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Best Demonstrated Available Technology (BDAT) Background Document for K015

Proposed

Volume 1

BEST DEMONSTRATED AVAILABLE TECHNOLOGY (BDAT) BACKGROUND DOCUMENT FOR K015

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Table of Contents

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

BDAT Treatment Standards for K015

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, the following treatment standards have been proposed as Best Demonstrated Available Technology (BDAT) for the listed waste identified in 40 CFR Part 261.32 as K015 (still bottoms from the distillation of benzyl chloride). Compliance with these treatment standards is a prerequisite for disposal of the waste in units designated as land disposal units according to 40 CFR Part 268.

BDAT treatment standards have been established for wastewater and EPA is considering establishing BDAT treatment standards for nonwastewater forms of K015 waste. While testing conducted by EPA produced no nonwastewater residuals, EPA is aware that some nonwastewater may be produced when subsequently treating the BDAT list metallic constituents of the K015 wastewaters. Until the final determination to establish standards for these nonwastewaters residuals is made by EPA, the treatment standard for nonwastewaters will be "no land disposal."

For wastewaters, treatment standards have been established for a total of five organic constituents and two metals. The regulated organic constituents are toluene, anthracene, benzal chloride, benzo(b and/or k)fluoranthene, and phenanthrene. The regulated metals are chromium and nickel.

The treatment standards for the organic constituents have been established based on performance data representing liquid injection incineration. The wastewater standards for metals have been transferred from performance achieved using chromium reduction, chemical precipitation, and dewatering of precipitate. These standards become effective as of August 8, 1988, as per the schedule set forth in 40 CFR 268.10.

The following table lists the specific BDAT standards for K015 wastewaters. The units for the total waste analyses are in milligrams per liter (mg/l). Testing and analysis procedures are specifically identified and discussed in Appendix B (QA/QC Section) of this background document.

1541g

BDAT Treatment Standards for K015
(Wastewater)

Constituent	Maximum for any single grab sample: Total waste concentration (mg/l)	Total TCLP concentration (mg/l)
Toluene	.148	NA
Anthracene	1.02	NA
Benzal chloride	0.28	NA
Benzo(b and/or k)fluoranthene	0.29	NA
Phenanthrene	0.27	NA
Chromium	0.30	NA
Nickel	0.44	NA

NA = Not applicable

BDAT Treatment Standards for K015
(Nonwastewater)

No land disposal

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, and which amended the Resource Conservation and Recovery Act of 1976 (RCRA), 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 Section 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 HSWA, 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 nonliquid 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 treatment of 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 waste 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 may combine two or more 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 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 40588). 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 bases for this determination are 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, pilot- and bench-scale operations, will not be considered in identifying demonstrated treatment technologies for a waste because these technologies would not necessarily be "demonstrated." 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 and (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 in which additional data are needed to supplement existing information, EPA collects these 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 before and during treatment.

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 in which 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. It also includes several ignitable constituents used as the basis for 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

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	75-34-3
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

Table 1-1 (continued)

BDAT reference no	Parameter	CAS no.
	Volatiles (continued)	
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	Methacrylonitrile	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	79-34-6
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	Trichloromonofluoromethane	75-69-4
49	1,2,3-Trichloropropane	96-18-4
231	1,1,2-Trichloro-1,2,2-trifluoro-ethane	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	108-98-5
61	Deleted	
62	Benzo(a)pyrene	50-32-8

Table 1-1 (continued)

BDAT reference no	Parameter	CAS no.
	Semivolatiles (continued)	
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)methane	111-91-1
68	Bis(2-chloroethyl)ether	111-44-4
69.	Bis(2-chloroisopropyl)ether	39638-32-9
70	Bis(2-ethylhexyl)phthalate	117-81-7
71	4-Bromophenyl phenyl ether	101-55-3
72	Butyl benzyl phthalate	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	542-76-7
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'-Dimethoxybenzidine	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

Table 1-1 (continued)

EDAT reference no	Parameter	CAS no.
	Semivolatiles (continued)	
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-Methylcholanthrene	56-49-5
120	4,4'-Methylenebis (2-chloroaniline)	101-14-4
36.	Methyl methanesulfonate	66-27-3
121	Naphthalene	91-20-3
122	1,4-Naphthoquinone	130-15-4
123.	1-Naphthylamine	134-32-7
124.	2-Naphthylamine	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.	5-Nitro-o-toluidine	99-65-8
136	Pentachlorobenzene	608-93-5
137	Pentachloroethane	76-01-7
138	Pentachloronitrobenzene	82-68-8

Table 1-1 (continued)

BDAT reference no	Parameter	CAS no.
	Semivolatiles (continued)	
139.	Pentachlorophenol	87-86-5
140	Phenacetin	62-44-2
141	Phenanthrene	85-01-8
142.	Phenol	108-95-2
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	7440-43-9
159.	Chromium (total)	7440-47-32
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

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	Methoxyclor	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

Table 1-1 (continued)

BDAT reference no	Parameter	CAS no.
	PCBs (continued)	
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	Hexachlorodibenzofurans	-
209.	Pentachlorodibenzo-p-dioxins	-
210	Pentachlorodibenzofurans	-
211	Tetrachlorodibenzo-p-dioxins	-
212	Tetrachlorodibenzofurans	-
213.	2,3,7,8-Tetrachlorodibenzo-p-dioxin	1746-01-6

constituents that can 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 the BDAT constituent list as other 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, 18 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. Including a constituent in Appendix VIII means that the constituent can be cited as a basis for listing toxic wastes.

Although Appendix VII, Appendix VIII, and the F003 and F005 ignitables provide a comprehensive list of RCRA-regulated 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.

There are five major reasons why constituents were not included on the BDAT constituent list:

(a) 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.

(b) 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.

(c) 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.

(d) 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 high pressure liquid chromatography (HPLC) presupposes a high expectation that specific constituents of interest will be found. 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, HPLC is not an appropriate analytical procedure for complex samples containing unknown constituents.

(e) 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 Appendices VII and VIII; 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 it is extremely unlikely that the constituent will be 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 in which EPA may regulate constituents that are not found in the untreated waste but are detected in the treated residual. This is generally the case when the 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 in which 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 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) use the TCLP value as a measure of performance. At the time 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 both 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 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 in which 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 performance 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 data from the treated waste. This screening criterion involves adjustment of treated data to take into account that the type 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 concentration data for organics, and total concentration 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 than others. 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 treatment standards are the level of performance achieved by the best technology multiplied by the corresponding variability factor for each regulated constituent.

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, 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 for each constituent (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 recovery 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 in which 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 Part 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 treatment standard 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 treatment standard 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 treatment standards 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 standards 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 Part 261.3(c)(2)(i)) or the mixture rule (40 CFR Part 261.3(a)(2)(iii) and (iv) or because the listed waste is contained in the matrix (see, for example, 40 CFR Part 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 treatment standards 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 Part 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, it will readdress the question to avoid any possible confusion.

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 Part 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. The language in 40 CFR Part 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 in which the untested wastes are generated from similar industries, have similar processing steps, or have similar waste characteristics affecting performance and treatment selection. Transfer of treatment standards to similar wastes or wastes from similar processing steps requires little formal analysis. However, when 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 Part 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 affecting treatment selection 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 Part 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 in which 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 40 CFR Part 268, Subpart D.

2. INDUSTRY AFFECTED AND WASTE CHARACTERIZATION

This section discusses the industry affected by the land disposal restrictions for K015 waste, describes the process that generates the waste, and presents available waste characterization data.

As discussed in Section 1, the Agency may establish treatability groups for wastes having similar physical and chemical properties and thus similar treatability characteristics. At this time, the Agency has determined that K015 waste represents a separate treatability group.

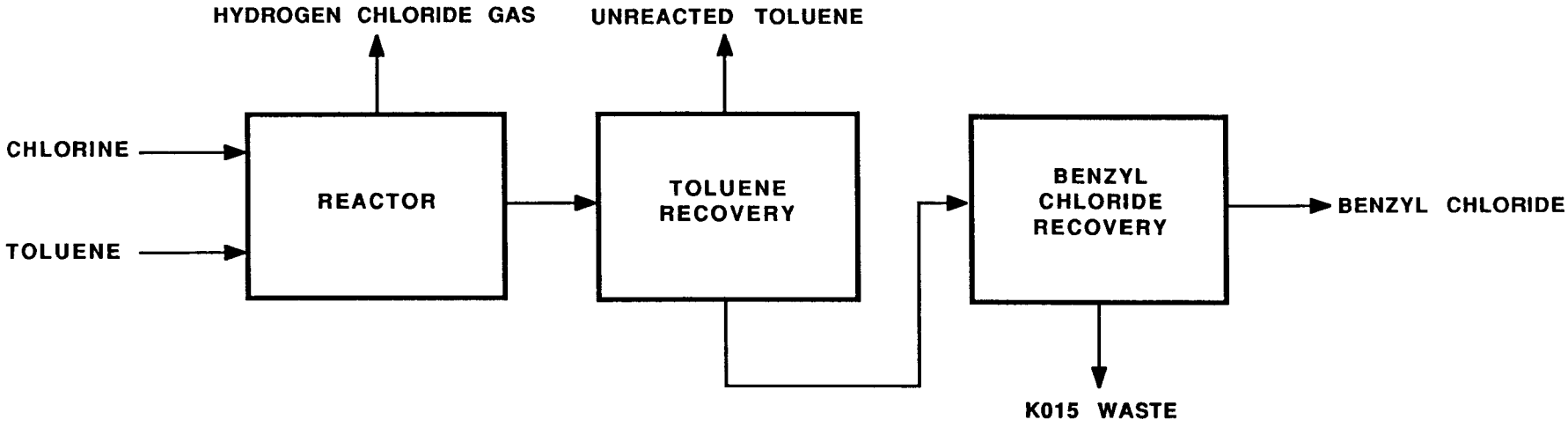
2.1 Industry Affected and Process Description

According to 40 CFR Part 261.32 (hazardous wastes from specific sources), waste identified as K015 is specifically generated by the organic chemicals industry and is listed as follows:

K015 - Still bottoms from the distillation of benzyl chloride.

The Agency estimates that two facilities in the United States currently generate K015 waste. These facilities are located in New Jersey and Tennessee (EPA Regions II and IV, respectively). Benzyl chloride is used as a raw material or chemical intermediate in the production of benzyl phthalates, pharmaceuticals, quaternary ammonium salts, benzyl alcohol, and other compounds including esters, dyes, and solvents.

In the United States, benzyl chloride is currently produced by photochemical chlorination of toluene. A flow diagram of the production process is presented in Figure 2-1. Chlorine is fed into a heated reactor or series of reactors containing boiling toluene. The toluene



(SOURCE: LISTING BACKGROUND DOCUMENT 1980)

FIGURE 2-1. BENZYL CHLORIDE PRODUCTION BY THE CHLORINATION OF TOLUENE

and chlorine react to form benzyl chloride and hydrogen chloride gas. The hydrogen chloride gas is purged from the reactor(s), while the unreacted toluene and the remaining reaction products are sent to a distillation column where toluene is recovered. The product stream is further distilled, producing purified benzyl chloride. The still bottoms from this step are the listed waste K015.

2.2 Waste Characterization

K015 waste generally contains greater than 88 percent benzal chloride, less than 12 percent benzotrichloride and other chlorinated benzenes, less than 5 percent benzyl chloride, less than 1 percent toluene, less than 1 percent other BDAT constituents, and less than 1 percent water. Other industry submitted information indicates the following approximations: 80 to 90 percent benzal chloride, 3 to 10 percent benzyl chloride, 8 to 12 percent other chlorinated hydrocarbons (usually toluene), and less than 1 percent water. These approximations are listed in Table 2-1. The constituent concentrations are estimates based on chemical analyses and information generated by earlier EPA studies. Results of the chemical analyses used in estimating the composition of K015 waste from tests conducted by the Agency are presented in Table 2-2. These tests determined that the heating value was 10,000 Btu/lb, the carbon and sulfur content were approximately 51 and 0.22 percent, respectively, and the waste had a low filterable solids content.

Table 2-1 Major Constituent Composition for K015 Waste

Constituent	Range of concentrations (percent) Source (1)	Source (2)
Benzal chloride	>88	80-90
Benzotrichloride and other chlorinated benzenes	<12	8-12
Benzyl chloride	<5	3-10
Toluene	<1	8-12
Other BDAT constituents	<1	-
Water	<1	<1

Source: (1) USEPA 1987a, p.2-2.
(2) USEPA 1987b.

Table 2-2 BDAT Constituent Composition and Other Data

Parameter	Untreated waste concentration
BDAT volatile organics (ug/kg)	
Toluene	<10
BDAT semivolatile organics (ug/kg)	
Anthracene	<5,000
Benzal chloride	880,000
Benzo(b and/or k)fluoranthene	<5,000
Phenanthrene	<5,000
Other parameters	
Ash content (%)	0.01 - 0.29 (0.09 average)
Heating value (Btu/lb)	10,000
Carbon content (%)	51.0 - 51.3 (51.1 average)
Dry loss (%)	96.0 - 99.0 (97.2 average)
Sulfur content (%)	0.03 - 0.32 (0.22 average)
Water content (%)	<1

Source: U.S. Environmental Protection Agency 1987, p. 6-3.

3. APPLICABLE/DEMONSTRATED TREATMENT TECHNOLOGIES

This section identifies the applicable treatment technologies, describes the demonstrated technologies, and presents performance data for K015 waste. As shown in Section 2, K015 waste primarily contains high concentrations of organic compounds and has a low filterable solids concentration and a low water content. The technologies considered to be applicable for K015 waste are those that reduce the hazardous organic constituent concentrations and/or reduce the volume of the waste.

3.1 Applicable Treatment Technologies

The Agency has identified two treatment technologies as applicable for K015 waste: liquid injection incineration and fuel substitution. Information for K015 waste is available from current literature sources, field testing, engineering site visits, and data submitted by industry.

Liquid injection incineration destroys the hazardous organic constituents in the waste; the technology also results in the formation of residual wastewater (i.e., quench and scrubber water) with reduced concentrations of organic constituents and with concentrations of BDAT metals. If EPA establishes nonwastewater treatment standards for subsequent treatment of metals in the K015 wastewater, EPA has identified the following demonstrated technologies: chromium reduction followed by chemical precipitation and, finally, stabilization of the precipitated residuals. These technologies are commonly practiced for metal-containing wastewaters. Chromium reduction reduces hexavalent chromium to the less soluble trivalent form. Chemical precipitation converts

soluble metals in the wastewater to an insoluble sludge suitable for stabilization. The technology is described in greater detail in Section 3.2.1.

Fuel substitution, similar to liquid injection incineration, destroys the organic constituents in the waste. In doing so, however, fuel substitution also derives fuel value from the waste. This technology is explained further in Section 3.2.2.

3.2 Demonstrated Treatment Technologies

Liquid injection incineration and fuel substitution have been identified as demonstrated treatment technologies for K015 waste.

The Agency tested liquid injection incineration for K015 waste, obtaining three sample sets of performance data. The performance data include constituent concentration information on both the untreated and treated forms of the waste incinerated during the interval, as well as design and operating information. Performance data for this technology are presented in Table 3-1. Further discussion of how these data were obtained is presented in USEPA 1987 (Onsite Engineering Report of Treatment Technology Performance and Operation for Incineration of K015 Waste at the John Zink Company Test Facility).

Unadjusted analytical data show that in the untreated waste for which detection limits were fairly high (parts per thousand for semivolatile organic compounds), only benzal chloride was detected. Concentrations detected were greater than 90 percent. Benzal chloride concentrations in the treated wastewaters ranged from less than 50 to 94 μg/l. Other organic constituents found in the treated waste were toluene, anthracene,

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Table 3-1 Performance Data Collected by EPA for Liquid Injection Incineration of K015 Waste

Sample set #1
Concentration data

Constituent	BDAT constituent concentration[a] Untreated waste (μg/g)	Treated waste[b] (μg/l)
Volatiles		
Toluene	<10	59
Semivolatiles		
Anthracene	<5,000	<50
Benzal chloride	930,000	<50
Benzo(b and/or k)fluoranthene	<5,000	<50
Phenanthrene	<5,000	<50
Metals		
Silver	-	130
Arsenic	-	250
Barium	-	110
Beryllium	-	<5
Cadmium	-	<20
Chromium	-	4,000
Copper	-	580
Mercury	-	5
Nickel	-	2,200
Lead	-	60
Antimony	-	<120
Selenium	-	60
Thallium	-	<750
Vanadium	-	50
Zinc	-	110

Design and operating data

Kiln	
Temperature	1841-2013°F
Feed rate	4.14-4.5 lb/min
Excess oxygen	3.74-5.29%
Carbon monoxide	0-520 ppm
Scrubber	
Flow	17 44 gal/min
Pressure drop	40-44 in. of water

[a] Concentration data have not been adjusted for accuracy. Accuracy-adjusted data are shown in Section 5 and Appendix B.

