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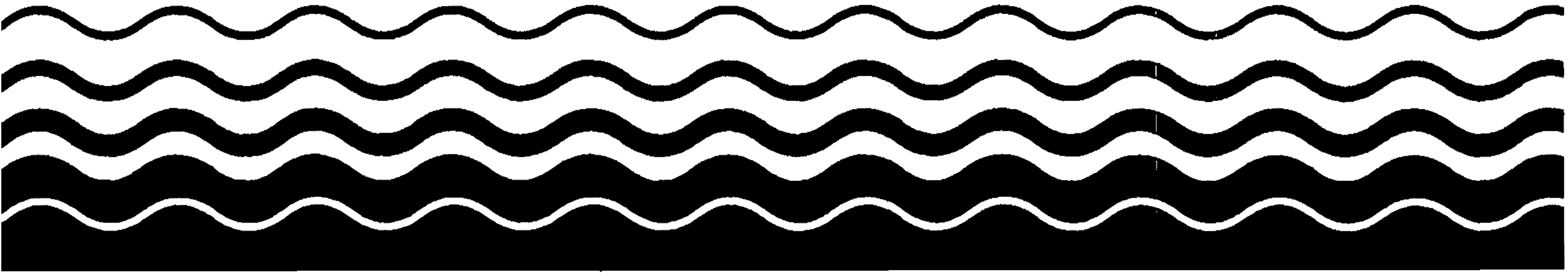
Technical Support Document for Sewage Sludge Incineration



TECHNICAL SUPPORT DOCUMENT
FOR
SEWAGE SLUDGE INCINERATION

Prepared for
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U.S. Environmental Protection Agency
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LIST OF UNITS AND ACRONYMS

APCD	air pollution control device
Btu	British thermal unit
BW	human body weight (kg)
cal	calories
CFR	Code of Federal Regulations
CO	carbon monoxide
CWA	Clean Water Act
DF	dispersion factor ($\mu g/m^3/g$/second)
dmt	dry metric ton
EPA	U.S. Environmental Protection Agency
ERG	Eastern Research Group, Inc.
ESP	electrostatic precipitator
FBF	fluidized-bed furnace
FC	fuel constant
FGF	fuel combustion gas flow rate (g-moles/day)
FID	flame-ionization detector
FR	annual average daily fuel usage rate (lb/day or ft^3/day)
ft^2	square feet
ft^3	cubic feet
g	gram
GF	gas flow rate (g-moles/day)
hr	hour
I_a	inhalation rate
in^2	square inches
IRIS	Integrated Risk Information System
ISCLT	Industrial Source Complex Long-Term model
kg	kilogram
kPa	kilopascals
L	liter
lb	pound
LC_{50}	inhalation dose (concentration of chemical) at which 50 percent of study animals die
LD_{50}	oral dose of chemical at which 50 percent of study animals die
LOAEL	Lowest Observed Adverse Effect Level (mg/kg•day)
LOEL	Lowest Observed Effect Level (mg/kg•day)
m	meter
MCL	maximum contaminant level
mg	milligram
MGD	million gallons/day
MHF	multiple-hearth furnace
MTD	maximum tolerated dose
NAAQS	National Ambient Air Quality Standard
NAS	National Academy of Sciences
NESHAPs	National Emission Standards for Hazardous Air Pollutants
ng	nanogram
NIOSH	National Institute for Occupational Safety and Health

LIST OF UNITS AND ACRONYMS (cont.)

NOAEL	No Observed Adverse Effect Level (mg/kg•day)
NOEL	No Observed Effect Level (mg/kg•day)
NPDES	National Pollution Discharge Elimination System
NSSS	National Sewage Sludge Survey
OST	Office of Science and Technology, EPA
OSW	Office of Solid Waste, EPA
OWRS	Office of Water Regulations and Standards, EPA
PCBs	polychlorinated biphenyls
PICs	products of incomplete combustion
POTW	publicly owned treatment works
ppm	parts per million
ppmv	parts per million, volume
q_1^*	human cancer potency (mg/kg•day)
r^2	correlation coefficient
RACs	reference air concentrations
RCRA	Resource Conservation and Recovery Act
RfC	reference concentration of inhalation exposure
RfD	oral reference dose (mg/kg•day)
RL_{sp}	site-specific risk level (unitless)
RSC	risk-specific concentration ($\mu g/m^3$)
RSC_{sp}	site-specific risk-specific concentration for THC ($\mu g/m^3$)
sec	second
SF	average daily amount of sewage sludge (dmt/day)
SGF	gas flow rate attributable to the combustible portion of sewage sludge (g-moles/day)
SRAB	Sludge Risk Assessment Branch, EPA
TCPD	tetrachlorinated paradioxin
THC	total hydrocarbons
TSCA	Toxic Substances Control Act
μ	microns
μg	microgram
VEHC	annual average heat value of volatile solids in sewage sludge (Kcal/g-volatile solids in sewage sludge)
VF	annual average volatile solids fraction of sewage sludge solids (unitless)
WESP	wet electrostatic precipitator
X	percent moisture content in the sewage sludge incinerator stack exit gas, in hundredths (volume/volume)
Y	percent oxygen concentration in the sewage sludge incinerator stack exit gas (volume/volume)

