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# Best Demonstrated Available Technology (BDAT) Background Document for K046

Proposed

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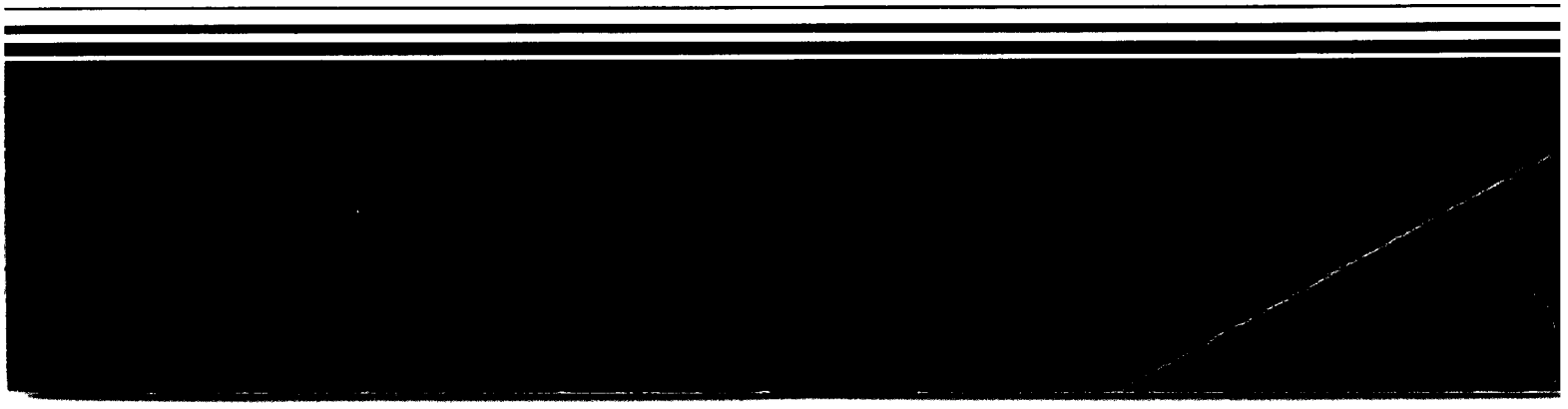

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# PROPOSED

# BEST DEMONSTRATED AND AVAILABLE TECHNOLOGY (BDAT)

# BACKGROUND DOCUMENT

# FOR K046

VOLUME 11

U.S. Environmental Protection Agency
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May 1988

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# EXECUTIVE SUMMARY

## BDAT Treatment Standards for K046

Pursuant to the Hazardous and Solid Waste Amendments (HSWA) enacted on November 8, 1984, and in accordance with the procedures for establishing treatment standards under section 3004 (m) of the Resource Conservation and Recovery Act (RCRA), the Environmental Protection Agency (EPA) is proposing treatment standards for the listed waste K046 based on the performance of treatment technologies determined by the Agency to represent Best Demonstrated Available Technology (BDAT). This background document provides the detailed analyses that support this determination.

These BDAT treatment standards represent instantaneous maximum acceptable concentration levels for selected hazardous constituents in the TCLP extracts of wastes or residuals from treatment and/or recycling. These levels are established as a prerequisite for disposal of these wastes in units designated as land disposal units according to 40 CFR Part 268. Wastes which, as generated, contain the regulated constituents at concentrations which do not exceed the treatment standards are not restricted from land disposal units. The Agency has chosen to set levels for these wastes rather than designating the use of a specific treatment technology. The Agency believes that this

allows the generators of these wastes a greater degree of flexibility in selecting a technology or train of technologies that can achieve these levels. These standards become effective as of August 8, 1988, as described in the schedule set forth in 40 CFR 268.10.

According to 40 CFR 261.32 (hazardous wastes from specific sources) waste code K046 is from the explosives industry and is listed as follows:

K046: Wastewater treatment sludges from the manufacturing, formulation, and loading of lead-based initiating compounds.

Descriptions of the industry and specific processes generating this waste, as well as descriptions of the physical and chemical waste characteristics, are provided in Section 2.0 of this document. The four digit Standard Industrial Classification (SIC) code most often reported for the industry generating this waste code is 2892 (explosives industry). The Agency estimates that 62 facilities in the United States are actively involved in the manufacture, formulation, and loading of lead-based initiating compounds and could generate K046 waste.

The Agency has examined the sources of this waste from the explosives industry, the waste composition, potential applicable and demonstrated technologies, and treatment performance, and has determined that this waste represents a separate waste

treatability group. While the Agency has not, at this time, specifically identified additional wastes which would fall into this treatability group, this does not preclude the Agency from using the treatment performance data used to establish these standards to establish standards for other similar wastes in the future.

The K046 waste, as generated, is typically classified as a nonwastewater. The Agency has proposed BDAT treatment standards for K046 waste. These treatment standards have been proposed for one (1) BDAT list metal constituent (lead). A detailed discussion of the selection of constituents to be regulated is presented in Section 5.0 of this document.

BDAT treatment standards for nonwastewater K046 are proposed based on performance data from a treatment system which consisted of stabilization using a Portland cement binder. Testing was performed on representative samples of K046. Stabilization using a Portland cement binder was determined to represent the best demonstrated available technology (BDAT). This determination was based on a statistical comparison of performance data. The Agency collected performance data for treatment technologies including stabilization using Portland cement, kiln dust, and lime/flyash binders. A statistical comparison was done of the performance data from these three stabilization technologies. Based on this analysis, the Agency has determined that the data

for stabilization using a Portland cement binder indicated the highest level of performance.

The following table lists the specific BDAT treatment standards for wastes identified as K046. The Agency is setting standards based on analyses of TCLP extracts for stabilized K046 nonwastewater. The units for TCLP extract analysis are expressed on a weight per unit volume basis (mg/l).

Testing procedures are specifically identified in the quality assurance sections of this document. The quality assurance analyses conducted indicate the validity of the testing done and the conclusions made.

BDAT TREATMENT STANDARDS FOR K046 WASTE

NONWASTEWATER

| Regulated Constituents | TCLP Extract (mg/l) |
|---|---|
| | K046 |
| Lead | 0.176 |

# 1. INTRODUCTION

This section of the background document presents a summary of the legal authority pursuant to which the BDAT treatment standards were developed, a summary of EPA's promulgated methodology for developing BDAT, and finally a discussion of the petition process that should be followed to request a variance from the BDAT treatment standards.

## 1.1 Legal Background

### 1.1.1 Requirements Under HSWA

The Hazardous and Solid Waste Amendments of 1984 (HSWA), enacted on November 8, 1984, impose substantial new responsibilities on those who handle hazardous waste. In particular, the amendments require the Agency to promulgate regulations that restrict the land disposal of untreated hazardous wastes. In its enactment of HSWA, Congress stated explicitly that "reliance on land disposal should be minimized or eliminated, and land disposal, particularly landfill and surface impoundment, should be the least favored method for managing hazardous wastes" (RCRA section 1002(b)(7), 42 U.S.C. 6901(b)(7)).

One part of the amendments specifies dates on which particular groups of untreated hazardous wastes will be prohibited from land disposal unless "it has been demonstrated to the Administrator, to a reasonable degree of certainty, that there will be no migration of hazardous constituents from the disposal unit or injection zone for as long as the wastes remain hazardous" (RCRA sections 3004(d)(1), (e)(1), (g)(5), 42 U.S.C. 6924 (d)(1), (e)(1), (g)(5)).

For the purpose of the restrictions, HSWA defines land disposal "to include, but not be limited to, any placement of ... hazardous waste in a landfill, surface impoundment, waste pile, injection well, land treatment facility, salt dome formation, salt bed formation, or underground mine or cave" (RCRA section 3004(k), 42 U.S.C. 6924 (k)). Although HSWA defines land disposal to include injection wells, such disposal of solvents, dioxins, and certain other wastes, known as the California List wastes, is covered on a separate schedule (RCRA section 3004(f)(2), 42 U.S.C. 6924 (f)(2)). This schedule requires that EPA develop land disposal restrictions for deep well injection by August 8, 1988.

The amendments also require the Agency to set "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), 42 U.S.C. 6924 (m)(1)). Wastes that meet treatment standards established by EPA are not prohibited and may be land disposed. In setting treatment standards for listed or characteristic wastes, EPA may establish different standards for particular wastes within a single waste code with differing treatability characteristics. One such characteristic is the physical form of the waste. This frequently leads to different standards for wastewaters and nonwastewaters.

Alternatively, EPA can establish a treatment standard that is applicable to more than one waste code when, in EPA's judgment, all the waste can be treated to the same concentration. In those instances where a generator can demonstrate that the standard promulgated for the generator's waste cannot be achieved, the Agency also can grant a variance from a treatment standard by revising the treatment standard for that particular waste through rulemaking procedures. (A further discussion of treatment variances is provided in Section 1.3.)

The land disposal restrictions are effective when promulgated unless the Administrator grants a national variance and establishes a different date (not to exceed 2 years beyond the statutory deadline) based on "the earliest date on which adequate alternative treatment, recovery, or disposal capacity

which protects human health and the environment will be available" (RCRA section 3004(h)(2), 42 U.S.C. 6924 (h)(2)).

If EPA fails to set a treatment standard by the statutory deadline for any hazardous waste in the First Third or Second Third of the schedule (see section 1.1.2), the waste may not be disposed in a landfill or surface impoundment unless the facility is in compliance with the minimum technological requirements specified in section 3004(o) of RCRA. In addition, prior to disposal, the generator must certify to the Administrator that the availability of treatment capacity has been investigated and it has been determined that disposal in a landfill or surface impoundment is the only practical alternative to treatment currently available to the generator. This restriction on the use of landfills and surface impoundments applies until EPA sets a treatment standard for the waste or until May 8, 1990, whichever is sooner. If the Agency fails to set a treatment standard for any ranked hazardous waste by May 8, 1990, the waste is automatically prohibited from land disposal unless the waste is placed in a land disposal unit that is the subject of a successful "no migration" demonstration (RCRA section 3004(g), 42 U.S.C. 6924(g)). "No migration" demonstrations are based on case-specific petitions that show there will be no migration of hazardous constituents from the unit for as long as the waste remains hazardous.

### 1.1.2 Schedule for Developing Restrictions

Under Section 3004(g) of RCRA, EPA was required to establish a schedule for developing treatment standards for all wastes that the Agency had listed as hazardous by November 8, 1984. Section 3004(g) required that this schedule consider the intrinsic hazards and volumes associated with each of these wastes. The statute required EPA to set treatment standards according to the following schedule:

(a) Solvents and dioxins standards must be promulgated by November 8, 1986;

(b) The "California List" must be promulgated by July 8, 1987;

(c) At least one-third of all listed hazardous wastes must be promulgated by August 8, 1988 (First Third);

(d) At least two-thirds of all listed hazardous wastes must be promulgated by June 8, 1989 (Second Third); and

(e) All remaining listed hazardous wastes and all hazardous wastes identified as of November 8, 1984, by one or more of the characteristics defined in 40 CFR Part 261 must be promulgated by May 8, 1990 (Third Third).

The statute specifically identified the solvent wastes as those covered under waste codes F001, F002, F003, F004, and F005; it identified the dioxin-containing hazardous wastes as those covered under waste codes F020, F021, F022, and F023.

Wastes collectively known as the California List wastes, defined under section 3004(d) of RCRA, are liquid hazardous wastes containing metals, free cyanides, PCBs, corrosives (i.e.,

a pH less than or equal to 2.0), and any liquid or non-liquid hazardous waste containing halogenated organic compounds (HOCs) above 0.1 percent by weight. Rules for the California List were proposed on December 11, 1986, and final rules for PCBs, corrosives, and HOC-containing wastes were established August 12, 1987. In that rule, EPA elected not to establish standards for metals. Therefore, the statutory limits became effective.

On May 28, 1986, EPA published a final rule (51 FR 19300) that delineated the specific waste codes that would be addressed by the First Third, Second Third, and Third Third. This schedule is incorporated into 40 CFR 268.10, .11, and .12.

## 1.2 Summary of Promulgated BDAT Methodology

In a November 7, 1986, rulemaking, EPA promulgated a technology-based approach to establishing treatment standards under section 3004(m). Section 3004(m) also specifies that treatment standards must "minimize" long- and short-term threats to human health and the environment arising from land disposal of hazardous wastes.

Congress indicated in the legislative history accompanying the HSWA that "[t]he requisite levels of [sic] methods of treatment established by the Agency should be the best that has

been demonstrated to be achievable," noting that the intent is "to require utilization of available technology" and not a "process which contemplates technology-forcing standards" (Vol. 130 Cong. Rec. S9178 (daily ed., July 25, 1984)). EPA has interpreted this legislative history as suggesting that Congress considered the requirement under 3004(m) to be met by application of the best demonstrated and achievable (i.e., available) technology prior to land disposal of wastes or treatment residuals. Accordingly, EPA's treatment standards are generally based on the performance of the best demonstrated available technology (BDAT) identified for the hazardous constituents. This approach involves the identification of potential treatment systems, the determination of whether they are demonstrated and available, and the collection of treatment data from well-designed and well-operated systems.

The treatment standards, according to the statute, can represent levels or methods of treatment, if any, that substantially diminish the toxicity of the waste or substantially reduce the likelihood of migration of hazardous constituents. Wherever possible, the Agency prefers to establish BDAT treatment standards as "levels" of treatment (i.e., performance standards) rather than adopting an approach that would require the use of specific treatment "methods." EPA believes that concentration-based treatment levels offer the regulated community greater flexibility to develop and implement compliance

strategies as well as an incentive to develop innovative technologies.

### 1.2.1 Waste Treatability Group

In developing the treatment standards, EPA first characterizes the waste(s). As necessary, EPA may establish treatability groups for wastes having similar physical and chemical properties. That is, if EPA believes that wastes represented by different codes could be treated to similar concentrations using identical technologies, the Agency combines the codes into one treatability group. EPA generally considers wastes to be similar when they are both generated from the same industry and from similar processing stages. In addition, EPA combines two separate wastes into the same treatability group when data are available showing that the waste characteristics affecting performance are similar or that one waste would be expected to be less difficult to treat.

Once the treatability groups have been established, EPA collects and analyzes data on identified technologies used to treat the wastes in each treatability group. The technologies evaluated must be demonstrated on the waste or a similar waste and must be available for use.

### 1.2.2 Demonstrated and Available Treatment Technologies

Consistent with legislative history, EPA considers demonstrated technologies to be those that are commercially used to treat the waste of interest or a similar waste with regard to parameters that affect treatment selection (see November 7, 1986, 51 FR 40572). EPA also will consider as treatment those technologies used to separate or otherwise process chemicals and other materials. Some of these technologies clearly are applicable to waste treatment, since the wastes are similar to raw materials processed in industrial applications.

For most of the waste treatability groups for which EPA will promulgate treatment standards, EPA will identify demonstrated technologies either through review of literature related to current waste treatment practices or on the basis of information provided by specific facilities currently treating the waste or similar wastes.

In cases where the Agency does not identify any facilities treating wastes represented by a particular waste treatability group, EPA may transfer a finding of demonstrated treatment. To do this, EPA will compare the parameters affecting treatment selection for the waste treatability group of interest to other wastes for which demonstrated technologies already have been determined. The parameters affecting treatment selection and

their use for this waste are described in Section 3.2 of this document. If the parameters affecting treatment selection are similar, then the Agency will consider the treatment technology also to be demonstrated for the waste of interest. For example, EPA considers rotary kiln incineration a demonstrated technology for many waste codes containing hazardous organic constituents, high total organic content, and high filterable solids content, regardless of whether any facility is currently treating these wastes. The basis for this determination is data found in literature and data generated by EPA confirming the use of rotary kiln incineration on wastes having the above characteristics.

If no commercial treatment or recovery operations are identified for a waste or wastes with similar physical or chemical characteristics that affect treatment selection, the Agency will be unable to identify any demonstrated treatment technologies for the waste, and, accordingly, the waste will be prohibited from land disposal (unless handled in accordance with the exemption and variance provisions of the rule). The Agency is, however, committed to establishing treatment standards as soon as new or improved treatment processes are demonstrated (and available).

Operations only available at research facilities will not be considered in identifying demonstrated treatment technologies for a waste because these technologies would not necessarily be

commercially available. Nevertheless, EPA may use data generated at research facilities in assessing the performance of demonstrated technologies.

As discussed earlier, Congress intended that technologies used to establish treatment standards under Section 3004(m) be not only "demonstrated," but also available. To decide whether demonstrated technologies may be considered "available," the Agency determines whether they (1) are commercially available, (2) substantially diminish the toxicity of the waste or substantially reduce the likelihood of migration of hazardous constituents from the waste.

EPA will only set treatment standards based on a technology that meets the above criteria. Thus, the decision to classify a technology as "unavailable" will have a direct impact on the treatment standard. If the best technology is unavailable, the treatment standard will be based on the next best treatment technology determined to be available. To the extent that the resulting treatment standards are less stringent, greater concentrations of hazardous constituents in the treatment residuals could be placed in land disposal units.

There also may be circumstances in which EPA concludes that for a given waste none of the demonstrated treatment technologies are "available" for purposes of establishing the 3004(m)

treatment performance standards. Subsequently, these wastes will be prohibited from continued placement in or on the land unless managed in accordance with applicable exemptions and variance provisions. The Agency is, however, committed to establishing new treatment standards as soon as new or improved treatment processes become "available."

(1) Proprietary or Patented Processes. If the demonstrated treatment technology is a proprietary or patented process that is not generally available, EPA will not consider the technology in its determination of the treatment standards. EPA will consider proprietary or patented processes available if it determines that the treatment method can be purchased or licensed from the proprietor or is commercially available treatment. The services of the commercial facility offering this technology often can be purchased even if the technology itself cannot be purchased.

(2) Substantial Treatment. To be considered "available," a demonstrated treatment technology must "substantially diminish the toxicity" of the waste or "substantially reduce the likelihood of migration of hazardous constituents" from the waste in accordance with section 3004(m). By requiring that substantial treatment be achieved in order to set a treatment standard, the statute ensures that all wastes are adequately treated before being placed in or on the land and ensures that the Agency does not require a treatment method that provides

little or no environmental benefit. Treatment will always be deemed substantial if it results in nondetectable levels of the hazardous constituents of concern. If nondetectable levels are not achieved, then a determination of substantial treatment will be made on a case-by-case basis. This approach is necessary because of the difficulty of establishing a meaningful guideline that can be applied broadly to the many wastes and technologies to be considered. EPA will consider the following factors in an effort to evaluate whether a technology provides substantial treatment on a case-by-case basis:

(a) Number and types of constituents treated;

(b) Performance (concentration of the constituents in the treatment residuals); and

(c) Percent of constituents removed.

If none of the demonstrated treatment technologies achieve substantial treatment of a waste, the Agency cannot establish treatment standards for the constituents of concern in that waste.

### 1.2.3 Collection of Performance Data

Performance data on the demonstrated available technologies are evaluated by the Agency to determine whether the data are representative of well-designed and well-operated treatment systems. Only data from well-designed and well-operated systems

are included in determining BDAT. The data evaluation includes data already collected directly by EPA and/or data provided by industry. In those instances where additional data are needed to supplement existing information, EPA collects additional data through a sampling and analysis program. The principal elements of this data collection program are: (a) identification of facilities for site visits, (b) engineering site visit, (c) Sampling and Analysis Plan, (d) sampling visit, and (e) Onsite Engineering Report.

(1) Identification of Facilities for Site Visits. To identify facilities that generate and/or treat the waste of concern, EPA uses a number of information sources. These include Stanford Research Institute's Directory of Chemical Producers, EPA's Hazardous Waste Data Management System (HWDMS), the 1986 Treatment, Storage, Disposal Facility (TSDF) National Screening Survey, and EPA's Industry Studies Data Base. In addition, EPA contacts trade associations to inform them that the Agency is considering visits to facilities in their industry and to solicit assistance in identifying facilities for EPA to consider in its treatment sampling program.

After identifying facilities that treat the waste, EPA uses this hierarchy to select sites for engineering visits: (1) generators treating single wastes on site; (2) generators treating multiple wastes together on site; (3) commercial

treatment, storage, and disposal facilities (TSDFs); and (4) EPA in-house treatment. This hierarchy is based on two concepts: (1) to the extent possible, EPA should develop treatment standards from data produced by treatment facilities handling only a single waste, and (2) facilities that routinely treat a specific waste have had the best opportunity to optimize design parameters. Although excellent treatment can occur at many facilities that are not high in this hierarchy, EPA has adopted this approach to avoid, when possible, ambiguities related to the mixing of wastes.

When possible, the Agency will evaluate treatment technologies using commercially operated systems. If performance data from properly designed and operated commercial treatment methods for a particular waste or a waste judged to be similar are not available, EPA may use data from research facilities operations. Whenever research facility data are used, EPA will explain why such data were used in the preamble and background document and will request comments on the use of such data.

Although EPA's data bases provide information on treatment for individual wastes, the data bases rarely provide data that support the selection of one facility for sampling over another. In cases where several treatment sites appear to fall into the same level of the hierarchy, EPA selects sites for visits strictly on the basis of which facility could most expeditiously

be visited and later sampled if justified by the engineering visit.

(2) Engineering Site Visit. Once a treatment facility has been selected, an engineering site visit is made to confirm that a candidate for sampling meets EPA's criteria for a well-designed facility and to ensure that the necessary sampling points can be accessed to determine operating parameters and treatment effectiveness. During the visit, EPA also confirms that the facility appears to be well operated, although the actual operation of the treatment system during sampling is the basis for EPA's decisions regarding proper operation of the treatment unit. In general, the Agency considers a well-designed facility to be one that contains the unit operations necessary to treat the various hazardous constituents of the waste as well as to control other nonhazardous materials in the waste that may affect treatment performance.

In addition to ensuring that a system is reasonably well designed, the engineering visit examines whether the facility has a way to measure the operating parameters that affect performance of the treatment system during the waste treatment period. For example, EPA may choose not to sample a treatment system that operates in a continuous mode, for which an important operating parameter cannot be continuously recorded. In such systems, instrumentation is important in determining whether the treatment

system is operating at design values during the waste treatment period.

(3) Sampling and Analysis Plan. If after the engineering site visit the Agency decides to sample a particular plant, the Agency will then develop a site-specific Sampling and Analysis Plan (SAP) according to the Generic Quality Assurance Project Plan for the Land Disposal Restriction Program ("BDAT"), EPA/530-SW-87-011. In brief, the SAP discusses where the Agency plans to sample, how the samples will be taken, the frequency of sampling, the constituents to be analyzed and the method of analysis, operational parameters to be obtained, and specific laboratory quality control checks on the analytical results.

The Agency will generally produce a draft of the site-specific Sampling and Analysis Plan within 2 to 3 weeks of the engineering visit. The draft of the SAP is then sent to the plant for review and comment. With few exceptions, the draft SAP should be a confirmation of data collection activities discussed with the plant personnel during the engineering site visit. EPA encourages plant personnel to recommend any modifications to the SAP that they believe will improve the quality of the data.

