separation and recovery technology. The process removes organic constituents from a waste by mixing the waste with a solvent that preferentially dissolves and removes the hazardous constituents from the waste. Wastes treated by this technology have a wide range of total organic content; selection of an appropriate solvent depends on the relative solubilities of the constituents to be removed and the other organic compounds in the waste. This technology generates two residuals: a treated waste residual and an extract.

Critical Fluid Extraction

This is a separation and recovery technology in which a solvent is brought to its critical state (liquified gas) to extract organic constituents from a waste. The solvents used are usually gases at ambient conditions. The solvent is converted from a gas to a liquid via pressurization. As a liquid, the solvent dissolved the organic constituents and extracts them from the waste matrix. Once it is extracted the solvent is returned to its original gaseous state. The technology generates two residuals: a treated waste residual and an extract. The extract is usually recycled or treated by incineration.

Pressure Filtration

Pressure filtration, also known as sludge dewatering, is a separation and recovery technology used for wastes that contain high concentrations (greater than 1 percent) of suspended solids. It separates particles from a fluid/particle mixture by passing the fluid through a medium that permits the flow of the fluid but retains particles. Pressure filtration generates two residuals: dewatered sludge and water. For dioxins and furans that are partitioned to suspended solids, this technology concentrates the organics in the solid residual, making the dioxins and furans more amenable for treatment using other technologies described in this section.

Thermal Drying

Thermal drying of biological treatment sludge is a destruction technology which uses controlled flame combustion or indirect heat transfer to elevate the temperature of the waste and, thereby volatilizes the organic constituents. Off-gas from the dryer is sent to an afterburner to complete combustion of the volatile component. This process generates two residuals: a treated waste residual and an extract.

Thermal Desorption

This is a separation and recovery technology in which direct or indirect heat exchange is used to volatilize organic constituents from wastes. Different from incineration, thermal desorption works by elevating the temperature of the organic constituents to effect a phase separation to a gaseous state without combustion. Thermal desorption units function by creating steam from the volatilization of the moisture in the waste from heating. The technology generates two residuals: a treated waste residual and an extract.

Total Recycle or Reuse

Total recycle or reuse within the same process or an external process eliminates waste generation. As a result of recycling, however, impurities may require removal from the system on a periodic or continuous basis.

6.3.3 Identification of BDAT and Treatment Standards for Nonwastewater Forms of K178

Thallium

For K178, EPA selected a treatment standard for thallium equivalent to the UTS of 0.2 mg/L TCLP. The UTS was finalized in the 1998 Phase IV rule, developed from stabilization data. In the Phase IV rule, EPA expected that both high temperature metals recovery and stabilization technology would be expected to achieve the treatment standards.

Dioxins/Furans

In its development of UTS, EPA identified incineration as BDAT for tetra, penta, and hexa dioxin/furan constituents (EPA, 1994a). Incineration is expected to perform equally well in treating hepta- and octa- dioxin and furan compounds, based on their similar structure to the other dioxin and furan constituents.

BDAT for Nonwastewater Forms of K178: Conclusion

As shown by the treatment performance data identified above, stabilization or HTMR technology should result in levels of thallium to below the K178 treatment standards.

As shown from the data in Section 2 of this report, dioxins and furans would require treatment to meet the numerical treatment standards. While combustion would likely result in the reduction of these contaminants to below UTS, the general composition of the waste (i.e., with significant concentrations of noncombustible inorganic components) may result in large quantities of treatment residuals requiring further management. Additionally, while incineration destroys a significant percentage of these components, smaller quantities may be released to the air and result in cross-media impacts. Finally, additional treatment may be required to reduce the mobility of thallium in the waste.

As a result of these concerns, EPA has identified technologies potentially applicable to destroying dioxins or reducing their mobility, and simultaneously reducing the mobility of thallium and other metals (at the least, the presence of these metals are not expected to decrease the efficiency of the technology towards dioxins and furans). These technologies are identified in Appendix A. EPA, however, is not finalizing alternative treatment standards based on any of these technologies.

Treatment Standards

EPA is finalizing numerical treatment standards as follows. These are equivalent to promulgated UTS for thallium and the dioxin/furan congeners. These standards for K178 are as follows:

- Thallium: 0.20 mg/L TCLP
- The following chlorinated dibenzo-p-dioxins (CDDs) and dibenzo-p-furans (CDFs):
  - 1,2,3,4,6,7,8-Heptachlorodibenzo-*p*-dioxin: 0.0025 mg/kg
  - 1,2,3,4,6,7,8-Heptachlorodibenzofuran: 0.0025 mg/kg
  - 1,2,3,4,7,8,9- Heptachlorodibenzofuran: 0.0025 mg/kg
  - HxCDDs (All hexachlorodibenzo-*p*-dioxins): 0.001 mg/kg
  - HxCDFs (All hexachlorodibenzofurans): 0.001 mg/kg
  - 1,2,3,4,6,7,8,9-Octachlorodibenzo-*p*-dioxin (OCDD): 0.005 mg/kg
  - 1,2,3,4,6,7,8,9-Octachlorodibenzofuran (OCDF): 0.005 mg/kg
  - PeCDDs (All pentachlorodibenzo-*p*-dioxins): 0.001 mg/kg
  - PeCDFs (All pentachlorodibenzofurans): 0.001 mg/kg
  - TCDDs (All tetrachlorodi-benzo-*p*-dioxins): 0.001 mg/kg
  - TCDFs (All tetrachlorodibenzofurans): 0.001 mg/kg

Since numerical treatment levels are finalized for nonwastewater forms of K178, the use of any technology (other than impermissible dilution) is allowed in complying with the treatment standards. Therefore, facilities are not required to use the above treatment technology to manage nonwastewater forms of K178, and may find they can use an alternative treatment technology to meet the numerical treatment standards.