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SECTION ONE

INTRODUCTION

1.1 BACKGROUND

Treatment works generate sewage sludge from domestic sewage in the process of maintaining the quality of our water resources. The sewage sludge must then be used or disposed in a manner that does not adversely impact public health or the environment. Sewage sludge is used or disposed of in a number of ways, including land application, surface disposal, incineration, and co-disposal with municipal solid waste. This document discusses the incineration of sewage sludge.

EPA's role is to control the potential adverse effects to public health and the environment that any use or disposal of sewage sludge may cause. Existing federal regulations are authorized under several legislative mandates and have been developed independently along media-specific concerns to regulate sewage sludge use and disposal. Section 405(d) of the Clean Water Act (CWA), as amended (33 U.S.C. 1345), directed the Agency to develop, propose, and promulgate regulations establishing standards for the use or disposal of sewage sludge. Additional authorizing legislation includes sections of the Clean Air Act, the Resource Conservation and Recovery Act (RCRA), and the Toxic Substances Control Act (TSCA).

In 1979, EPA responded to these mandates and promulgated criteria for using non-hazardous solid wastes, including sewage sludge when it is applied to land or disposed in landfills. These criteria were incorporated into 40 CFR Part 257, Criteria for Classification of Solid Waste Disposal Facilities and Practices, which contained specific requirements for managing sewage sludge. Any use or disposal of sewage sludge that caused the concentration of 10 inorganic and 6 organic chemicals in an underground drinking water source to exceed specified maximum contaminant levels (MCLs) was prohibited. Management standards for using or disposing of sewage sludge were set so that surface waters, flood plains, and endangered species were protected. Part 257 also established annual and cumulative rates (kg/ha) for cadmium and a numerical concentration of polychlorinated biphenyls (PCBs) in sewage sludge and pathogen reduction requirements for sewage sludge applied to land used for the production of animal feed or food-chain crops.

In 1982, the EPA established an Intra-Agency Sludge Task Force to recommend procedures for implementing a comprehensive regulatory program for sewage sludge management. The Task Force recommended that such a regulatory program be developed using the combined authorities of Section 405 of the CWA and other existing regulations so that comprehensive coverage could be provided. Accordingly, a regulation was recommended that would provide technical criteria for the use or disposal of sewage sludge.

The Office of Water Enforcement and Compliance proposed State Sludge Management Program Regulations (U.S. EPA, 1986a). These regulations proposed that states develop management programs that comply with existing federal criteria for the use or disposal of sewage sludge. The proposed State Sludge Management Program Regulations focused on the procedural requirements for submission, review, and approval of state sewage sludge management programs. On March 9, 1988, these regulations were proposed again (U.S. EPA, 1988a) to reflect changes in requirements for sewage sludge management programs imposed by the 1987 Water Quality Act. After public comment, these regulations were promulgated under 40 CFR Part 501 on May 2, 1989.

EPA began the task of preparing a comprehensive sewage sludge regulation in 1979 with the promulgation of 40 CFR Part 257, which included technical criteria. The overall task of completing the comprehensive sewage sludge regulation was transferred to the Office of Water in 1984. A Wastewater Solids Criteria Branch was established under the Office of Water Regulations and Standards (OWRS) within the Office of Water to develop the risk assessment to support the rule. After the Office of Water was reorganized, the OWRS was renamed the Office of Science and Technology (OST), and the Wastewater Solids Criteria Branch was renamed the Sludge Risk Assessment Branch (SRAB). The SRAB developed the Part 503 regulation.