It is important to note that sampling of a plant by EPA does not mean that the data will be used in the development of treatment standards for BDAT. EPA's final decision on whether to

use data from a sampled plant depends on the actual analysis of the waste being treated and on the operating conditions at the time of sampling. Although EPA would not plan to sample a facility that was not ostensibly well-designed and well-operated, there is no way to ensure that at the time of the sampling the facility will not experience operating problems. Additionally, EPA statistically compares its test data to suitable industry-provided data, where available, in its determination of what data to use in developing treatment standards. The methodology for comparing data is presented later in this section.

(Note: Facilities wishing to submit data for consideration in the development of BDAT standards should, to the extent possible, provide sampling information similar to that acquired by EPA. Such facilities should review the Generic Quality Assurance Project Plan for the Land Disposal Restriction Program ("BDAT"), which delineates all of the quality control and quality assurance measures associated with sampling and analysis. Quality assurance and quality control procedures are summarized in Section 1.2.6 of this document.)

(4) Sampling Visit. The purpose of the sampling visit is to collect samples that characterize the performance of the treatment system and to document the operating conditions that existed during the waste treatment period. At a minimum, the

Agency attempts to collect sufficient samples of the untreated waste and solid and liquid treatment residuals so that variability in the treatment process can be accounted for in the development of the treatment standards. To the extent practicable, and within safety constraints, EPA or its contractors collect all samples and ensure that chain-of-custody procedures are conducted so that the integrity of the data is maintained.

In general, the samples collected during the sampling visit will have already been specified in the SAP. In some instances, however, EPA will not be able to collect all planned samples because of changes in the facility operation or plant upsets; EPA will explain any such deviations from the SAP in its follow-up Onsite Engineering Report.

(5) Onsite Engineering Report. EPA summarizes all its data collection activities and associated analytical results for testing at a facility in a report referred to as the Onsite Engineering Report (OER). This report characterizes the waste(s) treated, the treated residual concentrations, the design and operating data, and all analytical results including methods used and accuracy results. This report also describes any deviations from EPA's suggested analytical methods for hazardous wastes (Test Methods for Evaluating Solid Waste, SW-846, Third Edition, November 1986).

After the Onsite Engineering Report is completed, the report is submitted to the plant for review. This review provides the plant with a final opportunity to claim any information contained in the report as confidential. Following the review and incorporation of comments, as appropriate, the report is made available to the public with the exception of any material claimed as confidential by the plant.

### 1.2.4 Hazardous Constituents Considered and Selected for Regulation

(1) Development of BDAT List. The list of hazardous constituents within the waste codes that are targeted for treatment is referred to by the Agency as the BDAT constituent list. This list, provided as Table 1-1, is derived from the constituents presented in 40 CFR Part 261, Appendix VII and Appendix VIII, as well as several ignitable constituents used as the basis of listing wastes as F003 and F005. These sources provide a comprehensive list of hazardous constituents specifically regulated under RCRA. The BDAT list consists of those constituents that could be analyzed using methods published in SW-846, Third Edition.

The initial BDAT constituent list was published in EPA's Generic Quality Assurance Project Plan, March 1987 (EPA/530-SW-87-011). Additional constituents will be added to

TABLE 1-1 BDAT Constituent List

| BDAT reference no. | Parameter | CAS No. |
|---|---|---|
| | Volatiles | |
| 222 | Acetone | 67-64-1 |
| 1 | Acetonitrile | 75-05-8 |
| 2 | Acrolein | 107-02-8 |
| 3 | Acrylonitrile | 107-13-1 |
| 4 | Benzene | 71-43-2 |
| 5 | Bromodichloromethane | 75-27-4 |
| 6 | Bromomethane | 74-83-9 |
| 223 | n-Butyl alcohol | 71-36-3 |
| 7 | Carbon Tetrachloride | 56-23-5 |
| 8 | Carbon disulfide | 75-15-0 |
| 9 | Chlorobenzene | 108-90-7 |
| 10 | 2-Chloro-1,3-butadiene | 126-99-8 |
| 11 | Chlorodibromomethane | 124-48-1 |
| 12 | Chloroethane | 75-00-3 |
| 13 | 2-Chloroethyl vinyl ether | 110-75-8 |
| 14 | Chloroform | 67-66-3 |
| 15 | Chloromethane | 74-87-3 |
| 16 | 3-Chloropropene | 107-05-1 |
| 17 | 1,2-Dibromo-3-chloropropane | 96-12-8 |
| 18 | 1,2-Dibromoethane | 106-93-4 |
| 19 | Dibromomethane | 74-95-3 |
| 20 | trans-1,4-Dichloro-2-butene | 110-57-6 |
| 21 | Dichlorodifluoromethane | 75-71-8 |
| 22 | 1,1-Dichloroethane | 75-35-3 |
| 23 | 1,2-Dichloroethane | 107-06-2 |
| 24 | 1,1-Dichloroethylene | 75-35-4 |
| 25 | trans-1,2-Dichloroethene | 156-60-5 |
| 26 | 1,2-Dichloropropane | 78-87-5 |
| 27 | trans-1,3-Dichloropropene | 10061-02-6 |
| 28 | cis-1,3-Dichloropropene | 10061-01-5 |
| 29 | 1,4-Dioxane | 123-91-1 |
| 224 | 2-Ethoxyethanol | 110-80-5 |
| 225 | Ethyl acetate | 141-78-6 |
| 226 | Ethyl benzene | 100-41-4 |
| 30 | Ethyl cyanide | 107-12-0 |
| 227 | Ethyl ether | 60-29-7 |
| 31 | Ethyl methacrylate | 97-63-2 |
| 214 | ethylene oxide | 75-21-8 |
| 32 | Iodomethane | 74-88-4 |

Continued

TABLE 1-1 (Continued)

| BDAT reference no. | Parameter | CAS No. |
|---|---|---|
| | Volatiles (cont.) | |
| 33 | Isobutyl alcohol | 78-83-1 |
| 228 | Methanol | 67-56-1 |
| 34 | Methyl ethyl ketone | 78-93-3 |
| 229 | Methyl isobutyl ketone | 108-10-1 |
| 35 | Methyl methacrylate | 80-62-6 |
| 37 | Methylacrylonitrile | 126-98-7 |
| 38 | Methylene chloride | 75-09-2 |
| 230 | 2-Nitropropane | 79-46-9 |
| 39 | Pyridine | 110-86-1 |
| 40 | 1,1,1,2-Tetrachloroethane | 630-20-6 |
| 41 | 1,1,2,2-Tetrachloroethane | 79-34-5 |
| 42 | Tetrachloroethene | 127-18-4 |
| 43 | Toluene | 108-88-3 |
| 44 | Tribromomethane | 75-25-2 |
| 45 | 1,1,1-Trichloroethane | 71-55-6 |
| 46 | 1,1,2-Trichloroethane | 79-00-5 |
| 47 | Trichloroethene | 79-01-6 |
| 48 | Trichloromonofluromethane | 75-69-4 |
| 49 | 1,2,3-Trichloropropane | 96-18-4 |
| 231 | 1,1,2-Trichloro-1,2,2-trifluoroethane | 76-13-1 |
| 50 | Vinyl chloride | 75-01-4 |
| 215 | 1,2-Xylene | 97-47-6 |
| 216 | 1,3-Xylene | 108-38-3 |
| 217 | 1,4-Xylene | 106-44-5 |
| | Semivolatiles | |
| 51 | Acenaphthalene | 208-96-8 |
| 52 | Acenaphthene | 83-32-9 |
| 53 | Acetophenone | 96-86-2 |
| 54 | 2-Acetylaminofluorene | 53-96-3 |
| 55 | 4-Aminobiphenyl | 92-67-1 |
| 56 | Aniline | 62-53-3 |
| 57 | Anthracene | 120-12-7 |
| 58 | Aramite | 140-57-8 |
| 59 | Benz(a)anthracene | 56-55-3 |
| 218 | Benzal chloride | 98-87-3 |
| 60 | Benzenethiol | 108-98-6 |
| 61 | Benzidine | 92-87-5 |
| 62 | Benzo(a)pyrene | 50-32-8 |

Continued

TABLE 1-1 (Continued)

| BDAT reference no. | Parameter | CAS No. |
|---|---|---|
| | Semivolatiles (cont.) | |
| 63 | Benzo(b)fluoranthene | 205-99-2 |
| 64 | Benzo(ghi)perylene | 191-24-2 |
| 65 | Benzo(k)fluoranthene | 207-08-9 |
| 66 | p-Benzoquinone | 106-51-4 |
| 67 | Bis(2-chloroethoxy)ethane | 111-91-1 |
| 68 | Bis(2-chloroethyl)ether | 111-44-4 |
| 69 | Bis(2-chloroisopropy)ether | 39638-32-9 |
| 70 | Bis(2-ethylhexy)phthalate | 117-81-7 |
| 71 | 4-Bromophenyl phenyl ether | 101-55-3 |
| 72 | Butyl benzyl phthlate | 85-68-7 |
| 73 | 2-sec-Butyl-4,6-dinitrophenol | 88-85-7 |
| 74 | p-Chloroaniline | 106-47-8 |
| 75 | Chlorobenzilate | 510-15-6 |
| 76 | p-Chloro-m-cresol | 59-50-7 |
| 77 | 2-Chloronaphthalene | 91-58-7 |
| 78 | 2-Chlorophenol | 95-57-8 |
| 79 | 3-Chloropropionitrile | 54-27-67 |
| 80 | Chrysene | 218-01-9 |
| 81 | ortho-Cresol | 95-48-7 |
| 82 | para-Cresol | 106-44-5 |
| 232 | Cyclohexanone | 108-94-1 |
| 83 | Dibenz(a,h)anthracene | 53-70-3 |
| 84 | Dibenzo(a,e)pyrene | 192-65-4 |
| 85 | Dibenzo(a,i)pyrene | 189-55-9 |
| 86 | m-Dichlorobenzene | 541-73-1 |
| 87 | o-Dichlorobenzene | 95-50-1 |
| 88 | p-Dichlorobenzene | 106-46-7 |
| 89 | 3,3'-Dichlorobenzidine | 91-94-1 |
| 90 | 2,4-Dichlorophenol | 120-83-2 |
| 91 | 2,6-Dichlorophenol | 87-65-0 |
| 92 | Diethyl phthalate | 84-66-2 |
| 93 | 3,3'-Dimethyoxlbenzidine | 119-90-4 |
| 94 | p-Dimethylaminoazobenzene | 60-11-7 |
| 95 | 3,3'-Dimethylbenzidine | 119-93-7 |
| 96 | 2,4-Dimethylphenol | 105-67-9 |
| 97 | Dimethyl phthalate | 131-11-3 |
| 98 | Di-n-butyl phthalate | 84-74-2 |
| 99 | 1,4-Dinitrobenzene | 100-25-4 |
| 100 | 4,6-Dinitro-o-cresol | 534-52-1 |
| 101 | 2,4-Dinitrophenol | 51-28-5 |

Continued

TABLE 1-1 (Continued)

| BDAT reference no. | Parameter | CAS No. |
|---|---|---|
| | Semivolatiles (cont.) | |
| 102 | 2,4-Dinitrotoluene | 121-14-2 |
| 103 | 2,6-Dinitrotoluene | 606-20-2 |
| 104 | Di-n-octyl phthalate | 117-84-0 |
| 105 | Di-n-propylnitrosamine | 621-64-7 |
| 106 | Diphenylamine | 122-39-4 |
| 219 | Diphenylnitrosamine | 86-30-6 |
| 107 | 1,2-Diphenylhydrazine | 122-66-7 |
| 108 | Fluoranthene | 206-44-0 |
| 109 | Fluorene | 86-73-7 |
| 110 | Hexachlorobenzene | 118-74-1 |
| 111 | Hexachlorobutadiene | 87-68-3 |
| 112 | Hexachlorocyclopentadiene | 77-47-4 |
| 113 | Hexachloroethane | 67-72-1 |
| 114 | Hexachlorophene | 70-30-4 |
| 115 | Hexachloropropene | 1888-71-7 |
| 116 | Indeno(1,2,3-cd)pyrene | 193-39-5 |
| 117 | Isosafrole | 120-58-1 |
| 118 | Methapyrilene | 91-80-5 |
| 119 | 3-Methycholanthrene | 56-49-5 |
| 120 | 4,4'-Methylenebis(2-chloroaniline) | 101-14-4 |
| 36 | Methyl methanesulfonate | 66-27-3 |
| 121 | Napthalene | 91-20-3 |
| 122 | 1,4-Naphthoquinone | 130-15-4 |
| 123 | 1-Napthylamine | 134-32-7 |
| 124 | 2-Napthylamine | 91-59-8 |
| 125 | p-Nitroaniline | 100-01-6 |
| 126 | Nitrobenzene | 98-95-3 |
| 127 | 4-Nitrophenol | 100-02-7 |
| 128 | N-Nitrosodi-n-butylamine | 924-16-3 |
| 129 | N-Nitrosodiethylamine | 55-18-5 |
| 130 | N-Nitrosodimethylamine | 62-75-9 |
| 131 | N-Nitrosomethylethylamine | 10595-95-6 |
| 132 | N-Nitrosomorpholine | 59-89-2 |
| 133 | N-Nitrosopiperidine | 100-75-4 |
| 134 | n-Nitrosopyrrolidine | 930-55-2 |
| 135 | 2-Methyl-5-nitroaniline | 99-55-5 |
| 136 | Pentachlorobenzene | 608-93-5 |
| 137 | Pentachloroethane | 76-01-7 |
| 138 | Pentachloronitrobenzene | 82-68-8 |

Continued

TABLE 1-1 (Continued)

| BDAT reference no. | Parameter | CAS No. |
|---|---|---|
| | Semivolatiles (cont.) | |
| 139 | Pentachlorophenol | 87-86-5 |
| 140 | Phenacetin | 62-44-2 |
| 141 | Phenanthrene | 85-01-8 |
| 142 | Phenol | 108-85-2 |
| 220 | Phthalic anhydride | 85-44-9 |
| 143 | 2-Picoline | 109-06-8 |
| 144 | Pronamide | 23950-58-5 |
| 145 | Pyrene | 129-00-0 |
| 146 | Resorcinol | 108-46-3 |
| 147 | Safrole | 94-59-7 |
| 148 | 1,2,4,5-Tetrachlorobenzene | 95-94-3 |
| 149 | 2,3,4,6-Tetrachlorophenol | 58-90-2 |
| 150 | 1,2,4-Trichlorobenzene | 120-82-1 |
| 151 | 2,4,5-Trichlorophenol | 95-95-4 |
| 152 | 2,4,6-Trichlorophenol | 88-06-2 |
| 153 | Tris(2,3-dibromopropyl)phosphate | 126-72-7 |
| | Metals | |
| 154 | Antimony | 7440-36-0 |
| 155 | Arsenic | 7440-38-2 |
| 156 | Barium | 7440-39-3 |
| 157 | Beryllium | 7440-41-7 |
| 158 | Cadmium | 7440-47-9 |
| 159 | Chromium (total) | 7440-50-3 |
| 221 | Chromium (hexavalent) | - |
| 160 | Copper | 7440-50-8 |
| 161 | Lead | 7439-92-1 |
| 162 | Mercury | 7439-97-6 |
| 163 | Nickel | 7440-02-0 |
| 164 | Selenium | 7782-49-2 |
| 165 | Silver | 7440-22-4 |
| 166 | Thallium | 7440-28-0 |
| 167 | Vanadium | 7440-62-2 |
| 168 | Zinc | 7440-66-6 |
| | Inorganics | |
| 169 | Cyanide | 57-12-5 |
| 170 | Fluoride | 16964-48-8 |
| 171 | Sulfide | 8496-25-8 |

Continued

TABLE 1-1 (Continued)

| BDAT reference no. | Parameter | CAS No. |
|---|---|---|
| | Organochlorine Pesticides | |
| 172 | Aldrin | 309-00-2 |
| 173 | alpha-BHC | 319-84-6 |
| 174 | beta-BHC | 319-85-7 |
| 175 | delta-BHC | 319-86-8 |
| 176 | gamma-BHC | 58-89-9 |
| 177 | Chlordane | 57-74-9 |
| 178 | DDD | 72-54-8 |
| 179 | DDE | 72-55-9 |
| 180 | DDT | 50-29-3 |
| 181 | Dieldrin | 60-57-1 |
| 182 | Endosulfan I | 939-98-8 |
| 183 | Endosulfan II | 33213-6-5 |
| 184 | Endrin | 72-20-8 |
| 185 | Endrin aldehyde | 7421-93-4 |
| 186 | Heptachlor | 76-44-8 |
| 187 | Heptachlor epoxide | 1024-57-3 |
| 188 | Isodrin | 465-73-6 |
| 189 | Kepone | 143-50-0 |
| 190 | Mehoxychlor | 72-43-5 |
| 191 | Toxaphene | 8001-35-2 |
| | Phenoxyacetic Acid Herbicides | |
| 192 | 2,4-Dichlorophenoxyacetic acid | 94-75-7 |
| 193 | Silvex | 93-72-1 |
| 194 | 2,4,5-T | 93-76-5 |
| | Organophosphorous Insecticides | |
| 195 | Disulfoton | 298-04-4 |
| 196 | Famphur | 52-85-7 |
| 197 | Methyl parathion | 298-00-0 |
| 198 | Parathion | 56-38-2 |
| 199 | Phorate | 298-02-2 |
| | PCBs | |
| 200 | Aroclor 1016 | 12674-11-2 |
| 201 | Aroclor 1221 | 11104-28-2 |
| 202 | Aroclor 1232 | 11141-16-5 |

Continued

TABLE 1-1 (Continued)

| BDAT reference no. | Parameter | CAS No. |
|---|---|---|
| | PCBs (cont.) | |
| 203 | Aroclor 1242 | 53469-21-9 |
| 204 | Aroclor 1248 | 12672-29-6 |
| 205 | Aroclor 1254 | 11097-69-1 |
| 206 | Aroclor 1260 | 11096-82-5 |
| | Dioxins and Furans | |
| 207 | Hexachlorodibenzo-p-dioxins | - |
| 208 | Hexachlorodibenzofuran | - |
| 209 | Pentachlorodibenzo-p-dioxins | - |
| 210 | Pentachlorodibenzofuran | - |
| 211 | Tetrachlorodibenzo-p-dioxins | - |
| 212 | Tetrachlorodibenzofuran | - |
| 213 | 2,3,7,8-Tetrachlorodibenzo-p-dioxin | 1746-01-6 |

the BDAT constituent list as additional key constituents are identified for specific waste codes or as new analytical methods are developed for hazardous constituents. For example, since the list was published in March 1987, eighteen additional constituents (hexavalent chromium, xylene (all three isomers), benzal chloride, phthalic anhydride, ethylene oxide, acetone, n-butyl alcohol, 2-ethoxyethanol, ethyl acetate, ethyl benzene, ethyl ether, methanol, methyl isobutyl ketone, 2-nitropropane, 1,1,2-trichloro-1,2,2-trifluoroethane, and cyclohexanone) have been added to the list.

Chemicals are listed in Appendix VIII if they are shown in scientific studies to have toxic, carcinogenic, mutagenic, or teratogenic effects on humans or other life-forms, and they include such substances as those identified by the Agency's Carcinogen Assessment Group as being carcinogenic. The significance of including a constituent in Appendix VIII is threefold. First, the constituent can be cited as a basis for listing toxic wastes. Second, permittees are required to monitor many of these constituents under the detection, compliance, and corrective action monitoring programs of 40 CFR 264.91(a)(2) and (3). Third, the Principal Organic Hazardous Constituents specified in incineration permits are drawn from Appendix VIII.

Although Appendix VII, Appendix VIII, and the F003 and F005 ignitables provide a comprehensive list of hazardous

constituents, not all of the constituents can be analyzed in a complex waste matrix. Therefore, constituents that could not be readily analyzed in an unknown waste matrix were not included on the initial BDAT list. As mentioned above, however, the BDAT constituent list is a continuously growing list that does not preclude the addition of new constituents when analytical methods are developed.

Constituents were dropped from the BDAT constituent list for five major reasons:

(1) Constituents are unstable. Based on their chemical structure, some constituents will either decompose in water or will ionize. For example, maleic anhydride will form maleic acid when it comes in contact with water and copper cyanide will ionize to form copper and cyanide ions. However, EPA may choose to regulate the decomposition or ionization products.

(2) EPA-approved or verified analytical methods are not available. Many constituents, such as 1,3,5-trinitrobenzene, are not measured adequately or even detected using any of EPA's analytical methods published in SW-846 Third Edition.

(3) The constituent is a member of a chemical group designated in Appendix VIII as not otherwise specified (N.O.S.). Constituents listed as N.O.S., such as chlorinated phenols, are a

generic group of some types of chemicals for which a single analytical procedure is not available. The individual members of each such group need to be listed to determine whether the constituents can be analyzed. For each N.O.S. group, all those constituents that can be readily analyzed are included in the BDAT constituents list.

(4) Available analytical procedures are not appropriate for a complex waste matrix. Some compounds, such as auramine, can be analyzed as a pure constituent. However, in the presence of other constituents the recommended analytical method does not positively identify the constituent. The use of HPLC presupposes a high expectation of finding the specific constituents of interest. In using this procedure to screen samples, protocols would have to be developed on a case-specific basis to verify the identity of constituents present in the samples. Therefore, high pressure liquid chromatography (HPLC) is not an appropriate analytical procedure for complex samples containing unknown constituents.

(5) Standards for analytical instrument calibration are not commercially available. For several constituents, such as benz(c)acridine, commercially available standards of a "reasonably" pure grade are not available. The unavailability of a standard was determined by a review of catalogs from specialty chemical manufacturers.

Two constituents (fluoride and sulfide) are not specifically included in EPA constituent lists; however, these compounds are included on the BDAT list as indicator constituents for compounds from Appendices VII and VIII such as hydrogen fluoride and hydrogen sulfide, which ionize in water.

The BDAT constituent list presented in Table 1-1 is divided into the following nine groups:

- Volatile organics
- Semivolatile organics
- Metals
- Other inorganics
- Organochlorine pesticides
- Phenoxyacetic acid herbicides
- Organophosphorous insecticides
- PCBs
- Dioxins and furans

The constituents were placed in these categories based on their chemical properties. The constituents in each group are expected to behave similarly during treatment and are also analyzed, with the exception of the metals and inorganics, by using the same analytical methods.

(2) Constituent Selection Analysis. The constituents that the Agency selects for regulation in each treatability group are, in general, those found in the untreated wastes at treatable concentrations. For certain waste codes, the target list for the untreated waste may have been shortened (relative to analyses performed to test treatment technologies) because of the extreme unlikelihood of the constituent being present.

In selecting constituents for regulation, the first step is to summarize all the constituents that were found in the untreated waste at treatable concentrations. This process involves the use of the statistical analysis of variance (ANOVA) test, described in Section 1.2.6, to determine if constituent reductions were significant. The Agency interprets a significant reduction in concentration as evidence that the technology actually "treats" the waste.