EPA selected an alternative treatment standard of combustion (CMBST) for K178. Combustion is the basis for the dioxin/furan numerical limits, and properly conducted combustion should effectively destroy dioxin/furan constituents. If this method of treatment is used to treat K178 in certain specified combustion devices,[6] there would be no need to monitor compliance with numerical limits established for dioxin/furan constituents. However, the other constituent (i.e., thallium) would require monitoring prior to land disposal.

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[6] The definition of CMBST is limited to: (1) combustion units operating under 40 CFR Part 266, (2) combustion units permitted under 40 CFR Part 264, Subpart O, or (3) combustion units operating under 40 CFR Part 265, Subpart O, which have obtained a determination of equivalent treatment under 40 CFR 268.42(b).

7.0 REFERENCES FOR SECTIONS 1 THROUGH 6

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APPENDIX A. REVIEW OF TECHNOLOGY ALTERNATIVES FOR THE TREATMENT OF K178 WASTE

1.0 Introduction

EPA is listing as hazardous waste No. K178. As identified in Section 3 of this report, constituents present in K178 waste (from the risk analysis or the LDR analysis) are dioxins/furans and thallium. Additionally, EPA initially proposed a treatment standard for manganese in this waste. EPA is deferring final action on this part of the proposal.

This appendix provides an overview of alternative technologies (other than incineration) with the potential to treat K178 waste. This review sought to identify individual technologies that potentially could (1) treat dioxins/furans, thallium, and manganese or (2) treat the dioxin/furan component without the metals interfering with the treatment system's effectiveness. None of the technologies have actually been applied to treating K178. However, based on review of these technologies, the most promising alternative technologies to simultaneously treat dioxin/furans and metals are as follows: vitrification, high temperature metals recovery, electrokinetic separation, and solvent extraction. A number of other technologies appear to be effective in treating the dioxin/furan component of the waste. This appendix retains information on the effectiveness of these treatment technologies towards manganese.

The primary sources of information for this review were the following:

- *EPA's Treatability Database*

  A database created by EPA's Risk Reduction Engineering Laboratory (RREL) that consolidates performance data for treatment technologies from a variety of literature sources. The database includes abstracts for each of the literature sources from which the performance data are taken.

- *EPA's Remediation and Characterization Innovative Technologies (REACH IT) database*

  An online searchable database that contains information about innovative and conventional technologies for treating hazardous waste. EPA REACH IT contains detailed information provided by technology vendors, EPA remedial project managers, and other federal and state project managers. EPA REACH IT is updated continuously and is available at the following site: http://www.epareachit.org/index3.html.

- *The Federal Remediation Technologies Roundtable Remediation Technologies Screening Matrix and Reference Guide, Version 3.0*

  A "yellow pages" of remediation technologies. It is intended to be used to screen and evaluate candidate cleanup technologies for contaminated installations and waste sites in order to assist remedial project managers (RPMs) in selecting a remedial alternative. This reference guide allows the reader to gather essential descriptive information on the respective technologies. It incorporates cost and performance data to the maximum extent available and focuses primarily on demonstrated technologies. It is available at the following site: http://www.frtr.gov/matrix2/top_page.html

- *Literature Search*. Other technologies applicable to the treatment of dioxins and furans in solid wastes were identified from a limited literature search.

2.0 Waste Profile

Table A–1 identifies several characteristics of the waste which would influence treatment. The waste would require treatment to reduce the mobility of thallium and reduce potential risks from dioxins and furans. In the past, EPA required that total levels of dioxins and furans meet UTS; technologies such as combustion or incineration typically were applied to meet these limits. While effective in meeting UTS and destroying organic constituents such as dioxins and furans, combustion may result in airborne emissions which could present further health risks. Therefore, EPA is investigating alternatives to combustion which may result in the reduction of the concentration and/or mobility of dioxins and furans, but without resulting in cross media impacts.

Table A–1. Characteristics of K178 Affecting Waste Treatment

Parameter	**Characteristic in K178**
Thallium	May require treatment to meet UTS of 0.20 mg/L TCLP. The maximum concentration in record sampling is 0.28 mg/L TCLP
Manganese	Total concentration 10,600 mg/kg (~1%) TCLP concentration 252 mg/L The proposed UTS for manganese is 3.6 mg/L TCLP

Parameter	**Characteristic in K178**
Chlorinated dibenzofurans	Levels of the octa furan congener exceeds UTS. The UTS for this congener is 5 ppb. OCDF was analyzed at 58 ppb.
Moisture content	60 percent
Generation volume	Thousands of tons per year, industry-wide

Source: EPA record sampling data from DuPont, Edgemoor DE.

Some of the characteristics identified in Table A–1 may present treatment difficulties; in other cases treatment data may be available only for wastes with different characteristics and would therefore present difficulties in interpreting available waste treatment data for combustion or for alternative technologies:

- Volume

  The waste is generated in high quantities (thousands of tons per year), and so a treatment technology must be capable of handling this quantity of waste.

- Moisture

  The waste has a high moisture content (60 percent). While this is not necessarily a difficulty, treatment data for many wastes are often limited to either fairly dry materials, or to materials with a much lower water content. Therefore, the performance of the technology for wastes with higher moisture content must be extrapolated, and may result in some uncertainty.

- Polychlorinated dibenzofuran content

  Levels of octachlorodibenzofuran (OCDF) are present at the highest concentrations, at levels up to 58 ppb (12 times its UTS). Existing performance data for many technologies are expressed in terms of the removal of other congeners or of the total concentration of dioxins or furans, rather than for OCDF. In particular, many studies have focused on the reduction of the levels of 2,3,7,8-TCDD and 2,3,7,8-TCDF, the two most toxic of the dioxins and furans. Fewer studies have examined the entire range of tetra- through octachlorinated dioxins and furans. The presence of four more chlorine atoms in OCDF relative to 2,3,7,8-TCDF has a marked effect on the toxicity of OCDF, as well as affecting its fate and transport in the environment. However, there are few data directly comparing the treatment or removal efficiencies for OCDF relative to the other dioxins and furans. Based on the structural similarities of the various dioxins and furan congeners, treatment performance data for these other congeners is expected to be similar to the expected treatment performance for OCDF.