[b] The concentrations represent scrubber water residuals and are considered treated relative to organics and not relative to metals

Table 3-1 (continued)

Sample set #2
Concentration data

Constituent	BDAT constituent concentration[a] Untreated waste (μg/g)	Treated waste[b] (μg/l)
Volatiles		
Toluene	<10	30
Semivolatiles		
Anthracene	<5,000	68
Benzal chloride	910,000	66
Benzo(b and/or k)fluoranthene	<5,000	<50
Phenanthrene	<5,000	58
Metals		
Silver	-	300
Arsenic	-	100
Barium	-	250
Beryllium	-	<5
Cadmium	-	<20
Chromium	-	18,000
Copper	-	1,600
Mercury	-	<2.5
Nickel	-	11,000
Lead	-	240
Antimony	-	120
Selenium	-	90
Thallium	-	<750
Vanadium	-	170
Zinc	-	750

Design and operating data

Kiln	
Temperature	2001-2077°F
Feed rate	4.48-4 55 lb/min
Excess oxygen	3.29-5.12%
Carbon monoxide	0-80 ppm
Scrubber	
Flow	17 44 gal/min
Pressure drop	40-41 in. of water

[a] Concentration data have not been adjusted for accuracy Accuracy-adjusted data are shown in Section 5 and Appendix B.

[b] The concentrations represent scrubber water residuals and are considered treated relative to organics and not relative to metals.

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Table 3-1 (continued)

Sample set #3
Concentration data

Constituent	BDAT constituent concentration[a] Untreated waste (µg/g)	Treated waste[b] (µg/l)
Volatiles		
Toluene	<10	15
Semivolatiles		
Anthracene	<5,000	210
Benzal chloride	1,100,000	94
Benzo(b and/or k)fluoranthene	<5,000	96
Phenanthrene	<5,000	<50
Metals		
Silver	-	<35
Arsenic	-	530
Barium	-	550
Beryllium	-	<5
Cadmium	-	<20
Chromium	-	34,000
Copper	-	3,500
Mercury	-	60
Nickel	-	25,000
Lead	-	300
Antimony	-	160
Selenium	-	60
Thallium	-	<750
Vanadium	-	390
Zinc	-	930

Design and operating data

Kiln	
Temperature	1780-2065°F
Feed rate	4.18-6.22 lb/min
Excess oxygen	3.17-5.77%
Carbon monoxide	0-614 ppm
Scrubber	
Flow	17.44 gal/min
Pressure drop	38-40 in. of water

[a]Concentration data have not been adjusted for accuracy

[b]Treated waste concentration data reflect the worst-case concentration from quench water sampling to ensure conservancy in determining a wastewater standard

benzo(b and/or k)fluoranthene, and phenanthrene. These constituents were detected at concentrations up to 210 μg/l. While not detected in the untreated waste, EPA's analysis of the process shows that these organic constituents could be present.

As shown in the table, chromium, copper, and nickel were detected in the wastewater at substantial concentrations.

No performance data were collected for fuel substitution and recovery.

3.2.1 Liquid Injection Incineration

Liquid injection incineration is discussed within the context of the incineration technology description that follows.

This section addresses the commonly used incineration technologies: liquid injection, rotary kiln, fluidized bed incineration, and fixed hearth. A discussion is provided regarding the applicability of these technologies, the underlying principles of operation, a technology description, the waste characteristics that affect performance, and, finally, important design and operating parameters. As appropriate, the subsections are divided by type of incineration unit.

(1) Applicability and use of this technology

(a) Liquid injection. Liquid injection is applicable to wastes that have viscosity values low enough so that the waste can be atomized in the combustion chamber. A range of maximum viscosity values is reported in the literature, with the low being 100 Saybolt Seconds Universal (SSU) and the high being 10,000 SSU. It is important to note that viscosity is temperature dependent; therefore, while liquid injection may not be

applicable to a waste at ambient conditions, it may be applicable when the waste is heated. Other factors that affect the use of liquid injection are particle size and the presence of suspended solids. Both of these waste parameters can cause plugging of the burner nozzle.

(b) Rotary kiln/fluidized bed/fixed hearth. These incineration technologies are applicable to a wide range of hazardous wastes. They can be used on wastes that contain high or low total organic content, high or low filterable solids, various viscosity ranges, and a range of other waste parameters. EPA has not found these technologies to be demonstrated on wastes that are comprised essentially of metals with low organic concentrations. In addition, the Agency expects that some of the high metal content wastes may not be compatible with existing and future air emission limits unless emission controls are far more extensive than currently practiced.

(2) Underlying principles of operation

(a) Liquid injection. The basic operating principle of this incineration technology is that incoming liquid wastes are first volatilized, and then additional heat is supplied to the waste to destabilize the chemical bonds. Once the chemical bonds are broken, these constituents react with oxygen to form carbon dioxide and water vapor. The energy needed to destabilize the bonds is referred to as the energy of activation.

(b) Rotary kiln and fixed hearth. These incineration technologies have two distinct principles of operation, one for each of the chambers involved. In the primary chamber, energy, in the form of heat, is transferred to the waste to achieve volatilization of the various organic waste constituents. During this volatilization process some of the organic constituents will oxidize to carbon dioxide (CO_2) and water vapor. In the secondary chamber, additional heat is supplied to overcome the energy requirements needed to destabilize the chemical bonds and allow the constituents to react with excess oxygen to form carbon dioxide and water vapor. The principle of operation for the secondary chamber is similar to liquid injection.

(c) Fluidized bed. The principle of operation for this incinerator technology differs somewhat from that for rotary kiln and fixed hearth incineration in that there is only one chamber which contains the fluidizing sand and a freeboard section above the sand. The purpose of the fluidized bed is to both volatilize the waste and combust the waste. Destruction of the waste organics can be better accomplished in the primary chamber because of (1) improved heat transfer from fluidization of the waste using forced air, and (2) the fact that the fluidization process provides sufficient oxygen and turbulence to convert the organics to carbon dioxide and water vapor. The freeboard generally does not have an afterburner; however, additional time is provided for the organic

constituents to convert to carbon dioxide, water vapor, and hydrochloric acid if chlorine is present in the waste.

(3) Description of incineration technologies

(a) Liquid injection. The liquid injection system is capable of incinerating a wide range of gases and liquids. The design of the combustion system is simple, having virtually no moving parts. A burner or nozzle atomizes the liquid waste and injects it into the combustion chamber where it burns in the presence of air or oxygen. A forced draft system supplies the combustion chamber with air to provide oxygen for combustion and turbulence for mixing. The combustion chamber is usually a cylinder lined with refractory (i.e., heat resistant) brick and can be fired horizontally, vertically upward, or vertically downward. Figure 3-1 illustrates a liquid injection incineration system.

(b) Rotary kiln. A rotary kiln is a slowly rotating, refractory-lined cylinder that is mounted at a slight incline from the horizontal (see Figure 3-2). Solid wastes enter at the high end of the kiln, and liquid or gaseous wastes enter through atomizing nozzles in the kiln or afterburner section. Rotation of the kiln exposes the solids to the heat, vaporizes them, and allows them to combust by mixing with air. The rotation also causes the ash to move to the lower end of the kiln where it can be removed. Rotary kiln systems usually have a secondary combustion chamber or afterburner following the kiln for further combustion of the volatilized components of solid wastes.

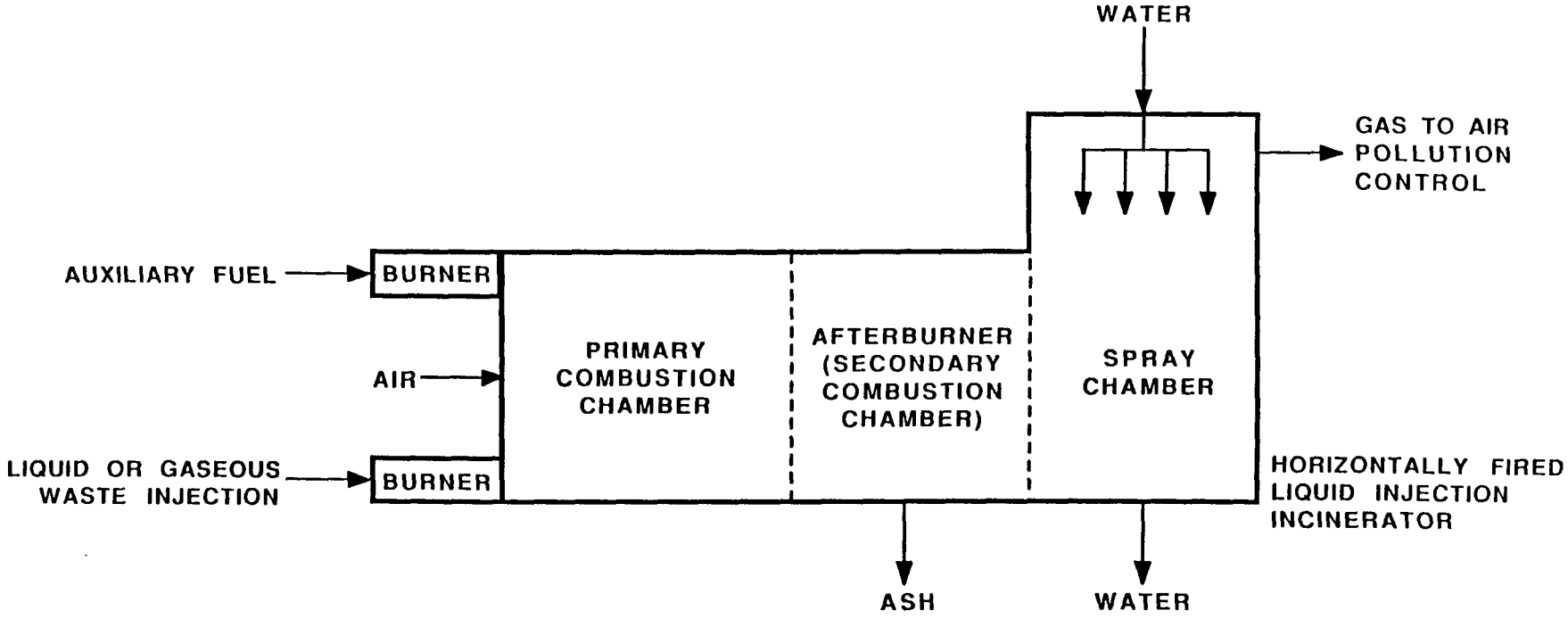


FIGURE 3-1. LIQUID INJECTION INCINERATOR

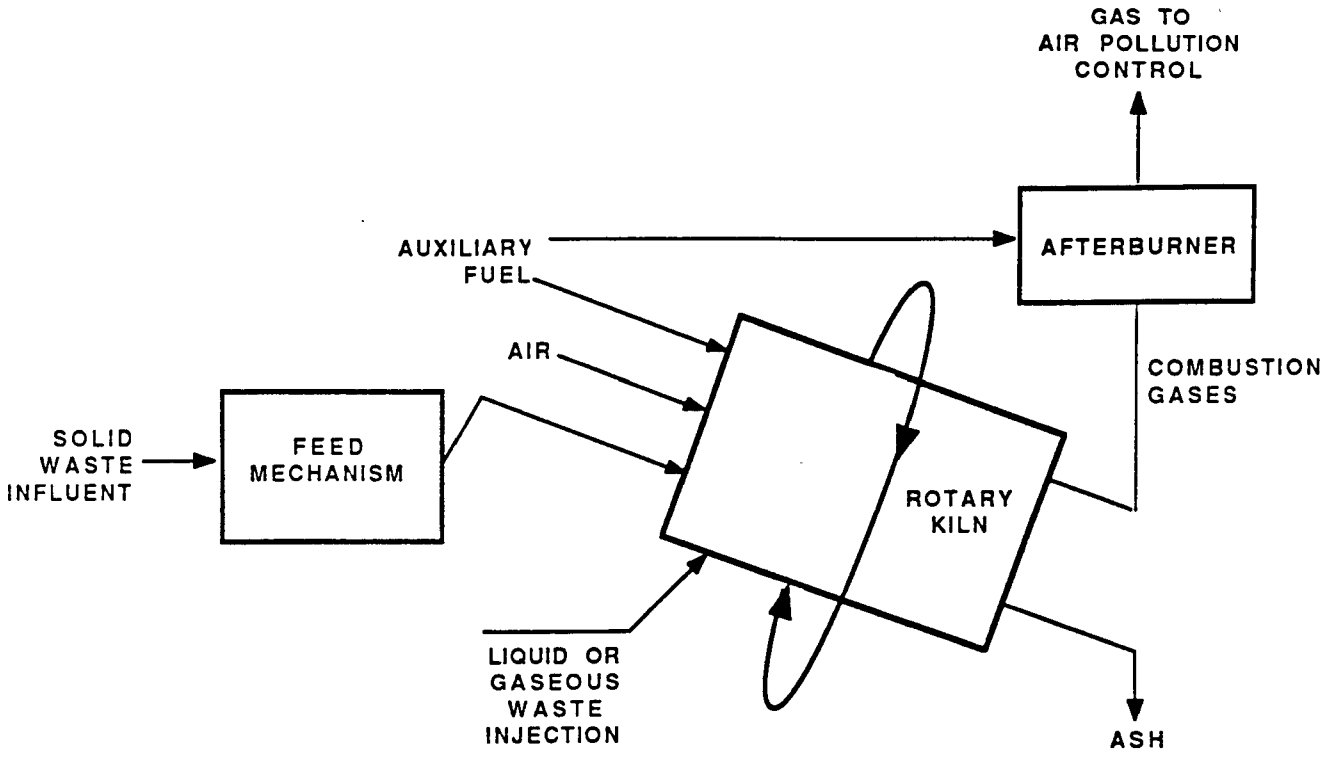


FIGURE 3-2. ROTARY KILN INCINERATOR

(c) Fluidized bed. A fluidized bed incinerator consists of a column containing inert particles such as sand, which is referred to as the bed. Air, driven by a blower, enters the bottom of the bed to fluidize the sand. Air passage through the bed promotes rapid and uniform mixing of the injected waste material within the fluidized bed. The fluidized bed has an extremely high heat capacity (approximately three times that of flue gas at the same temperature), thereby providing a large heat reservoir. The injected waste reaches ignition temperature quickly and transfers the heat of combustion back to the bed. Continued bed agitation by the fluidizing air allows larger particles to remain suspended in the combustion zone (see Figure 3-3).