There are some instances where EPA may regulate constituents that are not found in the untreated waste but are detected in the treated residual. This is generally the case where presence of the constituents in the untreated waste interferes with the quantification of the constituent of concern. In such instances, the detection levels of the constituent are relatively high, resulting in a finding of "not detected" when, in fact, the constituent is present in the waste.

After determining which of the constituents in the untreated waste are present at treatable concentrations, EPA develops a list of potential constituents for regulation. The Agency then reviews this list to determine if any of these constituents can be excluded from regulation because they would be controlled by regulation of other constituents in the list.

EPA performs this indicator analysis for two reasons: (1) it reduces the analytical cost burdens on the treater and (2) it facilitates implementation of the compliance and enforcement program. EPA's rationale for selection of regulated constituents for this waste code is presented in Section 5 of this background document.

(3) Calculation of Standards. The final step in the calculation of the BDAT treatment standard is the multiplication of the average treatment value by a factor referred to by the Agency as the variability factor. This calculation takes into account that even well-designed and well-operated treatment systems will experience some fluctuations in performance. EPA expects that fluctuations will result from inherent mechanical limitations in treatment control systems, collection of treated samples, and analysis of these samples. All of the above fluctuations can be expected to occur at well-designed and well-operated treatment facilities. Therefore, setting treatment standards utilizing a variability factor should be viewed not as a relaxing of 3004(m) requirements, but rather as a function of the normal variability of the treatment processes. A treatment facility will have to be designed to meet the mean achievable treatment performance level to ensure that the performance levels remain within the limits of the treatment standard.

The Agency calculates a variability factor for each constituent of concern within a waste treatability group using the statistical calculation presented in Appendix A. The equation for calculating the variability factor is the same as that used by EPA for the development of numerous regulations in the Effluent Guidelines Program under the Clean Water Act. The variability factor establishes the instantaneous maximum based on the 99th percentile value.

There is an additional step in the calculation of the treatment standards in those instances where the ANOVA analysis shows that more than one technology achieves a level of performance that represents BDAT. In such instances, the BDAT treatment standard is calculated by first averaging the mean performance value for each technology for each constituent of concern and then multiplying that value by the highest variability factor among the technologies considered. This procedure ensures that all the BDAT technologies used as the basis for the standards will achieve full compliance.

### 1.2.5 Compliance with Performance Standards

All the treatment standards reflect performance achieved by the Best Demonstrated Available Technology (BDAT). As such, compliance with these standards only requires that the treatment level be achieved prior to land disposal. It does not require

the use of any particular treatment technology. While dilution of the waste as a means to comply with the standard is prohibited, wastes that are generated in such a way as to naturally meet the standard can be land disposed without treatment. With the exception of treatment standards that prohibit land disposal, all treatment standards proposed today are expressed as a concentration level.

EPA has used both total constituent concentration and TCLP analyses of the treated waste as a measure of technology performance. EPA's rationale for when each of these analytical tests is used is explained in the following discussion.

For all organic constituents, EPA is basing the treatment standards on the total constituent concentration found in the treated waste. EPA based its decision on the fact that technologies exist to destroy the various organics compounds. Accordingly, the best measure of performance would be the extent to which the various organic compounds have been destroyed or the total amount of constituent remaining after treatment. (NOTE: EPA's land disposal restrictions for solvent waste codes F001-F005 (51 FR 40572) uses the TCLP value as a measure of performance. At the time that EPA promulgated the treatment standards for F001-F005, useful data were not available on total constituent concentrations in treated residuals and, as a result,

the TCLP data were considered to be the best measure of performance.)

For all metal constituents, EPA is using total constituent concentration and/or the TCLP as the basis for treatment standards. The total constituent concentration is being used when the technology basis includes a metal recovery operation. The underlying principle of metal recovery is the reduction of the amount of metal in a waste by separating the metal for recovery; therefore, total constituent concentration in the treated residual is an important measure of performance for this technology. Additionally, EPA also believes that it is important that any remaining metal in a treated residual waste not be in a state that is easily leachable; accordingly, EPA is also using the TCLP as a measure of performance. It is important to note that for wastes for which treatment standards are based on a metal recovery process, the facility has to comply with both the total constituent concentration and the TCLP prior to land disposal.

In cases where treatment standards for metals are not based on recovery techniques but rather on stabilization, EPA is using only the TCLP as a measure of performance. The Agency's rationale is that stabilization is not meant to reduce the concentration of metal in a waste but only to chemically minimize the ability of the metal to leach.

### 1.2.6 Identification of BDAT

(1) Screening of Treatment Data. This section explains how the Agency determines which of the treatment technologies represent treatment by BDAT. The first activity is to screen the treatment data from each of the demonstrated and available technologies according to the following criteria:

(a) Design and operating data associated with the treatment data must reflect a well-designed, well-operated system for each treatment data point. (The specific design and operating parameters for each demonstrated technology for this waste code are discussed in Section 3.2 of this document.)

(b) Sufficient QA/QC data must be available to determine the true values of the treated data. This screening criterion involves adjustment of treated data to take into account that the true value may be different from the measured value. This discrepancy generally is caused by other constituents in the waste that can mask results or otherwise interfere with the analysis of the constituent of concern.

(c) The measure of performance must be consistent with EPA's approach to evaluating treatment by type of constituents (e.g., total composition data for organics, and total composition and TCLP for metals in the leachate from the residual).

In the absence of data needed to perform the screening analysis, EPA will make decisions on a case-by-case basis of whether to include the data. The factors included in this case-by-case analysis will be the actual treatment levels achieved, the availability of the treatment data and their completeness (with respect to the above criteria), and EPA's assessment of whether the untreated waste represents the waste

code of concern. EPA's application of these screening criteria for this waste code are provided in Section 4 of this background document.

(2) Comparison of Treatment Data. In cases in which EPA has treatment data from more than one technology following the screening activity, EPA uses the statistical method known as analysis of variance (ANOVA) to determine if one technology performs significantly better. This statistical method (summarized in Appendix A) provides a measure of the differences between two data sets. If EPA finds that one technology performs significantly better (i.e., the data sets are not homogeneous), BDAT is the level of performance achieved by the best technology multiplied by its variability factor.

If the differences in the data sets are not statistically significant, the data sets are said to be homogeneous. Specifically, EPA uses the analysis of variance to determine whether BDAT represents a level of performance achieved by only one technology or represents a level of performance achieved by more than one (or all) of the technologies. If the Agency finds that the levels of performance for one or more technologies are not statistically different (i.e., the data sets are homogeneous), EPA averages the performance values achieved by each technology and then multiplies this value by the largest variability factor associated with any of the acceptable

technologies. A detailed discussion of the treatment selection method and an example of how EPA chooses BDAT from multiple treatment systems is provided in Section A-1.

(3) Quality Assurance/Quality Control. This section presents the principal quality assurance/quality control (QA/QC) procedures employed in screening and adjusting the data to be used in the calculation of treatment standards. Additional QA/QC procedures used in collecting and screening data for the BDAT program are presented in EPA's Generic Quality Assurance Project Plan for Land Disposal Restrictions Program ("BDAT") (EPA/530-SW-87-001, March 1987).

To calculate the treatment standards for the Land Disposal Restriction Rules, it is first necessary to determine the recovery value (the amount of constituent recovered after spiking, which is the addition of a known amount of the constituent, minus the initial concentration in the samples divided by the amount added) for a spike of the treated residual. Once the recovery value is determined, the following procedures are used to select the appropriate percent recovery value to adjust the analytical data:

(a) If duplicate spike recovery values are available for the constituent of interest, the data are adjusted by the lowest available percent recovery value (i.e., the value that will yield the most conservative estimate of treatment achieved). However, if a spike recovery value of less than 20 percent is reported for a specific constituent, the data are not used to set

treatment standards because the Agency does not have sufficient confidence in the reported value to set a national standard.

(b) If data are not available for a specific constituent but are available for an isomer, then the spike recovery data are transferred from the isomer and the data are adjusted using the percent recovery selected according to the procedure described in (a) above.

(c) If data are not available for a specific constituent but are available for a similar class of constituents (e.g., volatile organics, acid-extractable semivolatiles), then spike recovery data available for this class of constituents are transferred. All spike recovery values greater than or equal to 20 percent for a spiked sample are averaged and the constituent concentration is adjusted by the average recovery value. If spiked recovery data are available for more than one sample, the average is calculated for each sample and the data are adjusted by the lowest average value.

(d) If matrix spike recovery data are not available for a set of data to be used to calculate treatment standards, then matrix spike recovery data are transferred from a waste that the Agency believes is a similar matrix (e.g., if the data are for an ash from incineration, then data from other incinerator ashes could be used). While EPA recognizes that transfer of matrix spike recovery data from a similar waste is not an exact analysis, this is considered the best approach for adjusting the data to account for the fact that most analyses do not result in extraction of 100 percent of the constituent. In assessing the matrix spike data to be transferred, the procedures outlined in (a), (b), and (c) above are followed.

The analytical procedures employed to generate the data used to calculate the treatment standards are listed in Appendix B of this document. In cases where alternatives or equivalent procedures and/or equipment are allowed in EPA's SW-846, Third Edition (November 1986) methods, the specific procedures and equipment used are also documented in this Appendix. In

addition, any deviations from the SW-846, Third Edition, methods used to analyze the specific waste matrices are documented. It is important to note that the Agency will use the methods and procedures delineated in Appendix B to enforce the treatment standards presented in Section 6 of this document. Accordingly, facilities should use these procedures in assessing the performance of their treatment systems.

### 1.2.7 BDAT Treatment Standards for "Derived-From" and "Mixed" Wastes

(1) Wastes from Treatment Trains Generating Multiple Residues. In a number of instances, the proposed BDAT consists of a series of operations each of which generates a waste residue. For example, the proposed BDAT for a certain waste code is based on solvent extraction, steam stripping, and activated carbon adsorption. Each of these treatment steps generates a waste requiring treatment -- a solvent-containing stream from solvent extraction, a stripper overhead, and spent activated carbon. Treatment of these wastes may generate further residues; for instance, spent activated carbon (if not regenerated) could be incinerated, generating an ash and possibly a scrubber water waste. Ultimately, additional wastes are generated that may require land disposal. With respect to these wastes, the Agency wishes to emphasize the following points:

(a) All of the residues from treating the original listed wastes are likewise considered to be the listed waste

by virtue of the derived-from rule contained in 40 CFR 261.3(c)(2). (This point is discussed more fully in (2) below.) Consequently, all of the wastes generated in the course of treatment would be prohibited from land disposal unless they satisfy the treatment standard or meet one of the exceptions to the prohibition.

(b) The Agency's proposed treatment standards generally contain a concentration level for wastewaters and a concentration level for nonwastewaters. The treatment standards apply to all of the wastes generated in treating the original prohibited waste. Thus, all solids generated from treating these wastes would have to meet the treatability level for nonwastewaters. All derived-from wastes meeting the Agency definition of wastewater (less than 1 percent TOC and less than 1 percent total filterable solids) would have to meet the treatability level for wastewaters. EPA wishes to make clear that this approach is not meant to allow partial treatment in order to comply with the applicable standard.

(c) The Agency has not performed tests, in all cases, on every waste that can result from every part of the treatment train. However, the Agency's treatability levels are based on treatment of the most concentrated form of the waste. Consequently, the Agency believes that the less concentrated wastes generated in the course of treatment will also be able to be treated to meet this value.

(2) Mixtures and Other Derived-From Residues. There is a further question as to the applicability of the BDAT treatment levels to residues generated not from treating the waste (as discussed above), but from other types of management. Examples are contaminated soil or leachate that is derived from managing the waste. In these cases, the mixture is still deemed to be the listed waste, either because of the derived-from rule (40 CFR 261.3(c)(2)(i)) or the mixture rule (40 CFR 261.3(b)(2) or because the listed waste is contained in the matrix (see, for

example, 40 CFR 261.33(d)). The prohibition for the particular listed waste consequently applies to this type of waste.

The Agency believes that the majority of these types of residues can meet the treatment standards for the underlying listed wastes (with the possible exception of contaminated soil and debris for which the Agency is currently investigating whether it is appropriate to establish a separate treatability subcategorization). For the most part, these residues will be less concentrated than the original listed waste. The Agency's treatability levels also make a generous allowance for process variability by assuming that all treatability values used to establish the standard are lognormally distributed. The waste also might be amenable to a relatively nonvariable form of treatment technology such as incineration. Finally, and perhaps most important, the rules contain a treatability variance that allows a petitioner to demonstrate that its waste cannot be treated to the level specified in the rule (40 CFR 268.44(a). This provision provides a safety valve that allows persons with unusual waste matrices to demonstrate the appropriateness of a different standard. The Agency, to date, has not received any petitions under this provision (for example, for residues contaminated with a prohibited solvent waste), indicating, in the Agency's view, that the existing standards are generally achievable.

(3) Residues from Managing Listed Wastes or that Contain Listed Wastes. The Agency has been asked if and when residues from managing hazardous wastes, such as leachate and contaminated ground water, become subject to the land disposal prohibitions. Although the Agency believes this question to be settled by existing rules and interpretative statements, to avoid any possible confusion the Agency will address the question again.

Residues from managing First Third wastes, listed California List wastes, and spent solvent and dioxin wastes are all considered to be subject to the prohibitions for the underlying hazardous waste. Residues from managing California List wastes likewise are subject to the California List prohibitions when the residues themselves exhibit a characteristic of hazardous waste. This determination stems directly from the derived-from rule in 40 CFR 261.3(c)(2) or in some cases from the fact that the waste is mixed with or otherwise contains the listed waste. The underlying principle stated in all of these provisions is that listed wastes remain listed until delisted.

The Agency's historic practice in processing delisting petitions addressing mixing residuals has been to consider them to be the listed waste and to require that delisting petitioners address all constituents for which the derived-from waste (or other mixed waste) was listed as well as other constituents that could cause the waste to be defined as hazardous. The language

in 40 CFR 260.22(b) states that mixtures or derived-from residues can be delisted provided a delisting petitioner makes a demonstration identical to that which a delisting petitioner would make for the underlying waste. These residues consequently are treated as the underlying listed waste for delisting purposes. The statute likewise takes this position, indicating that soil and debris that are contaminated with listed spent solvents or dioxin wastes are subject to the prohibition for these wastes even though these wastes are not the originally generated waste, but rather are a residual from management (RCRA section 3004(e)(3)). It is EPA's view that all such residues are covered by the existing prohibitions and treatment standards for the listed hazardous waste that these residues contain and from which they are derived.

### 1.2.8 Transfer of Treatment Standards

EPA is proposing some treatment standards that are not based on testing of the treatment technology of the specific waste subject to the treatment standard. Instead, the Agency has determined that the constituents present in the subject waste can be treated to the same performance levels as those observed in other wastes for which EPA has previously developed treatment data. EPA believes that transferring treatment performance for use in establishing treatment standards for untested wastes is valid technically in cases where the untested wastes are

generated from similar industries or similar processing steps. As explained earlier, transfer of treatment standards to wastes from similar processing steps requires little formal analysis because of the likelihood that similar production processes will produce a waste matrix with similar characteristics. However, in the case where only the industry is similar, EPA more closely examines the waste characteristics prior to concluding that the untested waste constituents can be treated to levels associated with tested wastes.

EPA undertakes a two-step analysis when determining whether wastes generated by different processes within a single industry can be treated to the same level of performance. First, EPA reviews the available waste characteristic data to identify those parameters that are expected to affect treatment selection. EPA has identified some of the most important constituents and other parameters needed to select the treatment technology appropriate for a given waste. A detailed discussion of each analysis, including how each parameter was selected for each waste, can be found in the background document for each waste.

Second, when an individual analysis suggests that an untested waste can be treated with the same technology as a waste for which treatment performance data are already available, EPA analyzes a more detailed list of constituents that represent some of the most important waste characteristics that the Agency

believes will affect the performance of the technology. By examining and comparing these characteristics, the Agency determines whether the untested wastes will achieve the same level of treatment as the tested waste. Where the Agency determines that the untested waste is easier to treat than the tested waste, the treatment standards can be transferred. A detailed discussion of this transfer process for each waste can be found in later sections of this document.

## 1.3 Variance from the BDAT Treatment Standard

The Agency recognizes that there may exist unique wastes that cannot be treated to the level specified as the treatment standard. In such a case, a generator or owner/operator may submit a petition to the Administrator requesting a variance from the treatment standard. A particular waste may be significantly different from the wastes considered in establishing treatability groups because the waste contains a more complex matrix that makes it more difficult to treat. For example, complex mixtures may be formed when a restricted waste is mixed with other waste streams by spills or other forms of inadvertent mixing. As a result, the treatability of the restricted waste may be altered such that it cannot meet the applicable treatment standard.

Variance petitions must demonstrate that the treatment standard established for a given waste cannot be met. This

demonstration can be made by showing that attempts to treat the waste by available technologies were not successful or by performing appropriate analyses of the waste, including waste characteristics affecting performance, which demonstrate that the waste cannot be treated to the specified levels. Variances will not be granted based solely on a showing that adequate BDAT treatment capacity is unavailable. (Such demonstrations can be made according to the provisions in 268.5 of RCRA for case-by-case extensions of the effective date.) The Agency will consider granting generic petitions provided that representative data are submitted to support a variance for each facility covered by the petition.

Petitioners should submit at least one copy to:

The Administrator
U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, DC 20460

An additional copy marked "Treatability Variance" should be submitted to:

Chief, Waste Treatment Branch
Office of Solid Waste (WH-565)
U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, DC 20460

Petitions containing confidential information should be sent with only the inner envelope marked "Treatability Variance" and "Confidential Business Information" and with the contents marked

in accordance with the requirements of 40 CFR Part 2 (41 FR 36902, September 1, 1976, amended by 43 FR 4000).

The petition should contain the following information:

(1) The petitioner's name and address.

(2) A statement of the petitioner's interest in the proposed action.

(3) The name, address, and EPA identification number of the facility generating the waste, and the name and telephone number of the plant contact.

(4) The process(es) and feed materials generating the waste and an assessment of whether such process(es) or feed materials may produce a waste that is not covered by the demonstration.

(5) A description of the waste sufficient for comparison with the waste considered by the Agency in developing BDAT, and an estimate of the average and maximum monthly and annual quantities of waste covered by the demonstration. (Note: The petitioner should consult the appropriate BDAT background document for determining the characteristics of the wastes considered in developing treatment standards.)

(6) If the waste has been treated, a description of the system used for treating the waste, including the process design and operating conditions. The petition should include the reasons the treatment standards are not achievable and/or why the petitioner believes the standards are based on inappropriate technology for treating the waste. (Note: The petitioner should refer to the BDAT background document as guidance for determining the design and operating parameters that the Agency used in developing treatment standards.)

(7) A description of the alternative treatment systems examined by the petitioner (if any); a description of the treatment system deemed appropriate by the petitioner for the waste in question; and, as appropriate, the concentrations in the treatment residual or extract of the treatment residual (i.e., using the TCLP where appropriate for stabilized metals) that can be achieved by applying such treatment to the waste.

(8) A description of those parameters and waste characteristics that affect performance, including results of all analyses. (See Section 3.0 for a discussion of waste characteristics affecting performance that the Agency has identified for the technology representing BDAT.)

(9) The dates of the sampling and testing.

(10) A description of the methodologies and equipment used to obtain representative samples.

(11) A description of the sample handling and preparation techniques, including techniques used for extraction, containerization, and preservation of the samples.

(12) A description of analytical procedures used including QA/QC methods.

After receiving a petition for a variance, the Administrator may request any additional information or waste samples that may be required to evaluate and process the petition. Additionally, all petitioners must certify that the information provided to the Agency is accurate under 40 CFR 268.4(b).

In determining whether a variance will be granted, the Agency will first look at the design and operation of the treatment system being used. If EPA determines that the technology and operation are consistent with BDAT, the Agency will evaluate the waste to determine if the waste matrix and/or physical parameters are such that the BDAT treatment standards reflect treatment of this waste. Essentially, this latter analysis will concern the parameters affecting treatment selection and waste characteristics affecting performance parameters.

In cases where BDAT is based on more than one technology, the petitioner will need to demonstrate that the treatment standard cannot be met using any of the technologies, or that none of the technologies are appropriate for treatment of the waste. After the Agency has made a determination on the petition, the Agency's findings will be published in the Federal Register, followed by a 30-day period for public comment. After review of the public comments, EPA will publish its final determination in the Federal Register as an amendment to the treatment standards in Part 268, Subpart D.

# 2. INDUSTRY AFFECTED AND WASTE CHARACTERIZATION

The previous section provided the background for the Agency's study of K046 waste. The purpose of this section is to describe the industry that will be affected by land disposal restrictions on waste code K046, and to characterize this waste. This section includes a description of the industry affected and the production processes employed in this industry. Also included is a discussion of how K046 wastes are generated by these processes. This section concludes with a characterization of the K046 waste streams, and a determination of the waste treatability group for this waste.

The full list of hazardous waste codes from specific sources is given in 40 CFR 261.32 (see discussion in Section 1 of this document). Within this list, four specific hazardous waste codes are generated by the explosives industry. One of these is the listed waste K046.

## 2.1 Industry Affected and Process Description

According to 40 CFR 261.32 (hazardous wastes from specific sources), waste code K046 is specifically generated from the manufacture, formulation, and loading of lead-based initiating compounds. This waste is listed as follows:

K046: Wastewater treatment sludges from the manufacturing, formulation, and loading of lead-based initiating compounds.

The four digit standard industrial classification (SIC) code reported for the explosives industry is 2892 and includes both commercial firms and government-owned plants operated by private firms.

The Agency estimates that 62 facilities in the United States are actively involved in the manufacture, formulation, and loading of lead-based initiating compounds and could generate K046 waste. Information from EPA's HWDMS data base provides a geographic distribution of the number of these facilities across the United States.

Tables 2-1 and 2-2 present the location of those facilities which may generate waste code K046 in each state and in each EPA region. As can be seen in Tables 2-1 and 2-2, these facilities are concentrated in EPA Regions II, III, V, and VI. Figure 2-1 illustrates these data plotted on a map of the United States.

Table 2-1 Facilities Producing K046 by State

| State (EPA Region) | Number of Facilities |
|---|---|
| Arkansas (IV) | 2 |
| California (IX) | 4 |
| Colorado (VIII) | 1 |
| Connecticut (I) | 1 |
| Idaho (X) | 3 |
| Illinois (V) | 3 |
| Indiana (V) | 2 |
| Iowa (VII) | 1 |
| Louisiana (VI) | 5 |
| Maryland (III) | 2 |
| Massachusetts (I) | 1 |
| Michigan (V) | 2 |
| Minnesota (IV) | 2 |
| Missouri (VII) | 2 |
| New Jersey (II) | 5 |
| New York (II) | 3 |
| North Carolina (IV) | 1 |
| Ohio (V) | 4 |
| Oregon (X) | 1 |
| Pennsylvania (III) | 3 |
| Texas (VI) | 9 |
| Virginia (III) | 2 |
| West Virginia (III) | 1 |
| Wisconsin (V) | 1 |
| Puerto Rico (II) | 1 |
| | Total 62 |

Reference: HWDMS, January, 1986.