Traditionally, the Agency uses the standards, definitions, and approaches developed under other federal public health and environmental programs when they are consistent with the goals and objectives of the CWA. Such an approach minimizes duplicative, overlapping, and conflicting policies and programs. One principle followed in the Part 503 rule was to base pollutant limits on human health and environmental criteria established under other statutory authorities. Regarding sewage sludge incinerators, two statutes are referenced in the Part 503 rule. The National Ambient Air Quality Standard (NAAQS) for lead (40 CFR Part 50.12), promulgated under authority of the Clean Air Act, was used in developing the pollutant limit for lead when sewage sludge is fired in a sewage sludge incinerator. The National Emission Standards for Hazardous Air Pollutants (NESHAPs) for beryllium and mercury, developed under the authority of the Clean Air Act (40 CFR Part 61), are the pollutant limits for beryllium and mercury in Part 503.

1.2 DESCRIPTION OF PART 503

The Part 503 standards consist of five Subparts. Subpart A contains General Provisions that apply to each of the three sewage sludge use or disposal practices. Subparts B and C pertain to specific requirements for the land application and surface disposal of sewage sludge, respectively, while Subpart D, Pathogens and Vector Attraction Reduction, contains the requirements for pathogenic organisms in sewage sludge and the requirements to reduce the attraction of vectors, such as rodents, flies, and mosquitoes, which are capable of transporting infectious agents. Subpart E contains the requirements for sewage sludge incineration.

This section (Section One) provides an overview of Subpart A, General Provisions, and Subpart E, the sewage sludge incineration requirements. The text of both Subparts appears in full as Appendix A. Although much of the General Provisions section is relevant to all the regulated use or disposal practices, it also contains references that are specific to each practice. This discussion will focus on the general and specific requirements affecting sewage sludge incineration. Where there is overlap between the requirements of these two subparts as they affect sewage sludge incineration, the information will be presented in the General Provisions section.

1.2.1 General Provisions

Subpart A of Part 503, General Provisions, consists of nine basic parts: the purpose and applicability of the regulation; the compliance period; permits and direct enforceability; the relationship to other regulations; additional or more stringent requirements; exclusions; the requirement for a person who prepares sewage sludge; sampling and analysis; and general definitions.

1.2.1.1 Purpose and Applicability

Part 503 establishes standards for the final use or disposal of sewage sludge generated during the treatment of domestic sewage in a treatment works. For sewage sludge fired in a sewage sludge incinerator, the Subpart E consists of general requirements; pollutant limits; an operational standard; management practices; and frequency of monitoring, recordkeeping, and reporting requirements that protect public health from the reasonably anticipated adverse effects of pollutants in sewage sludge. These elements of the standard are discussed in Subpart E, which includes pollutant limits for arsenic, beryllium, cadmium, chromium, lead, mercury, and nickel. Subpart E also includes an operational standard for total hydrocarbons that, in the judgment of EPA's Administrator, protects public health from reasonably anticipated adverse effects of organic pollutants in the exit gas from a sewage sludge incinerator stack. In addition, Subpart E includes frequency of monitoring and recordkeeping requirements, as well as reporting requirements for sewage sludge incinerators considered Class I sludge management facilities and treatment works with flow rates equal to or greater than one million gallons per day or that serve a population of 10,000 people or greater.

As it pertains to sewage sludge incineration, Part 503 applies to the <u>person</u> who prepares sewage sludge; the <u>person</u> who fires sewage sludge in a sewage sludge incinerator; to <u>sewage sludge</u> fired in a sewage sludge incinerator; to the <u>sewage sludge incinerator</u>; and to the <u>exit gas</u> from a sewage sludge incinerator stack.

1.2.1.2 Compliance Period

Compliance with the Part 503 sewage sludge incineration standards has to be achieved as expeditiously as practicable, but in no case later than one year from the date of publication in the *Federal Register*. If compliance with the standards requires construction of new pollution control facilities, compliance has to be achieved within two years from the date of publication in the *Federal Register*, or sooner if practicable.

The frequency of monitoring, recordkeeping, and reporting requirements under Subpart E except total hydrocarbons become effective 120 days after the effective date of the regulation. The frequency of monitoring, recordkeeping, and reporting requirements for total hydrocarbons become effective no later than one year from the date of publication of the Part 503 regulation in the *Federal Register*. If compliance with the operational standard for total hydrocarbons requires construction of new pollution control facilities, these requirements become effective no later than two years from the date of publication of the regulation in the *Federal Register*.