  Based on the record sampling results, a technology would have to reduce OCDF levels by 12 times (i.e., 91+ percent destruction). Levels of dioxins and furans in the waste may actually be higher, to account for temporal variability.

- Treatment of other toxic contaminants

  In addition to octachlorodibenzofuran, the waste also contains mobile levels of manganese and thallium that present potential risks; treatment may be required to achieve the thallium and manganese treatment standards being promulgated for this waste. At a minimum, the metals should not interfere with any technology used in treating dioxins, and at best, these metals should be treated simultaneously to reduce their mobility in the treated waste.

3.0 Results of the Technology Review

The review of these sources found no individual technologies that have been applied to or tested on a waste with this specific combination of constituents (dioxins/furans, thallium, and manganese). It did, however, uncover several technology categories that (1) have been successfully applied both to wastes containing dioxins/furans and to separate waste streams containing metals (sometimes including thallium or manganese), (2) have been successfully applied to wastes containing dioxins/furans and also have the potential to treat metal-bearing waste, (3) have been successfully applied to wastes containing dioxins/furans and are unlikely to be made ineffective because of metals concentrations in the wastes, or (4) have been successfully applied to metal-bearing wastes and have the potential to treat dioxins/furans.

A total of ten technologies were identified and are described below. These technologies fall into three broad categories:

- Encapsulation: vitrification; solidification and stabilization.
- Destruction: dehalogenation; chemical oxidation/reduction; high temperature metals recovery; vacuum retorting; solvated electron technology.
- Extraction or separation: thermal desorption; electrokinetic separation; solvent extraction.

The descriptions include available performance data for the constituents of concern and a qualitative assessment of the potential for treating K178 waste. The data sources employed in this review are summarized at the end of this appendix, by technology.

4.0 Encapsulation Technologies

4.1 Vitrification

Vitrification processes employ heat (often using an electric current) to melt and convert waste materials into glass or crystalline matrices. The high temperatures can destroy organic constituents. Metals contained in the waste are incorporated into the glass/crystalline structure, which typically is resistant to leaching.

A number of vendors provide vitrification technologies that are generally similar in design. Vitrification has been demonstrated at least one Superfund site to achieve greater than 93.8 percent destruction of 2,3,7,8-tetracholorodibenzofuran and 89 to greater than 93.6 percent destruction of octachlorodibenzo-*p*-dioxin (Geosafe, 1991). At least two other vendors (McNeill, Ecogrind) have indicated that their vitrification technologies have been successfully applied for destruction of dioxins/furans, although no performance data were presented in the available sources for these applications. A number of other vendors also have indicated that their technologies are potentially applicable to dioxins/furans, although the technologies have not yet been demonstrated for this purpose.

No performance data are available on the effectiveness of vitrification technologies for encapsulating manganese and thallium. Vitrification, however, has been shown effective for encapsulating a wide range of other metals, including arsenic, barium, cadmium, chromium, copper, lead, mercury, nickel, vanadium, and zinc. Several vendors (Terra-VIT, PermaVIT) have indicated that their technologies should be applicable to waste containing up to 3 to 5 percent by weight manganese and up to 5 to 15 percent by weight thallium.

While vitrification has not been demonstrated for a waste containing this specific combination of constituents of concern, the limited available performance data suggest this technology is potentially applicable to K178. Most vitrification technologies, however, have been demonstrated only at the pilot scale, although a few vendors (PACT, McNeill, Seiler) have indicated that their technologies are sized and commercially available for full scale application. While vitrification most commonly is considered an *in-situ* soil remediation technology, most vendors have developed designs applicable to *ex-situ* soils and/or waste sludges.

4.2 Solidification and Stabilization

Solidification is the process by which contaminants are physically bound or enclosed within a stabilized mass. This is often accomplished by adding organic polymers to the waste. The polymers suspend the constituents of a solid waste rather than chemically binding them. As a result, any contaminants in the solidified mass may be subject to leaching by water passing through the mass.

Stabilization is the process by which chemical reactions are induced between a stabilizing agent and contaminants to reduce their mobility. Cement is commonly used to stabilize wastes. Cement is alkaline and, in addition to neutralizing the acidity of some waste, the alkaline components of the cement will bind many metals to some degree. Other than suspending the solids, cement stabilization does not affect any organic contaminants. Polymerization is similar to stabilization in that chemical reactions are induced between the contaminants in the waste and the polymer matrix.

The available literature and the databases identified in Section 1 were searched for applications of these technologies to dioxins and furans in wastes similar to K178. Based on review of these sources, there was very little information relevant to the effectiveness of these technologies in reducing the mobility of dioxins and furans in K178. Those studies that were identified during the review were found to have focused on the stabilization of various types of incinerator ash, a matrix with very different physical characteristics compared to the K178 waste.

5.0 Destruction Technologies

Technologies in this category involve the addition of chemical reagents to waste to destroy or detoxify organic constituents. Some technologies employ low levels of heat (80 to 450°C) in addition to chemical reagents to achieve the desired reaction.

5.1 Dehalogenation

Dehalogenation refers to techniques that remove halogen atoms (notably chlorine) from organic contaminants, resulting in nonhazardous or less toxic compounds.

The addition of dimethyl sulfoxide (DMSO) and potassium hydroxide (KOH), along with the application of heat at 80C for one hour, has been shown in the literature to achieve 74% destruction of total PCDDs, 99.42% destruction of octachlorodibenzo-*p*-dioxin, and 98.5% destruction of PCDFs (Tiernan, 1989).