Table 2-2 Facilities Producing K046 by EPA Region

| EPA Region | Number of Facilities |
|---|---|
| I | 2 |
| II | 9 |
| III | 8 |
| IV | 1 |
| V | 14 |
| VI | 16 |
| VII | 3 |
| VIII | 1 |
| IX | 4 |
| X | 4 |
| Total | 62 |

Reference: HWDMS, January, 1986

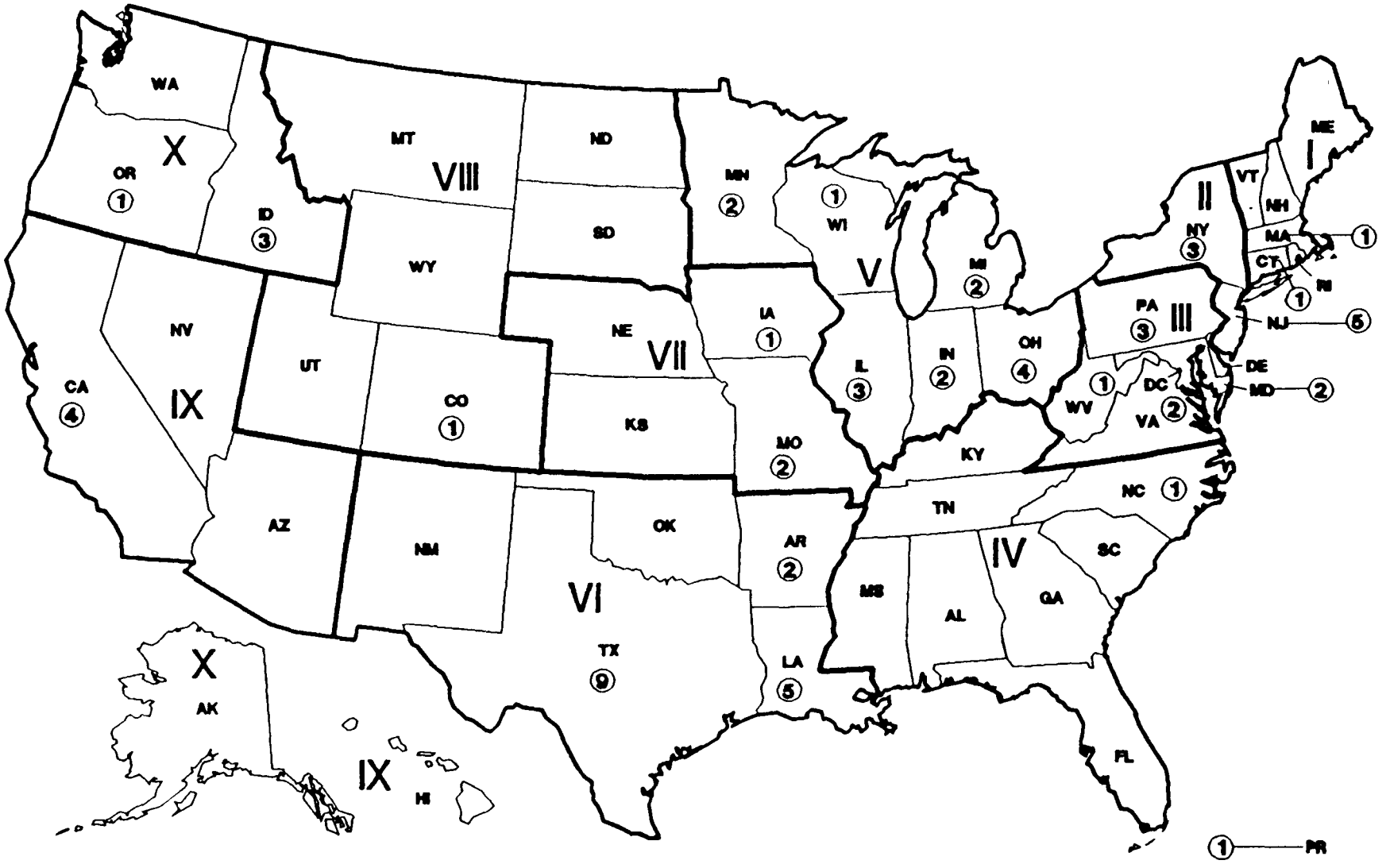


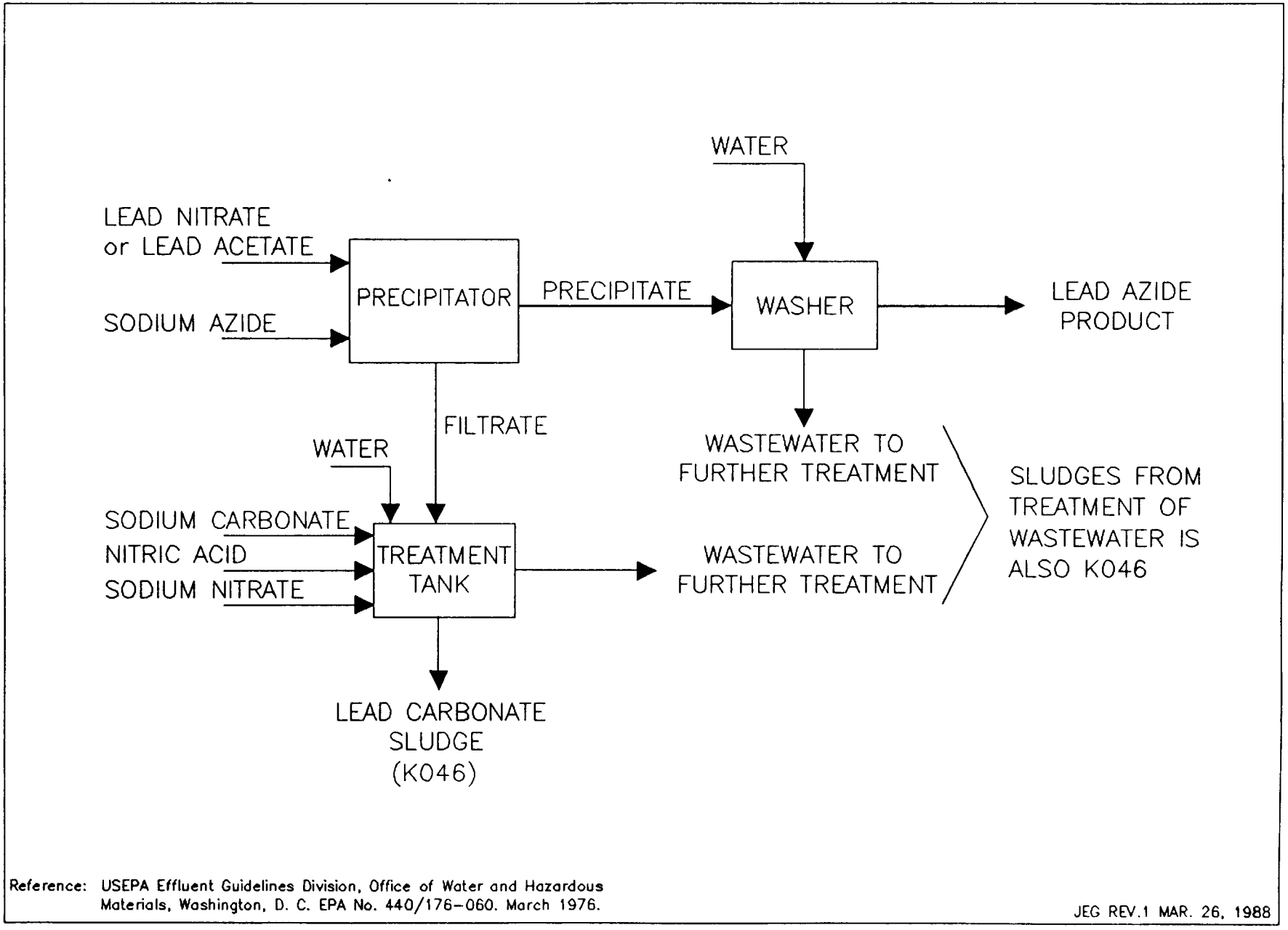

FIGURE 2-1 FACILITIES PRODUCING K046 BY STATE AND EPA REGION

Initiating compounds are generally organic- or lead-based. The major organic-based initiating compounds are as follows: tetracene, trinitroresorcinol (TNR), tetry, and nitromannite. The major lead-based initiating compounds are as follows: lead azide, lead styphnate, and lead mononitroresorcinate (LMR).

One manufacturing process for the production of lead azide is presented below.

The listed waste K046 is generated in the production of lead azide, and also in other processes. As shown in Figure 2-2, one process for producing lead azide is by reacting lead nitrate or lead acetate with sodium azide. The reaction takes place in a precipitator where the lead azide product is precipitated and separated from the reaction by-products. The precipitate, consisting mainly of lead azide, is washed with water to remove traces of impurities and is removed from the washer as the lead azide product. The wash water (wastewater) is further treated and discharged.

The filtrate from the precipitator goes to a treatment tank where chemicals are added to chemically transform traces of lead azide. Sodium carbonate, sodium nitrite, and nitric acid are generally used as treatment chemicals in the treatment tank. These chemicals convert the lead azide into a mixture of lead carbonate and lead nitrate. Water is also added to the treatment




Reference: USEPA Effluent Guidelines Division, Office of Water and Hazardous Materials, Washington, D. C. EPA No. 440/176-060. March 1976.

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**FIGURE 2-2 LEAD AZIDE MANUFACTURE**

tank to wash the filtrate stream from the precipitator. The sludge from the treatment tank is removed and sent to disposal or further treatment. This is the listed waste K046. The wastewater from the treatment tank is further treated and discharged. Sludges from the treatment of these wastewaters also constitute K046 waste.

### 2.1.1 Generation of K046 Waste

The listed waste K046 is generated in the production of initiating compounds such as lead azide. In the production of lead azide, K046 is generated at the treatment tank. The filtrate (wastewater) from the precipitator flows to the treatment tank where chemicals such as nitric acid, sodium nitrite, and sodium carbonate are added to chemically transform lead azide in the wastewater to a mixture of lead nitrate and lead carbonate. A sludge, consisting mainly of lead carbonate and other insoluble lead salts, is formed in the treatment tank. This sludge, which is the listed waste K046, is removed from the treatment tank and sent to disposal.

Wastewater treatment sludges are also generated in the manufacture and processing of other lead-based initiators, such as lead styphnate and lead mononitroresorcinate (LMR). The Agency has no data regarding the physical and chemical characteristics of the wastewater treatment sludges generated by

these processes. However, the Agency has no reason to believe that the wastewater treatment sludges generated by these processes are different from the K046 waste generated by lead azide production. Therefore, the Agency will use the K046 waste generated by lead azide manufacture to represent the wastewater treatment sludges generated by the above processes.

## 2.2 Waste Characterization

This section includes all waste characterization data available to the Agency for the K046 waste treatability group. An estimate of the major constituents which comprise this waste and their approximate concentrations is presented in Table 2-3. The percent concentration of each major constituent in the waste was determined from best estimates based on chemical analyses. Table 2-3 shows that the major constituent in K046 is water (95 percent). The primary BDAT list metal constituent present in K046 is lead.

The ranges of BDAT list constituents present in the waste and all other available data concerning parameters affecting treatment selection are presented in Table 2-4. This table lists the levels of BDAT list metals present in K046 waste. Other parameters analyzed in the waste are also given (sulfate, sulfide, total oil and grease, pH, and total organic carbon).

Familiarization samples of K046 were taken by the Agency prior to the sampling visit. No BDAT list organics were detected in these samples. Tables 2-3 and 2-4 together provide a thorough characterization of the K046 waste.

## 2.3 Determination of Waste Treatability Group

Fundamental to waste treatment is the concept that the type of treatment technology used and the level of treatment achieved depend on the physical and chemical characteristics of the waste. In cases where EPA believes that wastes represented by different waste codes can be treated to similar concentration using the same technologies, the Agency combines the codes into one treatability group. In this case, the K046 waste from the manufacturing, processing, and loading of lead-based initiating compounds was determined to represent a single waste treatability group.

Table 2-3 Major Constituent Composition for K046 Wastes*

| | K046 Waste |
|---|---|
| Constituent | Concentration (Wt. Percent) |
| Water | 95 |
| Lead | <1 |
| Other BDAT List Metals | <1 |
| Sodium Sulfide/Sodium Hydroxide | >3 |
| TOTAL | 100 |

*Percent concentrations presented here were determined based on chemical analyses.

Table 2-4

TABLE 2-4 BDAT CONSTITUENT COMPOSITION AND OTHER DATA

| | BDAT CONSTITUENTS | DETECTION LIMIT | UNTREATED WASTE K046* TOTAL | UNTREATED WASTE K046* TCLP |
|---|---|---|---|---|
| | Metals (mg/l) | | | |
| 154 | Antimony | 0.02 | 0.022 | ND |
| 155 | Arsenic | 0.01 | ND | ND |
| 156 | Barium | 0.2 | ND | 0.228 |
| 157 | Beryllium | 0.005 | ND | ND |
| 158 | Cadmium | 0.01 | ND | ND |
| 159 | Chromium | 0.02 | ND | ND |
| 160 | Copper | 0.025 | ND | ND |
| 161 | Lead | 0.01 | 967 | 103 |
| 162 | Mercury | 0.0003 | 0.00084 | ND |
| 163 | Nickel | 0.04 | ND | ND |
| 164 | Selenium | 0.005 | ND | ND |
| 165 | Silver | 0.05 | ND | ND |
| 166 | Thallium | 0.01 | ND | ND |
| 167 | Vanadium | 0.05 | ND | ND |
| 168 | Zinc | 0.05 | 0.295 | 0.335 |
| | Other Parameters (mg/l) | | | |
| | Sulfate | 2 | 190 | NA |
| | Sulfide | 1 | ND | NA |
| | Oil & Grease | | 3.8 | NA |
| | Total Organic Carbon (Avg.) | | 461 | NA |
| | pH | | 11.91 | NA |

* - Values obtained from Onsite Engineering Report for K046 (Waterways Experiment Station).

NA - Not analyzed.

ND - Not detected.

Note: Only one sample of K046 was analyzed. Total organic carbon results are an average of four analyses on the same sample.

# 3. APPLICABLE/DEMONSTRATED TREATMENT TECHNOLOGIES

The previous section described the industry that will be affected by restrictions on K046 waste, and presented a characterization of this waste. The purpose of this section is to describe treatment technologies for K046 waste that EPA has identified as applicable, and to describe which of the applicable technologies EPA has determined to be demonstrated. The performance data available for these technologies are also presented.

## 3.1 Applicable Treatment Technologies

Familiarization samples taken by the EPA prior to the sampling visit showed that K046 waste consists primarily of water, with BDAT list metals present at treatable concentrations and BDAT list organics present at untreatable (de minimis) concentrations. Because the levels of BDAT list metals were treatable, while the levels of BDAT list organics were untreatable, the treatment technologies considered applicable for treatment of K046 waste are those which treat BDAT list metals. No treatment for BDAT list organics is required.

The EPA has therefore identified the following applicable technology for treatment of K046 waste: stabilization using various binder materials (cement, kiln dust and lime/flyash).

Metals recovery is not judged to be an applicable technology due to the low metal concentrations present.

Analysis of the K046 sludge indicates that it consists mainly of water (95 percent). BDAT constituents constitute less than two percent, and non-BDAT constituents (sodium sulfide and sodium hydroxide) constitute greater than three percent of the K046 waste. Of the BDAT list metals present, lead is present in the highest concentration. The selection of the treatment technologies applicable for stabilizing metal constituents in K046 waste is based on available literature sources and field testing.

For K046 waste, the Agency has identified the following stabilization technologies as being applicable: cement-based processes, which use cement binder additives to chemically bind the metal constituents in a solidified waste matrix; lime-based processes, which use lime and other additives to chemically bind the metal constituents in a solidified waste matrix; kiln dust (or pozzolan) processes, which use flyash from cement kilns and lime to chemically bind metal components in a solidified waste matrix.

## 3.2 Demonstrated Treatment Technologies

The Agency believes that none of the above applicable technologies are currently in commercial use for treating K046 waste. The Agency therefore decided to collect performance data for treatment systems that are demonstrated commercially for wastes similar to K046.

Three stabilization processes were tested by the Agency as follows:

- cement-based process;
- kiln dust process; and
- lime/flyash process

These three stabilization systems were chosen by the EPA for collecting performance data because they are currently being used to stabilize wastes similar to K046 (in terms of parameters affecting treatment selection) on a commercial basis.

Performance data collected by EPA for the three stabilization processes, namely cement, kiln dust, and lime/flyash, are presented in Tables 3-1 to 3-3. Tables 3-1 through 3-3 present the analytical data for samples sets 1 through 3 for waste code K046 collected during the Agency's sampling visit. The untreated K046 waste and the treated (stabilized) K046 waste for each sample set were analyzed for BDAT metals, inorganics, and other parameters. Also included in Tables 3-1 through 3-3 are the design values and actual operating

ranges for the key operating parameters of the cement, kiln dust, and lime/flyash processes. A more detailed discussion of the treatment technology systems for which the Agency has collected performance data follows.

## 3.3 Detailed Description of Treatment Technologies

### 3.3.1 Stabilization of Metals

Stabilization refers to a broad class of treatment processes that chemically reduce the mobility of hazardous constituents in a waste. Solidification and fixation are other terms that are sometimes used synonymously for stabilization or to describe specific variations within the broader class of stabilization. Related technologies are encapsulation and thermoplastic binding; however, EPA considers these technologies to be distinct from stabilization in that the operational principles are significantly different.

#### Applicability and Use of Stabilization

Stabilization is used when a waste contains metals that will leach from the waste when it is contacted by water. In general, this technology is applicable to wastes containing BDAT list metals, having a high filterable solids content, low TOC content, and low oil and grease content. This technology is commonly used

to treat residuals generated from treatment of electroplating wastewaters. For some wastes, an alternative to stabilization is metal recovery.

## Underlying Principles of Operation

The basic principle underlying this technology is that stabilizing agents and other chemicals are added to a waste in order to minimize the amount of metal that leaches. The reduced leachability is accomplished by the formation of a lattice structure and/or chemical bonds that bind the metals to the solid matrix and, thereby, limit the amount of metal constituents that can be leached when water or a mild acid solution comes into contact with the waste material.

There are two principal stabilization processes used; these are cement based and lime based. A brief discussion of each is provided below. In both cement-based or lime/pozzolan-based techniques, the stabilizing process can be modified through the use of additives, such as silicates, that control curing rates or enhance the properties of the solid material.

## Portland Cement-Based Process

Portland cement is a mixture of powdered oxides of calcium, silica, aluminum, and iron, produced by kiln burning of materials

rich in calcium and silica at high temperatures (i.e., 1400°C to 1500°C). When the anhydrous cement powder is mixed with water, hydration occurs and the cement begins to set. The chemistry involved is complex because many different reactions occur depending on the composition of the cement mixture.

As the cement begins to set, a colloidal gel of indefinite composition and structure is formed. Over a period of time, the gel swells and forms a matrix composed of interlacing, thin, densely-packed silicate fibrils. Constituents present in the waste slurry (e.g., hydroxides and carbonates of various heavy metals, are incorporated into the interstices of the cement matrix. The high pH of the cement mixture tends to keep metals in the form of insoluble hydroxide and carbonate salts.) It has been hypothesized that metal ions may also be incorporated into the crystal structure of the cement matrix, but this hypothesis has not been verified.

Lime/Pozzolan-Based Process

Pozzolan, which contains finely divided, noncrystalline silica (e.g., fly ash or components of cement kiln dust), is a material that is not cementitious in itself, but becomes so upon the addition of lime. Metals in the waste are converted to silicates or hydroxides which inhibit leaching. Additives,

again, can be used to reduce permeability and thereby further decrease leaching potential.

Description of Stabilization Processes

In most stabilization processes, the waste, stabilizing agent, and other additives, if used, are mixed and then pumped to a curing vessel or area and allowed to cure. The actual operation (equipment requirements and process sequencing) will depend on several factors such as the nature of the waste, the quantity of the waste, the location of the waste in relation to the disposal site, the particular stabilization formulation to be used, and the curing rate.After curing, the solid formed is recovered from the processing equipment and shipped for final disposal.

In instances where waste contained in a lagoon is to be treated, the material should be first transferred to mixing vessels where stabilizing agents are added. The mixed material is then fed to a curing pad or vessel. After curing, the solid formed is removed for disposal. Equipment commonly used also includes facilities to store waste and chemical additives. Pumps can be used to transfer liquid or light sludge wastes to the mixing pits and pumpable uncured wastes to the curing site. Stabilized wastes are then removed to a final disposal site.

Commercial concrete mixing and handling equipment generally can be used with wastes. Weighing conveyors, metering cement hoppers, and mixers similar to concrete batching plants have been adapted in some operations. Where extremely dangerous materials are being treated, remote-control and in-drum mixing equipment, such as that used with nuclear waste, can be employed.

## Waste Characteristics Affecting Performance

In determining whether stabilization is likely to achieve the same level of performance on an untested waste as on a previously tested waste, the Agency will focus on the characteristics that inhibit the formation of either the chemical bonds or the lattice structure. The four characteristics EPA has identified as affecting treatment performance are the presence of (1) fine particulates, (2) oil and grease, (3) organic compounds, and (4) certain inorganic compounds.

## Fine Particulates

For both cement-based and lime/pozzolan-based processes, the literature states that very fine solid materials (i.e., those that pass through a No. 200 mesh sieve, 74 um particle size) can weaken the bonding between waste particles and cement by coating the particles. This coating can inhibit chemical bond formation and decreases the resistance of the material to leaching.

## Oil and Grease

The presence of oil and grease in both cement-based and lime/pozzolan-based systems results in the coating of waste particles and the weakening of the bonding between the particle and the stabilizing agent. This coating can inhibit chemical bond formation and thereby, decrease the resistance of the material to leaching.

## Organic Compounds

The presence of organic compounds in the waste interferes with the chemical reactions and bond formation which inhibit curing of the stabilized material. This results in a stabilized waste having decreased resistance to leaching.

## Sulfate and Chlorides

The presence of certain inorganic compounds will interfere with the chemical reactions, weakening bond strength and prolonging setting and curing time. Sulfate and chloride compounds may reduce the dimensional stability of the cured matrix, thereby increasing leachability potential.

Accordingly, EPA will examine these constituents when making decisions regarding transfer of treatment standards based on stabilization.

Design and Operating Parameters

In designing a stabilization system, the principal parameters that are important to optimize so that the amount of leachable metal constituents is minimized are (1) selection of stabilizing agents and other additives, (2) ratio of waste to stabilizing agents and other additives, (3) degree of mixing, and (4) curing conditions.

(1) Selection of stabilizing agents and other additives. The stabilizing agent and additives used will determine the chemistry and structure of the stabilized material and, therefore, will affect the leachability of the solid material. Stabilizing agents and additives must be carefully selected based on the chemical and physical characteristics of the waste to be stabilized. For example, the amount of sulfates in a waste must be considered when a choice is being made between a lime/pozzolan and a Portland cement-based system.