1.2.1.3 Permits and Direct Enforceability

The Part 503 requirements for sewage sludge incineration pertaining to the frequency of monitoring, recordkeeping, and reporting may be implemented through a permit under the following two conditions:

- a permit issued to a "treatment works treating domestic sewage" (TWTDS), as defined in 40 CFR Section 122.2 and in accordance with 40 CFR Parts 122 and 124, either by EPA or by a State that has a state sludge management program approved by EPA in accordance with 40 CFR Part 123 or 40 CFR Part 501.
- a permit issued under the Clean Air Act.

A TWTDS is required to submit a permit application in accordance with either 40 CFR Section 122.21 or an approved state program. The standards in Subpart E are enforceable directly against any person who fires sewage sludge in a sewage sludge incinerator.

1.2.1.4 Relationship to Other Regulations

The last part of Section 1.1 discussed existing statutes pertaining to sewage sludge incineration that are referenced in the Part 503 rule. Subpart A does not include any further stipulations regarding the relationship of the sewage sludge incineration standards to other regulations.

1.2.1.5 Additional or More Stringent Requirements

On a case-by-case basis, the permitting authority (either EPA or a state with an EPA-approved sludge management program) may impose more stringent or additional requirements for the use or disposal of sewage sludge if necessary to protect public health and the environment from an adverse effect of pollutants in sewage sludge. A state, a political subdivision, or an interstate agency also can impose requirements for the use or disposal of sewage sludge that either are more stringent than, or are in addition to, the requirements of Part 503.

1.2.1.6 Exclusions

Exclusions to the Part 503 rule can be classified according to whether they relate directly to sewage sludge incineration or are general to all three use or disposal practices. The two exclusions that are specific to sewage sludge incineration for which the Part 503 rule does not apply are:

- Co-firing of sewage sludge - sewage sludge co-fired in an incinerator with other wastes (excluding auxiliary fuel) or the incinerator in which sewage sludge and other wastes are co-fired.
- Incinerator ash - ash generated during the firing of sewage sludge in a sewage sludge incinerator.

In addition, there are eight exclusions that apply to all three use or disposal practices:

- Treatment processes - processes used to treat domestic sewage or processes used to treat sewage sludge prior to final use or disposal, except as provided in 503.32 and 503.33.
- Selection of a use or disposal practice - the selection of a sewage sludge use or disposal practice. The determination of the manner in which sewage sludge is used or disposed is a local determination.
- Sludge generated at an industrial facility - sludge generated in industrial wastewater treatment works, including sewage sludge generated during the treatment of industrial wastewater combined with domestic sewage. This exemption does not apply to sewage sludge treated separately from industrial waste at an industrial facility.
- Hazardous sewage sludge - sewage sludge determined to be hazardous in accordance with 40 CFR Part 261.
- Sewage sludge with high PCB concentration - sewage sludge that has a concentration of polychlorinated biphenyls (PCBs) equal to or greater than 50 milligrams per kilogram of total solids (dry weight basis).
- Grit and screenings - grit (e.g., sand, gravel, cinders, or other materials with a high specific gravity) or screenings (e.g., relatively large materials such as rags) generated during preliminary treatment of domestic sewage in a treatment works.
- Drinking water treatment sludge - sludge generated during the treatment of either surface water or ground water used for drinking water.
- Commercial and industrial septage - commercial septage or industrial septage, even if mixed with domestic septage.

*1.2.1.7 **Requirement for a Person Who Prepares Sewage Sludge***

A person who prepares sewage sludge that is either fired in a sewage sludge incinerator, applied to the land, or placed on a surface disposal site must meet the applicable requirements of the Part 503 rule.

1.2.1.8 Sampling and Analysis

Representative samples of sewage sludge fired in a sewage sludge incinerator have to be collected and analyzed. Samples of sewage sludge have to be analyzed for inorganic pollutants according to the publication, "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods," U.S. Environmental Protection Agency, 1982 and 1986. (For the specific reference, see the regulation, Section 503.8(b)(4), located in Appendix A of this document.)

1.2.1.9 General and Special Definitions

The following words, phrases, acronyms, and concepts apply to information provided in this sewage sludge incineration technical support document and are defined in Appendix A, either under the General Provisions subpart, Subpart A (503.9) or the Incineration subpart, Subpart E (503.41).