(d) Fixed hearth incineration. Fixed hearth incinerators, also called controlled air or starved air incinerators, are another major technology used for hazardous waste incineration. Fixed hearth incineration is a two-stage combustion process (see Figure 3-4). Waste is ram-fed into the first stage, or primary chamber, and burned at less than stoichiometric conditions. The resultant smoke and pyrolysis products, consisting primarily of volatile hydrocarbons and carbon monoxide, along with the normal products of combustion, pass to the secondary chamber. Here, additional air is injected to complete the combustion. This two-stage process generally yields low stack particulate and carbon monoxide (CO) emissions. The primary chamber combustion reactions and combustion gas are maintained at low levels by

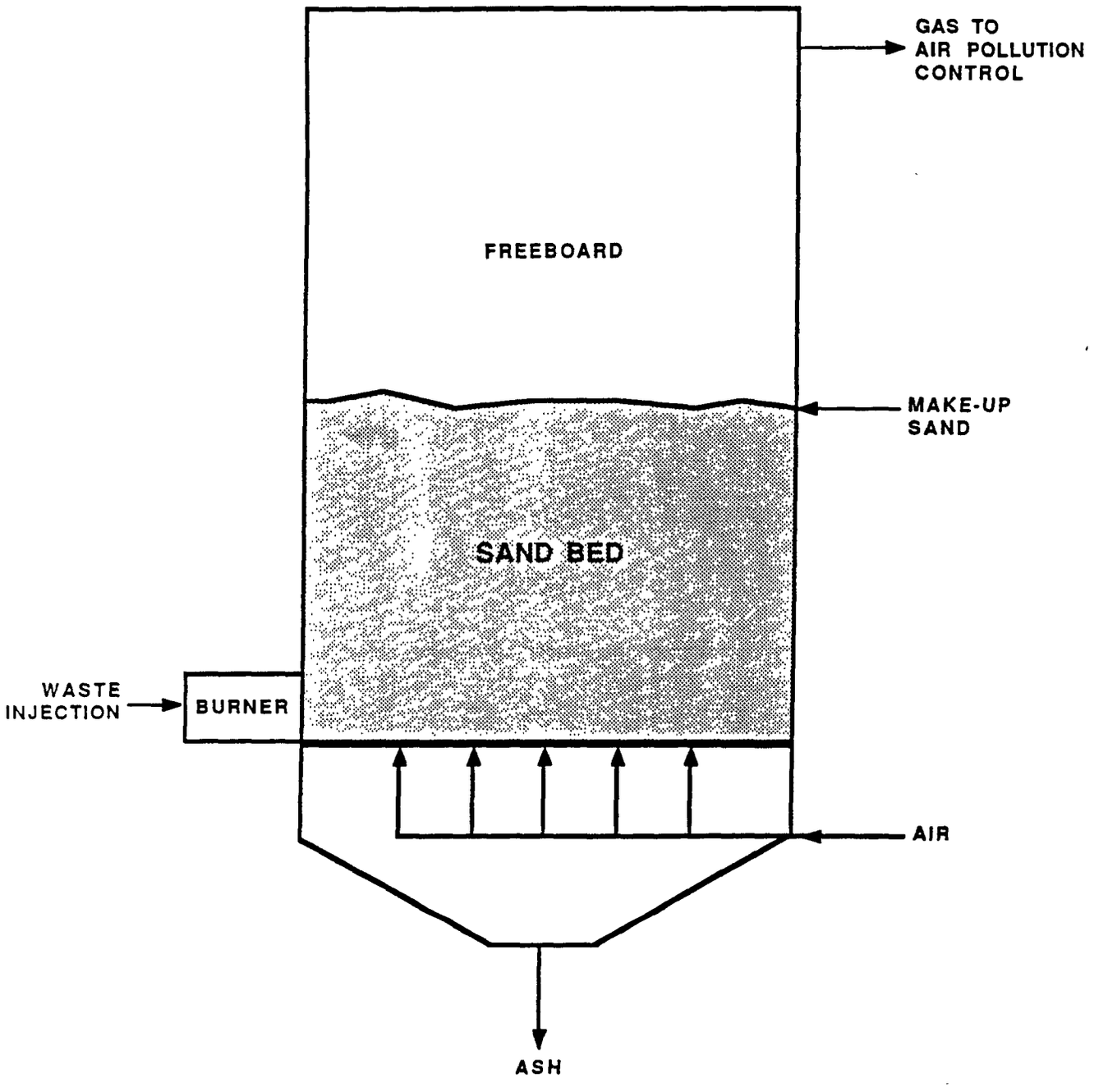


FIGURE 3-3. FLUIDIZED BED INCINERATOR

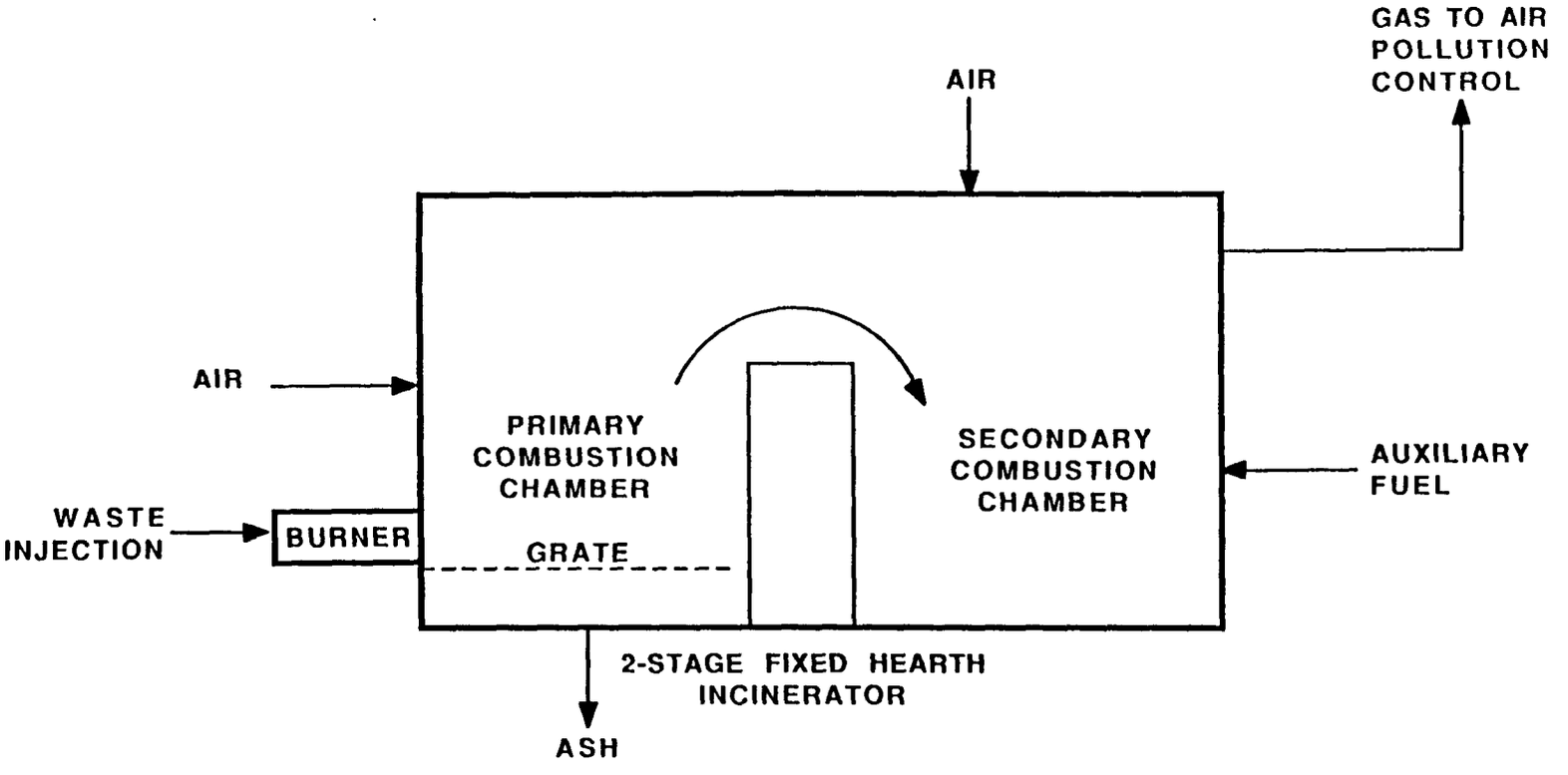


FIGURE 3-4. FIXED HEARTH INCINERATOR

the starved air conditions so that particulate entrainment and carryover are minimized.

(e) Air pollution controls. Following incineration of hazardous wastes, combustion gases generally are further treated in an air pollution control system. The presence of chlorine or other halogens in the waste requires a scrubbing or absorption step to remove hydrogen chloride (HCl) and other halo-acids from the combustion gases. Ash in the waste is not destroyed in the combustion process. Depending on its composition, ash will either exit as bottom ash, at the discharge end of a kiln or hearth for example, or as particulate matter (fly ash) suspended in the combustion gas stream. Particulate emissions from most hazardous waste combustion systems generally have particle diameters less than 1 micron and require high efficiency collection devices to minimize air emissions. In addition, scrubber systems provide an additional buffer against accidental releases of incompletely destroyed waste products resulting from poor combustion efficiency or combustion upsets such as flameouts.

(4) Waste characteristics affecting performance (WCAP)

(a) Liquid injection. In determining whether liquid injection is likely to achieve the same level of performance on an untested waste as on a previously tested waste, the Agency will compare dissociation bond energies of the constituents in the untested and tested wastes. This parameter is being used as a surrogate indicator of activation energy,

which, as discussed previously, destabilizes molecular bonds. In theory, the bond dissociation energy would be equal to the activation energy; in practice, however, this is not always the case. Other energy effects (e.g., vibrational, the formation of intermediates, and interactions between different molecular bonds) may have a significant influence on activation energy.

Because of the shortcomings of bond energies in estimating activation energy, EPA analyzed other waste characteristic parameters to determine if these parameters would provide a better basis for transferring treatment standards from an untested waste to a tested waste. These parameters include heat of combustion, heat of formation, use of available kinetic data to predict activation energies, and general structural class. All of these parameters were rejected for the reasons cited below.

The heat of combustion only measures the difference in energy of the products and reactants; it does not provide information on the transition state (i.e., the energy input needed to initiate the reaction). While heat of formation is used as a predictive tool for determining whether reactions are likely to proceed, there are a significant number of hazardous constituents for which these data are not available. Use of kinetic data was rejected because these data are limited and could not be used to calculate free energy values (ΔG) for the numerous hazardous constituents to be addressed by this rule. Finally, EPA decided not to use structural classes because the Agency believes that evaluation of

bond dissociation energies allows for a more direct determination of whether a constituent will be destabilized.

(b) Rotary kiln/fluidized bed/fixed hearth. Unlike liquid injection, these incineration technologies also generate a residual ash. Accordingly, to determine whether these technologies are likely to achieve the same level of performance on an untested waste as on a previously tested waste, EPA would need to examine the waste characteristics that affect volatilization of organics from the waste, as well as destruction of the organics once volatilized. Relative to volatilization, EPA will examine thermal conductivity of the entire waste and the boiling point of the various constituents. As with liquid injection, EPA will examine bond energies in determining whether treatment standards for scrubber water residuals can be transferred from a tested waste to an untested waste. Below is a discussion of how EPA arrived at thermal conductivity and boiling point as the best method to assess volatilization of organics from the waste; the discussion relative to bond energies is the same for these technologies as for liquid injection and will not be repeated here.

(i) Thermal conductivity. Consistent with the underlying principles of incineration, a major factor in determining whether a particular constituent will volatilize is the transfer of heat through the waste. In the case of rotary kiln, fluidized bed, and fixed hearth incineration, heat is transferred through the waste by three mechanisms: radiation, convection, and conduction. For a given incinerator, heat transferred

through various wastes by radiation is more a function of the design and type of incinerator than the waste being treated. Accordingly, the type of waste treated will have a minimal impact on the amount of heat transferred by radiation. With regard to convection, EPA also believes that the type of heat transfer will generally be more a function of the type and design of the incinerator than of the waste itself. However, EPA is considering particle size as a waste characteristic that may significantly impact the amount of heat transferred to a waste by convection and thus may impact volatilization of the various organic compounds. The final type of heat transfer, conduction, is the mechanism believed by EPA to have greatest impact on volatilization of organic constituents. To measure this characteristic, EPA will use thermal conductivity. An explanation of this parameter, as well as how it can be measured, is provided below.

Heat flow by conduction is proportional to the temperature gradient across the material. The proportionality constant is a property of the material and is referred to as the thermal conductivity. (Note: The analytical method identified by EPA for measurement of thermal conductivity is named the "Guarded, Comparative, Longitudinal Heat Flow Technique"; it is described in more detail in Appendix C) In theory, thermal conductivity would always provide a good indication as to whether a constituent in an untested waste would be treated to the same extent in the primary incinerator chamber as the same constituent in a previously tested waste. In practice, however, thermal conductivity has some

limitations in assessing the transferability of treatment standards. Nevertheless, EPA has not identified a parameter that can provide a better indication of heat transfer characteristics of a waste. A discussion of both the limitations associated with thermal conductivity, as well as the other parameters considered follows.

Thermal conductivity measurements, as part of a treatability comparison for two different wastes through a single incinerator, are most meaningful when applied to wastes that are homogeneous (i.e., major constituents are essentially the same). As wastes exhibit greater degrees of nonhomogeneity (e.g., significant concentration of metals in soil), thermal conductivity becomes less accurate in predicting treatability, because the measurement essentially reflects heat flow through regions having the greatest conductivity (i.e., the path of least resistance) and not heat flow through all parts of the waste.

Btu value, specific heat, and ash content were also considered for predicting heat transfer characteristics. These parameters can no better account for nonhomogeneity than can thermal conductivity; additionally, they are not directly related to heat transfer characteristics. Therefore, these parameters do not provide a better indication of heat transfer that will occur in any specific waste.

(ii) Boiling point. Once heat is transferred to a constituent within a waste, removal of this constituent from the waste will depend on its volatility. As a surrogate of volatility, EPA is using boiling point of the constituent. Compounds with lower boiling points have higher vapor pressures and therefore would be more likely to vaporize. The

Agency recognizes that this parameter does not take into consideration the impact of other compounds in the waste on the boiling point of a constituent in a mixture; however, the Agency is not aware of a better measure of volatility that can be easily determined.

(5) Design and Operating Parameters

(a) Liquid injection. For a liquid injection unit, EPA's analysis of whether the unit is well designed will focus on (1) the likelihood that sufficient energy is provided to the waste to overcome the activation level for breaking molecular bonds, and (2) whether sufficient oxygen is present to convert the waste constituents to carbon dioxide and water vapor. The specific design parameters that the Agency will evaluate to assess whether these conditions are met are temperature, excess oxygen, and residence time. Below is a discussion of why EPA believes these parameters to be important, as well as a review of how these parameters will be monitored during operation.

It is important to point out that, relative to the development of land disposed restriction standards, EPA is only concerned with these design parameters when a quench water or scrubber water residual is generated from treatment of a particular waste. If treatment of a particular waste in a liquid injection unit would not generate a wastewater stream, then the Agency, for purposes of land disposal treatment standards, would only be concerned with the waste characteristics that affect selection of the unit, not the above-mentioned design parameters.

(i) Temperature. Temperature is important in that it provides an indirect measure of the energy available (i.e., Btu/hr) to overcome the activation energy of waste constituents. As the design temperature increases, the more likely it is that the molecular bonds will be destabilized and the reaction completed.

The temperature is normally controlled through the use of instrumentation that senses the temperature and automatically adjusts the amount of fuel and/or waste being fed. The temperature signal transmitted to the controller can be simultaneously transmitted to a recording device, referred to as a strip chart, and thereby continuously recorded. To fully assess the operation of the unit, it is important to know not only the exact location in the incinerator that the temperature is being monitored, but also the location of the design temperature.

(ii) Excess oxygen. It is important that the incinerator contain oxygen in excess of the stoichiometric amount necessary to convert the organic compounds to carbon dioxide and water vapor. If insufficient oxygen is present, then destabilized waste constituents could recombine to the same or other BDAT list organic compounds and potentially cause the scrubber water to contain higher concentrations of BDAT list constituents than would be the case for a well operated unit.

In practice, the amount of oxygen fed to the incinerator is controlled by continuous sampling and analysis of the stack gas. If the amount of oxygen drops below the design value, then the analyzer transmits a signal to the valve controlling the air supply and thereby

increases the flow of oxygen to the afterburner. The analyzer simultaneously transmits a signal to a recording device so that the amount of excess oxygen can be continuously recorded. Again, as with temperature, it is important to know the location from which the combustion gas is being sampled.

(iii) Carbon monoxide. Carbon monoxide is an important operating parameter because it provides an indication of the extent to which the waste organic constituents are being converted to CO_2 and water vapor. As the carbon monoxide level increases, it indicates that greater amounts of organic waste constituents are unreacted or partially reacted. Increased carbon monoxide levels can result from insufficient excess oxygen, insufficient turbulence in the combustion zone, or insufficient residence time.