Another technology employs alkaline polyethylene glycol reagents (APEGs). The KPEG reagent (potassium hydroxide and polyethylene glycol) has been used in many instances. The addition of KPEG and heating to 100C for 45 minutes has been shown to achieve 99.908 % destruction of total PCDDs and 99.926 % destruction of octachlorodibenzo-p-dioxin (Tiernan, 1989).

A third treatability study shows that the addition of various reagents and heat between 340 and 450°C can achieve 24 to 99.974 % destruction of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin, 0 to 99.89% destruction of 2,3,7,8-tetracholorodibenzofuran, and 97.4 to 99.973% destruction of octachlorodibenzo-*p*-dioxin (Peer Consultants, 1990).

Finally, the commercial vendor of a dechlorination technology has indicated that its process (Agent 313) has been demonstrated to reduce dioxins and furans in Love Canal soils to non-detect (parts per trillion) levels.

Although these chemical destruction technologies have not been tested on wastes that also contain metals, based on the available process descriptions, the presence of metals should not interfere with the effectiveness of the dioxin/furan destruction. However, these technologies, also are unlikely to have any effect on the metals content of K178 waste. Thus, they can be considered a potential approach for treating only the dioxin/furan component of the waste.

5.2 Chemical Oxidation/Reduction

Technologies in this category apply an oxidizing or reducing agent, typically in the presence of relatively high levels of heat, to convert hazardous contaminants into compounds that are less toxic, more stable, or less mobile. Four specific oxidation or reduction technologies are described below.

ECO LOGIC Process

This process involves the gas-phase reduction of organic compounds by hydrogen at temperatures of 850 to 900C in a thermal reduction mill equipped with a sequencing batch vaporizer. The process excludes oxygen and uses hydrogen to reduce organic compounds. While no quantitative performance data are available, the vendor states that chlorinated hydrocarbons, including dioxins/furans, are chemically reduced to primarily methane and hydrogen chloride (HCl). The HCl produced is removed in a caustic scrubber downstream of the process reactor as an industrial grade product. Any inorganic constituents (e.g., thallium and manganese) of the waste will either remain in the treated waste or exit as metal hydrides in the grit or scrubber sludge. Thus, this technology can be considered a potential approach for treating only the dioxin/furan component of K178.

Pulse Enhanced® Steam Reforming

This technology involves the injection of the material to be converted, along with steam, into a fluidized bed reactor to break down the molecular structure of organic materials. The constituents of the organic materials are then reformed into simple gases that can be used as fuels or feedstock for industrial processes. In certain applications, the fluid bed material is selected to either serve as a catalyst or as a sorbent. While no quantitative performance data are available, the vendor states that the technology has been used effectively for treatment of waste containing dioxins/furans. Based on the technology description, the presence of metals should not interfere with the effectiveness of the dioxin/furan destruction, but the technology also is unlikely to have any effect on the metals content of K178 waste. Thus, this technology can be considered a potential approach for treating only the dioxin/furan component of K178.

DETOX

This is a patented, catalyzed wet oxidation process that involves the nonthermal oxidation of organics with oxygen in a water solution. Products of the process typically are carbon dioxide, water, any inert solids contained in the waste, and a concentrated residue of any toxic metals as oxides or salts. While no quantitative performance data for dioxins/furans are available, the vendor states that the process can destroy all organic compounds except fluoropolymers. Destruction efficiencies in batch tests have been greater than 99.9999 %. The technology, therefore, appears to have the potential for treating the dioxin/furan component of K178. The vendor also states that the solution dissolves and concentrates arsenic, barium, beryllium, cadmium, cerium, chromium, lead, mercury, neodymium, nickel, vanadium, and other metals with chemical properties similar to these. No data for manganese or thallium are available to indicate whether the process would reduce the leachability of these metals in K178. Because the technology is intended to affect only organic compounds, further treatment (such as stabilization) may be required to reduce the mobility of metals in K178.

Catalytic Extraction Processing (CEP)

This technology was developed and commercially applied by Molten Metal Technology, which has since ceased operations. The CEP process is presently (2000) being licensed by Quantum Catalytics L.L.C., however it is not known whether any commercial sites are currently available. The CEP technology is believed to be in use at a government facility. CEP is a proprietary technology, at the core of which is a high-temperature molten metal bath. The liquid metal acts as a catalyst and solvent in dissociating the feed into its constituent elements. The catalytic effect of the molten metal causes complex compounds in the feed to be dissociated into their elements, which readily dissolve in the liquid metal solution. By adding select co-reactants and/or controlling process operating conditions, the dissolved elemental intermediates can be reacted to form desired products of commercial value. The process has been applied to wastes containing a variety of metals, including arsenic, cadmium, iron, lead, mercury, molybdenum, silver, uranium, vanadium, and zinc. While no performance data are available for wastes containing thallium or manganese, these constituents in K178 could potentially be bound in the process' ceramic or metallic products. The vendor states that the process is potentially applicable to wastes containing dioxins/furans, and that, in the treatment of other wastes containing organics, the process does not provide pathways for the formation of dioxins or furans in the off-gas. Presumably, dioxins/furans would be destroyed by the heat of the metal bath. Thus, while further investigation would be required to determine the processes applicability, this technology is potentially applicable to K178 waste.

5.3 High Temperature Metals Recovery

High Temperature Metals Recovery (HTMR) technologies apply heat (often in excess of 2,000°C) to waste using a flame burner or plasma torch, usually in an oxygen-enriched atmosphere. These processes typically result in a metallic alloy product and a ceramic slag. Inorganic constituents in the waste are either partitioned to the alloy product or bound in the slag in a non-leachable form. The high heat in HTMR reactors vaporizes and can destroy organic constituents in the waste.