General Definitions (503.9)

Class I sludge management facility
CWA
Dry weight basis
EPA
Permitting Authority
Person who prepares sewage sludge
Pollutant
Pollutant limit
Sewage sludge
Treatment works

Special Definitions (503.41)

Air pollution control device (APCD)
Auxiliary fuel
Control efficiency
Dispersion factor
Fluidized bed furnace (FBF)
Hourly average
Incineration
Monthly average
Risk specific concentration (RSC)
Sewage sludge feed rate
Sewage sludge incinerator
Stack height
Total hydrocarbons
Wet electrostatic precipitator
Wet scrubber

1.2.2 Part 503 Standard

For each sewage sludge use or disposal practice, a number of requirements must be met, including general requirements, pollutant limits, management practices, and an operational standard(s), as well as other requirements related to frequency of monitoring, recordkeeping, and reporting. The information presented below relates directly to sewage sludge fired in a sewage sludge incinerator. Section 1.3, Scope of the Sewage Sludge Incineration Technical Support Document, outlines the sections of the document where more detailed discussions of the Subpart E requirements are presented.

1.2.2.1 General Requirements

No person is permitted to fire sewage sludge in a sewage sludge incinerator unless the requirements of Subpart E are met.

1.2.2.2 Pollutant Limits

Subpart E of Part 503 regulates seven inorganic pollutants, all of which are metals. For five of these metals—arsenic, cadmium, chromium, lead, and nickel—Subpart E requires that site-specific limits on the concentration of the pollutants in the sewage sludge be met. The National Emission Standards for Hazardous Air Pollutants (NESHAPs) for beryllium, if applicable, and mercury (40 CFR Part 61) also be met.

1.2.2.3 Operational Standard

In addition to inorganic pollutants, Subpart E also regulates total hydrocarbons (THC) as a measure of the organic pollutants emitted from a sewage sludge incinerator stack. The limit for THC is a technology-based operational standard, not a risk-based limit, because a methodology for developing a site-specific risk-based approach for THC is not well established.

The regulation requires that the THC concentration in the exit gas be corrected to 7-percent oxygen and for zero percent moisture, and that it be equal to or less than 100 parts per million on a volumetric basis when measured using a flame ionization detector with a heated sampling line. Compliance with the monthly average THC emission limit of 100 ppm is determined by calculating the arithmetic mean of the hourly averages for the hours a sewage sludge incinerator operates during the calendar month. An hourly average is the arithmetic mean of all THC measurements taken during each operating hour with a minimum of two measurements taken during the hour. The THC operational standard is based on an analysis of operating data from several sewage sludge incinerators.

1.2.2.4 Management Practices

Under Subpart E, data used to determine compliance with the pollutant limits and operational standard must be measured and recorded. The regulation requires the use of four instruments to measure and record the following data for each sewage sludge incinerator continuously: the THC concentration in the stack exit gas; the oxygen concentration in the stack gas; information used to determine the moisture content in the stack gas; and combustion temperature. The management practices specify that these instruments be installed, calibrated, operated, and maintained as specified by the permitting authority.

Subpart E also requires that the sampling line to the THC monitor be maintained at a temperature of 150°C or higher and that the THC monitor be calibrated using propane at least once every 24-hour operating period. In addition, the regulation requires that the maximum combustion temperature for a sewage sludge incinerator and the operating parameters for the air pollution control devices (APCDs) be specified by the permitting authority and be based on information obtained during the performance test of the sewage sludge incinerator. A final requirement prohibits the firing of sewage sludge in a sewage sludge incinerator if it would adversely affect a threatened or endangered species listed under Section 4 of the Endangered Species Act or its designated critical habitat. EPA will develop guidance to carry out this provision consistent with the Endangered Species Act.

1.2.2.5 Other Requirements (frequency of monitoring, recordkeeping, and reporting)

Requirements concerning frequency of monitoring, recordkeeping, and reporting also must be met when sewage sludge is fired in a sewage sludge incinerator. The frequency of monitoring for arsenic, cadmium, chromium, lead, and nickel is set by the regulation according to the amount of sewage sludge fired in a sewage sludge incinerator, ranging from once per year to once per month, unless otherwise specified by the permitting authority. The regulation allows the permitting authority to modify the frequency of monitoring for these five pollutants after the sewage sludge is monitored for two years in accordance with Subpart E, as long as the frequency of monitoring is at least once per year. The frequency of monitoring for beryllium and mercury is to be specified by the permitting authority. As stated in Section 1.2.2.4, the regulation also requires the determination of the sewage sludge feed rate and the continuous monitoring of THC, the oxygen concentration, and information used to determine moisture content in the exit gas, as well as maximum combustion temperature. The operating parameters for the sewage sludge incinerator APCD(s) are to be monitored as specified by the permitting authority.