(iv) Waste feed rate. The waste feed rate is important to monitor because it is correlated to the residence time. The residence time is associated with a specific Btu energy value of the feed and a specific volume of combustion gas generated. Prior to incineration, the Btu value of the waste is determined through the use of a laboratory device known as a bomb calorimeter. The volume of combustion gas generated from the waste to be incinerated is determined from an analysis referred to as an ultimate analysis. This analysis determines the amount of elemental constituents present, which include carbon, hydrogen, sulfur, oxygen, nitrogen, and halogens. Using this analysis plus the total amount of air added, the volume of combustion gas can be calculated. Having determined

both the Btu content and the expected combustion gas volume, the feed rate can be fixed at the desired residence time. Continuous monitoring of the feed rate will determine whether the unit was operated at a rate corresponding to the designed residence time.

(b) Rotary kiln. For this incineration, EPA will examine both the primary and secondary chamber in evaluating the design of a particular incinerator. Relative to the primary chamber, EPA's assessment of design will focus on whether sufficient energy is likely to be provided to the waste in order to volatilize the waste constituents. For the secondary chamber, analogous to the sole liquid injection incineration chamber, EPA will examine the same parameters discussed for liquid injection incineration. These parameters will not be reviewed again here.

The particular design parameters to be evaluated for the primary chamber are kiln temperature, residence time, and revolutions per minute. Below is a discussion of why EPA believes these parameters to be important, as well as a review of how these parameters will be monitored during operation.

(i) Temperature. The primary chamber temperature is important because it provides an indirect measure of the energy input (i.e., BTU/hr) that is available for heating the waste. The higher the temperature is designed to be in a given kiln, the more likely it is that the constituents will volatilize. As discussed previously under "Liquid Injection," temperature should be continuously monitored and recorded.

Additionally, it is important to know the location of the temperature sensing device in the kiln.

(ii) Residence time. This parameter is important in that it affects whether sufficient heat is transferred to a particular constituent in order for volatilization to occur. As the time that the waste is in the kiln is increased, a greater quantity of heat is transferred to the hazardous waste constituents. The residence time will be a function of the specific configuration of the rotary kiln, including the length and diameter of the kiln, the waste feed rate, and the rate of rotation.

(iii) Revolutions per minute (RPM). This parameter provides an indication of the turbulence that occurs in the primary chamber of a rotary kiln. As the turbulence increases, the quantity of heat transferred to the waste would also be expected to increase. As the RPM value increases, however, the residence time decreases, resulting in a reduction of the quantity of heat transferred to the waste. This parameter needs to be carefully evaluated because it provides a balance between turbulence and residence time.

(c) Fluidized bed. As discussed in the section "Underlying Principles of Operation," the primary chamber accounts for almost all of the conversion of organic wastes to carbon dioxide, water vapor, and acid gas if halogens are present. The secondary chamber will generally provide additional residence time for thermal oxidation of the waste constituents. Relative to the primary chamber, the parameters that the Agency will examine in assessing the effectiveness of the design are

temperature, residence time, and bed pressure differential. The first two were discussed under rotary kiln and will not be addressed here. Bed pressure differential is important in that it provides an indication of the amount of turbulence and, thus, indirectly the amount of heat supplied to the waste. In general, as the pressure drop increases, both the turbulence and heat supplied increase. The pressure drop through the bed should be continuously monitored and recorded to ensure that the designed valued is achieved.

(d) Fixed hearth. The design considerations for this incineration unit are similar to a rotary kiln, except that rate of rotation (i.e., RPM) is not an applicable design parameter. For the primary chamber of this unit, the parameters that the Agency will examine in assessing how well the unit is designed are the same as discussed under rotary kiln; for the secondary chamber (i.e., afterburner), the design and operating parameters of concern are the same as were cited under "Liquid Injection."

3.2.2 Fuel Substitution

Fuel substitution involves using hazardous waste as a fuel in industrial furnaces or in boilers for generation of steam. The hazardous waste may be blended with other nonhazardous wastes (e.g., municipal sludge) and/or fossil fuels.

(1) Applicability and use of this technology. Fuel substitution has been used with industrial waste solvents, refinery wastes, synthetic fibers/petrochemical wastes, and waste oils. It can also be used when combusting other waste types produced during the manufacturing of pharmaceuticals, pulp and paper, and pesticides. These wastes can be handled in a solid, liquid, or gaseous form.

The most common types of units in which waste fuels are burned are industrial furnaces and industrial boilers. Industrial furnaces include a variety of industrial processes that produce heat and/or products by burning fuels. They include blast furnaces, smelters, and coke ovens. Industrial boilers are units wherein fuel is used to produce steam for process and plant use. Industrial boilers typically use coal, oil, or gas as the primary fuel source.

A number of parameters affect the selection of fuel substitution, including:

- Halogen content of the waste;
- Inorganic solids content (ash content) of the waste, particularly heavy metals;
- Heating value of the waste;
- Viscosity of the waste (for liquids);

- Filterable solids concentration (for liquids); and
- Sulfur content.

If halogenated organics are burned, halogenated acids and free halogen are among the products of combustion. These released corrosive gases may require subsequent treatment prior to venting to the atmosphere. Also, halogens and halogenated acids formed during combustion are likely to severely corrode boiler tubes and other process equipment. To minimize such problems, halogenated wastes are blended into fuels only at very low concentrations. High chlorine content can also lead to the incidental production (at very low concentrations) of other hazardous compounds such as PCBs (polychlorinated biphenyls), PCDDs (chlorinated dibenzo-p-dioxins), PCDFs (chlorinated dibenzofurans), and chlorinated phenols.

High inorganic solids content (i.e., ash content) of wastes may cause two problems: (1) scaling in the boiler and (2) particulate air emissions. Scaling results from deposition of inorganic solids on the walls of the boiler. Particulate emissions are produced by noncombustible inorganic constituents that flow out of the boiler with the gaseous combustion products. Because of these problems, wastes with significant concentrations of inorganic materials are not usually handled in boilers unless they have an air pollution control system.

Industrial furnaces vary in their tolerance to inorganic constituents. Heavy metal concentrations, found in both halogenated and nonhalogenated wastes used as fuel, can cause environmental concern because they may be emitted either in the gaseous emissions from the

combustion process, in the ash residues, or in any produced solids. The partitioning of the heavy metals to these residual streams primarily depends on the volatility of the metal, waste matrix, and furnace design.

The heating value of the waste must be sufficiently high (either alone or in combination with other fuels) to maintain combustion temperatures consistent with efficient waste destruction and operation of the boiler or furnace. For many applications, only supplemental fuels having minimum heating values of 4,400 to 5,600 kcal/kg (8,000 to 10,000 Btu/lb) are considered to be feasible. Below this value, the unblended fuel would not be likely to maintain a stable flame, and its combustion would not release sufficient energy to provide needed steam generation potential in the boiler or the necessary heat for an industrial furnace. Some wastes with heating values of less than 4,400 kcal/kg (8,000 Btu/lb) can be used if sufficient auxiliary fuel is employed to support combustion or if special designs are incorporated into the combustion device. Occasionally, for wastes with heating values higher than virgin fuels, blending with auxiliary fuel may be required to prevent overheating or overcharging of the combustion device.

In combustion devices designed to burn liquid fuels, the viscosity of liquid waste must be low enough that it can be atomized in the combustion chamber. If viscosity is too high, heating of storage tanks may be required prior to combustion. For atomization of liquids, a viscosity of 165 centistokes (750 Saybolt Seconds Universal (SSU)) or less is typically required.

If filterable material suspended in the liquid fuel prevents or hinders pumping or atomization, it will be unacceptable.

Sulfur content in the waste may prevent burning of the waste because of potential atmospheric emissions of sulfur oxides. For instance, there are proposed Federal sulfur oxide emission regulations for certain new source industrial boilers (51 FR 22385). Air pollution control devices are available to remove sulfur oxides from the stack gases.

(2) Underlying principles of operation. For a boiler and most industrial furnaces there are two distinct principles of operation. Initially, energy in the form of heat is transferred to the waste to achieve volatilization of the various waste constituents. For liquids, volatilization energy may also be supplied by using pressurized atomization. The energy used to pressurize the liquid waste allows the atomized waste to break into smaller particles, thus enhancing its rate of volatilization. The volatilized constituents then require additional energy to destabilize the chemical bonds and allow the constituents to react with oxygen to form carbon dioxide and water vapor. The energy needed to destabilize the chemical bonds is referred to as the energy of activation.

(3) Physical Description of the Process. As stated, a number of industrial applications can use fuel substitution. Therefore, there is no one process description that will fit all of these applications. However, the following section provides a general description of industrial kilns (one form of industrial furnace) and industrial boilers.

(a) Kilns. Combustible wastes have the potential to be used as fuel in kilns and, for waste liquids, are often used with oil to co-fire kilns. Coal-fired kilns are capable of handling some solid wastes. In the case of cement kilns, there are usually no residuals requiring land disposal, since any ash formed becomes part of the product or is removed by particulate collection systems and recycled back to the kiln. The only residuals may be low levels of unburned gases escaping with combustion products. If this is the case, air pollution control devices may be required.

Three types of kilns are particularly applicable: cement kilns, lime kilns, and lightweight aggregate kilns.

(i) Cement kilns. The cement kiln is a rotary furnace that is a refractory-lined steel shell used to calcine a mixture of calcium, silicon, aluminum, iron, and magnesium-containing minerals. The kiln is normally fired by coal or oil. Liquid and solid combustible wastes may then serve as auxiliary fuel. Temperatures within the kiln are typically between 1,380 and 1,540°C (2,500° to 2,800°F). To date, only liquid hazardous wastes have been burned in cement kilns.

Most cement kilns have a dry particulate collection device (i.e., either an electrostatic precipitator or a baghouse), with the collected fly ash recycled back to the kiln. Buildup of metals or other noncombustibles is prevented through their incorporation into the product cement. Many types of cement require a source of chloride so that most

halogenated liquid hazardous wastes currently can be burned in cement kilns. Available information shows that scrubbers are not used.

(ii) Lime kilns. Quick-lime (CaO) is manufactured in a calcination process using limestone ($CaCO_3$) or dolomite ($CaCO_3$ and $MgCO_3$). These raw materials are also heated in a refractory-lined rotary kiln, typically to temperatures of 980 to 1,260°C (1,800° to 2,300°F). Lime kilns are less likely than cement kilns to burn hazardous wastes because product lime is often added to potable water systems. Only one lime kiln currently burns hazardous waste in the U.S. That particular facility sells its product lime for use as flux or as refractory in blast furnaces.

As with cement kilns, any collected fly ash is recycled back to the lime kiln; thus, no residual streams result from the kiln. Available information shows that scrubbers are not used.

(ii) Lightweight aggregate kilns. Lightweight aggregate kilns heat clay to produce an expanded lightweight inorganic material used in portland cement formulations and other applications. The kiln has a normal temperature range of 1,100 to 1,150°C (2,000 to 2,100°F). Lightweight aggregate kilns are less amenable to combustion of hazardous wastes as fuels than the other kilns described above because these kilns lack the material to adsorb halogens. As a result, burning of halogenated organics in these kilns would likely require afterburners to ensure the complete destruction of the halogenated organics and scrubbers to control acid gas production. Such controls would produce a wastewater residual stream subject to treatment standards.

(b) Industrial boilers. A boiler is a closed vessel in which water is transformed into steam by the application of heat. Normally, heat is supplied by the combustion of pulverized coal, fuel oil, or gas. These fuels are fired into a combustion chamber with nozzles and burners that provide mixing with air. Liquid wastes, and granulated solid wastes in the case of grate-fired boilers, can be burned as auxiliary fuel in a boiler. Few grate-fired boilers burn hazardous wastes, however. For liquid-fired boilers, residuals requiring land disposal are only generated when the boiler is shut down and cleaned. This is generally done once or twice per year. Other residuals from liquid-fired boilers would be the gas emission stream, which would consist of any products of incomplete combustion, along with the normal combustion products. For example, chlorinated wastes would produce acid gases. If this is the case, air pollution control devices may be required. For solid-fired boilers, an ash normally is generated. This ash may contain residual amounts of organics from the blended waste/fuels as well as noncombustible materials. Land disposal of this ash would require compliance with applicable BDAT treatment standards.

(4) Waste characteristics affecting performance. For cement kilns, lime kilns, and lightweight aggregate kilns burning nonhalogenated wastes (i.e., no scrubber is needed to control acid gases), no residual waste streams would be produced. Any noncombustible material in the waste would leave the kiln in the product stream. As a result, in transferring standards EPA would not examine waste characteristics affecting

performance, but rather would determine the applicability of fuel substitution. That is, EPA would investigate the parameters affecting treatment selection. For kilns, these parameters (as mentioned previously) are Btu content, percent filterable solids, halogenated organics content, viscosity, and sulfur content.

Lightweight aggregate kilns burning halogenated organics and boilers burning wastes containing any noncombustibles will produce residual streams subject to treatment standards. In determining whether fuel substitution is likely to achieve the same level of performance on an untreated waste as a previously treated waste, EPA will examine: (1) relative volatility of the waste constituents, (2) the heat transfer characteristics (for solids), and (3) the activation energy for combustion.

(a) Relative volatility. The term relative volatility (α) refers to the ease with which a substance present in a solid or liquid waste will vaporize from that waste upon application of heat from an external source. Hence, it bears a relationship to the equilibrium vapor pressure of the substance.

EPA recognizes that the relative volatilities cannot be measured or calculated directly for the types of wastes generally treated in an industrial boiler or furnace. The Agency believes that the best measure of relative volatility is the boiling point of the various hazardous constituents and will, therefore, use this parameter in assessing volatility of the organic constituents.

(b) Heat transfer characteristics. Consistent with the underlying principles of combustion in aggregate kilns or boilers, a major factor with regard to whether a particular constituent will volatilize is the transfer of heat through the waste. In the case of industrial boilers burning solid fuels, heat is transferred through the waste by three mechanisms: radiation, convection, and conduction. For a given boiler it can be assumed that the type of waste will have a minimal impact on the heat transferred from radiation. With regard to convection, EPA believes that the range of wastes treated would exhibit similar properties with regard to the amount of heat transferred by convection. Therefore, EPA will not evaluate radiation convection heat transfer properties of wastes in determining similar treatability. For solids, the third heat transfer mechanism, conductivity, is the one principally operative or most likely to change between wastes.

Using thermal conductivity measurements as part of a treatability comparison for two different wastes through a given boiler or furnace is most meaningful when applied to wastes that are homogeneous. As wastes exhibit greater degrees of nonhomogeneity, then thermal conductivity becomes less accurate in predicting treatability, because the measurement essentially reflects heat flow through regions having the greatest conductivity (i.e., the path of least resistance and not heat flow through all parts of the waste). Nevertheless, EPA has not identified a better alternative to thermal conductivity, even for wastes that are nonhomogeneous.

Other parameters considered for predicting heat transfer characteristics were Btu value, specific heat, and ash content. These parameters can neither better account for nonhomogeneity nor better predict heat transferability through the waste.

(c) Activation energy. Given an excess of oxygen, an organic waste in an industrial furnace or boiler would be expected to convert to CO_2 and H_2O provided that the activation energy is achieved. Activation energy is the quantity of heat (energy) needed to destabilize molecular bonds and create reactive intermediates so that the oxidation (combustion) reaction will proceed to completion. As a measure of activation energy, EPA is using bond dissociation energies. In theory, the bond dissociation energy would be equal to the activation energy; in practice however, this is not always the case.

In some instances, bond energies will not be available and will have to be estimated or other energy effects (e.g., vibrational) and other reactions will have a significant influence on activation energy. Because of the shortcomings of bond energies in estimating activation energy, EPA analyzed other waste characteristic parameters to determine if these parameters would provide a better basis for transferring treatment standards from an untested waste to a tested waste. These parameters included heat of combustion, heat of formation, use of available kinetic data to predict activation energies, and general structural class. All of these parameters were rejected for the reasons provided below.

The heat of combustion only measures the difference in energy of the products and reactants; it does not provide information on the transition state (i.e., the energy input needed to initiate the reaction). Heat of formation is used as a predictive tool for determining whether reactions are likely to proceed; however, there are a significant number of hazardous constituents for which these data are not available. Use of available kinetic data were rejected because, while it could be used to calculate some free energy values (ΔG), it could not be used for the wide range of hazardous constituents. Finally, EPA decided not to use structural classes because the Agency believes that evaluation of bond dissociation energies allows for a more direct comparison.