In order to select the type of stabilizing agents and additives, the waste should be tested in the laboratory with a variety of materials to determine the best combination.

(2) Amount of stabilizing agents and additives. The amount of stabilizing agents and additives is a critical parameter in that sufficient stabilizing materials are necessary in the mixture to bind the waste constituents of concern properly, thereby making them less susceptible to leaching. The appropriate weight ratios of waste to stabilizing agent and other additives are established empirically by setting up a series of laboratory tests that allow separate leachate testing of different mix ratios. The ratio of water to stabilizing agent (including water in waste) will also impact the strength and leaching characteristics of the stabilized material. Too much water will cause low strength; too little will make mixing difficult and, more importantly, may not allow the chemical reactions that bind the hazardous constituents to be fully completed.

(3) Mixing. The conditions of mixing include the type and duration of mixing. Mixing is necessary to ensure homogeneous distribution of the waste and the stabilizing agents. Both undermixing and overmixing are undesirable. The first condition results in a nonhomogeneous mixture; therefore, areas will exist within the waste where waste particles are neither chemically bonded to the stabilizing agent nor physically held within the lattice structure. Overmixing, on the other hand, may inhibit gel formation and ion adsorption in some stabilization systems. As with the relative amounts of waste, stabilizing agent, and

additives within the system, optimal mixing conditions generally are determined through laboratory tests. During treatment it is important to monitor the degree (i.e., type and duration) of mixing to ensure that it reflects design conditions.

(4) Curing conditions. The curing conditions include the duration of curing and the ambient curing conditions (temperature and humidity). The duration of curing is a critical parameter to ensure that the waste particles have had sufficient time in which to form stable chemical bonds and/or lattice structures. The time necessary for complete stabilization depends upon the waste type and the stabilization used. The performance of the stabilized waste (i.e., the levels of constituents in the leachate) will be highly dependent upon whether complete stabilization has occurred. Higher temperatures and lower humidity increase the rate of curing by increasing the rate of evaporation of water from the solidification mixtures. However, if temperatures are too high, the evaporation rate can be excessive and result in too little water being available for completion of the stabilization reaction. The duration of the curing process should also be determined during the design stage and typically will be between 7 and 28 days.

TABLE 3-1 TREATMENT DATA FOR K046 STABILIZATION USING CEMENT

| | | UNTREATED WASTE | | TREATED WASTE* | | |
|---|---|---|---|---|---|---|
| | BDAT CONSTITUENTS | TOTAL | TCLP | SS 1 | SS 2 | SS 3 |
| | Metals (mg/l) | | | | | |
| 154 | Antimony | 0.022 | ND | ND | ND | ND |
| 155 | Arsenic | ND | ND | ND | ND | ND |
| 156 | Barium | ND | 0.228 | 1.8 | 1.8 | 1.8 |
| 157 | Beryllium | ND | ND | ND | ND | ND |
| 158 | Cadmium | ND | ND | ND | ND | ND |
| 159 | Chromium | ND | ND | 0.033 | ND | .03 |
| 160 | Copper | ND | ND | ND | ND | 0.019 |
| 161 | Lead | 967 | 103 | 0.072 | 0.1 | 0.062 |
| 162 | Mercury | 0.00084 | ND | 0.0003 | ND | ND |
| 163 | Nickel | ND | ND | ND | ND | ND |
| 164 | Selenium | ND | ND | ND | ND | ND |
| 165 | Silver | ND | ND | ND | ND | ND |
| 166 | Thallium | ND | ND | ND | ND | ND |
| 167 | Vanadium | ND | ND | ND | ND | ND |
| 168 | Zinc | 0.295 | 0.335 | 0.036 | 0.027 | 0.112 |
| | Other Parameters (mg/l) | | | | | |
| | Sulfate | 190 | NA | NA | NA | NA |
| | Sulfide | ND | NA | NA | NA | NA |
| | Oil & Grease | 3.8 | NA | NA | NA | NA |
| | Total Organic Carbon (Avg.) | 461 | NA | NA | NA | NA |
| | pH | 11.91 | NA | NA | NA | NA |

* - Treated waste data reflect analysis of TCLP extracts.
NA - Not analyzed.
ND - Not detected (see Appendix C for detection limits).

OPERATING PARAMETERS

| Binder to Waste Ratio | Run | Dry Waste + Water Weight (g) | Binder Weight (g) | Mixture pH (standard units) |
|---|---|---|---|---|
| 1.2 | A | 600 | 720 | 12.35 |
| 1.2 | B | 600 | 720 | 12.35 |
| 1.2 | C | 600 | 720 | 12.35 |

TABLE 3-2 TREATMENT DATA FOR K046 STABILIZATION USING KILN DUST

| | | UNTREATED WASTE | | TREATED WASTE* | | |
|---|---|---|---|---|---|---|
| | BDAT CONSTITUENTS | TOTAL | TCLP | SS 1 | SS 2 | SS 3 |
| | Metals (mg/l) | | | | | |
| 154 | Antimony | 0.022 | ND | ND | ND | ND |
| 155 | Arsenic | ND | ND | ND | ND | ND |
| 156 | Barium | ND | 0.228 | 0.3 | 0.4 | 0.3 |
| 157 | Beryllium | ND | ND | ND | ND | ND |
| 158 | Cadmium | ND | ND | ND | ND | ND |
| 159 | Chromium | ND | ND | 0.06 | 0.1 | 0.06 |
| 160 | Copper | ND | ND | ND | 0.1 | ND |
| 161 | Lead | 967 | 103 | 0.9 | 1.1 | 1 |
| 162 | Mercury | 0.00084 | ND | ND | ND | ND |
| 163 | Nickel | ND | ND | ND | 0.07 | ND |
| 164 | Selenium | ND | ND | 0.014 | 0.015 | 0.012 |
| 165 | Silver | ND | ND | ND | ND | ND |
| 166 | Thallium | ND | ND | 0.008 | 0.009 | 0.007 |
| 167 | Vanadium | ND | ND | ND | ND | ND |
| 168 | Zinc | 0.295 | 0.335 | ND | ND | ND |
| | Other Parameters (mg/l) | | | | | |
| | Sulfate | 190 | NA | NA | NA | NA |
| | Sulfide | ND | NA | NA | NA | NA |
| | Oil & Grease | 3.8 | NA | NA | NA | NA |
| | Total Organic Carbon (Avg.) | 461 | NA | NA | NA | NA |
| | pH | 11.91 | NA | NA | NA | NA |

* - Treated waste data reflect analysis of TCLP extracts.
NA - Not analyzed.
ND - Not detected (see Appendix C for detection limits).

OPERATING PARAMETERS

| Binder to Waste Ratio | Run | Dry Waste + Water Weight (g) | Binder Weight (g) | Mixture pH (standard units) |
|---|---|---|---|---|
| 1.4 | A | 600 | 840 | 12.25 |
| 1.4 | B | 600 | 840 | 12.15 |
| 1.4 | C | 600 | 840 | 12.35 |

TABLE 3-3 TREATMENT DATA FOR K046 STABILIZATION USING LIME/FLYASH

| | | UNTREATED WASTE | | TREATED WASTE* | | |
|---|---|---|---|---|---|---|
| | BDAT CONSTITUENTS | TOTAL | TCLP | SS 1 | SS 2 | SS 3 |
| | Metals (mg/l) | | | | | |
| 154 | Antimony | 0.022 | ND | ND | ND | ND |
| 155 | Arsenic | ND | ND | ND | ND | ND |
| 156 | Barium | ND | 0.228 | 3.7 | 3.5 | 3.5 |
| 157 | Beryllium | ND | ND | ND | ND | ND |
| 158 | Cadmium | ND | ND | ND | ND | ND |
| 159 | Chromium | ND | ND | ND | ND | ND |
| 160 | Copper | ND | ND | 0.008 | ND | 0.01 |
| 161 | Lead | 967 | 103 | 0.4 | 0.4 | 0.4 |
| 162 | Mercury | 0.00084 | ND | ND | ND | ND |
| 163 | Nickel | ND | ND | ND | 0.07 | ND |
| 164 | Selenium | ND | ND | ND | ND | ND |
| 165 | Silver | ND | ND | ND | ND | ND |
| 166 | Thallium | ND | ND | 0.001 | 0.002 | 0.002 |
| 167 | Vanadium | ND | ND | ND | ND | ND |
| 168 | Zinc | 0.295 | 0.335 | 0.04 | ND | ND |
| | Other Parameters (mg/l) | | | | | |
| | Sulfate | 190 | NA | NA | NA | NA |
| | Sulfide | ND | NA | NA | NA | NA |
| | Oil & Grease | 3.8 | NA | NA | NA | NA |
| | Total Organic Carbon (Avg.) | 461 | NA | NA | NA | NA |
| | pH | 11.91 | NA | NA | NA | NA |

* - Treated waste data reflect analysis of TCLP extracts.
NA - Not analyzed.
ND - Not detected (see Appendix C for detection limits).

OPERATING PARAMETERS

| Lime to Waste Ratio | Flyash to Waste Ratio | Run | Dry Waste + Water Weight (g) | Lime Weight (g) | Flyash Weight (g) | Mixture pH (standard units) |
|---|---|---|---|---|---|---|
| 0.7 | 0.7 | A | 600 | 420 | 420 | 12.95 |
| 0.7 | 0.7 | B | 600 | 420 | 420 | 13.05 |
| 0.7 | 0.7 | C | 600 | 420 | 420 | 12.95 |

# 4. IDENTIFICATION OF BEST DEMONSTRATED AVAILABLE TREATMENT TECHNOLOGY FOR K046

The previous section described applicable treatment technologies for waste code K046, and the available performance data for these technologies. This section describes how the performance data collected by the Agency were evaluated to determine which treatment technology system should be considered BDAT for waste code K046. Three stabilization techniques are considered in this section in the selection of BDAT for K046 nonwastewater. These techniques are:

- stabilization using a Portland cement binder,
- stabilization using a kiln dust binder, and
- stabilization using a lime/flyash binder.

As discussed in Section 3, the Agency collected performance data for the treatment of waste code K046 from these three stabilization systems.

No additional performance data were available for the treatment of K046 waste.

The topics covered in this section include descriptions of the data screening process employed for selecting BDAT, the methods used to ensure accuracy of the analytical data, and the

analysis of variance (ANOVA) tests performed in identifying the best technology for the treatment of K046 waste.

In general, performance data are screened according to the following three conditions:

- proper design and operation of the treatment system;
- the existence of quality assurance/quality control measures in the data analysis; and
- the use of proper analytical tests in assessing treatment performance.

Sets of performance data which do not meet these three conditions are not considered in the selection of BDAT. In addition, if performance data indicate that the treatment system was not well-designed and well-operated at the time of testing, these data would also not be used.

The remaining performance data are then corrected to account for incomplete recovery of certain constituents during the analyses. Finally, in cases where the Agency has adequate performance data for treatment of the waste by more than one technology, an analysis of variance (ANOVA) test is used to select the best treatment technology.

## 4.1 Review of Performance Data

In the selection of BDAT for treatment of K046 nonwastewater, the only performance data available were those collected during the Agency's sampling visit. Three data sets were collected by the Agency for treatment of the nonwastewater by stabilization using each of the following binder materials: Portland cement, kiln dust, and lime/flyash. These data were evaluated to determine whether any of the data represented poor design or operation of the system. None of the data sets were deleted due to poor operation of the stabilization system during the time data were being collected. Therefore, all data sets were used in the selection of BDAT and the development of treatment standards for K046 nonwastewater.

Toxic Characteristic Leaching Procedure (TCLP) data were used in setting treatment standards for waste code K046, since BDAT list metals were present in the untreated waste at treatable levels. For a discussion on the use of TCLP data in setting treatment standards, refer to Section 1 of this background document.

In instances where a selected constituent was not detected in the treated waste, the treated value for that constituent was assumed to be the practical quantification level. This was the case for several of the BDAT list metal constituents. Analytical

values for the BDAT list metals of concern in the treated waste are presented in Table 4-1. These numbers are taken from Tables 3-1 to 3-3 of this document.

## 4.2 Accuracy Correction of Performance Data

After the analytical data were screened as described above, the Agency adjusted the remaining data using analytical recovery values in order to take into account analytical interferences and incomplete recoveries associated with the chemical makeup of the sample. The Agency developed the recovery data (also referred to as accuracy data), by first analyzing a waste sample for a given constituent and then adding a known amount of the same constituent (i.e., spike) to the waste material. The total amount recovered after spiking, minus the initial concentration in the sample, divided by the amount added, is the recovery value. At least two recovery values were calculated for spiked constituents, and the analytical data were adjusted for accuracy using the lowest recovery value for each constituent.

Adjustment of the analytical data was accomplished by calculating an accuracy factor from the percent recoveries for each selected constituent. The reciprocal of the lower of the two recovery values divided by 100, yields the accuracy factor. The corrected concentration for each sample set is obtained by

TABLE 4-1 Treatment Data Used for Regulation of K046 Waste

| BDAT List Constituent | Analytical Concentrations (1) SS1 (TCLP) (mg/l) | SS2 (TCLP) (mg/l) | SS3 (TCLP) (mg/l) | Matrix Spike (TCLP) (% recovery) | Matrix Spike Duplicate (TCLP) (% recovery) | Accuracy Correction Factor | Accuracy-Corrected Concentrations (2) SS1 (TCLP) (mg/l) | SS2 (TCLP) (mg/l) | SS3 (TCLP) (mg/l) | Average (TCLP) (mg/l) |
|---|---|---|---|---|---|---|---|---|---|---|
| Cement: | | | | | | | | | | |
| Barium | 1.8 | 1.8 | 1.8 | 104 | 110 | 0.96 | 1.728 | 1.728 | 1.728 | 1.728 |
| Lead | 0.072 | 0.1 | 0.061 | 77.4 | 77.4 | 1.29 | 0.093 | 0.129 | 0.080 | 0.101 |
| Zinc | 0.036 | 0.027 | 0.112 | 96 | 98 | 1.04 | 0.038 | 0.028 | 0.117 | 0.061 |
| Kiln Dust: | | | | | | | | | | |
| Barium | 0.3 | 0.4 | 0.3 | 108 | 106 | 0.94 | 0.282 | 0.376 | 0.282 | 0.313 |
| Lead | 0.9 | 1.1 | 0.68 | 90.5 | 94.5 | 1.10 | 0.994 | 1.215 | 1.105 | 1.105 |
| Zinc | <0.02 | <0.02 | <0.02 | 69 | 72 | 1.45 | 0.029 | 0.029 | 0.029 | 0.029 |
| Lime/Flyash: | | | | | | | | | | |
| Barium | 3.7 | 3.5 | 3.5 | 99 | 84 | 1.19 | 4.140 | 4.165 | 4.165 | 4.157 |
| Lead | 0.4 | 0.4 | 0.56 | 69.5 | 77.2 | 1.44 | 0.576 | 0.576 | 0.576 | 0.576 |
| Zinc | 0.04 | <0.02 | <0.02 | 67 | 74 | 1.49 | 0.060 | 0.030 | 0.030 | 0.040 |

1. Onsite Engineering Report for K046 (Waterways Experiment Station).
2. A sample calculation is shown in Appendix B of this Background Document.

multiplying the accuracy factor by the uncorrected data value. The actual recovery values for the selected constituents are presented in Table 4-1 along with the calculated accuracy factors.

The accuracy factors calculated for the selected constituents in K046 varied from a high value of 1.29 for lead to a low value of 0.96 for barium. The corrected concentration values for the selected constituents in the waste are shown for the three treatment systems in Table 4-1. These corrected concentration values were obtained by multiplying the accuracy factors by the uncorrected concentration values for the selected constituents in the treated waste. An arithmetic average value, representing the treated waste concentration, was calculated for each selected constituent from the three corrected values. These averages are presented in Table 4-1. These adjusted values for the three stabilization techniques tested were then used to determine BDAT for waste code K046.

## 4.3 Statistical Comparison of Performance Data

In cases where the Agency has adequate performance data on treatment of the same or similar wastes using more than one technology, an analysis of variance (ANOVA) test is performed to determine if one of the technologies provides significantly the best treatment compared to the others. In cases where a

particular treatment technology is shown to provide the best treatment, the treatment standards will be based on this best technology. The procedure followed for the analysis of variance (ANOVA) test is described in Appendix A.

In order to determine BDAT for waste code K046, three demonstrated technologies, for which adequate performance data were available, were considered for the treatment of these wastes:

- stabilization using a Portland cement binder,
- stabilization using a kiln dust binder, and
- stabilization using a lime/flyash binder.

The corrected data for all sample sets were used to perform analysis of variance (ANOVA) tests to compare these three stabilization technologies. The three treatment technologies were compared based on the concentration of primary waste constituents (lead and zinc) in the treated waste. The rationale for selecting these constituents for the ANOVA comparison is presented in Section 5. The ANOVA calculations are summarized in Appendix D.

The statistical results of the ANOVA test for K046 waste indicate the following:

1) Stabilization using a Portland cement binder gives better treatment for lead in K046 than stabilization using a kiln dust or lime/flyash binder.

2) All three stabilization techniques achieved equivalent treatment for zinc in K046.

## 4.4 BDAT for K046 Waste

Stabilization using a Portland cement binder provides significantly better or equivalent treatment overall for the primary constituents present in waste code K046 when compared to either stabilization using a kiln dust binder or stabilization using a lime/flyash binder. Therefore, the Agency determined stabilization using a Portland cement binder to be BDAT for waste code K046.

Stabilization is judged to be available to treat K046 nonwastewater. The Agency believes this technology to be available because (1) this technology is commercially available; and (2) this technology provides a substantial reduction in the levels of BDAT list constituents present in waste K046.

# 5. SELECTION OF REGULATED CONSTITUENTS

In the previous section, the best demonstrated available technology (BDAT) for treating waste code K046 was determined to be stabilization using a Portland cement binder material. In this section, the necessary constituents are identified for assuring the most effective treatment of the wastes. This is done by following a four-step procedure:

- selecting those BDAT list constituents which will be analyzed;
- identifying the BDAT list constituents found in both the untreated and treated waste;
- determining the BDAT list constituents which are present at treatable levels, and
- selecting the regulated constituents.

As discussed in Section 1, the Agency has developed a list of hazardous constituents (Table 1-1) from which the constituents to be regulated are selected. The list is a "growing list" that does not preclude the addition of new constituents as additional key parameters are identified. The list is divided into the following categories: volatile organics, semivolatile organics, metals, inorganics, organochlorine pesticides, phenoxyacetic acid herbicides, organophosphorous pesticides, PCBs, and dioxins and furans. The constituents in each category have similar chemical properties and are expected to behave similarly during treatment, with the exception of the inorganics.

## 5.1 BDAT List Constituents Detected in the Untreated and Treated Waste

Using EPA-collected data, the Agency identified those constituents that were detected in the untreated and treated K046 waste. The BDAT list of constituents (see Table 1-1, Section 1) provided the target list of constituents. EPA collected nine sets of data at one facility (see the Onsite Engineering Report for K046 for more details) to evaluate the treatment of waste code K046 by stabilization. These nine data sets were used to identify the constituents detected in the untreated and treated waste. The detection limits for the BDAT list of constituents are presented in Appendix C.

The familiarization sample of K046 taken by the Agency prior to the sampling visit indicated that the organic and inorganic classes of BDAT list constituents (other than metals) are not present at treatable concentrations in the untreated waste (see Section 2). Therefore, the untreated and treated waste samples of K046 taken during the sampling visit were not analyzed for any of the classes of BDAT list organics (volatiles, semivolatiles, organochlorine pesticides, phenoxyacetic acid herbicides, organophosphorus pesticides, PCBs, and dioxins/furans), or for BDAT list inorganics (other than metals).

Table 5-1 indicates which of the BDAT list metals were detected in the untreated and treated waste. The following

TABLE 5-1 BDAT List Metals Detected in Untreated and Treated Waste

| | Parameter | Untreated K046 Total | Untreated K046 TCLP | Treated K046 TCLP |
|---|---|---|---|---|
| Metals | | | | |
| 154 | Antimony | D | ND | ND |
| 155 | Arsenic | ND | ND | ND |
| 156 | Barium | ND | D | D |
| 157 | Beryllium | ND | ND | ND |
| 158 | Cadmium | ND | ND | ND |
| 159 | Chromium | ND | ND | D |
| 160 | Copper | D | ND | D |
| 161 | Lead | D | D | D |
| 162 | Mercury | ND | ND | D |
| 163 | Nickel | ND | ND | ND |
| 164 | Selenium | ND | ND | ND |
| 165 | Silver | ND | ND | ND |
| 166 | Thallium | ND | ND | ND |
| 167 | Vanadium | ND | ND | ND |
| 168 | Zinc | D | D | D |

D - Detected
ND - Not detected

constituents were detected in the untreated waste K046: antimony, lead, mercury, and zinc. The TCLP extract for untreated K046 contained barium, lead, and zinc. The following constituents were detected in the TCLP extract of treated waste K046: barium, chromium, copper, lead, mercury, and zinc.

The Agency believes that copper and mercury were present in the TCLP extract from untreated K046 waste, but were not detected due to the detection limits (0.025 mg/l and 0.0003 mg/l, respectively). The chromium in treated K046 is thought to have come from the cement binder used. However, no analysis for BDAT list metals was performed on the cement binder to determine if chromium was present in the cement binder.

## 5.2 Constituents Detected in Untreated Waste But Not Considered for Regulation

The Agency evaluated the analytical data for each constituent to determine if the constituent should be selected for regulation. The Agency was guided by the criteria for selecting regulated constituents as described in Section 1 of this background document.

The metals detected in the TCLP extract for untreated K046 were barium, lead, and zinc. ANOVA calculations were performed to determine which of these BDAT list metals were treated by the treatment system. The results of these calculations follow.

Barium was present in the TCLP extract for untreated K046 waste at 0.228 mg/l. The concentration of barium in the TCLP extract for stabilized K046 was 1.8 mg/l. Barium was not selected as a regulated constituent for K046 because it was not treated by the treatment system.

Zinc was present in the TCLP extract for untreated K046 waste at 0.335 mg/l. The concentration of zinc in the TCLP extract for treated K046 waste ranged from 0.027 to 0.112 mg/l. Zinc was not selected as a regulated constituent for waste code K046 because it was not treated significantly by the treatment system. Also, stabilization of the selected constituent serves as an effective surrogate for the treatment of zinc.

## 5.3 Constituents Selected for Regulation

Lead was present in the TCLP extract for untreated K046 waste at 103 mg/l. The concentration of lead in the TCLP extract for treated K046 waste ranged from 0.061 to 0.100 mg/l. Lead was selected as a regulated constituent for K046 waste because it was present in the untreated waste at significant levels and its regulation will control the concentration of other metals present in the untreated waste.

# 6. CALCULATION OF BDAT TREATMENT STANDARDS

In this section, the actual treatment standards for waste code K046 are presented. These standards were calculated based on the performance of the demonstrated treatment system which was determined by the Agency to be the best for treating both waste codes. In Section 4, BDAT for waste code K046 was determined to be stabilization using a Portland cement binder. The previous section identified the constituents to be regulated for waste code K046.