In a test of a flash smelting HTMR process, leachable (TCLP) concentrations of manganese and thallium in the slag were reduced by 65% and 38 % respectively, from their initial TCLP concentrations in the waste (Versar, 1992). Performance data for manganese and thallium are not available for other HTMR technologies, but these technologies have been used to treat wastes containing a variety of other metals, including arsenic, cadmium, cobalt, copper, iron, lead, nickel, and zinc.

No performance data are available on the effectiveness of HTMR technologies for destroying dioxins/furans. Technology vendors, however, universally claim that their technologies are potentially applicable to wastes containing dioxins/furans. Two vendors (PEAT and MSE) report that their technologies have been successfully used to treat wastes containing both metals and halogenated organics other than dioxins/furans. Thus, while further investigation would be required to determine the processes' applicability, HTMR technology is potentially applicable to both the metals and dioxins/furans components of K178 waste.

5.4 Vacuum Retorting

Vacuum retorting is a process by which a waste is heated to a high temperature under a partial vacuum. The vacuum removes oxygen from contact with the waste, thereby minimizing oxidative reactions in the waste and eliminating the production of various products of incomplete combustion, including dioxins and furans, that characterize incineration processes.

The Sepradyne Corporation has developed and patented an indirectly heated, high temperature, high vacuum rotary kiln that has been used to treat dioxin-contaminated incinerator ash from a mixed waste (hazardous and radioactive) incinerator. In bench-scale tests at the Brookhaven National Laboratory, samples of a dioxin- and furan-containing incinerator ash were treated in experiments at 450C and 750C.

The concentrations of the total homologues of the dioxins and furans in the original ash ranged from 30 µg/kg for total TCDD to 565 µg/kg for total HpCDD and 78 µg/kg to 287 µg/kg for the total TCDF and total HpCDF. The penta- and hexa-chlorinated homologue totals fell in between the tetra and hepta concentrations listed above. No data were provided for OCDD or OCDF.

The concentrations of these homologues were reduced to “not detected” for the tetra- and pentachlorinated dioxins and furans at both treatment temperatures and the hexa- and heptachlorinated furans were reduced below the unspecified detections limits for the 450°C experiments. The concentrations of the hexachlorinated and heptachlorinated dioxins and furans were reduced to the range of 20 to 70 ng/kg (e.g., parts per trillion) for the 700°C experiments.

While these results show promise, the report on this study notes that additional treatment may be required to reduce the leachable metal concentrations below the toxicity characteristic levels. In addition, the bench-scale test involved an apparatus with a capacity of only 500-mL. Thus, the applicability of this technique may be limited to treating the dioxin/furan component of the K178 and would have to be evaluated on a much larger scale relative to the volume of K178 produced.

5.5 Solvated Electron Technology

Solvated electron technology (SET®) is a proprietary chemical process developed by Commodore Applied Technologies, Inc., for the destruction of organochlorine wastes. The process is based on the use of a solution of a reactive metal such as sodium in ammonia to treat halogen-containing contaminants.

In the mid-1800s, chemists discovered that dissolving a reactive alkaline-earth metal such as sodium, calcium, or lithium in ammonia resulted in a vivid blue solution. It was later determined that the blue color is due to the presence of free electrons in the solution. When contaminated soils or wastes are mixed with the ammonia-metal solution, these free electrons readily interact with halogen atoms, releasing them from the organic compounds and allowing them to react with the dissolved metal to form a salt such as sodium chloride. The ammonia from the solution is recycled and reused.

Commodore has received a PCB destruction permit from EPA for on-site soil treatment. The SET® process has been validated for the commercial-scale treatment of PCB-contaminated soils, solids, wet sludges, oils, wastewaters. According to information provided by the company, soils contaminated with PCBs, pesticides, dioxins, furans, and other contaminants at levels up to 10,000 mg/kg (10,000,000 : g/kg) have been treated and the contaminants reduced to less than 1 mg/kg.

The SET® process does not affect the metal concentrations in the material being treated, nor do metals appear to interfere with the destruction of organochlorine compounds. Thus, while this technology shows considerable promise for the treatment of the dioxin/furan constituents of the K178 waste on a large scale, it is unlikely to address either manganese or thallium.

6.0 Extraction/Separation Technologies

The goal of extraction or separation technologies is to selectively remove the contaminants of concern from the bulk of the waste material. When successful, these technologies can significantly reduce the volume of waste that is hazardous. Therefore, although the hazardous constituents may remain intact, they are present in a much smaller volume of material, thereby significantly lowering the cost of disposal relative to the original waste material.

6.1 Thermal Desorption

In thermal desorption, wastes are heated to volatilize water and organic constituents. The temperatures involved are such that organics are not destroyed, but are physically separated from the waste. The physically separated constituents are then transported to a gas treatment system.

Tests of a thermal desorption system developed by IT Corporation have been demonstrated to remove greater than 99.8 % of total PCDDs and from 65 to greater than 99.81 % of 2,3,7,8-tetrachlorodibenzo-*p*-dioxin, depending on the subject waste and operating conditions. Tests of another thermal desorption system (SAREX) at a Superfund site demonstrated removal of 62.5 to 99.7 % of dioxins and furans. At least three other vendors (Etts Ecotechniek, Thermatek, WRI) have indicated that their thermal desorption technologies have been successfully applied for removal of dioxins/furans, although no performance data were presented in the available sources for these applications.

While some thermal desorption technologies have been applied for removal of mercury, these technologies generally are not applicable for removal of less volatile metals such as thallium and manganese. The presence of metals, however, is unlikely to interfere with the effectiveness of dioxin/furan removal. Thus, this technology is potentially applicable to separate the dioxin/furan component of K178 waste for further treatment.

6.2 Electrokinetic Separation

Electrokinetic separation involves application of a low-intensity direct current through the waste medium using ceramic electrodes. The resulting electrochemical and electrokinetic processes desorb and then remove, metals and polar organics.