(5) Design and operating parameters

(a) Design parameters. Cement kilns and lime kilns, along with aggregate kilns burning nonhalogenated wastes, produce no residual streams. Their design and operation are such that any wastes that are incompletely destroyed will be contained in the product. As a result, the Agency will not consider design and operating values for such devices, since treatment, per se, cannot be measured through detection of constituents in residual streams. In this instance, it is important merely to ensure that the waste is appropriate for combustion in the kilns and that the kiln is operated in a manner that will produce a usable product.

Specifically, cement, lime, and aggregate kilns are only demonstrated on liquid hazardous wastes. Such wastes must be sufficiently free of filterable solids as to avoid plugging the burners at the hot end of the

kiln. Viscosity also must be low enough to inject the waste into the kiln through the burners. The sulfur content is not a concern unless the concentration in the waste is sufficiently high as to exceed Federal, State, or local air pollution standards promulgated for industrial boilers.

The design parameters that normally affect the operation of an industrial boiler (and aggregate kilns with residual streams) with respect to hazardous waste treatment are (1) the design temperature, (2) the design retention time of the waste in the combustion chamber, and (3) turbulence in the combustion chamber. Evaluation of these parameters would be important in determining if an industrial boiler or industrial furnace is adequately designed for effective treatment of hazardous wastes. The rationale for selection of these three parameters is given below.

(i) Design temperature. Industrial boilers are generally designed based on their steam generation potential (Btu output). This factor is related to the design combustion temperature, which in turn depends on the amount of fuel burned and its Btu value. The fuel feed rates and combustion temperatures of industrial boilers are generally fixed based on the Btu values of fuels normally handled (e.g., No. 2 versus No. 6 fuel oils). When wastes are to be blended with fossil fuels for combustion, the blending, based on Btu values, must be such that the resulting Btu value of the mixture is close to that of the fuel value used in the design of the boiler. Industrial furnaces also are designed to operate at specific ranges of temperature in order to produce the

desired product (e.g., lightweight aggregate). The blended waste/fuel mixture should be capable of maintaining the design temperature range.

(ii) Retention time. A sufficient retention time of combustion products is normally necessary to ensure that the hazardous substances being combusted (or formed during combustion) are completely oxidized. Retention times on the order of a few seconds are generally needed at normal operating conditions. For industrial furnaces and boilers, the retention time is a function of the size of the furnace and the fuel feed rates. For most boilers and furnaces, the retention time usually exceeds a few seconds.

(iii) Turbulence. Boilers are designed so that fuel and air are intimately mixed. This helps ensure that complete combustion takes place. The shape of the boiler and the method of fuel and air feed influence the turbulence required for good mixing. Industrial furnaces also are designed for turbulent mixing where fuel and air are mixed.

(b) Operating parameters. The operating parameters that normally affect the performance of an industrial boiler and many industrial furnaces with respect to treatment of hazardous wastes are (1) air flow rate, (2) fuel feed rate, (3) steam pressure or rate of production, and (4) temperature. EPA believes that these four parameters will be used to determine if an industrial boiler that burns blended fuels containing hazardous waste constituents is properly operated. The rationale for selection of these four operating parameters is given below. Most

industrial furnaces will monitor similar parameters, but some exceptions are noted.

(i) Air feed rate. An important operating parameter in boilers and many industrial furnaces is the oxygen content in the flue gas, which is a function of the air feed rate. Stable combustion of a fuel generally occurs within a specific range of air-to-fuel ratios. An oxygen analyzer in the combustion gases can be used to control the feed ratio of air to fuel to assure complete thermal destruction of the waste and efficient operation of the boiler. When necessary, the air flow rate can be increased or decreased to maintain proper fuel-to-oxygen ratios. Some industrial furnaces do not completely combust fuels (e.g., coke ovens and blast furnaces); hence, oxygen concentration in the flue gas is a meaningless variable.

(ii) Fuel feed rate. The rate at which fuel is injected into the boiler or industrial furnace will determine the thermal output of the system per unit of time (Btu/hr). If steam is produced, steam pressure monitoring will indirectly determine if the fuel feed rate is adequate. However, various velocity and mass measurement devices can be used to monitor fuel flow directly.

(iii) Steam pressure or rate of production. Steam pressure in boilers provides a direct measure of the thermal output of the system and is directly monitored by use of in-system pressure gauges. Increases or decreases in steam pressure can be caused by increasing or decreasing the fuel and air feed rates within certain operating design limits. Most

industrial furnaces do not produce steam, but instead a product (e.g., cement, aggregate), and they also monitor the rate of production.

(iv) Temperature. Temperatures are monitored and controlled in industrial boilers to assure the quality and flow rate of steam. Therefore, complex monitoring systems are frequently installed in the combustion unit to provide a direct temperature reading. The efficiency of combustion in industrial boilers is dependent on combustion temperatures. Temperature may be adjusted to design settings by increasing or decreasing air and fuel feed rates.

Wastes should not be added to primary fuels until the boiler temperature reaches the minimum needed for destruction of the wastes. Temperature instrumentation and control should be designed to stop waste addition in the event of process upsets.

Monitoring and control of temperature in industrial furnaces are also critical to the product quality; e.g., lime, cement, or aggregate kilns require minimum operating temperatures. Kilns have very high thermal inertia in the refractory and in-process product, high residence times, and high air flow rates, so that even in the case of a momentary stoppage of fuel flow to the kiln, organic constituents are likely to continue to be destroyed. The main operational control required for wastes burned in kilns is to stop waste flow in the event of low kiln temperature, loss of the electrical power to the combustion air fan, and loss of primary fuel flow.

(c) Other operating parameters. In addition to the four operating parameters discussed above, EPA considered and then discarded one additional parameter. Fuel-to-waste blending ratios were also considered. However, while the blending is done to yield a uniform Btu content fuel, blending ratios will vary on a wide range dependent on the Btu content of the wastes and fuels being used.

4. IDENTIFICATION OF BEST DEMONSTRATED AVAILABLE TECHNOLOGY FOR K015 WASTE

In this section, EPA explains its determination of which technology represents the "best" level of performance, as well as being demonstrated and available. As discussed in Section 3, the demonstrated treatment technologies for K015 waste are liquid injection incineration and fuel substitution.

For the two technologies identified as demonstrated, the Agency has performance data for liquid injection incineration only. Accordingly, it is not possible to perform the statistical comparison test (ANOVA) between these technologies as discussed in Section 1 of this document.

While performance data are not available for fuel substitution, EPA would not expect this technology to improve the BDAT list organic constituent removal achieved by liquid injection incineration for two reasons. First, the concentrations of the BDAT list organics in the treated waste are essentially at the level of treatability, with anthracene (present at .414 ppm), the highest organic constituent concentration. Second, the temperature and residence time of the liquid injection incinerator are equal or higher and equal or longer, respectively, to the temperature and residence times found in fuel substitution devices. For these reasons, EPA believes that the performance achieved by liquid injection represents "best" technology.

Demonstrated technologies are considered "available" if they (1) are commercially available and (2) substantially diminish the toxicity of the waste or substantially reduce the likelihood that hazardous constituents

will migrate from the waste. Because the two demonstrated technologies for K015 waste meet all of the above criteria, they are also considered "available."

In addition to meeting the criteria of "availability," EPA believes that liquid injection provides "substantial" treatment by significantly reducing the concentrations of the hazardous organic constituents of concern. For example, anthracene, benzal chloride, and phenanthrene were detected in the untreated waste at concentrations of less than 5,000 μg/l, 910,000 μg/l, and less than 5,000 μg/l, respectively. Treated waste concentrations ranged from 210 to greater than 50 μg/l for anthracene; 94 to greater than 50 μg/l for benzal chloride and 58 to greater than 50 μg/l for phenanthrene. Therefore, liquid injection incineration is believed to ensure adequate waste treatment by reducing both the toxicity of the waste and the likelihood that the hazardous constituents will migrate from the waste.

For the reasons stated above, EPA believes that liquid injection incineration represents the best demonstrated available technology for K015 organic constituents.

For the BDAT list metals present in the wastewater residual from the scrubber water used in the liquid injection incinerator, EPA is transferring performance achieved by hexavalent chromium reduction, followed by chemical precipitation, followed by dewatering of the precipitate.

These treatment technologies have been used with K062 (spent pickle liquor from steel finishing operations producing iron and steel) wastewaters and their performance levels have been determined. The concentration of metals in K062 wastewaters is relatively high compared to the K015 scrubber wastewater. Accordingly, EPA believes that K015 scrubber water is less difficult to treat and this transfer of technology performance is thereby warranted. This transfer technology train also provides a nonwastewater (the dewatered precipitate), that could be subject to regulation (as discussed in Section 3.1). For treatment of this nonwastewater, EPA might consider transferring performance achieved by stabilization. Performance by stabilization has been measured for a number of hazardous wastes. EPA believes that the nonwastewater generated from treatment of F006 (wastewater treatment sludges from electroplating operations) would be sufficiently similar to the K015 dewatered precipitate because of its metals content.

5. SELECTION OF REGULATED CONSTITUENTS

This section describes the step-by-step process used to select the pollutants to be regulated. The selected pollutants must be present in the untreated waste and must be treatable by the chosen BDAT, as discussed in Section 4. The analytical data from the three sets of performance data from liquid injection incineration of K015 waste were examined to identify the major BDAT constituents present in the waste.

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", which means that it does not preclude the addition of new constituents as additional key data and information are identified. The list is divided into the following categories: volatile organics, semivolatile organics, metals, inorganics other than metals, organochlorine pesticides, phenoxyacetic acid herbicides, organophosphorous pesticides, PCBs, and dioxins and furans.

Also discussed in Section 1 is EPA's procedure for selecting BDAT constituents to regulate. Essentially, this process comprises a number of steps. The first step involves summarizing all the constituents that were found in the untreated waste at treatable concentrations. The statistical ANOVA is used (also described in Section 1 and Appendix A) to ascertain if there were significant reductions in the constituent levels. This significant reduction is viewed by the Agency as evidence that the technology "treats" the waste.

In some cases, constituents may be regulated by EPA even though they were not present in the untreated waste but were found in the treated residual. This can occur when other constituents in the untreated waste interfere with or "mask" the quantification of the constituent of concern. The detection levels for the constituent of concern, then, are fairly high, and a "not detected" finding can result even though the constituent may be present in the waste.

After it is determined that the constituents are present at treatable concentrations, EPA will develop a list of potential regulated constituents. EPA will then review this regulated constituent list to eliminate any constituents that could be controlled by the subsequent regulation of other constituents on that list.

5.1 Identification of Treatable Constituents in the Untreated Waste

Table 5-1 presents the BDAT list of constituents and indicates which of the BDAT list constituents were analyzed in the untreated waste and of those that were analyzed which were detected. A few compounds have been added to the BDAT list of constituents since the treatment analysis for K015 was performed; therefore, no analytical data exist for these constituents. While the Agency does not expect any of the additional compounds to be present in the K015 waste, these additional compounds are also noted on Table 5-1. Certain BDAT list categories were not analyzed in the untreated waste because there was not thought to be an in-process source of these constituents. These categories include all the constituents listed in the inorganics other than metals, organochlorine

1541g

Table 5-1 Detection Status for K015 Untreated and Treated Waste Constituents

BDAT no	Parameter	CAS no	Detection limit: Untreated waste (μg/g)	Detection limit: Treated waste (μg/l)	Detection status
BDAT volatile organics					
222	Acetone	67-64-1	10	250	ND
1	Acetonitrile	75-05-8	250	250	ND
2	Acrolein	107-02-8	250	250	ND
3	Acrylonitrile	107-13-1	50	50	ND
4	Benzene	71-43-2	10	10	ND
5	Bromodichloromethane	75-27-4	10	10	ND
6	Bromomethane	74-83-9	10	10	ND
223	n-Butyl alcohol	71-36-3	-[b]	-[b]	NA
7	Carbon Tetrachloride	56-23-5	10	10	ND
8	Carbon disulfide	75-15-0	10	10	ND
9	Chlorobenzene	108-90-7	10	10	ND
10	2-Chloro-1,3-butadiene	126-99-8	0.25	250	ND
11	Chlorodibromomethane	108-90-7	10	10	ND
12	Chloroethane	75-00-3	10	10	ND
13	2-Chloroethyl vinyl ether	110-75-8	50	50	ND
14	Chloroform	67-66-3	10	10	ND
15	Chloromethane	74-87-3	10	10	ND
16	3-Chloropropene	107-05-1	10	10	ND
17	1,2-Dibromo-3-chloropropane	96-12-8	10	10	ND
18	1,2-Dibromoethane	106-93-4	10	10	ND
19	Dibromomethane	74-95-3	10	10	ND
20	Trans-1,4-Dichloro-2-butene	110-57-6	0.25	250	ND
21	Dichlorodifluoromethane	75-71-8	10	10	ND
22	1,1-Dichloroethane	75-35-3	10	10	ND
23	1,2-Dichloroethane	105-06-2	10	10	ND
24	1,1-Dichloroethylene	75-35-4	10	10	ND
25	Trans-1,2-Dichloroethene	156-60-5	10	10	ND
26	1,2-Dichloropropane	78-87-5	25	25	ND
27	Trans-1,3-Dichloropropene	10061-02-6	25	25	ND
28	cis-1,3-Dichloropropene	10061-01-5	25	25	ND
29	1,4-Dioxane	123-91-1	-[a]	-[a]	ND
224	2-Ethoxyethanol	60-29-7	-[b]	-[b]	NA
225	Ethyl acetate	141-78-6	250	10	ND
226	Ethyl benzene	100-41-4	10	10	ND
30	Ethyl cyanide	10712-0	0.5	500	ND
227	Ethyl ether	60-29-7	250	250	ND
31	Ethyl methacrylate	97-63-2	10	10	ND
214	Ethylene oxide	75-21-8	250	250	ND
32	Iodomethane	74-88-4	10	10	ND
33	Isobutyl alcohol	78-83-1	NA	NA	NA
228	Methanol	67-56-1	-[b]	-[b]	NA

Table 5-1 (continued)

BDAT no	Parameter	CAS no	Detection limit: Untreated waste (μg/g)	Detection limit: Treated waste (μg/l)	Detection status
BDAT volatile organics (continued)					
34	Methyl ethyl ketone	78-93-3	50	50	ND
229	Methyl isobutyl ketone	108-10-1	250	50	ND
35	Methyl methacrylate	80-62-6	10	10	ND
37	Methylacrylonitrile	126-98-7	-[a]	-[a]	ND
38	Methylene chloride	75-09-2	50	50	ND
230	2-Nitropropane	79-46-9	-[b]	-[b]	NA
39	Pyridine	110-86-1	25	25	ND
40	1,1,1,2-Tetrachloroethane	630-20-6	10	10	ND
41	1,1,2,2-Tetrachloroethane	79-34-5	10	10	ND
42	Tetrachloroethene	127-18-4	10	10	ND
43	Toluene*	108-88-3	10	10	D
44	Tribromomethane	75-25-2	10	10	ND
45	1,1,1-Trichloroethane	71-55-6	10	10	ND
46	1,1,2-Trichloroethane	79-00-5	10	10	ND
47	Trichloroethene	79-01-6	10	10	ND
48	Trichloromonofluoromethane	75-69-4	10	10	ND
49	1,2,3-Trichloropropane	96-18-4	250	250	ND
231	1,1,2-Trichloro-1,2,2-trifluoroethane	76-13-1	-[b]	-[b]	NA
50	Vinyl chloride	75-01-4	10	10	ND
215	1,2-Xylene	97-47-6	-[b]	-[b]	NA
216	1,3-Xylene	108-38-3	-[b]	-[b]	NA
217	1,4-Xylene	106-44-5	-[b]	-[b]	NA
BDAT semivolatiles					
51	Acenaphthalene	208-96-8	5,000	50	ND
52	Acenaphthene	83-32-9	5,000	50	ND
53	Acetophenone	96-86-2	5,000	50	ND
54	2-Acetylaminofluorene	53-96-3	500,000	5,000	ND
55	4-Aminobiphenyl	92-67-1	100,000	1,000	ND
56	Aniline	62-53-3	10,000	100	ND
57	Anthracene*	120-12-7	5,000	50	D
58	Aramite	140-57-8	-[a]	-[a]	ND
59	Benz(a)anthracene	56-55-3	5,000	50	ND
218	Benzal chloride*	98-87-3	5,000	50	D
60	Benzenethiol	108-98-5	500,000	5,000	ND
62	Benzo(a)pyrene	50-32-8	5,000	50	ND
63 and/or 65	Benzo(b and/or k)fluoranthene*	205-99-2, 207-08-9	5,000	50	D
64	Benzo(ghi)perylene	191-24-2	5,000	50	ND
66	p-Benzoquinone	106-51-4	500,000	50	ND[c]