As discussed in Section 1, the Agency calculated the BDAT treatment standards for waste code K046 by following a four-step procedure: (1) editing the data; (2) correcting the remaining data for analytical interference; (3) calculating adjustment factors (variability factors) to account for process variability; and (4) calculating the actual treatment standards using variability factors and average treatment values. The four steps in this procedure are discussed in detail in Sections 6.1 through 6.4.

## 6.1 Editing the Data

Three sets of treatment data for waste code K046 were collected by the Agency at one facility which operated a treatment system consisting of stabilization using a Portland

cement binder. The Agency evaluated the three data sets to determine if the treatment system was well operated at the time of the sampling visit. The operating data collected indicate that the treatment system was well operated during the collection of all data sets. For further details on the three data sets, see the Onsite Engineering Report for K046. All of the available data sets were used to calculate treatment standards.

Toxic Characteristic Leaching Procedure (TCLP) data were used in setting treatment standards for waste code K046, since BDAT list metals were present in the untreated waste at relatively high concentrations. For a discussion on the use of TCLP data in setting treatment standards, refer to Section 1 of this background document.

In instances where a selected constituent was not detected in the treated waste, the treated value for that constituent was assumed to be the Practical Quantification Level. This was not the case for any of the regulated constituents in K046. Analytical values for the treated waste are presented in Section 3, Tables 3-1 through 3-3 of this report.

## 6.2 Correcting the Remaining Data

Data values for the constituents selected for regulation were taken from the three data sets. These values were corrected

in order to take into account analytical interferences associated with the chemical make-up of the treated sample. This was accomplished by calculating an accuracy factor from the percent recoveries for each selected constituent. The reciprocal of the lower of the two recovery values divided by 100, yields the accuracy factor. The corrected concentration for each constituent in each sample set is obtained by multiplying the accuracy factor by the uncorrected data value. The calculation of recovery values is described in Section 1 of this background document. The actual recovery values and accuracy factors for the selected constituents are presented in Table 4-1.

The accuracy factor calculated for lead in K046 was 1.29. The corrected concentration values for the selected constituent are shown for the three data sets for cement stabilization in Table 6-1. These corrected concentration values were obtained by multiplying the accuracy factors by the concentration values for the selected constituent in the treated waste. An arithmetic average value, representing the treated waste concentration, was calculated for the selected constituent from the three corrected values. This average is presented in Table 6-1.

## 6.3 Calculating Variability Factors

It is expected that in normal operation of a well-designed and well-operated treatment system there will be some variability

Table 6-1 Regulated Constituents and Calculated Treatment Standards for K046 Wastewaters [1]

| Constituent | Accuracy-Corrected Concentration (mg/l) Sample Set #1 | Sample Set #2 | Sample Set #3 | Average Treated Waste Concentration (mg/l) | Variability Factor (VF) | Treatment Standard (mg/l) (Average X VF) |
|---|---|---|---|---|---|---|
| K046 | | | | | | |
| Lead | 0.093 | 0.129 | 0.079 | 0.100 | 1.76 | 0.176 |

1 - Accuracy Correction Factors and Variability Factors were determined as discussed in Appendix D.

in performance. Based on the test data, a measure of this variability is expressed by the variability factor (see Appendix A). This factor was calculated for the selected regulated constituent. The methodology for calculating variability factors is explained in Appendix A of this report. Table 6-1 presents the results of calculations for the selected constituent. Appendix D of this report shows how the actual value in Table 6-1 was calculated.

The variability factor calculated for lead in K046 was 1.76. For comparison, a variability factor of 1.0 represents test data from a process measured without variation and analytical interferences.

## 6.4 Calculating the Treatment Standards

The treatment standard for the selected constituent was calculated by multiplying the variability factor by the average concentration value for the treated waste. The treatment standard is presented in Table 6-1.

The BDAT Treatment Standard for waste code K046 is as follows:

| Constituent | TCLP Extract (mg/l) |
|---|---|
| Lead | 0.176 |

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# APPENDIX A - STATISTICAL ANALYSIS

## A.1 F Value Determination for ANOVA Test

As noted earlier in Section 1.0, EPA is using the statistical method known as analysis of variance in the determination of the level of performance that represents "best" treatment where more than one technology is demonstrated. This method provides a measure of the differences between data sets. If the differences are not statistically significant, the data sets are said to be homogeneous.

If the Agency found that the levels of performance for one or more technologies are not statistically different (i.e., the data sets are homogeneous), EPA would average the long term performance values achieved by each technology and then multiply this value by the largest variability factor associated with any of the acceptable technologies. If EPA found that one technology performs significantly better (i.e., the data sets are not homogeneous), BDAT would be the level of performance achieved by the best technology multiplied by its variability factor.

To determine whether any or all of the treatment performance data sets are homogeneous using the analysis of variance method, it is necessary to compare a calculated "F value" to what is known as a "critical value." (See Table A-1.) These critical

values are available in most statistics texts (see, for example, Statistical Concepts and Methods by Bhattacharyya and Johnson, 1977, John Wiley Publications, New York).

Where the F value is less than the critical value, all treatment data sets are homogeneous. If the F value exceeds the critical value, it is necessary to perform a "pair wise F" test to determine if any of the sets are homogeneous. The "pair wise F" test must be done for all of the various combinations of data sets using the same method and equation as the general F test.

The F value is calculated as follows:

(i) All data are natural logtransformed.

(ii) The sum of the data points for each data set is computed ($T_i$).

(iii) The statistical parameter known as the sum of the squares between data sets (SSB) is computed:

$$SSB = \left[ \sum_{i=1}^{k} \left( \frac{T_i^2}{n_i} \right) \right] - \left( \left[ \frac{\sum_{i=1}^{k} T_i}{N} \right]^2 \right)$$

where:

$k$ = number of treatment technologies
$n_i$ = number of data points for technology i
$N^i$ = number of data points for all technologies
$T_i$ = sum of natural logtransformed data points for each technology.

(iv) The sum of the squares within data sets (SSW) is computed:

$$SSW = \left[ \sum_{i=1}^{k} \sum_{j=1}^{n_i} x^2_{i,j} \right] - \sum_{i=1}^{k} \left( \frac{T_i^2}{n_i} \right)$$

where:

$x_{i,j}$ = the natural logtransformed observations (j) for treatment technology (i).

(v) The degrees of freedom corresponding to SSB and SSW are calculated. For SSB, the degree of freedom is given by k-1. For SSW, the degree of freedom is given by N-k.

(vi) Using the above parameters, the F value is calculated as follows:

$$F = \frac{MSB}{MSW}$$

where:

MSB = SSB/(k-1) and

MSW = SSW/(N-k).

A computational table summarizing the above parameters is shown below.

Computational Table for the F Value

| Source | Degrees of freedom | Sum of squares | Mean square | F |
|---|---|---|---|---|
| Between | K-1 | SSB | MSB = SSB/k-1 | MSB/MSW |
| Within | N-k | SSW | MSW = SSW/N-k | |

Below are three examples of the ANOVA calculation. The first two represent treatment by different technologies that achieve statistically similar treatment; the last example represents a case where one technology achieves significantly better treatment than the other technology.

# Table A-1

## F Distribution at the 95 Percent Confidence Level

$F_{0.95}$

| Denominator degrees of freedom | Numerator degrees of freedom | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1 | 161 4 | 199 5 | 215 7 | 224 6 | 230 2 | 234 0 | 236 8 | 238 9 | 240 5 |
| 2 | 18 51 | 19 00 | 19 16 | 19 25 | 19 30 | 19 33 | 19 35 | 19 37 | 19 38 |
| 3 | 10 13 | 9 55 | 9 28 | 9 12 | 9 01 | 8 94 | 8 89 | 8 85 | 8 81 |
| 4 | 7 71 | 6 94 | 6 59 | 6 39 | 6 26 | 6 16 | 6 09 | 6 04 | 6 00 |
| 5 | 6 61 | 5 79 | 5 41 | 5 19 | 5 05 | 4 95 | 4 88 | 4 82 | 4 77 |
| 6 | 5 99 | 5 14 | 4 76 | 4 53 | 4 39 | 4 28 | 4 21 | 4 15 | 4 10 |
| 7 | 5 59 | 4 74 | 4 35 | 4 12 | 3 97 | 3 87 | 3 79 | 3 73 | 3 68 |
| 8 | 5 32 | 4 46 | 4 07 | 3 84 | 3 69 | 3 58 | 3 50 | 3 44 | 3 39 |
| 9 | 5.12 | 4 26 | 3 86 | 3 63 | 3 48 | 3 37 | 3 29 | 3 23 | 3 18 |
| 10 | 4 96 | 4 10 | 3 71 | 3 48 | 3 33 | 3 22 | 3.14 | 3.07 | 3 02 |
| 11 | 4 84 | 3 98 | 3 59 | 3 36 | 3 20 | 3 09 | 3 01 | 2 95 | 2 90 |
| 12 | 4 75 | 3 89 | 3 49 | 3.26 | 3 11 | 3 00 | 2 91 | 2.85 | 2 80 |
| 13 | 4 67 | 3 81 | 3 41 | 3 18 | 3 03 | 2 92 | 2 83 | 2 77 | 2 71 |
| 14 | 4 60 | 3 74 | 3 34 | 3 11 | 2 96 | 2.85 | 2.76 | 2 70 | 2 65 |
| 15 | 4 54 | 3 68 | 3 29 | 3 06 | 2 90 | 2.79 | 2 71 | 2.64 | 2 59 |
| 16 | 4 49 | 3 63 | 3 24 | 3 01 | 2 85 | 2 74 | 2 66 | 2.59 | 2 54 |
| 17 | 4 45 | 3 59 | 3 20 | 2 96 | 2 81 | 2.70 | 2 61 | 2 55 | 2 49 |
| 18 | 4 41 | 3 55 | 3 16 | 2 93 | 2 77 | 2 66 | 2 58 | 2 51 | 2 46 |
| 19 | 4 38 | 3 52 | 3 13 | 2 90 | 2 74 | 2 63 | 2 54 | 2 48 | 2 42 |
| 20 | 4 35 | 3 49 | 3 10 | 2 87 | 2 71 | 2 60 | 2 51 | 2 45 | 2 39 |
| 21 | 4 32 | 3 47 | 3 07 | 2 84 | 2 68 | 2.57 | 2 49 | 2 42 | 2 37 |
| 22 | 4 30 | 3 44 | 3 05 | 2 82 | 2 66 | 2 55 | 2 46 | 2.40 | 2 34 |
| 23 | 4 28 | 3 42 | 3 03 | 2 80 | 2 64 | 2.53 | 2 44 | 2.37 | 2 32 |
| 24 | 4 26 | 3 40 | 3 01 | 2 78 | 2 62 | 2 51 | 2.42 | 2 36 | 2 30 |
| 25 | 4 24 | 3 39 | 2 99 | 2 76 | 2 60 | 2 49 | 2 40 | 2 34 | 2 28 |
| 26 | 4 23 | 3 37 | 2 98 | 2 74 | 2 59 | 2 47 | 2.39 | 2 32 | 2 27 |
| 27 | 4 21 | 3 35 | 2 96 | 2 73 | 2 57 | 2 46 | 2.37 | 2 31 | 2 25 |
| 28 | 4 20 | 3 34 | 2 95 | 2 71 | 2 56 | 2 45 | 2.36 | 2 29 | 2 24 |
| 29 | 4 18 | 3.33 | 2 93 | 2 70 | 2 55 | 2 43 | 2 35 | 2 28 | 2 22 |
| 30 | 4 17 | 3 32 | 2 92 | 2 69 | 2 53 | 2 42 | 2.33 | 2.27 | 2 21 |
| 40 | 4 08 | 3 23 | 2 84 | 2 61 | 2.45 | 2 34 | 2 25 | 2.18 | 2 12 |
| 60 | 4 00 | 3.15 | 2 76 | 2 53 | 2 37 | 2.25 | 2.17 | 2.10 | 2 04 |
| 120 | 3 92 | 3 07 | 2 68 | 2 45 | 2 29 | 2.17 | 2.09 | 2 02 | 1 96 |
| ∞ | 3.84 | 3.00 | 2.60 | 2.37 | 2.21 | 2.10 | 2.01 | 1 94 | 1 88 |

Example 1
Methylene Chloride

| Steam stripping | | | | Biological treatment | | | |
|---|---|---|---|---|---|---|---|
| Influent (mg/l) | Effluent (mg/l) | ln(effluent) | [ln(effluent)]$^2$ | Influent (mg/l) | Effluent (mg/l) | ln(effluent) | [ln(effluent)]$^2$ |
| 1550.00 | 10.00 | 2.30 | 5.29 | 1960.00 | 10.00 | 2.30 | 5.29 |
| 1290.00 | 10.00 | 2.30 | 5.29 | 2568.00 | 10.00 | 2.30 | 5.29 |
| 1640.00 | 10.00 | 2.30 | 5.29 | 1817.00 | 10.00 | 2.30 | 5.29 |
| 5100.00 | 12.00 | 2.48 | 6.15 | 1640.00 | 26.00 | 3.26 | 10.63 |
| 1450.00 | 10.00 | 2.30 | 5.29 | 3907.00 | 10.00 | 2.30 | 5.29 |
| 4600.00 | 10.00 | 2.30 | 5.29 | | | | |
| 1760.00 | 10.00 | 2.30 | 5.29 | | | | |
| 2400.00 | 10.00 | 2.30 | 5.29 | | | | |
| 4800.00 | 10.00 | 2.30 | 5.29 | | | | |
| 12100.00 | 10.00 | 2.30 | 5.29 | | | | |
| Sum: | | | | | | | |
| - | - | 23.18 | 53.76 | - | - | 12.46 | 31.79 |
| Sample Size: | | | | | | | |
| 10 | 10 | 10 | - | 5 | 5 | 5 | - |
| Mean: | | | | | | | |
| 3669 | 10.2 | 2.32 | - | 2378 | 13.2 | 2.49 | - |
| Standard Deviation: | | | | | | | |
| 3328.67 | .63 | .06 | - | 923.04 | 7.15 | .43 | - |
| Variability Factor: | | | | | | | |
| | 1.15 | - | - | - | 2.48 | - | - |

ANOVA Calculations:

$$SSB = \left[ \sum_{i=1}^{k} \left( \frac{T_i^2}{n_i} \right) \right] - \left( \left[ \frac{\sum_{i=1}^{k} T_i}{N} \right]^2 \right)$$

$$SSW = \left[ \sum_{i=1}^{k} \sum_{j=1}^{n_i} x^2_{i,j} \right] - \sum_{i=1}^{k} \left( \frac{T_i^2}{n_i} \right)$$

MSB = SSB/(k-1)

MSW = SSW/(N-k)

$F$ = MSB/MSW

where:

$k$ = number of treatment technologies

$n_i$ = number of data points for technology i

$N$ = number of natural log transformed data points for all technologies

$T_i$ = sum of log transformed data points for each technology

$X_{ij}$ = the nat. log transformed observations (j) for treatment technology (i)

$n_1 = 10$, $n_2 = 5$, $N = 15$, $k = 2$, $T_1 = 23.18$, $T_2 = 12.46$, $T = 35.64$, $T^2 = 1270.21$

$T_1^2 = 537.31$ $T_2^2 = 155.25$

$$SSB = \left( \frac{537.31}{10} + \frac{155.25}{5} \right) - \frac{1270.21}{15} = 0.10$$

$$SSW = (53.76 + 31.79) - \left( \frac{537\ 31}{10} + \frac{155.25}{5} \right) = 0.77$$

MSB = 0.10/1 = 0.10

MSW = 0.77/13 = 0.06

$$F = \frac{0.10}{0.06} = 1.67$$

ANOVA Table

| Source | Degrees of freedom | SS | MS | F |
|---|---|---|---|---|
| Between(B) | 1 | 0.10 | 0.10 | 1.67 |
| Within(W) | 13 | 0.77 | 0.06 | |

The critical value of the F test at the 0.05 significance level is 4.67. Since the F value is less than the critical value, the means are not significantly different (i.e., they are homogeneous).

Note: All calculations were rounded to two decimal places. Results may differ depending upon the number of decimal places used in each step of the calculations.

Example 2
Trichloroethylene

| Steam stripping | | | | Biological treatment | | | |
|---|---|---|---|---|---|---|---|
| Influent (mg/l) | Effluent (mg/l) | ln(effluent) | [ln(effluent)]$^2$ | Influent (mg/l) | Effluent (mg/l) | ln(effluent) | [ln(effluent)]$^2$ |
| 1650.00 | 10.00 | 2.30 | 5.29 | 200.00 | 10.00 | 2.30 | 5.29 |
| 5200.00 | 10.00 | 2.30 | 5.29 | 224.00 | 10.00 | 2.30 | 5.29 |
| 5000.00 | 10.00 | 2.30 | 5.29 | 134.00 | 10.00 | 2.30 | 5.29 |
| 1720.00 | 10.00 | 2.30 | 5.29 | 150.00 | 10.00 | 2.30 | 5.29 |
| 1560.00 | 10.00 | 2.30 | 5.29 | 484.00 | 16.25 | 2.79 | 7.78 |
| 10300.00 | 10.00 | 2.30 | 5.29 | 163.00 | 10.00 | 2.30 | 5.29 |
| 210.00 | 10.00 | 2.30 | 5.29 | 182.00 | 10.00 | 2.30 | 5.29 |
| 1600.00 | 27.00 | 3.30 | 10.89 | | | | |
| 204.00 | 85.00 | 4.44 | 19.71 | | | | |
| 160.00 | 10.00 | 2.30 | 5.29 | | | | |
| Sum: | | | | | | | |
| - | - | 26.14 | 72.92 | - | - | 16.59 | 39.52 |
| Sample Size: | | | | | | | |
| 10 | 10 | 10 | - | 7 | 7 | 7 | - |
| Mean: | | | | | | | |
| 2760 | 19.2 | 2.61 | - | 220 | 10.89 | 2.37 | - |
| Standard Deviation: | | | | | | | |
| 3209.6 | 23.7 | .71 | - | 120.5 | 2.36 | .19 | - |
| Variability Factor: | | | | | | | |
| - | 3.70 | - | - | - | 1.53 | - | - |

ANOVA Calculations:

$$SSB = \left[ \sum_{i=1}^{k} \left( \frac{T_i^2}{n_i} \right) \right] - \left( \left[ \frac{\sum_{i=1}^{k} T_i}{N} \right]^2 \right)$$

$$SSW = \left[ \sum_{i=1}^{k} \sum_{j=1}^{n_i} x^2_{i,j} \right] - \sum_{i=1}^{k} \left( \frac{T_i^2}{n_i} \right)$$

$MSB = SSB/(k-1)$

$MSW = SSW/(N-k)$

Appendix A-8

$F$ = MSB/MSW

where:

$k$ = number of treatment technologies

$n_i$ = number of data points for technology i

$N$ = number of data points for all technologies

$T_i$ = sum of natural log transformed data points for each technology

$X_{ij}$ = the natural log transformed observations (j) for treatment technology (i)

$N_1 = 10$, $N_2 = 7$, $N = 17$, $k = 2$, $T_1 = 26.14$, $T_2 = 16.59$, $T = 42.73$, $T^2 = 1825.85$, $T_1^2 = 683.30$, $T_2^2 = 275.23$

$$SSB = \left(\frac{683\ 30}{10} + \frac{275.23}{7}\right) - \frac{1825.85}{17} = 0.25$$

$$SSW = (72.92 + 39.52) - \left(\frac{683.30}{10} + \frac{275.23}{7}\right) = 4.79$$

MSB = 0.25/1 = 0.25

MSW = 4.79/15 = 0.32

$$F = \frac{0.25}{0.32} = 0.78$$

ANOVA Table

| Source | Degrees of freedom | SS | MS | F |
|---|---|---|---|---|
| Between(B) | 1 | 0.25 | 0.25 | 0.78 |
| Within(W) | 15 | 4.79 | 0.32 | |

The critical value of the F test at the 0.05 significance level is 4.54. Since the F value is less than the critical value, the means are not significantly different (i.e., they are homogeneous).

Note: All calculations were rounded to two decimal places. Results may differ depending upon the number of decimal places used in each step of the calculations.

Example 3
Chlorobenzene

| Activated sludge followed by carbon adsorption | | | | Biological treatment | | | |
|---|---|---|---|---|---|---|---|
| Influent (mg/l) | Effluent (mg/l) | ln(effluent) | [ln(effluent)]$^2$ | Influent (mg/l) | Effluent (mg/l) | ln(effluent) | ln[(effluent)]$^2$ |
| 7200.00 | 80.00 | 4.38 | 19.18 | 9206.00 | 1083.00 | 6.99 | 48.86 |
| 6500.00 | 70.00 | 4.25 | 18.06 | 16646.00 | 709.50 | 6.56 | 43.03 |
| 6075.00 | 35.00 | 3.56 | 12.67 | 49775.00 | 460.00 | 6.13 | 37.58 |
| 3040.00 | 10.00 | 2.30 | 5.29 | 14731.00 | 142.00 | 4.96 | 24.60 |
| | | | | 3159.00 | 603.00 | 6.40 | 40.96 |
| | | | | 6756.00 | 153.00 | 5.03 | 25.30 |
| | | | | 3040.00 | 17.00 | 2.83 | 8.01 |
| Sum: | | | | | | | |
| - | - | 14.49 | 55.20 | - | - | 38.90 | 228.34 |
| Sample Size: | | | | | | | |
| 4 | 4 | 4 | - | 7 | 7 | 7 | - |
| Mean: | | | | | | | |
| 5703 | 49 | 3.62 | - | 14759 | 452.5 | 5.56 | - |
| Standard Deviation: | | | | | | | |
| 1835.4 | 32.24 | .95 | | 16311.86 | 379.04 | 1.42 | - |
| Variability Factor: | | | | | | | |
| - | 7.00 | - | - | - | 15.79 | - | - |

ANOVA Calculations:

$$SSB = \left[ \sum_{i=1}^{k} \left( \frac{T_i^2}{n_i} \right) \right] - \left( \left[ \frac{\sum_{i=1}^{k} T_i}{N} \right]^2 \right)$$

$$SSW = \left[ \sum_{i=1}^{k} \sum_{j=1}^{n_i} x^2_{i,j} \right] - \sum_{i=1}^{k} \left( \frac{T_i^2}{n_i} \right)$$

MSB = SSB/(k-1)

MSW = SSW/(N-k)

F = MSB/MSW

where,

$k$ = number of treatment technologies

$n_i$ = number of data points for technology i

$N$ = number of data points for all technologies

$T_i$ = sum of natural log transformed data points for each technology

$X_{ij}$ = the natural log transformed observations (j) for treatment technology (i)

$N_1 = 4$, $N_2 = 7$, $N = 11$, $k = 2$, $T_1 = 14.49$, $T_2 = 38.90$, $T = 53.39$, $T^2 = 2850.49$, $T_1^2 = 209.96$

$T_2^2 = 1513.21$

$$SSB = \left\{\frac{209.96}{4} + \frac{1513.21}{7}\right\} - \frac{2850.49}{11} = 9.52$$

$$SSW = (55.20 + 228.34) - \left\{\frac{209.96}{4} + \frac{1513.21}{7}\right\} = 14.88$$

$MSB = 9.52/1 = 9.52$

$MSW = 14.88/9 = 1.65$

$F = 9.52/1.65 = 5.77$

ANOVA Table

| Source | Degrees of freedom | SS | MS | F |
|---|---|---|---|---|
| Between(B) | 1 | 9.53 | 9.53 | 5.77 |
| Within(W) | 9 | 14.89 | 1.65 | |

The critical value of the F test at the 0.05 significance level is 5.12. Since the F value is larger than the critical value, the means are significantly different (i.e., they are heterogeneous).