Any person who fires sewage sludge in a sewage sludge incinerator must retain certain data for a period of five years. These data include the concentration of arsenic, cadmium, chromium, lead, and nickel in the sewage sludge; the concentration of THC in the exit gas; information that indicates that the NESHAPs requirements are met for beryllium, if applicable, and mercury; and the sewage sludge feed rate. Other data obtained from the exit gas must also be kept, including the oxygen concentration and information used to measure the moisture content. Subpart E also requires that data be kept on certain characteristics of the sewage sludge incinerator and APCDs, and that a calibration and maintenance log be kept for the instruments measuring THC concentration, oxygen concentration, combustion temperatures, and information needed to determine moisture content in the exit gas.

The reporting requirements under Subpart E pertain to Class I sludge management facilities and treatment works with a flow rate equate to or greater than one million gallons per day (MGD) or that serve a population of 10,000 people or greater. All treatment works operating sewage sludge incinerators are classified as Class I sludge management facilities. These facilities are required to report annually.

1.3 SCOPE OF THE SEWAGE SLUDGE INCINERATION TECHNICAL SUPPORT DOCUMENT

This document consists of nine sections, including this introduction. The next section, Section Two, provides an overview of incineration technologies, including current furnace technologies and APCDs. Section Three is a summary of EPA risk assessment methodology, which is the basis for the development of limits on the concentration of five of the inorganic pollutants in sewage sludge. In Section Four, the process by which EPA selected the eight pollutants for regulation under Subpart E is presented.

Section Five provides a detailed discussion of the limits for the seven inorganic pollutants and begins with an overview explaining the different origins of the limits for all eight pollutants. This section contains the factors EPA used to develop the risk assessment methodology and provides several examples of calculations to better explain how the pollutant limits are derived. The operational standard for THC is described in Section Six and includes the basis for the standard, as well as the assessment used to judge whether the operational standard protects public health.

Section Seven provides more detail on the management practices required under Subpart E, while Section Eight presents the frequency of monitoring, recordkeeping, and reporting requirements. References appear in Section Nine and 14 appendices are provided as supporting material. Appendix A consists of the text of Part 503, Subpart A and Subpart E. Appendix B lists the current sewage sludge incinerators subject to Part 503. Appendix C provides data on the ratio of hexavalent chromium to total chromium measured during tests of sewage sludge incinerator emissions. Appendix D summarizes data from nickel speciation tests at three sewage sludge incinerators. In Appendix E, general guidelines on conducting a performance test at a sewage sludge incinerator are provided for determining a unit's control efficiency, while Appendix F provides emissions data for THC, carbon monoxide, and 21 organics from four sewage sludge incinerators.

Appendix G describes the statistical basis for the THC operational standard and Appendix H explains the estimated difference between THC measurements taken with a heated (hot) monitor and those taken with an unheated (cold) monitor. In Appendix I, a table is provided for the molecular weights and response factors for organic compounds used to develop the cancer potency value (q_1^*) for THC. Appendix J presents an extensive table of calculations that derives site-specific risk-specific concentrations and risk levels at 23 sewage sludge incinerators listed in the National Sewage Sludge Survey.

In Appendix K, a table is provided to support the evaluation of the risk posed by the THC standard. The table shows the weighted q_1^* values for over 100 carcinogenic and noncarcinogenic organics used in development of the THC q_1^*. Appendix L provides emissions data for organic compounds that were used to derive the q_1^* for THC. The next appendix, Appendix M, provides summary details on performance indicator parameters for APCDs. Finally, in Appendix N, the calculation used to derive the frequency of monitoring requirement at sewage sludge incinerators is presented.

SECTION TWO

SEWAGE SLUDGE INCINERATION TECHNOLOGY

This section describes the major sewage sludge incinerator technologies currently used in the United States. The section begins with a brief description of sewage sludge incineration. Section 2.2 discusses the design characteristics and operating conditions of the three main incinerator furnace technologies: multiple-hearth furnaces, fluidized-bed furnaces, and electric infrared furnaces. The final part, Section 2.3, describes a variety of air pollution control devices (APCDs), including wet scrubbers, electrostatic precipitators, fabric filters, and afterburners. that are installed in incinerators to further combust organic material or to remove particulates and associated metals from the exhaust gas.