Table 5-1 (continued)

BDAT no	Parameter	CAS no	Detection limit: Untreated waste (µg/g)	Detection limit: Treated waste (µg/l)	Detection status
BDAT semivolatiles (continued)					
67	Bis(2-chloroethoxy)methane	111-91-1	5,000	50	ND
68	Bis(2-chloroethyl)ether	111-44-4	5,000	50	ND
69	Bis(2-chloroisopropyl)ether	39638-32-9	5,000	50	ND
70	Bis(2-ethylhexyl)phthalate	117-81-7	5,000	50	ND
71	4-Bromophenyl phenyl ether	101-55-3	5,000	50	ND
72	Butyl benzyl phthalate	85-68-7	5,000	50	ND
73	2-sec-Butyl-4,6-dinitrophenol	88-85-7	-[a]	-[a]	ND
74	p-Chloroaniline	106-47-8	50,000	500	ND
75	Chlorobenzilate	510-15-6	-[a]	-[a]	ND
76	p-Chloro-m-cresol	59-50-7	5,000	50	ND
77	2-Chloronaphthalene	91-58-7	5,000	50	ND
78	2-Chlorophenol	95-57-8	5,000	50	ND
79	3-Chloropropionitrile	542-76-7	5,000	50	ND
80	Chrysene	218-01-9	5,000	50	ND
81	ortho-Cresol	95-48-7	5,000	50	ND
82	para-Cresol	106-44-5	5,000	50	ND
232	Cyclohexanone	108-94-1	-[b]	-[b]	NA
83	Dibenz(a,h)anthracene	53-70-3	5,000	50	ND
84	Dibenzo(a,e)pyrene	192-65-4	5,000	50	ND
85	Dibenzo(a,i)pyrene	189-55-9	5,000	50	ND
86	m-Dichlorobenzene	541-73-1	5,000	50	ND
87	o-Dichlorobenzene	95-50-1	5,000	50	ND
88	p-Dichlorobenzene	106-46-7	5,000	50	ND
89	3,3'-Dichlorobenzidine	91-94-1	10,000	50	ND
90	2,4-Dichlorophenol	120-83-2	5,000	50	ND
91	2,6-Dichlorophenol	87-65-0	5,000	50	ND
92	Diethyl phthalate	84-66-2	5,000	50	ND
93	3,3'-Dimethoxybenzidine	119-90-4	5,000,000	50,000	ND
94	p-Dimethylaminoazobenzene	60-11-7	100,000	1,000	ND
95	3,3'-Dimethylbenzidine	119-93-7	5,000,000	50,000	ND
96	2,4-Dimethylphenol	105-67-9	5,000	50	ND
97	Dimethyl phthalate	131-11-3	5,000	50	ND
98	Di-n-butyl phthalate	84-74-2	5,000	50	ND
99	1,4-Dinitrobenzene	100-25-4	50,000	500	ND
100	4,6-Dinitro-o-cresol	534-52-1	25,000	250	ND
101	2,4-Dinitrophenol	51-28-5	25,000	250	ND
102	2,4-Dinitrotoluene	121-14-2	5,000	50	ND
103	2,6-Dinitrotoluene	606-20-2	5,000	50	ND
104	Di-n-octyl phthalate	117-84-0	5,000	50	ND
105	Di-n-propylnitrosamine	621-64-7	-[a]	-[a]	ND
106	Diphenylamine	122-39-4	5,000	50	ND

Table 5-1 (continued)

BDAT no	Parameter	CAS no	Detection limit: Untreated waste (μg/g)	Detection limit: Treated waste (μg/l)	Detection status
BDAT semivolatiles (continued)					
219	Diphenylnitrosamine	86-30-6	5,000	50	ND
107	1,2-Diphenylhydrazine	122-66-7	5,000	50	ND
108	Fluoranthene	206-44-0	5,000	50	ND
109	Fluorene	86-73-7	5,000	50	ND
110	Hexachlorobenzene	118-74-1	5,000	50	ND
111	Hexachlorobutadiene	87-68-3	5,000	50	ND
112	Hexachlorocyclopentadiene	77-47-4	5,000	50	ND
113	Hexachloroethane	67-72-1	5,000	50	ND
114	Hexachlorophene	70-30-4	-[a]	-[a]	ND
116	Indeno(1,2,3-cd)pyrene	193-39-5	5,000	50	ND
117	Isosafrole	120-58-1	50,000	500	ND
118	Methapyrilene	91-80-5	-[a]	-[a]	ND
119	3-Methylcholanthrene	56-49-5	50,000	500	ND
120	4,4'-Methylenebis (2-chloroaniline)	101-14-4	100,000	1,000	ND
36	Methyl methanesulfonate	66-27-3	25	25	ND
121	Naphthalene	91-20-3	5,000	50	ND
122	1,4-Naphthoquinone	130-15-4	50,000	500	ND
123	1-Naphthylamine	134-32-7	50,000	500	ND
124	2-Naphthylamine	91-59-8	50,000	500	ND
125	p-Nitroaniline	100-01-6	25,000	250	ND
126	Nitrobenzene	98-95-3	5,000	50	ND
127	4-Nitrophenol	100-02-7	25,000	250	ND
128	N-Nitrosodi-n-butylamine	924-16-3	50,000	500	ND
129	N-Nitrosodiethylamine	55-18-5	50,000	500	ND
130	N-Nitrosodimethylamine	62-75-9	50,000	500	ND
131	N-Nitrosomethylethylamine	10595-95-6	NA	NA	NA
132	N-Nitrosomorpholine	59-89-2	100,000	1,000	ND
133	N-Nitrosopiperidine	100-75-4	100,000	1,000	ND
134	n-Nitrosopyrrolidine	930-55-2	100,000	1,000	ND
135	5-Nitro-o-toluidine	99-65-8	100,000	1,000	ND
136	Pentachlorobenzene	608-93-5	5,000	50	ND
137	Pentachloroethane	76-01-7	5,000	50	ND
138	Pentachloronitrobenzene	82-68-8	50,000	500	ND
139	Pentachlorophenol	87-86-5	25,000	250	ND
140	Phenacetin	62-44-2	50,000	500	ND
141	Phenanthrene*	85-01-8	5,000	50	D
142	Phenol	108-95-2	5,000	50	ND
220	Phthalic anhydride	85-44-9	-[b]	-[b]	NA
143	2-Picoline	109-06-8	50,000	500	ND
144	Pronamide	23950-58-5	50,000	500	ND
145	Pyrene	129-00-0	5,000	50	ND
146	Resorcinol	108-46-3	5,000	50	ND
147	Safrole	94-59-7	50,000	500	ND

Table 5-1 (continued)

BDAT no	Parameter	CAS no.	Detection limit: Untreated waste (μg/g)	Detection limit: Treated waste (μg/l)	Detection status
BDAT semivolatiles (continued)					
148	2,4,5-Tetrachlorobenzene	95-94-3	50,000	500	ND
149	2,3,4,6-Tetrachlorophenol	58-90-2	50,000	500	ND
150	1,2,4-Trichlorobenzene	120-82-1	5,000	50	ND
151	2,4,5-Trichlorophenol	95-95-4	25,000	250	ND
152	2,4,6-Trichlorophenol	88-06-2	5,000	50	ND
153	Tris(2,3-dibromopropyl) phosphate	126-72-7	-[a]	-[a]	ND
Metals (μg/ml)[c]					
154	Antimony	7440-36-0	-	.17/.3	D
155	Arsenic	7440-38-2	-	.020/1.0	D
156	Barium	7440-39-3	-	.010/.045	D
157	Beryllium	7440-41-7	-	.005	ND
158	Cadmium	7440-43-9	-	.020	D
159	Chromium (total)*	7440-47-32	-	.035	D
221	Chromium (hexavalent)	-	-[b]	-[b]	NA
160	Copper	7440-50-8	-	.030	D
161	Lead	7439-92-1	-	.010/.05	D
162	Mercury	7439-97-6	-	0025/.001	D
163	Nickel*	7440-02-0	-	075/.1	D
164	Selenium	7782-49-2	-	.020/1.0	D
165	Silver	7440-22-4	-	0.035	D
166	Thallium	7440-28-0	-	0.75/.015	D
167	Vanadium	7440-62-2	-	.040	D
168	Zinc	7440-66-6	-	.010/.03	D
Inorganics					
169	Cyanide	57-12-5	NA	NA	NA
170	Fluoride	16964-48-8	NA	NA	NA
171	Sulfide	8496-25-8	NA	NA	NA
Organochlorine Pesticides					
172	Aldrin	309-00-2	NA	NA	NA
173	alpha-BHC	319-84-6	NA	NA	NA
174	beta-BHC	319-85-7	NA	NA	NA
175	delta-BHC	319-86-8	NA	NA	NA

Table 5-1 (continued)

BDAT no	Parameter	CAS no	Detection limit: Untreated waste (µg/g)	Detection limit: Treated waste (µg/l)	Detection status
Organochlorine Pesticides (continued)					
176	gamma-BHC	58-89-9	NA	NA	NA
177	Chlordane	57-74-9	NA	NA	NA
178	DDD	72-54-8	NA	NA	NA
179	DDE	72-55-9	NA	NA	NA
180	DDT	50-29-3	NA	NA	NA
181	Dieldrin	60-57-1	NA	NA	NA
182	Endosulfan I	939-98-8	NA	NA	NA
183	Endosulfan II	33213-6-5	NA	NA	NA
184	Endrin	72-20-8	NA	NA	NA
185	Endrin aldehyde	7421-93-4	NA	NA	NA
186	Heptachlor	76-44-8	NA	NA	NA
187	Heptachlor epoxide	1024-57-3	NA	NA	NA
188	Isodrin	465-73-6	NA	NA	NA
189	Kepone	143-50-0	NA	NA	NA
190	Methoxyclor	72-43-5	NA	NA	NA
191	Toxaphene	8001-35-2	NA	NA	NA
Phenoxyacetic acid herbicides					
192	2,4-Dichlorophenoxyacetic acid	94-75-7	NA	NA	NA
193	Silvex	93-72-1	NA	NA	NA
194	2,4,5-T	93-76-5	NA	NA	NA
Organophosphorous insecticides					
195	Disulfoton	298-04-4	NA	NA	NA
196	Famphur	52-85-7	NA	NA	NA
197	Methyl parathion	298-00-0	NA	NA	NA
198	Parathion	56-38-2	NA	NA	NA
199	Phorate	298-02-2	NA	NA	NA
PCBs					
200	Aroclor 1016	12674-11-2	NA	NA	NA
201	Aroclor 1221	11104-28-2	NA	NA	NA
202	Aroclor 1232	11141-16-5	NA	NA	NA
203	Aroclor 1242	53469-21-9	NA	NA	NA
204	Aroclor 1248	12672-29-6	NA	NA	NA
205	Aroclor 1254	11097-69-1	NA	NA	NA
206	Aroclor 1260	11096-82-5	NA	NA	NA

Table 5-1 (continued)

BDAT no	Parameter	CAS no	Detection limit: Untreated waste (µg/g)	Detection limit: Treated waste (µg/l)	Detection status
Dioxins and furans					
207	Hexachlorodibenzo-p-dioxins	1746-01-6	NA	NA	NA
208	Hexachlorodibenzofuran	1746-01-6	NA	NA	NA
209	Pentachlorodibenzo-p-dioxins	1746-01-6	NA	NA	NA
210	Pentachlorodibenzofuran	1746-01-6	NA	NA	NA
211	Tetrachlorodibenzo-p-dioxins	1746-01-6	NA	NA	NA
212	Tetrachlorodibenzofuran	1746-01-6	NA	NA	NA
213	2,3,7,8-Tetrachlorodibenzo-p-dioxin	1746-01-6	NA	NA	NA

ND - Not detected.
NA - Not analyzed.
D - Detected

[a] The compound was not detected The detection limit is not given because the analytical standard was not available. The compound was searched using an NBS data base of 42,000 compounds.

[b] Constituents have been added to the BDAT list since the time that EPA tested and analyzed these samples for K015. Therefore, data are not available for these particular waste constituents.

[c] Detection limits for treated metals represent quench samples and scrubber water samples, respectively.

* - Constituents to be regulated.

pesticides, phenoxyacetic herbicides, organophosphorous insecticides, PCBs, and dioxin/furans.

Of the 232 current BDAT list constituents, the Agency analyzed for 158 constituents in the untreated wastes. Eleven BDAT constituents were not on the BDAT list at the time the K015 waste was analyzed; thus, no data exist on them. Another 45 BDAT constituents were not analyzed because the Agency believed that there was no in-process source for them. For 2 of the BDAT list organics (isobutyl alcohol and N-nitrosomethylethylamine), there was no information available to indicate if they had been analyzed; therefore, the Agency will assume that they were not. The remaining 16 BDAT list metal constituents were detected in the treated waste.

Of the 158 BDAT list constituents analyzed, the Agency has no data for 11. Of these 11 constituents, 2 have no data, as discussed in the preceding paragraph. The remaining 9 constituents could not be detected because there was no analytical standard available to set detection limits. Therefore, of the 147 constituents for which there were laboratory analyses, only 5 were detected; the remaining 142 constituents were below nondetection levels.

Metals were not analyzed in the untreated waste, but were analyzed in the treated waste. Of the 16 metals analyzed, 14 were detected in the treated waste stream. These BDAT list metals are thought to result from reaction of stainless steel process equipment with hydrogen chloride gas liberated from the process reactions. They must therefore be considered a part of the BDAT list selected constituents. Of these 19 detected BDAT

list constituents, EPA has determined that all are treatable. These constituents will then form the list of potential constituents for regulation.

Table 5-2 presents those organic constituents determined by EPA to have treatable concentrations that would be treatable by liquid injection incineration. This technology would thus significantly reduce these concentrations. The table also presents those metals thought to be treatable by the transfer technology train described in Section 4. In the case of K015, any organic constituent detected in the untreated or treated waste was identified as treatable for two reasons: (1) detection limits were fairly high in the untreated waste (parts per thousand for semivolatile organic compounds), and (2) any constituent detected in the treated waste was likely to have been present in the untreated waste. (A detection limit is defined as a practical quantitation limit (PQL) that is five times the method detection limit achievable when using an EPA-approved analytical method specified for a particular analyte (i.e., constituent of interest) in SW-846, 3rd Edition.

Those organic constituents that were not detected in the treated or untreated waste are not deemed treatable. They are therefore not regulated because (1) the currently available analytical methods and recommended procedures are inadequate for these constituents and thus are considered unreliable; (2) the constituents, if present, are likely to be at low level concentrations; or (3) it is assumed that the majority of these constituents are treated, if present at low levels, along with the

1825g

Table 5-2 K015 Waste Constituents with Treatable Concentrations

BDAT number	Constituent	CAS number	Concentration in untreated waste (ug/g)	Concentration in treated waste (ug/l)
43	Toluene	108-88-3	<10	15 59
57	Anthracene	120-12-7	<5,000	<50-210
218	Benzal chloride	98-87-3	930,000-1,100,000	<50-94
63 and/or 65	Benzo (b and/or k) fluoranthene	205-99-2/ 207-08-9	<5,000	<50-96
141	Phenanthrene	85-01-8	<5,000	<50-58
154	Antimony	7440-36-0	NA	<120-160
155	Arsenic	7440-38-2	NA	100-530
156	Barium	7440-39-3	NA	110-550
158	Cadmium	7440-43-9	NA	<20
159	Chromium	7440-47-32	NA	4,000-34,000*
160	Copper	7440-50-8	NA	580-3,500
161	Lead	7439-92-1	NA	60-300
162	Mercury	7439-97-6	NA	<2.5-60
163	Nickel	7440-02-0	NA	2,200-25,000*
164	Selenium	7782-49-2	NA	60-90
165	Silver	7440-22-4	NA	<35-300
166	Thallium	7440-28-0	NA	<750
167	Vanadium	7440-62-2	NA	50-390
168	Zinc	7440-66-6	NA	110-930

NA - Not analyzed in the untreated waste. See Section 5.1.