Note: All calculations were rounded to two decimal places. Results may differ depending upon the number of decimal places used in each step of the calculations.

A.2. Variability Factor

$$VF = \frac{C_{99}}{Mean}$$

where:

VF = estimate of daily maximum variability factor determined from a sample population of daily data.

$C_{99}$ = Estimate of performance values for which 99 percent of the daily observations will be below. $C_{99}$ is calculated using the following equation: $C_{99} = Exp(y + 2.33\ Sy)$ where y and Sy are the mean and standard deviation, respectively, of the logtransformed data.

Mean = average of the individual performance values.

EPA is establishing this figure as an instantaneous maximum because the Agency believes that on a day-to-day basis the waste should meet the applicable treatment standards. In addition, establishing this requirement makes it easier to check compliance on a single day. The 99th percentile is appropriate because it accounts for almost all process variability.

In several cases, all the results from analysis of the residuals from BDAT treatment are found at concentrations less than the detection limit. In such cases, all the actual concentration values are considered unknown and hence, cannot be used to estimate the variability factor of the analytical results. Below is a description of EPA's approach for calculating the variability factor for such cases with all concentrations below the detection limit.

It has been postulated as a general rule that a lognormal distribution adequately describes the variation among concentrations. Therefore, the lognormal model has been used routinely in the EPA development of numerous regulations in the Effluent Guidelines program and is being used in the BDAT program. The variability factor (VF) was defined as the ratio of the 99th percentile ($C_{99}$) of the lognormal distribution to its arithmetic mean (Mean).

$$VF = \frac{C_{99}}{Mean} \qquad (1)$$

The relationship between the parameters of the lognormal distribution and the parameters of the normal distribution created by taking the natural logarithms of the lognormally-distributed concentrations can be found in most mathematical statistics texts (see for example: Distribution in Statistics-Volume 1 by Johnson and Kotz, 1970). The mean of the lognormal distribution can be expressed in terms of the mean ($\mu$) and standard deviation ($\sigma$) of the normal distribution as follows:

$$C_{99} = Exp\ (\mu + 2.334\sigma) \qquad (2)$$

$$Mean = Exp\ (\mu + .54\sigma^2) \qquad (3)$$

Substituting (2) and (3) in (1) the variability factor can then be expressed in terms of $\sigma$ as follows:

$$VF = \text{Exp} \quad (2.33\,\sigma \quad - \quad .54\sigma^2) \qquad (4)$$

For residuals with concentrations that are not all below the detection limit, the 99th percentile and the mean can be estimated from the actual analytical data and accordingly, the variability factor (VF) can be estimated using equation (1). For residuals with concentrations that are below the detection limit, the above equations can be used in conjunction with the assumptions below to develop a variability factor.

Step 1: The actual concentrations follow a lognormal distribution. The upper limit (UL) is equal to the detection limit. The lower limit (LL) is assumed to be equal to one tenth of the detection limit. This assumption is based on the fact that data from well-designed and well-operated treatment systems generally falls within one order of magnitude.

Step 2: The natural logarithms of the concentrations have a normal distribution with an upper limit equal to ln (UL) and a lower limit equal to ln (LL).

Step 3: The standard deviation ( $\sigma$ ) of the normal distribution is approximated by

$$\sigma = [(\ln (UL) - \ln (LL)] \,/\, [(2)(2.33)] = [\ln(UL/LL)] \,/4.66$$

when $LL = (0.1)(UL)$ then $\sigma = (\ln 10) \,/\, 4.66 = 0.494$

Step 4: Substitution of the value from Step 3 in equation (4) yields the variability factor, VF.

$$VF = 2.8$$

# APPENDIX B - ANALYTICAL QA/QC

The analytical methods used for analysis of the regulated constituents identified in Section 5 are listed in Table B-1. SW-846 methods (EPA's Test Methods for Evaluating Solid Waste; Physical/Chemical Methods, SW-846, Third Edition, November 1986) are used in most cases for determining total waste concentrations.

SW-846 allows for the use of alternative or equivalent procedures or equipment; these are described in Table B-2. These alternatives or equivalents included use of alternative sample preparation methods and/or use of different extraction techniques to reduce sample matrix interferences.

The accuracy factor determination for a constituent is based on the matrix spike recovery values. Table B-3 present the matrix spike recovery values for TCLP extract concentrations of BDAT list metals and non-BDAT list metals for K046.

The accuracy correction factors were determined in accordance with the general methodology presented in the Introduction. For example, for lead, actual spike recovery data were obtained for analysis of liquid matrices, and the lowest percent recovery value was used to calculate the accuracy correction factor. An example of the calculation of the

corrected concentration value for lead in K046 (using a cement binder) is shown below. The analytical value is the uncorrected concentration from Table 4-1 (or Table B-3). The percent recovery value is taken from Table B-3.

| Analytical Value | % Recovery | Correction Factor | Corrected Value |
|---|---|---|---|
| 0.061 mg/l | 77 | $\frac{100}{77} = 1.30$ | 1.30 x 0.061 = 0.079 mg/l |

TABLE B-1 Analytical Methods

| Analytical Method | Method No. | Reference |
|---|---|---|
| Inductively Coupled Plasma Atomic Emission Spectroscopy (aluminum/antimony/barium/beryllium/ cadmium/calcium/chromium/cobalt/copper/ iron/magnesium/manganese/nickel/silver/ sodium/tin/vanadium/zinc/lead) | 6010 | 1 |
| Arsenic (Atomic Absorption, Furnace Technique) | 7060 | 1 |
| Selenium (Atomic Absorption, Furnace Technique) | 7740 | 1 |
| Mercury in Liquid Waste (Manual Cold-Vapor Technique | 7470 | 1 |
| Lead (Atomic Absorption, Furnace Technique) | 7421 | 1 |
| Thallium (Atomic Absorption, Furnace Technique) | 7841 | 1 |
| Hexavalent Chromium | 7196 | 1 |
| TCLP | 51 FR 40643 | 2 |
| TOC | 9060 | 1 |
| Chloride | 9252 | 1 |
| Sulfate | 9038 | 1 |
| Oil and Grease | 9071 | 1 |
| Particle Size Distribution | D 422 | 3 |

References.

1. U.S. Environmental Protection Agency. 1986. Test Methodology for Evaluating Solid Waste. Third Edition, U.S.E.P.A. Office of Solid Waste and Emergency Response, November 1986.

2. Federal Register, 1986. Hazardous Waste Management Systems; Land Disposal Restrictions; Final Rule; Appendix I to Part 268 - Toxicity Leaching Procedure (TCLP). Vol. 51, No. 216. November 7, 1986. pp. 40643-40654.

3. American Society for Testing and Materials. 1986. Annual Book of ASTM Standards. Philadelphia, PA. 1986.

TABLE B-2 Specific Procedures or Equipment Used in Preparation and Analysis of Metals When Alternative or Equivalents Allowed in the SW-846 Methods

| Analysis | SW-846 Method | Equipment | Alternative or Equivalent Allowed by SW-846 Methods | Specific Procedures or Equipment Used |
|---|---|---|---|---|
| Inductively coupled plasma atomic emission spectroscopy | 6010 | Perkin Elmer Plasma II Emission Spectrophotometers | • Operate equipment following instructions provided by instrument's manufacturer. | • Equipment operated using procedures specified in the Perkin Elmer Plasma II Emission Spectrophotometer Operator's Manual |
| | | | • For operation with organic solvents, auxiliary argon gas inlet is recommended. | • Auxiliary argon gas was not required for sample matrix. |
| Metals by Furnace AA<br>Thalium<br>Selenium<br>Lead<br>Arsenic | <br>7841<br>7740<br>7421<br>7060 | (1) Perkin Elmer 560<br>(2) Perkin Elmer HGA 2200 Graphite Furnaces | • Operate equipment following instructions provided by instrument's manufacturer. | • Equipment operated using procedures specified in Perkin Elmer instruction manuals. |
| | | | • For background correction, use either continuous correction or alternatives, e.g., Zeeman correction | • Background detection was used. |
| | | | • If samples contain a large amount of organic material, they should be oxidized by conventional acid digestion before being analyzed. | • Sample preparation using a hydrochloric acid digestion was not used. |
| Mercury | 7471 | Perkin Elmer 560 | • Operate equipment following instructions by instrument's manufacturer | • Equipment operated using procedures specified in Perkin Elmer 560 Instruction Manual. |
| | | | • Cold vapor apparatus is described in SW-846 or an equivalent apparatus may be used. | • Mercury was analyzed by cold vapor method using the apparatus as specified in SW-846. |
| | | | • Sample may be prepared using the water bath method or the autoclave method described in SW-846. | • Samples were prepared using the water bath method. |

TABLE B-3 - Matrix Spike for Metals for the TCLP Extract for the Cement Binder
K046

| Spike Constituent | Original Amount Found (mg/l) | Amount Spiked (mg/l) | Matrix Spike Amount Found (mg/l) | Matrix Spike Percent Recovery* | Matrix Spike Duplicate Amount Found (mg/l) | Matrix Spike Duplicate Percent Recovery* | Relative Percent Recovery** |
|---|---|---|---|---|---|---|---|
| BDAT Metals | | | | | | | |
| Antimony | <0.017 | 1 | 0.96 | 96 | 0.95 | 95 | 1 |
| Arsenic | <0.003 | 0 1 | 0 118 | 118 | 0.113 | 113 | 4 |
| Barium | 1.8 | 1 | 2.84 | 104 | 2.90 | 110 | 6 |
| Beryllium | <0.002 | 1 | 0.89 | 89 | 0.96 | 96 | 8 |
| Cadmium | <0.005 | 1 | 0.96 | 96 | 0.99 | 99 | 3 |
| Chromium-total | 0.03 | 1 | 0.98 | 95 | 0.98 | 95 | 0 |
| Chromium-hexavalent | 0.06 | 1 | 0.38 | 94 | NA | NA | NC |
| Copper | 0.019 | 1 | 0.86 | 84 | 0.82 | 81 | 4 |
| Lead | 0.061 | 1 | 0 82 | 77 | 0.82 | 77 | 0 |
| Mercury | <0 0003 | 0.05 | 0.0471 | 94 | 0.0505 | 101 | 7 |
| Nickel | <0.03 | 1 | 0.88 | 88 | 0.98 | 98 | 11 |
| Selenium | <0.002 | 0.05 | 0.054 | 108 | 0.043 | 87 | 22 |
| Silver | <0.006 | 1 | 0.25 | 25 | 0.42 | 42 | 51 |
| Thallium | <0.001 | 1 | 0.20 | 20 | 0.15 | 15 | 29 |
| Vanadium | <0.008 | 1 | 0 91 | 91 | 0.95 | 95 | 4 |
| Zinc | <0 02 | 1 | 1 07 | 96 | 1 09 | 98 | 2 |
| Non-BDAT Metals | | | | | | | |
| Aluminum | 0 311 | 1 | 1.20 | 89 | 1.19 | 88 | 1 |
| Calcium | 2140 | 1 | NC | NC | NC | NC | NC |
| Cobalt | <0.04 | 1 | 0.93 | 93 | 0.90 | 90 | 3 |
| Iron | 0.112 | 1 | 0.93 | 82 | 0.98 | 86 | 5 |
| Magnesium | 0 025 | 1 | 0.92 | 90 | 0.99 | 96 | 6 |
| Manganese | <0 002 | 1 | 0.93 | 93 | 0.96 | 96 | 3 |
| Sodium | 331 | 1 | NC | NC | NC | NC | NC |
| Tin | <0.983 | 1 | 0 60 | 60 | 0 76 | 76 | 24 |

NA - Not Analyzed
NC - Not Calculatable

*Percent Recovery = 100 $(C_1 - C_o)/C_t$, where $C_o$ is the initial concentration, $C_1$ is the concentration of the spiked aliquot, and $C_t$ is the concentration of the spike added.

**Relative Percent Difference - 100 $(D_1 - D_2/(D_1 + D_2)/2)$, where $D_1$ is the larger of the two observed values for Percent Recovery.

Continued

TABLE B-3 - Matrix Spike for Metals for the TCLP Extract for the Kiln Dust K046

| Spike Constituent | Original Amount Found (mg/l) | Amount Spiked (mg/l) | Matrix Spike Amount Found (mg/l) | Matrix Spike Percent Recovery* | Matrix Spike Duplicate Amount Found (mg/l) | Matrix Spike Duplicate Percent Recovery* | Relative Percent Recovery** |
|---|---|---|---|---|---|---|---|
| BDAT Metals | | | | | | | |
| Antimony | <0.017 | 1 | 0.85 | 85 | 0.92 | 92 | 1 |
| Arsenic | <0.003 | 0.1 | 0.115 | 115 | 0.122 | 107 | 4 |
| Barium | 0.3 | 1 | 1.38 | 108 | 1 36 | 106 | 6 |
| Beryllium | <0.002 | 1 | 0 70 | 70 | 0 72 | 72 | 8 |
| Cadmium | <0 005 | 1 | 0.77 | 77 | 0.73 | 73 | 3 |
| Chromium-total | 0 06 | 1 | 0 85 | 79 | 0 87 | 81 | 0 |
| Chromium-hexavalent | 0 06 | 1 | 1 29 | 123 | 1.23 | 117 | - |
| Copper | <0.006 | 1 | 0.83 | 83 | 0.83 | 83 | 4 |
| Lead | 0.68 | 1 | 1.52 | 91 | 1.59 | 95 | 4 |
| Mercury | <0 0003 | 0.05 | 0.0540 | 108 | 0.0575 | 115 | 7 |
| Nickel | <0.03 | 1 | 0.74 | 74 | 0.73 | 73 | 11 |
| Selenium | 0.012 | 0.05 | 0.058 | 91 | 0.067 | 110 | 22 |
| Silver | <0.006 | 1 | 0.13 | 13 | 0.32 | 32 | 84 |
| Thallium | 0.007 | 1 | 0.55 | 55 | 0 51 | 51 | 8 |
| Vanadium | <0 008 | 1 | 0.86 | 86 | 0.88 | 88 | 4 |
| Zinc | <0.002 | 1 | 0 69 | 69 | 0.72 | 72 | 2 |
| Non-BDAT Metals | | | | | | | |
| Aluminum | <0.016 | 1 | 0.89 | 89 | 0.87 | 87 | 1 |
| Calcium | 2134 | 1 | NC | NC | NC | NC | NC |
| Cobalt | <0.04 | 1 | 0.77 | 77 | 0.81 | 81 | 3 |
| Iron | <0.02 | 1 | 0.71 | 71 | 0.76 | 76 | 5 |
| Magnesium | 0 02 | 1 | 0.76 | 74 | 0.78 | 76 | 6 |
| Manganese | <0 002 | 1 | 0.89 | 89 | 0 76 | 76 | 3 |
| Sodium | 201 | 1 | NC | NC | NC | NC | NC |
| Tin | <0.983 | 1 | 0.67 | 67 | 0.70 | 71 | 24 |

NA - Not Analyzed
NC - Not Calculatable

*Percent Recovery = 100 $(C_1 - C_o)/C_t$, where $C_o$ is the initial concentration, $C_i$ is the concentration of the spiked aliquot, and $C_t$ is the concentration of the spike added.

**Relative Percent Difference - 100 $(D_1 - D_2/(D_1 + D_2)/2)$, where $D_1$ is the larger of the two observed values for Percent Recovery.

Continued

TABLE B-3 - Matrix Spike for Metals for the TCLP Extract for the Lime Fly Ash Binder
K046

| Spike Constituent | Original Amount Found (mg/l) | Amount Spiked (mg/l) | Matrix Spike Amount Found (mg/l) | Matrix Spike Percent Recovery* | Matrix Spike Duplicate Amount Found (mg/l) | Matrix Spike Duplicate Percent Recovery* | Relative Percent Recovery** |
|---|---|---|---|---|---|---|---|
| BDAT Metals | | | | | | | |
| Antimony | <0.017 | 1 | 0.74 | 74 | 0.77 | 77 | 4 |
| Arsenic | <0.003 | 0.1 | 0 122 | 122 | 0.124 | 124 | 2 |
| Barium | 3.5 | 1 | 4.49 | 99 | 4.34 | 84 | 16 |
| Beryllium | <0 002 | 1 | 0 66 | 66 | 0.72 | 72 | 9 |
| Cadmium | <0 005 | 1 | 0 69 | 69 | 0.69 | 69 | 0 |
| Chromium-total | <0 02 | 1 | 0.75 | 75 | 0.82 | 82 | 9 |
| Chromium-hexavalent | <0.064 | 1 | 0.94 | 94 | NA | NA | NC |
| Copper | 0 01 | 1 | 0 84 | 83 | 0.83 | 82 | 1 |
| Lead | 0.56 | 1 | 1.08 | 70 | 1.20 | 77 | 10 |
| Mercury | <0.0003 | 0.05 | 0.0489 | 98 | 0.0458 | 92 | 6 |
| Nickel | <0.03 | 1 | 0.67 | 67 | 0.74 | 75 | 11 |
| Selenium | <0 002 | 0 05 | 0.037 | 75 | 0.037 | 74 | 1 |
| Silver | <0.006 | 1 | 0.22 | 22 | 0.39 | 39 | 56 |
| Thallium | 0.002 | 1 | 0.68 | 67 | 0.71 | 71 | 6 |
| Vanadium | <0 008 | 1 | 0.87 | 87 | 0.86 | 86 | 1 |
| Zinc | <0 02 | 1 | 0.67 | 67 | 0 74 | 74 | 9 |
| Non-BDAT Metals | | | | | | | |
| Aluminum | 0.2 | 1 | 1.16 | 96 | 1.12 | 92 | 4 |
| Calcium | 2366 | 1 | NC | NC | NC | NC | NC |
| Cobalt | <0.04 | 1 | 0.77 | 77 | 0.79 | 79 | 3 |
| Iron | <0.02 | 1 | 0.76 | 76 | 0.75 | 75 | 1 |
| Magnesium | 0.003 | 1 | 0.79 | 79 | 0.77 | 77 | 3 |
| Manganese | <0.002 | 1 | 0.78 | 78 | 0.77 | 77 | 1 |
| Sodium | 280 | 1 | NC | NC | NC | NC | NC |
| Tin | <0.983 | 1 | 0 77 | 77 | 0.70 | 70 | 10 |

NA - Not Analyzed
NC - Not Calculatable

*Percent Recovery = 100 $(C_1 - C_0)/C_t$, where $C_0$ is the initial concentration, $C_1$ is the concentration of the spiked aliquot, and $C_t$ is the concentration of the spike added.

**Relative Percent Difference - 100 $(D_1 - D_2/(D_1 + D_2)/2)$, where $D_1$ is the larger of the two observed values for Percent Recovery.



Continued

TABLE C-1 DETECTION LIMITS FOR UNTREATED K046

| | BDAT CONSTITUENTS | DETECTION LIMIT (mg/l) UNTREATED K046 |
|---|---|---|
| | Metals | |
| 154 | Antimony | 0.02 |
| 155 | Arsenic | 0.01 |
| 156 | Barium | 0.2 |
| 157 | Beryllium | 0.005 |
| 158 | Cadmium | 0.01 |
| 159 | Chromium | 0.02 |
| 160 | Copper | 0.025 |
| 161 | Lead | 0.01 |
| 162 | Mercury | 0.0003 |
| 163 | Nickel | 0.04 |
| 164 | Selenium | 0.005 |
| 165 | Silver | 0.05 |
| 166 | Thallium | 0.01 |
| 167 | Vanadium | 0.05 |
| 168 | Zinc | 0.05 |

TABLE C-2 DETECTION LIMITS FOR TREATED K046

| BDAT CONSTITUENTS | DETECTION LIMIT (mg/l) CEMENT | KILN DUST | LIME/FLYASH |
|---|---|---|---|
| Metals | | | |
| 154 Antimony | 0.17 | 0.17 | 0.17 |
| 155 Arsenic | 0.003 | 0.003 | 0.003 |
| 156 Barium | 0.002 | 0.002 | 0.002 |
| 157 Beryllium | 0.002 | 0.002 | 0.002 |
| 158 Cadmium | 0.005 | 0.005 | 0.005 |
| 159 Chromium | 0.02 | 0.02 | 0.02 |
| 160 Copper | 0.006 | 0.006 | 0.006 |
| 161 Lead | 0.002 | 0.002 | 0.002 |
| 162 Mercury | 0.0003 | 0.0003 | 0.0003 |
| 163 Nickel | 0.03 | 0.03 | 0.03 |
| 164 Selenium | 0.002 | 0.002 | 0.002 |
| 165 Silver | 0.006 | 0.006 | 0.006 |
| 166 Thallium | 0.0007 | 0.0007 | 0.0007 |
| 167 Vanadium | 0.008 | 0.008 | 0.008 |
| 168 Zinc | 0.02 | 0.02 | 0.02 |

APPENDIX D CALCULATION OF TREATMENT STANDARDS

Constituent: Lead

| Sample Set | 1 Treated (TCLP) Concentration (mg/l) | 2 Percent Recovery | 3 Accuracy Correction Factor | 4 Corrected Concentration (mg/l) | 5 Log Transform |
|---|---|---|---|---|---|
| 1 | 0.072 | 77.4 | 1.29 | 0.093 | -2.375 |
| 2 | 0.100 | 77.4 | 1.29 | 0.129 | -2.048 |
| 3 | 0.061 | 77.4 | 1.29 | 0.079 | -2.538 |
| | | | x = | 0.100 | y = -2.320 |
| | | | | | s = 0.250 |

1 - Obtained from the Onsite Engineering Report for K046 (Waterways Experiment Station).
2 - Obtained from the Onsite Engineering Report for K046 (Waterways Experiment Station).
3 - Accuracy Correction Factor = 100 / Percent Recovery.
4 - Corrected Concentration = Effluent Concentration X Accuracy Correction Factor.
5 - Log Transform using the natural logarithm, ln, of the Corrected Concentration.

Treatment Standard = Corrected Effluent Mean X VF

Calculation of Variability Factor (VF):

C99 = exp (y + 2.33s)
where
y = the mean of the log transforms
s = the standard deviation of the log transforms.

Therefore, C99 = exp (-2.320 + 0.583)
= exp (-1.737)
= 0.176

and VF = C99 / x
where
x = the mean of the corrected effluent concentrations.