One vendor (Lynntech) has developed an electrokinetic separation technology at the pilot scale that has been demonstrated to achieve 99 % dioxin removal in field trials at Eglin Air Force Base. The Lynntech technology also has been used for removal of lead. No performance data, however, are available for other metals such as manganese and thallium. To date, the technology has been applied only to *in situ* and *ex situ* soil treatment, although the vendor states that it is adaptable to sludge and waste solids treatment. Thus, this technology is potentially applicable for removal of dioxins/furans and possibly metals from K178 waste, although further investigation and commercial development might be required.

6.3 Solvent Extraction

Solvent extraction applies a solvent to the waste matrix for removal of a targeted constituent or constituents. The specific solvent applied depends on the constituent targeted and the other physical and chemical characteristics of the waste.

Propane has been shown to remove 47 percent of octachlorodibenzo-*p*-dioxin from soils at a Superfund site (Weston, 1989). In another test, addition of a surfactant was shown to remove 98.6 to 99.31 % of PCDFs (Kuhn, undated). The vendor of a proprietary solvent extraction system (Terra-Kleen) reports that its technology has been used to treat wastes containing dioxins/furans, although no performance data are presented in the available sources.

Solvent extraction also has proven effective in removal of metals. Bench-scale tests on wastewater sludge have resulted in 46 to 97.5 % removal of manganese using mono-(2-ethyl hexyl) phosphoric acid and di-(2-ethyl hexyl) phosphoric acid (Cornell, *et al.*, not dated). No performance data are available for solvent extraction of thallium.

Finally, a commercial vendor (Solv-Ex) reports that its proprietary solvent extraction technology has been used to selectively remove both metals and halogenated organics from wastes. The vendor reports that the technology is potentially applicable to dioxins/furans, although it has not yet been applied for this purpose. Thus, solvent extraction is potentially applicable for removing both metals and dioxins/furan from K178 waste, although further investigation would be required to identify a series of solvents that would be effective.

7.0 Data Sources for Appendix A

The following is a list of the data sources that were employed during this review of alternative treatment technologies for the K178 waste. The sources are listed in the order in which the technologies are discussed above. For many of the technologies, there is a list of "other potential data sources." These other sources were those that were uncovered during the review process, but were not reviewed directly.

7.1 Encapsulation Technologies

Vitrification

Federal Remediation Technologies Roundtable Remediation Technologies Screening Matrix and Reference Guide, Version 3.0. Section 4.10: Solidification/Stabilization (in situ soil remediation technology).

Federal Remediation Technologies Roundtable Remediation Technologies Screening Matrix and Reference Guide, Version 3.0. Section 4.24: Solidification/Stabilization (ex situ soil remediation technology).

EPA REACH IT Database. Technology Overview: Plasma ARC Centrifugal (PACT) System.

EPA REACH IT Database. Technology Overview: Terra-VIT.

EPA REACH IT Database. Technology Overview: PERMAVIT.

EPA REACH IT Database. Technology Overview: Ecogrind.

EPA REACH IT Database. Technology Overview: McNeill Vitrification Process.

EPA REACH IT Database. Technology Overview: Seiler High Temperature Converter.

Geosafe Corp. "Engineering-Scale Test Report for Application of In Situ Vitrification Technology to Soils Contaminated with Polychlorinated Biphenyls at the Northwest Transformer Superfund Site." GSC 1006, Volume 1: Project Report, February 1991.

Other Potential Data Sources

Eschenbach, R.C. "Vitrification of PACT." Stabilization of Mixed Radioactive Waste, Williamsburg, Virginia, November 1993.

Hoeffelner, W., et al. "Plasma Technology for Rapid Oxidation and Vitrification." Nuclear Engineering International, October 1992.

Schienger, M.E., et al. "Waste Minimization with Plasma Processing." Waste Management ‘93, Tucson, Arizona, February 1993.

Warf, W.R., et al. "The Mobile PACT-2." Waste Management ‘93, Tuscon, Arizona, February 1993.

Yeast, T.F., et al. "Volatility Studies in a Rotating Hearth Furnace." 1994 American Nuclear Society Meeting, November 1994.

Balasco, A.A., et al. "Bench-Scale Glassification Test on Rocky Mountain Arsenal." USATHAMA Reference AMXTH-TE-CR 88015, August 1988.

Chapman, C.C. "Evaluation of Vitrifying Municipal Incinerator Ash." 5th International Symposium on Ceramics in Nuclear and Hazardous Waste Management, April 1991.

Janke, D.S. "Results of Vitrifying Fernald K-65 Residue." 5th International Symposium on Ceramics in Nuclear and Hazardous Waste Management, April 1991.

Klinger, L.M. "Glass Furnace Processing of Rocky Flats Plant Wastes." MLM-3493, April 1988.

Koegler, S.S., et al. "Vitrification Technologies for Weldon Spring Raffinate Sludge." PNL-7125, November 1989.

Merrill, R.A., et al. "Results of Vitrifying Fernald OU-4 Wastes." Waste Management ‘93, Tucson, Arizona, March 1993.

Bryan, Jeremy. "The McNeill Vitrification Process." European Waste Management Conference, Denmark, May 1992.

Waring, Steve. "Gas Cleanup Requirements for Soil Vitrification Plant." Atomic Energy Authority, April 1990.

Weber, Eric J. "Vitrification Technology Targeted at Site Cleanups." EI Digest, May 1994.

EPA. "Silicate Technology Corporation Solidification/Stabilization of Organic/Inorganic Contaminants." RREL, Demonstration Bulletin, EPA/540/MR-92/010; Applications Analysis, EPA/540/AR-92/010, PB93-172948. 1992.

U.S. Atomic Energy Commission. "Plasma Arc Technology Evaluation." Innovative Technology Demonstration, Evaluation and Transfer Activities, FY 96 Annual Report, Report No. SFIM-AEC-ET-CR-97013, 1997.