2.1 DESCRIPTION OF SEWAGE SLUDGE INCINERATION

Sewage sludge incineration is the combustion of organic matter and inorganic matter in sewage sludge and auxiliary fuel by high temperatures in an enclosed device. Incineration is a practice through which about 16 percent of the sewage sludge generated annually in the United States is disposed. In 1988, EPA began to update data on sewage sludge incinerators as part of the National Sewage Sludge Survey (NSSS). Completed in September 1989, the survey data base revealed that, in 1988, approximately 0.7 million dry metric tons (dmt) per year of sewage sludge were fired in sewage sludge incinerators operated by an estimated 150 publicly owned treatment works (POTWs) across the country, with some of these POTWs operating more than one incinerator unit. This sewage sludge quantity includes sewage sludge transferred to these POTWs by an estimated 178 additional POTWs, but excludes sewage sludge that is co-incinerated in municipal solid waste combustors.

2.2 CURRENT FURNACE TECHNOLOGY

The three major furnace technologies currently used in the United States to fire sewage sludge are listed below. Based on the NSSS, an estimated 207 sewage sludge incinerator units installed in the estimated 150 onsite POTWs firing sewage sludge were of the following types (see Appendix B for a list of sewage sludge incinerator units currently subject to Part 503):

- 156 multiple-hearth furnaces (MHFs) (75 percent of the incinerators firing sewage sludge)
- 49 fluidized-bed furnaces (FBFs) (24 percent of the incinerators firing sewage sludge)
- 2 electric infrared furnaces (1 percent of the incinerators firing sewage sludge)

Although three-quarters of the operating sewage sludge incinerators are estimated to be multiple-hearths, newly installed sewage sludge incinerators are divided evenly between the fluidized-bed and multiple-hearth varieties. Regardless of incinerator type, a main factor involved in combustion efficiency is the water content of the sewage sludge. To increase the efficiency of the combustion process, treatment works operators remove enough water from the sewage sludge mechanically to bring its solids content to at least 25 to 35 percent through a series of dewatering steps involving filtration and centrifugation systems. Most treatment works also add a chemical conditioner to the sewage sludge, which acts as a dewatering agent. While ferric chloride and lime were used most often in the past, operators are now finding that organic polymers act as better dewatering agents.

By increasing the heating value of the sewage sludge, dewatering decreases the need for auxiliary fuel and thus reduces operating costs. For typical multiple-hearth furnaces, a sewage sludge solids content of 35 percent or greater can result in an idealized condition known as autogenous combustion. Theoretically, combustion can become self-sustaining (or "autogenous") so that no auxiliary fuel needs to be added. This condition can occur when sewage sludge is burned that has a combustible solids fraction with a heating value of at least 5.54 Kcal/g, a solids content of 30 percent or greater, and a volatile solids fraction of at least 60 to 65 percent. In practice, however, few MHFs are operated autogenously. Most of these units use various quantities of auxiliary fuel. In modern fluidized-bed furnaces, an autogenous condition can be reached at a lower solids content.

2.2.1 Multiple-Hearth Furnaces

Multiple-hearth furnaces (MHFs) were initially designed nearly a century ago for baking mineral ores in the metals extraction industry. Since the 1930s, an air-cooled variant of the original Herreshoff design has been used to fire sewage sludges.