Therefore, VF = C99 / x
= 0.176 / 0.100
= 1.76

Treatment Standard = Corrected Effluent Mean X VF
= 0.100 X 1.76
= 0.176 mg/l

ANOVA FOR K046

I. DETERMINE ACCURACY FACTORS

| | CEMENT | | | KILN DUST | | | LIME/FLYASH | | |
|---|---|---|---|---|---|---|---|---|---|
| Component | MS | MSD | AF | MS | MSD | AF | MS | MSD | AF |
| Lead | 77.4 | 77.4 | 1.29 | 90.5 | 94.5 | 1.10 | 69.5 | 77.2 | 1.44 |
| Zinc | 96 | 98 | 1.04 | 69 | 72 | 1.45 | 67 | 74 | 1.49 |

II. CORRECT AND LOG-TRANSFORM ALL DATA
(all results are in mg/L)

| | CEMENT | | | KILN DUST | | | LIME/FLYASH | | |
|---|---|---|---|---|---|---|---|---|---|
| Component | A | B | C | A | B | C | A | B | C |
| Lead | | | | | | | | | |
| Raw | 0.072 | 0.100 | 0.062 | 0.900 | 1.100 | 1.000 | 0.400 | 0.400 | 0.400 |
| Correct | 0.093 | 0.129 | 0.080 | 0.994 | 1.215 | 1.105 | 0.576 | 0.576 | 0.576 |
| Log | -2.375 | -2.046 | -2.524 | -0.006 | 0.195 | 0.100 | -0.552 | -0.552 | -0.552 |
| Log2 | 5.640 | 4.188 | 6.373 | 0.000 | 0.038 | 0.010 | 0.305 | 0.305 | 0.305 |
| Zinc | | | | | | | | | |
| Raw | 0.036 | 0.027 | 0.112 | 0.020 | 0.020 | 0.020 | 0.040 | 0.020 | 0.020 |
| Correct | 0.038 | 0.028 | 0.117 | 0.029 | 0.029 | 0.029 | 0.060 | 0.030 | 0.030 |
| Log | -3.283 | -3.571 | -2.148 | -3.541 | -3.541 | -3.541 | -2.818 | -3.512 | -3.512 |
| Log2 | 10.781 | 12.753 | 4.616 | 12.538 | 12.538 | 12.538 | 7.943 | 12.331 | 12.331 |

III. USE F-TEST TO COMPARE ALL TREATMENTS

1) Lead

Units = mg/l

| | CEMENT | | | | KILN DUST | | | | LIME/FLYASH | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Component | A | B | C | SUM | A | B | C | SUM | A | B | C | SUM |
| Lead | | | | | | | | | | | | |
| Raw | 0.072 | 0.100 | 0.062 | | 0.900 | 1.100 | 1.000 | | 0.400 | 0.400 | 0.400 | |
| Correct | 0.093 | 0.129 | 0.080 | | 0.994 | 1.215 | 1.105 | | 0.576 | 0.576 | 0.576 | |
| Log | -2.375 | -2.046 | -2.524 | -6.946 | -0.006 | 0.195 | 0.100 | 0.289 | -0.552 | -0.552 | -0.552 | -1.657 |
| Log2 | 5.640 | 4.188 | 6.373 | 16.201 | 0.000 | 0.038 | 0.010 | 0.048 | 0.305 | 0.305 | 0.305 | 0.916 |

| | | |
|---|---|---|
| k = | 3 | number of treatments |
| n1 = | 3 | number of data points for technology 1 (cement) |
| n2 = | 3 | number of data points for technology 2 (kiln dust) |
| n3 = | 3 | number of data points for technology 3 (lime/flyash) |
| N = | 9 | number of data points for all technologies |

SSB = 9.34
MSB = 4.67

SSW = 0.14
MSW = 0.02

F = 200.61

F(k-1,N-k,0.05) = F(2,6,0.05) = 5.14

2) Zinc

Units = mg/l

| | CEMENT | | | | KILN DUST | | | | LIME/FLYASH | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Component | A | B | C | SUM | A | B | C | SUM | A | B | C | SUM |
| Zinc | | | | | | | | | | | | |
| Raw | 0.036 | 0.027 | 0.112 | | 0.020 | 0.020 | 0.020 | | 0.040 | 0.020 | 0.020 | |
| Correct | 0.038 | 0.028 | 0.117 | | 0.029 | 0.029 | 0.029 | | 0.060 | 0.030 | 0.030 | |
| Log | -3.283 | -3.571 | -2.148 | -9.003 | -3.541 | -3.541 | -3.541 | -10.623 | -2.818 | -3.512 | -3.512 | -9.841 |
| Log2 | 10.781 | 12.753 | 4.616 | 28.149 | 12.538 | 12.538 | 12.538 | 37.615 | 7.943 | 12.331 | 12.331 | 32.605 |

| | | |
|---|---|---|
| k = | 3 | number of treatments |
| n1 = | 3 | number of data points for technology 1 (cement) |
| n2 = | 3 | number of data points for technology 2 (kiln dust) |
| n3 = | 3 | number of data points for technology 3 (lime/flyash) |
| N = | 9 | number of data points for all technologies |

| | |
|---|---|
| SSB = | 0.44 |
| MSB = | 0.22 |
| SSW = | 1.45 |
| MSW = | 0.24 |
| F = | 0.90 |

F(k-1,N-k,0.05) = F(2,6,0.05) = 5.14

ANOVA FOR K046 (CEMENT/KILN DUST)

I. DETERMINE ACCURACY FACTORS

| Component | CEMENT MS | CEMENT MSD | CEMENT AF | KILN DUST MS | KILN DUST MSD | KILN DUST AF | LIME/FLYASH MS | LIME/FLYASH MSD | LIME/FLYASH AF |
|---|---|---|---|---|---|---|---|---|---|
| Lead | 77.4 | 77.4 | 1.29 | 90.5 | 94.5 | 1.10 | 69.5 | 77.2 | 1.44 |
| Zinc | 96 | 98 | 1.04 | 69 | 72 | 1.45 | 67 | 74 | 1.49 |

II. CORRECT AND LOG-TRANSFORM ALL DATA
(all results are in mg/L)

| Component | CEMENT A | CEMENT B | CEMENT C | KILN DUST A | KILN DUST B | KILN DUST C | LIME/FLYASH A | LIME/FLYASH B | LIME/FLYASH C |
|---|---|---|---|---|---|---|---|---|---|
| Lead | | | | | | | | | |
| Raw | 0.072 | 0.100 | 0.062 | 0.900 | 1.100 | 1.000 | 0.400 | 0.400 | 0.400 |
| Correct | 0.093 | 0.129 | 0.080 | 0.994 | 1.215 | 1.105 | 0.576 | 0.576 | 0.576 |
| Log | -2.375 | -2.046 | -2.524 | -0.006 | 0.195 | 0.100 | -0.552 | -0.552 | -0.552 |
| Log2 | 5.640 | 4.188 | 6.373 | 0.000 | 0.038 | 0.010 | 0.305 | 0.305 | 0.305 |
| Zinc | | | | | | | | | |
| Raw | 0.036 | 0.027 | 0.112 | 0.020 | 0.020 | 0.020 | 0.040 | 0.020 | 0.020 |
| Correct | 0.038 | 0.028 | 0.117 | 0.029 | 0.029 | 0.029 | 0.060 | 0.030 | 0.030 |
| Log | -3.283 | -3.571 | -2.148 | -3.541 | -3.541 | -3.541 | -2.818 | -3.512 | -3.512 |
| Log2 | 10.781 | 12.753 | 4.616 | 12.538 | 12.538 | 12.538 | 7.943 | 12.331 | 12.331 |

III. USE F-TEST TO COMPARE TWO TREATMENTS

1) Lead

Units = mg/l

| | CEMENT | | | | KILN DUST | | | |
|---|---|---|---|---|---|---|---|---|
| Component | A | B | C | SUM | A | B | C | SUM |
| Lead | | | | | | | | |
| Raw | 0.072 | 0.100 | 0.062 | | 0.900 | 1.100 | 1.000 | |
| Correct | 0.093 | 0.129 | 0.080 | | 0.994 | 1.215 | 1.105 | |
| Log | -2.375 | -2.046 | -2.524 | -6.946 | -0.006 | 0.195 | 0.100 | 0.289 |
| Log2 | 5.640 | 4.188 | 6.373 | 16.201 | 0.000 | 0.038 | 0.010 | 0.048 |

| | | |
|---|---|---|
| k = | 2 | number of treatments |
| n1 = | 3 | number of data points for technology 1 (cement) |
| n2 = | 3 | number of data points for technology 2 (kiln dust) |
| n3 = | 0 | number of data points for technology 3 (lime/flyash) |
| N = | 6 | number of data points for all technologies |

| | |
|---|---|
| SSB = | 8.72 |
| MSB = | 8.72 |
| SSW = | 0.14 |
| MSW = | 0.03 |
| F = | 249.72 |

F(k-1,N-k,0.05) = F(1,4,0.05) = 7.71

2) Zinc

Units = mg/l

| | CEMENT | | | | KILN DUST | | | |
|---|---|---|---|---|---|---|---|---|
| Component | A | B | C | SUM | A | B | C | SUM |
| Zinc | | | | | | | | |
| Raw | 0.036 | 0.027 | 0.112 | | 0.020 | 0.020 | 0.020 | |
| Correct | 0.038 | 0.028 | 0.117 | | 0.029 | 0.029 | 0.029 | |
| Log | -3.283 | -3.571 | -2.148 | -9.003 | -3.541 | -3.541 | -3.541 | -10.623 |
| Log2 | 10.781 | 12.753 | 4.616 | 28.149 | 12.538 | 12.538 | 12.538 | 37.615 |

| | | |
|---|---|---|
| k = | 2 | number of treatments |
| n1 = | 3 | number of data points for technology 1 (cement) |
| n2 = | 3 | number of data points for technology 2 (kiln dust) |
| n3 = | 0 | number of data points for technology 3 (lime/flyash) |
| N = | 6 | number of data points for all technologies |

| | |
|---|---|
| SSB = | 0.44 |
| MSB = | 0.44 |
| SSW = | 1.13 |
| MSW = | 0.28 |
| F = | 1.55 |

F(k-1,N-k,0.05) = F(1,4,0.05) = 7.71

ANOVA FOR K046 (CEMENT/LIME)

I. DETERMINE ACCURACY FACTORS

| | CEMENT | | | KILN DUST | | | LIME/FLYASH | | |
|---|---|---|---|---|---|---|---|---|---|
| Component | MS | MSD | AF | MS | MSD | AF | MS | MSD | AF |
| Lead | 77.4 | 77.4 | 1.29 | 90.5 | 94.5 | 1.10 | 69.5 | 77.2 | 1.44 |
| Zinc | 96 | 98 | 1.04 | 69 | 72 | 1.45 | 67 | 74 | 1.49 |

II. CORRECT AND LOG-TRANSFORM ALL DATA
(all results are in mg/L)

| | CEMENT | | | KILN DUST | | | LIME/FLYASH | | |
|---|---|---|---|---|---|---|---|---|---|
| Component | A | B | C | A | B | C | A | B | C |
| Lead | | | | | | | | | |
| Raw | 0.072 | 0.100 | 0.062 | 0.900 | 1.100 | 1.000 | 0.400 | 0.400 | 0.400 |
| Correct | 0.093 | 0.129 | 0.080 | 0.994 | 1.215 | 1.105 | 0.576 | 0.576 | 0.576 |
| Log | -2.375 | -2.046 | -2.524 | -0.006 | 0.195 | 0.100 | -0.552 | -0.552 | -0.552 |
| Log2 | 5.640 | 4.188 | 6.373 | 0.000 | 0.038 | 0.010 | 0.305 | 0.305 | 0.305 |
| Zinc | | | | | | | | | |
| Raw | 0.036 | 0.027 | 0.112 | 0.020 | 0.020 | 0.020 | 0.040 | 0.020 | 0.020 |
| Correct | 0.038 | 0.028 | 0.117 | 0.029 | 0.029 | 0.029 | 0.060 | 0.030 | 0.030 |
| Log | -3.283 | -3.571 | -2.148 | -3.541 | -3.541 | -3.541 | -2.818 | -3.512 | -3.512 |
| Log2 | 10.781 | 12.753 | 4.616 | 12.538 | 12.538 | 12.538 | 7.943 | 12.331 | 12.331 |

III. USE F-TEST TO COMPARE TWO TREATMENTS (CEMENT AND LIME/FLYASH)

1) Lead

Units = mg/l

| | CEMENT | | | | LIME/FLYASH | | | |
|---|---|---|---|---|---|---|---|---|
| Component | A | B | C | SUM | A | B | C | SUM |
| Lead | | | | | | | | |
| Raw | 0.072 | 0.100 | 0.062 | | 0.400 | 0.400 | 0.400 | |
| Correct | 0.093 | 0.129 | 0.080 | | 0.576 | 0.576 | 0.576 | |
| Log | -2.375 | -2.046 | -2.524 | -6.946 | -0.552 | -0.552 | -0.552 | -1.657 |
| Log2 | 5.640 | 4.188 | 6.373 | 16.201 | 0.305 | 0.305 | 0.305 | 0.916 |

| | | |
|---|---|---|
| k = | 2 | number of treatments |
| n1 = | 3 | number of data points for technology 1 (cement) |
| n2 = | 0 | number of data points for technology 2 (kiln dust) |
| n3 = | 3 | number of data points for technology 3 (lime/flyash) |
| N = | 6 | number of data points for all technologies |

| | |
|---|---|
| SSB = | 4.66 |
| MSB = | 4.66 |
| SSW = | 0.12 |
| MSW = | 0.03 |
| F = | 155.90 |

F(k-1,N-k,0.05) = F(1,4,0.05) = 7.71

2) Zinc

Units = mg/l

| | CEMENT | | | | LIME/FLYASH | | | |
|---|---|---|---|---|---|---|---|---|
| Component | A | B | C | SUM | A | B | C | SUM |
| Zinc | | | | | | | | |
| Raw | 0.036 | 0.027 | 0.112 | | 0.040 | 0.020 | 0.020 | |
| Correct | 0.038 | 0.028 | 0.117 | | 0.060 | 0.030 | 0.030 | |
| Log | -3.283 | -3.571 | -2.148 | -9.003 | -2.818 | -3.512 | -3.512 | -9.841 |
| Log2 | 10.781 | 12.753 | 4.616 | 28.149 | 7.943 | 12.331 | 12.331 | 32.605 |

| | | |
|---|---|---|
| k = | 2 | number of treatments |
| n1 = | 3 | number of data points for technology 1 (cement) |
| n2 = | 0 | number of data points for technology 2 (kiln dust) |
| n3 = | 3 | number of data points for technology 3 (lime/flyash) |
| N = | 6 | number of data points for all technologies |

| | |
|---|---|
| SSB = | 0.12 |
| MSB = | 0.12 |
| SSW = | 1.45 |
| MSW = | 0.36 |
| F = | 0.32 |

F(k-1,N-k,0.05) = F(1,4,0.05) = 7.71

ANOVA FOR K046 (KILN DUST/LIME)

I. DETERMINE ACCURACY FACTORS

| Component | CEMENT MS | CEMENT MSD | CEMENT AF | KILN DUST MS | KILN DUST MSD | KILN DUST AF | LIME/FLYASH MS | LIME/FLYASH MSD | LIME/FLYASH AF |
|---|---|---|---|---|---|---|---|---|---|
| Lead | 77.4 | 77.4 | 1.29 | 90.5 | 94.5 | 1.10 | 69.5 | 77.2 | 1.44 |
| Zinc | 96 | 98 | 1.04 | 69 | 72 | 1.45 | 67 | 74 | 1.49 |

II. CORRECT AND LOG-TRANSFORM ALL DATA
(all results are in mg/L)

| Component | CEMENT A | CEMENT B | CEMENT C | KILN DUST A | KILN DUST B | KILN DUST C | LIME/FLYASH A | LIME/FLYASH B | LIME/FLYASH C |
|---|---|---|---|---|---|---|---|---|---|
| Lead | | | | | | | | | |
| Raw | 0.072 | 0.100 | 0.062 | 0.900 | 1.100 | 1.000 | 0.400 | 0.400 | 0.400 |
| Correct | 0.093 | 0.129 | 0.080 | 0.994 | 1.215 | 1.105 | 0.576 | 0.576 | 0.576 |
| Log | -2.375 | -2.046 | -2.524 | -0.006 | 0.195 | 0.100 | -0.552 | -0.552 | -0.552 |
| Log2 | 5.640 | 4.188 | 6.373 | 0.000 | 0.038 | 0.010 | 0.305 | 0.305 | 0.305 |
| Zinc | | | | | | | | | |
| Raw | 0.036 | 0.027 | 0.112 | 0.020 | 0.020 | 0.020 | 0.040 | 0.020 | 0.020 |
| Correct | 0.038 | 0.028 | 0.117 | 0.029 | 0.029 | 0.029 | 0.060 | 0.030 | 0.030 |
| Log | -3.283 | -3.571 | -2.148 | -3.541 | -3.541 | -3.541 | -2.818 | -3.512 | -3.512 |
| Log2 | 10.781 | 12.753 | 4.616 | 12.538 | 12.538 | 12.538 | 7.943 | 12.331 | 12.331 |

III. USE F-TEST TO COMPARE TWO TREATMENTS (KILN DUST AND LIME/FLYASH)

1) Lead

Units = mg/l

| | KILN DUST | | | | LIME/FLYASH | | | |
|---|---|---|---|---|---|---|---|---|
| Component | A | B | C | SUM | A | B | C | SUM |
| Lead | | | | | | | | |
| Raw | 0.900 | 1.100 | 1.000 | | 0.400 | 0.400 | 0.400 | |
| Correct | 0.994 | 1.215 | 1.105 | | 0.576 | 0.576 | 0.576 | |
| Log | -0.006 | 0.195 | 0.100 | 0.289 | -0.552 | -0.552 | -0.552 | -1.657 |
| Log2 | 0.000 | 0.038 | 0.010 | 0.048 | 0.305 | 0.305 | 0.305 | 0.916 |

| | | |
|---|---|---|
| k = | 2 | number of treatments |
| n1 = | 0 | number of data points for technology 1 (cement) |
| n2 = | 3 | number of data points for technology 2 (kiln dust) |
| n3 = | 3 | number of data points for technology 3 (lime/flyash) |
| N = | 6 | number of data points for all technologies |

SSB = 0.63
MSB = 0.63

SSW = 0.02
MSW = 0.01

F = 125.38

F(k-1,N-k,0.05) = F(1,4,0.05) = 7.71

2) Zinc

Units = mg/l

| Component | KILN DUST A | KILN DUST B | KILN DUST C | KILN DUST SUM | LIME/FLYASH A | LIME/FLYASH B | LIME/FLYASH C | LIME/FLYASH SUM |
|---|---|---|---|---|---|---|---|---|
| Zinc | | | | | | | | |
| Raw | 0.020 | 0.020 | 0.020 | | 0.040 | 0.020 | 0.020 | |
| Correct | 0.029 | 0.029 | 0.029 | | 0.060 | 0.030 | 0.030 | |
| Log | -3.541 | -3.541 | -3.541 | -10.623 | -2.818 | -3.512 | -3.512 | -9.841 |
| Log2 | 12.538 | 12.538 | 12.538 | 37.615 | 7.943 | 12.331 | 12.331 | 32.605 |

| | | |
|---|---|---|
| k = | 2 | number of treatments |
| n1 = | 0 | number of data points for technology 1 (cement) |
| n2 = | 3 | number of data points for technology 2 (kiln dust) |
| n3 = | 3 | number of data points for technology 3 (lime/flyash) |
| N = | 6 | number of data points for all technologies |

| | |
|---|---|
| SSB = | 0.10 |
| MSB = | 0.10 |
| SSW = | 0.32 |
| MSW = | 0.08 |
| F = | 1.27 |

F(k-1,N-k,0.05) = F(1,4,0.05) = 7.71

DETERMINATION OF SIGNIFICANT TREATMENT

I. DETERMINE ACCURACY FACTORS

| Component | CEMENT MS | CEMENT MSD | AF |
|---|---|---|---|
| Lead | 77.4 | 77.4 | 1.29 |
| Zinc | 96 | 98 | 1.04 |

II. CORRECT AND LOG-TRANSFORM ALL DATA
(all results are in mg/l)

| Component | UNTREATED TCLP | CEMENT A | CEMENT B | CEMENT C |
|---|---|---|---|---|
| Lead | | | | |
| Raw | 103 | 0.072 | 0.100 | 0.061 |
| Correct | 133.075 | 0.093 | 0.129 | 0.079 |
| Log | 4.891 | -2.375 | -2.046 | -2.541 |
| Log2 | 23.921 | 5.640 | 4.188 | 6.455 |
| Zinc | | | | |
| Raw | 0.335 | 0.036 | 0.027 | 0.112 |
| Correct | 0.349 | 0.038 | 0.028 | 0.117 |
| Log | -1.053 | -3.283 | -3.571 | -2.148 |
| Log2 | 1.108 | 10.781 | 12.753 | 4.616 |

III. USE F-TEST TO COMPARE UNTREATED AND TREATED WASTE (FOR CEMENT BINDER)

1) Lead

Units = mg/l

| Component | | CEMENT A | B | C | SUM |
|---|---|---|---|---|---|
| Lead | | | | | |
| Raw | 103.000 | 0.072 | 0.100 | 0.061 | |
| Correct | 133.075 | 0.093 | 0.129 | 0.079 | |
| Log | 4.891 | -2.375 | -2.046 | -2.541 | -6.962 |
| Log2 | 23.921 | 5.640 | 4.188 | 6.455 | 16.283 |

| | | |
|---|---|---|
| k = | 2 | number of treatments |
| n1 = | 1 | number of data points for technology 1 (untreated) |
| n2 = | 3 | number of data points for technology 2 (treated) |
| n3 = | 0 | number of data points for technology 3 |
| N = | 4 | number of data points for all technologies |

| | |
|---|---|
| SSB = | 39.01 |
| MSB = | 39.01 |
| SSW = | 0.13 |
| MSW = | 0.06 |
| F = | 616.31 |

F(k-1,N-k,0.05) = F(1,2,0.05) = 18.5

2) Zinc

Units = mg/l

| Component | | CEMENT A | B | C | SUM |
|---|---|---|---|---|---|
| Zinc | | | | | |
| Raw | 0.335 | 0.036 | 0.027 | 0.112 | |
| Correct | 0.349 | 0.038 | 0.028 | 0.117 | |
| Log | -1.053 | -3.283 | -3.571 | -2.148 | -9.003 |
| Log2 | 1.108 | 10.781 | 12.753 | 4.616 | 28.149 |

| | | |
|---|---|---|
| k = | 2 | number of treatments |
| n1 = | 1 | number of data points for technology 1 (untreated) |
| n2 = | 3 | number of data points for technology 2 (treated) |
| n3 = | 0 | number of data points for technology 3 |
| N = | 4 | number of data points for all technologies |
| SSB = | 2.85 | |
| MSB = | 2.85 | |
| SSW = | 1.13 | |
| MSW = | 0.57 | |
| F = | 5.03 | |

F(k-1,N-k,0.05) = F(1,2,0.05) = 18.5