Wittle, J.K., et al. "Graphite Electrod DC Arc Technology Program for Buried Waste Treatment." Electro-Pyrolysis, Inc., Wayne, Pennsylvania, 1995.

Campbell, B.E., et al. "Large-scale Commercial Application of the In-situ Vitrification Remediation Technology." Superfund XV Conference Proceedings, Volume 1, Hazardous Materials Control Resources Institute, Rockville, Maryland, 1994.

7.2 Destruction Technologies

<u>Dehalogenation</u>

EPA REACH IT Database. Technology Overview: Agent 313.

Tiernan, T.O., et al. "Laboratory and Field Tests to Demonstrate the Efficiency of KPEG Reagent for Detoxification of Hazardous Wastes Containing Polychlorinated Dibenzo-*p*-Dioxins (PCDD) and Dibenzofurans (PCDF) and Soils Contaminated with Such Chemical Wastes." Chemosphere, Vol. 18, pp 835–841, 1989.

Peer Consultants, P.C. "Treatability Study of the Base Catalyzed Decomposition Process, Jacksonville & Rogers Road Landfills, Jacksonville, Arkansas." Document Control Number 01/09-FS1-TS-290, 12300 Twinbrook Parkway, Rockville, Maryland, December 1990.

Chemical Oxidiation/Reduction

Federal Remediation Technologies Roundtable Remediation Technologies Screening Matrix and Reference Guide, Version 3.0. Section 4.18: Chemical Reduction/Oxidation (ex situ soil remediation technology).

EPA REACH IT Database. Technology Overview: Eco Logic Process.

EPA REACH IT Database. Technology Overview: PulseEnhanced (TM) Steam Reforming.

EPA REACH IT Database. Technology Overview: DETOX (SM).

EPA REACH IT Database. Technology Overview: Catalytic Extraction Process (CEP).

Other Potential Data Sources

Hallett, D.J., et al. "The ECO LOGIC Process: A Gas-Phase Chemical Reduction Process for PCBs." U.S. EPA 5th Forum on Innovative Hazardous Waste Treatment Technologies, May 1994.

Hallett, D.J., et al. "The ECO LOGIC Gas-Phase Chemical Reduction Process." 1994 Superfund XV Conference and Exhibition, November 1994.

Kimbell, D.G., et al. "The ECO LOGIC Process: New Developments and Applications." Canadian Electricity Forum, 8th Annual Industry and PCBs Forum, September 1994.

Duraiswamy, K., et al. "Indirect Steam Gasification of Paper Mill Sludge Waste." TAPPI Journal, pp. 137–143, October 1991.

Mansour, M.N., et al. "Pulsed Combustion Process for Black Liquor Gasification." DOE/CE/40893-T2, February 1993.

Dhooge, P., et al. "Catalytic Wet Oxidation for Cleanup of Gaseous Emissions." Proceedings of the 1995 International Incineration Conference, University of California: Irvine, May 1995.

Dhooge, P., et al. "Engineering Development and Demonstration of Detox(sm) Wet Oxidation for Mixed Waste Treatment." Proceedings of the 1997 Symposium on Waste Management, March 1997.

Goldblatt, S., et al. "Engineering Design and Test Plan for Demonstrating Detox(sm) Treatment of Mixed Wastes." Proceedings of the 1995 Symposium on Waste Management, March 1995.

Goldblatt, S., et al. "Representative Waste Types, Estimated Emissions, Permitting Issues, and Operational Safety for Demonstration of Detox(sm) Wet Oxidation." Proceedings of the 1996 Symposium on Waste Management, February 1996.

Nagel, C.J., et al. "Catalytic Extraction Processing: An Elemental Recycling Technology." Environmental Science and Technology, 1996.

Evans, L., et al. "Processing Mixed Waste via Quantum-CEP, A Case Study." ASME/EPRI Radwaste Workshop, July 1997.

Mather, R., et al. "Molten Metal Processes Reap Profit from Waste." Environmental Engineering World, May 1996.

High Temperature Metals Recovery

EPA REACH IT Database. Technology Overview: Plasma Energy Applied Technology (PEAT) Thermal Destruction and Recovery (TDR).

EPA REACH IT Database. Technology Overview: MSE Plasma High Temperature Recovery.

EPA REACH IT Database. Technology Overview: Horsehead Resource Development (HRD) Flame Reactor

Versar, Inc. "Final Onsite Engineering Report for the High Temperature Metals Recovery Test of Soil from C&R Battery Site, Chesterfield County, Virginia." 6850 Versar Center, Springfield, Virginia, May 1992.

Other Potential Data Sources

Springer, M.D., et al. "A Versatile Thermal Destruction and Recovery System." ACS Symposium Emerging Technologies in Hazardous Waste Management, September 1994.

Fillius, K., et al. "Results of High Metal Content Waste Demonstrations in a Plasma Centrifugal Furnace, Document PTP-4, MSE Inc." DOE Western Environmental Technology Office, Butte, Montana, June 1995.

EPA. "Retech Inc., Plasma Centrifugal Furnace Applications Report." EPA Superfund Innovative Technology Evaluation Report, EPA/540/A5-91/007, June 1992.

Bounds, C.O., et al. "EAF Dust Processing in the Gas-Fired Flame Reactor Process." TMS-AIME, Lead-Zinc-Tin ‘90 World Symposium, February 1990.

Zagrocki, R.J., et al. "The HRD Flame Reactor Process for the Treatment of Contaminated Soils." Air and Waste Management Association 85th Meeting, June 1992.

Vacuum Retorting

Adams, J.W., *et al.* "Sepradyne/Raduce High Vacuum Thermal Process for Destruction of Dioxins in INEEL/WERF Fly Ash." Report of Work Conducted by the Department of Advanced Technology, Environmental & Waste Technoloy Group, Brookhaven National Laboratory, Upton, NY, August 2, 1999.