* Those K015 waste constituents believed to be treatable by transfer technology.

treatable organic BDAT list constituents determined by EPA during the liquid injection incineration.

The constituents identified as major treatable constituents of K015 waste are toluene, anthracene, benzal chloride, benzo(b and/or k)fluoranthene, phenanthrene, and several metals, (i.e., antimony, arsenic, barium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, vanadium, and zinc). Concentration data from the testing of K015 waste for these constituents are summarized in Table 5-3. The table shows concentrations detected in the untreated waste, as well as those in the treated waste. Values in parentheses under treated waste are accuracy-corrected data. Data accuracy is discussed in Section 1.2.6. The correction factors are derived as described in Appendix B.

5.2 Comparison of the Untreated and Treated Waste Data for the Major Treatable Constituents

Having identified the major treatable BDAT list constituents present in the waste, EPA compared the analytical data to determine if the constituent concentration was reduced significantly from the untreated to the treated waste. When the concentration of a constituent was above the detection limit, comparisons were based on percent reduction, defined as the ratio of the concentration of the constituent in the untreated waste to the concentration in the treated waste. For constituents present in the treated waste but not detected in the untreated waste, it was assumed that the constituent was present in the untreated waste at or near the

Table 5-3 Major Constituent Concentration Data

Major constituent	Concentration (accuracy-corrected concentration)[a]									Correction factor
	Untreated waste (mg/kg)			Treated waste (ug/l)						
	Sample set			Sample set						
	#1	#2	#3	#1		#2		#3		
Volatile organics										
Toluene	<10	<10	<10	59	(59)	30	(30)	15	(15)	1 00
Semivolatile organics										
Anthracene	<5,000	<5,000	<5,000	<50	(<98.6)	68	(134)	210	(414)	1.97
Benzal chloride	930,000	910,000	1,100,000	<50	(<98.6)	66	(130)	94	(185)	1.97
Benzo(b and/or k)-fluoranthene	<5,000	<5,000	<5,000	<50	(<98.6)	<50	(<98.6)	96	(189)	1.97
Phenanthrene	<5,000	<5,000	<5,000	<50	(<98.6)	58	(114)	110	(217)	1 97
Metals[b]										
Silver	-	-	-	130	(160)	300	(370)	<35	(<43)	1.23
Arsenic	-	-	-	250	(260)	100	(100)	530	(540)	1.02
Barium	-	-	-	110	(150)	250	(330)	550	(720)	1.32
Chromium	-	-	-	4,000	(5,000)	18,000	(23,000)	34,000	(44,000)	1.28
Copper	-	-	-	580	(660)	1,600	(1,820)	3,500	(3,980)	1.14
Mercury	-	-	-	5	(5)	<2.5	(<2.5)	60	(60)	1.00
Nickel	-	-	-	2,200	(2,900)	11,000	(14,500)	25,000	(32,900)	1.32
Lead	-	-	-	60	(130)	240	(510)	300	(640)	2.13
Antimony	-	-	-	<120	(<250)	120	(250)	160	(340)	2.13[c]
Selenium	-	-	-	60	(80)	90	(130)	60	(80)	1.39
Vanadium	-	-	-	50	(66)	170	(220)	390	(510)	1.32
Zinc	-	-	-	110	(130)	750	(850)	930	(1,050)	1.14

[a] The data in parentheses have been adjusted for accuracy using the correction factors provided.

[b] As stated in Section 3, metals were not analyzed in the untreated waste.

[c] The wastewater matrix spike was not analyzed for antimony; accuracy-corrected values were calculated using an assumed correction factor of 2.13. (See Appendix B.)

detection limit. This assumption was based on the likelihood that the constituents would be masked by other constituents in the untreated waste.

If the concentration of a major treatable constituent is not reduced significantly by treatment deemed BDAT, the Agency eliminates the constituent from the list of identified constituents to be considered as regulated unless the concentration in the treated waste is high. BDAT list metals were found at high concentrations in the scrubber water residual. In such a case, treatment standards may be established for that constituent using some other demonstrated and available technology on a matrix similar to the treated residual. As shown in Table 5-3, all identified organic constituents in K015 waste were significantly reduced by liquid injection incineration. As discussed in Section 5.1, liquid injection incineration of K015 waste was not expected to treat metals, but metals were found in the treated wastewater. Except for chromium and nickel, all metals were eliminated from consideration as regulated pollutants. Chromium and nickel were present in the treated waste at concentrations for which treatment has been demonstrated by other technologies (i.e., BDAT for K062 wastewaters). The Agency is still considering possible regulation of copper at this time, since it is also present at relatively higher concentrations than the other metals but not as high as chromium and nickel. The Agency believes that treatment of chromium and nickel will result in subsequent treatment of the other detected metals, since they are present at relatively lower concentrations.

5.3 Evaluation of Waste Characteristics Affecting Performance (WCAP) and Other Related Factors

The WCAPs given in Sections 3.2.1 and 3.2.2 are used to evaluate the major constituents to determine which organic constituents should be given priority in the final selection of the regulated constituents. Such an evaluation is necessary and is generally performed when a significant number of major constituents have been identified as potential regulated constituents. Under these circumstances, the major constituents need to be prioritized based on either of two criteria: (1) the greatest attenuation in concentration or (2) the identification of those constituents that are the most difficult to remove and which may, in many instances, require further treatment. For example, in the case of K015 waste, toluene was given the lowest priority for regulatory selection since its reduction in concentration from the untreated waste was not readily apparent yet it was still detected in the treated waste. Furthermore, its chemical structure is considered easier to treat by liquid injection than are the other major organic constituents in the waste. Moreover, if toluene were present in any concentration, it would be treated more quickly than the other major organic constituents.

5.4 Selection of Regulated Constituents

In summary, EPA has selected five BDAT organic constituents, toluene, anthracene, benzal chloride, benzo(b and/or k)fluoranthene, and phenanthrene, and two metal constituents, chromium and nickel, as the regulated constituents for K015 wastewaters. (As stated in Section 5.2, the Agency is still considering copper as a potential regulated metal constituent.)

6. CALCULATION OF THE BDAT TREATMENT STANDARDS

The purpose of this section is to present the calculation of the actual treatment standards for the regulated constituents determined in Section 5. EPA has three sets of influent and effluent data from one facility for treatment of K015 using liquid injection incineration. EPA believes that the treated constituent concentrations substantially diminish the toxicity or mobility of K015 waste. As discussed in the introduction, the following steps were taken to derive the BDAT treatment standards for K015 waste.

1. The Agency evaluated the data collected from the liquid injection treatment system to determine whether any of the data represented poor design or operation of the treatment system. The available data show that all three data sets do not represent poor design or operation. All three data sets for liquid injection incineration are used for establishing treatment standards for regulation of the organic constituents in K015 wastewaters. For the regulated constituents chromium and nickel, treatment data were transferred from standards established for those metals in K062 wastewaters (see the Background Document for K062 waste).

2. Accuracy-corrected constituent concentrations were calculated for all BDAT list constituents. An arithmetic average concentration level and a variability factor were determined for each BDAT list constituent regulated in this waste. These are shown for the organic constituents in Table 6-1. The calculation of the variability factor is explained in Appendix A.

3. The BDAT treatment standard for each constituent regulated in this rulemaking was determined by multiplying the average accuracy-corrected total composition by the appropriate variability factor. The BDAT treatment standards for the organic constituents are also shown in Table 6-1.

Table 6-1 Calculation of BDAT Treatment Standards for Regulated Organic Constituents in K015 Wastewaters

Constituent (units)	Accuracy-corrected concentration: Sample set #1	Sample set #2	Sample set #3	Average treated waste concentration	Variability factor (VF)	Treatment standard (average x VF)
Toluene (μg/l)	59	30	15	34 7	4.26	148
Anthracene (μg/l)	<98.6	134	414	216	4 15	1,020
Benzal chloride (μg/l)	<98.6	130	185	138	2.02	280
Benzo(b and/or k) fluoranthene (μg/l)	<98.6	<98.6	189	129	2.28	290
Phenanthrene (μg/l)	<98.6	114	217	107	2 50	270

7. CONCLUSIONS

The Agency has proposed treatment standards for the listed waste code K015. Standards for nonwastewater and wastewater forms of this waste are presented in Table 7-1.

The treatment standards proposed for K015 waste have been developed consistent with EPA's promulgated methodology for BDAT (November 7, 1986, 51FR 40572). Only two facilities are known to produce benzyl chloride and to generate K015 waste. The BDAT constituents generally present in the K015 waste are benzal chloride and toluene.

Through available data bases, EPA's technology testing program, and data submitted by industry, the Agency has identified the following demonstrated technologies for treatment of organic constituents present in the K015 waste: liquid injection incineration and fuel substitution.

Regulated constituents were selected based on a careful evaluation of the constituents detected at treatable levels in the untreated wastes and constituents detected in the treated wastes. All available waste characterization data and applicable treatment data consistent with the type and quality of data required by the Agency for this program were used to make this determination.

In the development of treatment standards for K015 wastes, the Agency examined all available data, conducted tests on liquid injection incineration of the waste, and collected performance data for three sample sets. Design and operating data collected during the testing of

1590g

Table 7-1 BDAT Treatment Standards for K015 Waste

NONWASTEWATER

No land disposal

WASTEWATER

Constituent	Maximum for any single grab sample	
	Total constitution (mg/l)	TCLP (mg/l)
Toluene	.1478	NA
Anthracene	1.02	NA
Benzal chloride	0.28	NA
Benzo(b and/or k)fluoranthene	0.29	NA
Phenanthrene	0.27	NA
Chromium	0 3[illegible]6	NA
Nickel	0 44	NA

NA = Not applicable.

the technology indicate that the technology was properly operated during all three sample sets; accordingly, the treatment performance data were used in the development of the BDAT treatment standards.

Two categories of treatment standards were developed for K015 waste: wastewater and nonwastewater. (For the purpose of the land disposal restrictions rule, wastewaters are defined as wastes containing less than 1 percent (weight basis) filterable solids and less than 1 percent (weight basis) total organic carbon.) The nonwastewater standard is "no land disposal" for K015 as generated. Wastewater standards for organic constituents in K015 waste are based on the performance data from EPA's test of liquid injection incineration. Wastewater standards for metal constituents in K015 are based on the transfer of BDAT standards for K062 waste.

Treatment standards for these wastes were derived after adjustment of laboratory data to account for recovery. Subsequently, the mean of the adjusted data points was multiplied by a variability factor to derive the standard. The variability factor represents the variability inherent in the treatment process and sampling and analytical methods. Variability factors were determined by statistically calculating the variability seen for a number of data points for a given constituent. For constituents for which specific variability factors could not be calculated, a variability factor of 2.8 was used (although this was not necessary for K015).

Wastes determined to be K015 residuals may be land disposed if they meet the standards at the point of disposal. The BDAT upon which the treatment standards are based need not be specifically utilized prior to land disposal, provided the alternative technology used achieves the standards.

These standards were to become effective as of August 8, 1986, as per the schedule set forth in 40 CFR 268.10. Because of the lack of nationwide incineration capacity at this time, the Agency has proposed to grant a 2-year nationwide variance to the effective date of the land disposal ban for K015 waste. A detailed discussion of the Agency's determination that a lack of nationwide incineration capacity exists is presented in the Capacity Background Document, which is available in the Administrative Record for the First Sixths' Rule.

Consistent with Executive Order 12291, EPA prepared a regulatory impact analysis (RIA) to assess the economic effect of compliance with this proposed rule. The RIA prepared for this proposed rule is available in the Administrative Record for the First Sixths' Rule.

REFERENCES

Ackerman, D.G., McGaughey, J.F., Wagoner D.E.1983., At sea incineration of PCB-containing wastes on board the M/T Vulcanus, 600/7-83-024, Washington, D.C.: U.S. Environmental Protection Agency.

Bonner, T.A., et al. 1981. Engineering handbook for hazardous waste incineration. SW-889. Prepared by Monsanto Research Corporation for U.S. Environmental Protection Agency. NTIS PB 81-248163. June 1981.

Castaldini, C., et al. 1986. Disposal of hazardous wastes in industrial boilers on furnaces, New Jersey, Noyes Publications.

Hughes, C.S., Shimosato, J., and Bakker, J. 1983. CEH product review: benzyl chloride. In Chemical economics handbook. Menlo Park, Calif.: Stanford Research Institute International.

Novak, R.G., Troxler W.L., and Dehnke, T.H., 1984. Recovering energy from hazardous waste incineration, Chemical Engineering Progress 91:146.

Oppelt, E.T., Incineration of hazardous waste. 1987. JAPCA. 37(5).

Santoleri, J.J., 1983. Energy recovery-a-by-product of hazardous waste incineration systems, in Proceedings of the 15th Mid-Atlantic Industrial Waste Conference on Toxic and Hazardous Waste.

SRI. 1986. Stanford Research Institute. Benzyl chloride, butyl benzyl phthalate, p-benzylphenol, and benzyl alcohol. In Directory of chemical producers United States of America. Menlo Park, Calif.: Stanford Research Institute International.

USEPA. 1980. U.S. Environmental Protection Agency. RCRA listing background document. Waste code K015.

USEPA. 1986a. U.S. Environmental Protection Agency. Best demonstrated available technology (BDAT) background document for F001-F005 spent solvents. Vol. 1, EPA/530-SW-86-056, November 1986.

USEPA. 1986b. U.S. Environmental Protection Agency. Office of Solid Waste and Emergency Response. Test methods for evaluating solid waste, SW-846. 3rd ed. Washington, D.C.: U.S. Environmental Protection Agency.

USEPA. 1986c. U.S. Environmental Protection Agency. Summary of available waste composition data from review of literature and data bases for use in treatment technology application and evaluation for "California List" waste streams. Contract No. 68-01-7053. Washington, D.C.: U.S. Environmental Protection Agency.

USEPA. 1987a. U.S. Environmental Protection Agency. Onsite engineering report of treatment technology performance and operation for incineration of K015 waste at the John Zink Company test facility.

USEPA. 1987b. Memoranda concerning industry data from Monsanto Company and Velsicol Chemical Corporation of their handling of K015 hazardous waste. Contract No. 68-03-3389. Washington, D.C.: U.S. Environmental Protection Agency.

Versar. 1984. Estimating PMN incineration results (Draft). U.S. Environmental Protection Agency, Exposure Evaluation Division, Office of Toxic Substances, Washington, D.C. EPA Contract No. 68-01-6271, Task No. 66.

Vogel G, et al. 1986. Incineration and cement kiln capacity for hazardous waste treatment In Proceedings of the 12th Annual Research Symposium. Incineration and Treatment of Hazardous Wastes. Cincinnati, Ohio. April 1986.

APPENDIX A

APPENDIX A

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 different, 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." 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 = 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 in which one technology achieves significantly better treatment than the other technology.