Solvated Electron Technology

Commodore Applied Technologies, Inc., web site: http://www.commodore.com

Other Potential Data Sources

Abel, Albert E. "Solvated Electron Chemistry Achieves Breakthrough Waste Detoxification." Presented at I&EC Special Symposium, September 1995.

Abel, Albert E. "PCB Destruction in Soils using Solvated Electrons." Presented to the American Institute of Chemical Engineers, August 1995.

Abel, Albert E, et al. "Commercial Systems for Selective and Full Destruction of CFCs and Halons." Presented at the International CFC and Halon Alternatives Conference, October 1995.

7.3 Extraction/Separation

Thermal Desorption

Federal Remediation Technologies Roundtable Remediation Technologies Screening Matrix and Reference Guide, Version 3.0. Section 4.29: Thermal Desorption (*ex situ* soil remediation technology).

EPA REACH IT Database. Technology Overview: IT Corporation Thermal Desorption System.

EPA REACH IT Database. Vendor Source Site Data: NCBC Gulfport.

EPA REACH IT Database. Technology Overview: SAREX MX-1500, MX-2000/2500/3000 Thermal Processor.

EPA REACH IT Database. Vendor Source Site Data: Koppers Company.

EPA REACH IT Database. Technology Overview: Thermatek.

EPA REACH IT Database. Technology Overview: Thermall Corp. Thermal Desorption Process.

EPA REACH IT Database. Technology Overview: Etts Ecotechniek Thermal Treatment System.

EPA REACH IT Database. Technology Overview: Western Research Institute (WRI) Thermal Treatment Using Screw Reactors.

Helsel, R., et al. "Technology Demonstration of a Thermal Desorption/UV Photolysis Process for Decontaminating Soils Containing Herbicide Orange." I.T. Corporation, Knoxville, Tennessee, June 1987.

Other Potential Data Sources

Alperin, E.S., et al. "Soils, Removal of Toxics." Encyclopedia of Chemical Processing and Design, Volume 51, 1995.

Alperin, E.S. "Thermal Treatment of Mixed Waste Sludges." Proceedings of American Institute of Chemical Engineers Summer National Conference, August 1992.

Fox, R.D., et al. "Thermal Treatment for the Removal of PCBs and Other Organics." Environmental Progress, pp 40–44, February 1991.

Morris, M., et al. "Bench- and Pilot-Scale Demonstration of Thermal Desorption." Proceedings of Waste Management 1995, Tucson, Arizona, February 1995.

Miller, Bradford H. "Thermal Desorption Experience in Treating Refinery Waste." 1993 Incineration Conference, May 1993.

Miller, Bradford H., et al. "Remediation Using Indirect Heated Thermal Desorption." HAZMACON 94, San Jose, California, March 29–31, 1994.

Sheehan, William. "Thermal Desorption Utilizing Hollow Screw Technology." 1992 Incineration Conference, Session 15, May 1992.

McCabe, M., et al. "Managing Petroleum Refining Wastes by Thermal Desorption." Remediation Magazine, December 1991.

Abrishamian, R. "Thermal Desorption of Oily Soils and Sludges, Air and Waste." Incinerable Hazardous Waste Minimization Workshop, January 1, 1991.

Schuler, C., et al. "Thermal Treatment of Soil Contaminated with Halogenated Hydrocarbons." Ecotechniek, July 1993.

Electrokinetic Separation

Federal Remediation Technologies Roundtable Remediation Technologies Screening Matrix and Reference Guide, Version 3.0. Section 4.6: Electrokinetic Separation (in situ soil remediation technology).

EPA REACH IT Database. Technology Overview: Lynntech Electrokinetic Remediation Technique.

Other Potential Data Sources

EPA. "Recent Development for In Situ Treatment of Metal Contaminated Soil." Office of Solid Waste and Emergency Response, Technology Innovation Office, Washington, D.C., 1996.

U.S. Atomic Energy Commission. "In-situ Electrokinetic Remediation for Metal Contaminated Soils." Innovative Technology Demonstration, Evaluation and Transfer Activities, FY 96 Annual Report, Report No. SFIM-AEC-ET-CR-97013, 1997.

U.S. Department of Energy. "Electrokinetic Remediation of Heavy Metals and Radionuclides." Technology Catalogue, Second Edition. Office of Environmental Management Office of Technology Development. DOE/EM-2035, 1995.

Solvent Extraction

EPA REACH IT Database. Technology Overview: Terra-Kleen Solvent Extraction Unit.

EPA REACH IT Database. Technology Overview: Solv-Ex.

Kuhn, R.C. and Piontek, K.R. "A Site Specific *In Situ* Treatment Process Development Program for a Wood Preserving Site, CH2M-Hill, Denver, CO. Not dated.

Cornell, D.A., et al. "Batch Feasibility Testing for Heavy Metals Removal from Wastewater Sludges with Liquid Ion Exchange." Not dated.

Weston. "Feasibility Study Amendment, Preferred Alternatives Analysis, United Creosoting Superfund Site." Texas Water Commission, Austin, Texas, September 1989.

Other Potential Data Sources

Cash, A. "Full Scale PCB Soil Remediation Treatment with Solvent Extraction." PCB Remediation Conference, Boston, Massachusetts, September 1995.

Cash, A.B. "Full Scale Solvent Extraction Remedial Results." I&ED Symposium, American Chemical Society, September 1993.

Cash, A.B. "Removal of Chlorinated Pesticides from Soil." I&ED Symposium, American Chemical Society, September 1993.

Cash, et al. "Solvent Extraction for the Remediation of Soils." Environmental Geotechnology, May 1992.

Engle, et al. "Solvent Extraction of PCB-Contaminated Soils Using Terra-Kleen." HMCRI Superfund, Washington, D.C., December 1994.

EPA. "Terra-Kleen Solvent Extraction." EPA Superfund Innovative Technology Evaluation, May 1996.