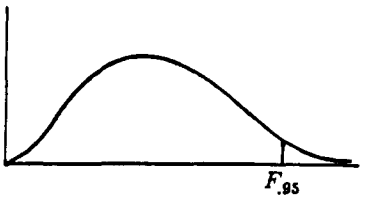
Table A-1

95th PERCENTILE VALUES FOR THE F DISTRIBUTION

n_1 = degrees of freedom for numerator

n_2 = degrees of freedom for denominator

(shaded area = .95)



n_2 \ n_1	1	2	3	4	5	6	8	12	16	20	30	40	50	100	∞
1	161.4	199.5	215.7	224.6	230.2	234.0	238.9	243.9	246.3	248.0	250.1	251.1	252.2	253.0	254.3
2	18.51	19.00	19.16	19.25	19.30	19.33	19.37	19.41	19.43	19.45	19.46	19.46	19.47	19.49	19.50
3	10.13	9.55	9.28	9.12	9.01	8.94	8.85	8.74	8.69	8.66	8.62	8.60	8.58	8.56	8.53
4	7.71	6.94	6.59	6.39	6.26	6.16	6.04	5.91	5.84	5.80	5.75	5.71	5.70	5.66	5.63
5	6.61	5.79	5.41	5.19	5.05	4.95	4.82	4.68	4.60	4.56	4.50	4.46	4.44	4.40	4.36
6	5.99	5.14	4.76	4.53	4.39	4.28	4.15	4.00	3.92	3.87	3.81	3.77	3.75	3.71	3.67
7	5.59	4.74	4.35	4.12	3.97	3.87	3.73	3.57	3.49	3.44	3.38	3.34	3.32	3.28	3.23
8	5.32	4.46	4.07	3.84	3.69	3.58	3.44	3.28	3.20	3.15	3.08	3.05	3.03	2.98	2.93
9	5.12	4.26	3.86	3.63	3.48	3.37	3.23	3.07	2.98	2.93	2.86	2.82	2.80	2.76	2.71
10	4.96	4.10	3.71	3.48	3.33	3.22	3.07	2.91	2.82	2.77	2.70	2.67	2.64	2.59	2.54
11	4.84	3.98	3.59	3.36	3.20	3.09	2.95	2.79	2.70	2.65	2.57	2.53	2.50	2.45	2.40
12	4.75	3.89	3.49	3.26	3.11	3.00	2.85	2.69	2.60	2.54	2.46	2.42	2.40	2.35	2.30
13	4.67	3.81	3.41	3.18	3.03	2.92	2.77	2.60	2.51	2.46	2.38	2.34	2.32	2.26	2.21
14	4.60	3.74	3.34	3.11	2.96	2.85	2.70	2.53	2.44	2.39	2.31	2.27	2.24	2.19	2.13
15	4.54	3.68	3.29	3.06	2.90	2.79	2.64	2.48	2.39	2.33	2.25	2.21	2.18	2.12	2.07
16	4.49	3.63	3.24	3.01	2.85	2.74	2.59	2.42	2.33	2.28	2.20	2.16	2.13	2.07	2.01
17	4.45	3.59	3.20	2.96	2.81	2.70	2.55	2.38	2.29	2.23	2.15	2.11	2.08	2.02	1.96
18	4.41	3.55	3.16	2.93	2.77	2.66	2.51	2.34	2.25	2.19	2.11	2.07	2.04	1.98	1.92
19	4.38	3.52	3.13	2.90	2.74	2.63	2.48	2.31	2.21	2.15	2.07	2.02	2.00	1.94	1.88
20	4.35	3.49	3.10	2.87	2.71	2.60	2.45	2.28	2.18	2.12	2.04	1.99	1.96	1.90	1.84
22	4.30	3.44	3.05	2.82	2.66	2.55	2.40	2.23	2.13	2.07	1.98	1.93	1.91	1.84	1.78
24	4.26	3.40	3.01	2.78	2.62	2.51	2.36	2.18	2.09	2.03	1.94	1.89	1.86	1.80	1.73
26	4.23	3.37	2.98	2.74	2.59	2.47	2.32	2.15	2.05	1.99	1.90	1.85	1.82	1.76	1.69
28	4.20	3.34	2.95	2.71	2.56	2.45	2.29	2.12	2.02	1.96	1.87	1.81	1.78	1.72	1.65
30	4.17	3.32	2.92	2.69	2.53	2.42	2.27	2.09	1.99	1.93	1.84	1.79	1.76	1.69	1.62
40	4.08	3.23	2.84	2.61	2.45	2.34	2.18	2.00	1.90	1.84	1.74	1.69	1.66	1.59	1.51
50	4.03	3.18	2.79	2.56	2.40	2.29	2.13	1.95	1.85	1.78	1.69	1.63	1.60	1.52	1.44
60	4.00	3.15	2.76	2.53	2.37	2.25	2.10	1.92	1.81	1.75	1.65	1.59	1.56	1.48	1.39
70	3.98	3.13	2.74	2.50	2.35	2.23	2.07	1.89	1.79	1.72	1.62	1.56	1.53	1.45	1.35
80	3.96	3.11	2.72	2.48	2.33	2.21	2.05	1.88	1.77	1.70	1.60	1.54	1.51	1.42	1.32
100	3.94	3.09	2.70	2.46	2.30	2.19	2.03	1.85	1.75	1.68	1.57	1.51	1.48	1.39	1.28
150	3.91	3.06	2.67	2.43	2.27	2.16	2.00	1.82	1.71	1.64	1.54	1.47	1.44	1.34	1.22
200	3.89	3.04	2.65	2.41	2.26	2.14	1.98	1.80	1.69	1.62	1.52	1.45	1.42	1.32	1.19
400	3.86	3.02	2.62	2.39	2.23	2.12	1.96	1.78	1.67	1.60	1.49	1.42	1.38	1.28	1.13
∞	3.84	2.99	2.60	2.37	2.21	2.09	1.94	1.75	1.64	1.57	1.46	1.40	1.32	1.24	1.00

Example 1
Methylene Chloride

Steam stripping				Biological treatment			
Influent (μg/l)	Effluent (μg/l)	ln(effluent)	[ln(effluent)]^2	Influent (μg/l)	Effluent (μg/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)

Example 1 (continued)

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 ($\mu g/l$)	Effluent ($\mu g/l$)	ln(effluent)	$[\ln(\text{effluent})]^2$	Influent ($\mu g/l$)	Effluent ($\mu g/l$)	ln(effluent)	$[\ln(\text{effluent})]^2$
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:

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

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

$MSB = SSB/(k-1)$

$MSW = SSW/(N-k)$

Example 2 (continued)

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 ($\mu g/l$)	Effluent ($\mu g/l$)	ln(effluent)	$[\ln(\text{effluent})]^2$	Influent ($\mu g/l$)	Effluent ($\mu g/l$)	ln(effluent)	$\ln[(\text{effluent})]^2$
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:

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

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

$MSB = SSB/(k-1)$

$MSW = SSW/(N-k)$

$F = MSB/MSW$

Example 3 (continued)

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.

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. Agency data shows that the treatment residual concentrations are distributed approximately lognormally. 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).

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

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 (μ) and standard deviation (σ) of the normal distribution as follows:

$$C_{99} = \text{Exp}\ (\mu + 2.33\sigma) \quad (2)$$

$$\text{Mean} = \text{Exp}\ (\mu + .5\sigma^2) \quad (3)$$

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

$$VF = \text{Exp}\ (2.33\ \sigma - .5\sigma^2) \quad (4)$$

For residuals with concentrations that are not all below the detection limit, the 99^{th} 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 (σ) 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

APPENDIX B

Analytical QA/QC

The methods used to analyze the constituents identified in Section 5 are presented in Table B-1. All methods are described in SW-846 Third Edition (EPA's Test Methods for Evaluating Solid Waste).

The accuracy determination for a constituent is based on matrix spike recovery values. The inverse of the recovery is the correction factor. An accuracy-corrected value is simply the analytical result multipled by the correction factor as shown in the following example:

Analytical Result		Correction Factor		Accuracy-Corrected Value
0.13 mg/l	x	1.23	=	0.16 mg/l.

Only one of the organic compounds identified as a major constituent in K015 wastewaters, toluene, served as a spiking component. Its recovery was 100 percent. Thus, the detected values and accuracy-corrected values for toluene are identical. For the remaining organics in the wastewaters (all semivolatiles), the recovery value for each was taken to be the average of the recoveries for similar compounds. The identified semivolatiles were all base neutral compounds; thus, the average recovery for the base neutral spiking compounds was used as a recovery value. The matrix spike data for the base neutral semivolatile compounds in K015 wastewaters are presented in Table B-2. As shown, the average recovery is 50.7 percent, corresponding to a correction factor of 1.97.

1541g

Table B-1 Analytical Methods

Analysis/methods	Method	Reference
Volatile Organics		
Purge-and-trap	5030	1
Gas chromatography/mass spectrometry for volatile organics	8240	1
Semivolatile Organics		
Continuous liquid-liquid extraction (treated waste)	3520	1
Soxhlet extraction (untreated waste)	3540	1
Gas chromatography/mass spectrometry for semi-volatile organics· Capillary Column Technique	8270	1
Metals		
Digestion		
Aqueous liquids analyzed by ICP	3010	1
Aqueous liquids analyzed by graphite furnace	3020	1
Inductively coupled plasma atomic emission spectroscopy (antimony/barium/chromium/copper/nickel/silver/vanadium/zinc)	6010	1
Arsenic (atomic absorption, furnace technique)	7060	1
Selenium (atomic absorption, furnace technique)	7740	1
Mercury in solid or semisolid waste (manual cold-vapor technique)	7471	1
Lead (atomic absorption, furnace technique)	7421	1

Reference 1. (US EPA 1986b).

1541g

Table B-2 Base Neutral Matrix Spike Data for K015 Wastewater

Compound	Percent recovery	
	Matrix spike	Matrix spike duplicate
1,4-Dichlorobenzene	40	37
N-nitroso-di-n-propylamine	75	65
1,2,4-Trichlorobenzene	37	35
Acenaphthene	76	80
2,4-Dinitrotoluene	25	25
Pyrene	52	62
Average:	50.83	50.66
Combined averages:	50.7	

For each metal compound identified as a major constituent, the data were adjusted using the lower of the matrix spike and matrix spike duplicate recoveries for that compound, except in the case of antimony. Because the wastewater matrix spike was not analyzed for antimony, the data were adjusted using the lowest recovery of all major metal constituents in the waste (i.e., for lead). Table B-3 summarizes the major constituents in the K015 wastewater, their recovery values, and the respective correction factors used to obtain the accuracy-corrected concentrations displayed on Table 5-3.

Table B-3 Metal Matrix Spike Data for K015 Wastewater

Compound	Lowest percent recovery	Correction factor
Silver	81	1.23
Arsenic	98	1.02
Barium	76	1.32
Chromium	78	1.28
Copper	88	1.14
Mercury	100	1.00
Nickel	76	1.32
Lead	47	2.13
Antimony	47[a]	2.13[a]
Selenium	72	1.39
Vanadium	76	1.32
Zinc	88	1.14

[a]These are assumed values See text.

APPENDIX C

APPENDIX C

The comparative method of measuring thermal conductivity has been proposed as an ASTM test method under the name "Guarded, Comparative, Longitudinal Heat Flow Technique." A thermal heat flow circuit is used which is the analog of an electrical circuit with resistances in series. A reference material is chosen to have a thermal conductivity close to that estimated for the sample. Reference standards (also known as heat meters) having the same cross-sectional dimensions as the sample are placed above and below the sample. An upper heater, a lower heater, and a heat sink are added to the "stack" to complete the heat flow circuit. See Figure 1.

The temperature gradients (analogous to potential differences) along the stack are measured with type K (chromel/alumel) thermocouples placed at known separations. The thermocouples are placed into holes or grooves in the references and also in the sample whenever the sample is thick enough to accommodate them.

For molten samples, pastes, greases, and other materials that must be contained, the material is placed into a cell consisting of a top and bottom of Pyrex 7740 and a containment ring of marinite. The sample is 2 inch in diameter and .5 inch thick. Thermocouples are not placed into the sample but rather the temperatures measured in the Pyrex are extrapolated to give the temperature at the top and bottom surfaces of the sample material. The Pyrex disks also serve as the thermal conductivity reference material.

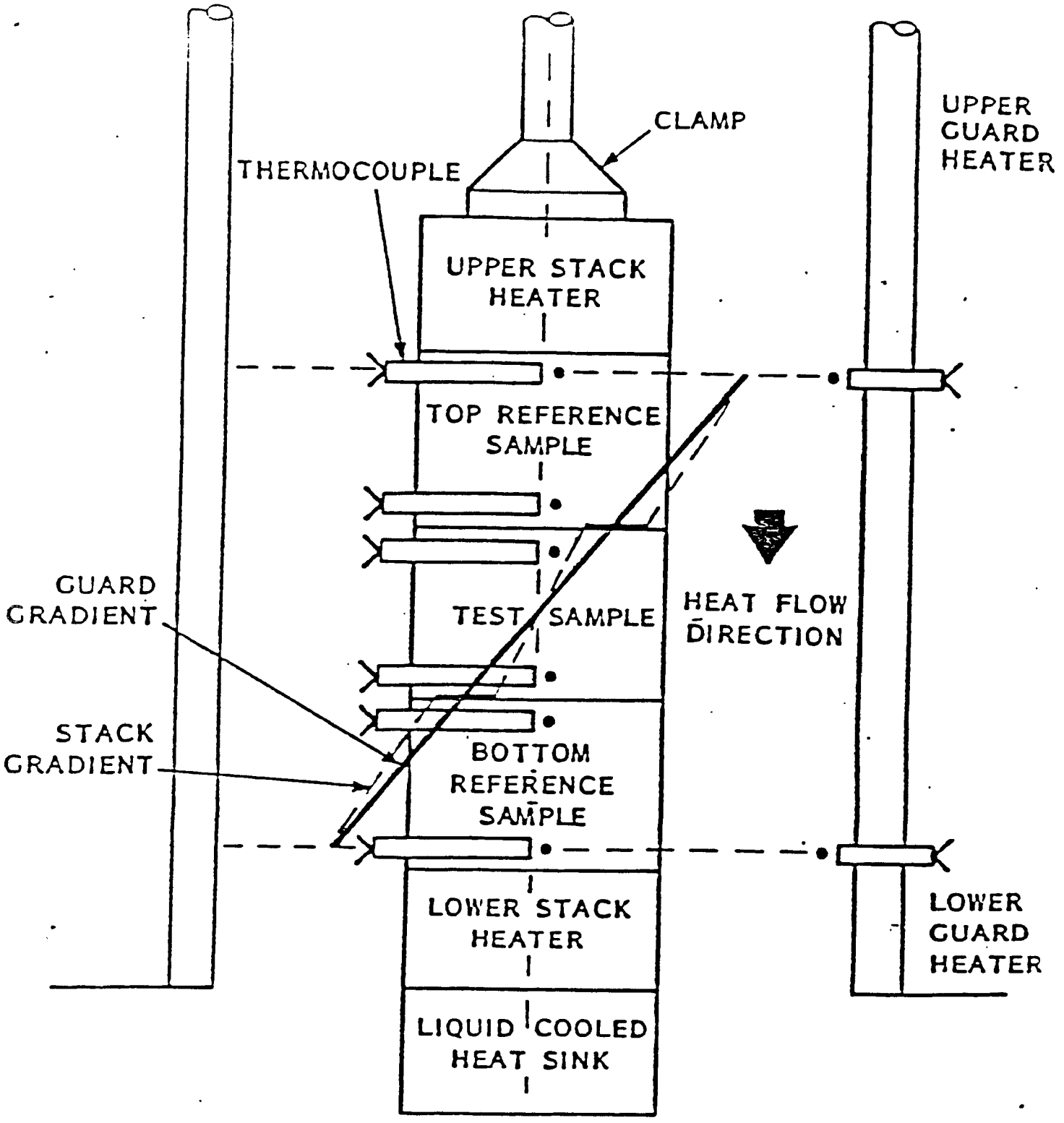


Figure C-1 SCHEMATIC DIAGRAM OF THE COMPARATIVE METHOD

The stack is clamped with a reproducible load to insure intimate contact between the components. In order to produce a linear flow of heat down the stack and reduce the amount of heat that flows radially, a guard tube is placed around the stack and the intervening space is filled with insulating grains or powder. The temperature gradient in the guard is matched to that in the stack to further reduce radial heat flow.

The comparative method is a steady state method of measuring thermal conductivity. When equilibrium is reached the heat flux (analogous to current flow) down the stack can be determined from the references. The heat into the sample is given by

$$Q_{in} = \lambda_{top}(dT/dx)_{top}$$

and the heat out of the sample is given by

$$Q_{out} = \lambda_{bottom}(dT/dx)_{bottom}$$

where

λ = thermal conductivity

dT/dx = temperature gradient

and top refers to the upper reference while bottom refers to the lower reference. If the heat was confined to flow just down the stack, then Q_{in} and Q_{out} would be equal. If Q_{in} and Q_{out} are in reasonable agreement, the average heat flow is calculated from

$$Q = (Q_{in} + Q_{out})/2$$

The sample thermal conductivity is then found from

$$\lambda_{sample} = Q/(dT/dx)_{sample}$$