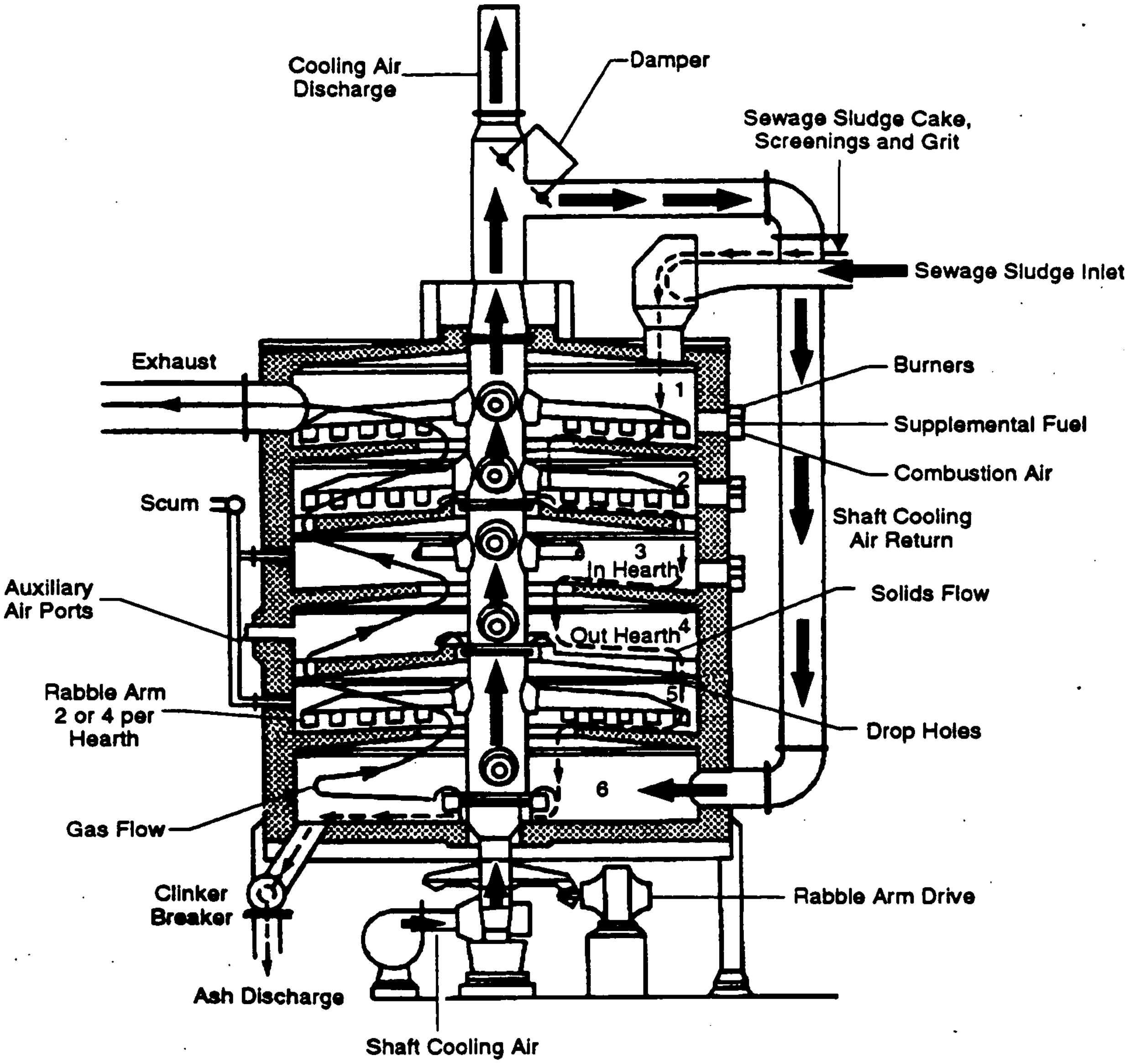
2.2.1.1 Design Characteristics

MHFs are cylindrically shaped and oriented vertically. Those used to fire sewage sludge range in size from an outer diameter of approximately 1.8 meters with a total effective hearth area of 7.9 square meters (m^2) (6-hearth furnaces) to 6.7 meters in diameter with hearth areas of over 280 m^2 (12-hearth furnaces). Hearth loading rates range from 7 to 12 wet $lb/hr/ft^2$ of hearth area. This amount corresponds to furnace capacities of 0.3 tons/hr up to 18 tons/hr of wet sewage sludge.

Figure 2-1 illustrates the overall design of a typical MHF unit. The outer shell is constructed of steel and surrounds a series of horizontal refractory hearths. A hollow cast-iron rotating shaft runs through the center of the hearths. A fan located at the base of the shaft introduces cool air into the shaft and rabble arms to keep the metal from deforming under the high temperatures.

The rabble arms are attached to the central shaft and extend above the hearths. Attached to the rabble arms are angled plows less than a meter in length that rake the sewage sludge in a spiral motion. The plows alternate direction between hearths. If the plows in one hearth are angled from the outside in, those in the next hearth are then angled from the inside out. Burners that provide auxiliary fuel are located in the sidewalls of the hearths.

Figure 2-1. Cross-Section of a Multiple-Hearth Furnace



2.2.1.2 Operating Conditions

In MHFs, partially dewatered sewage sludge (25 to 35 percent solids) is fed into the periphery of the top hearth. Next, the rabble arms rake the sewage sludge toward the center shaft and break up the solid material so that a larger amount of surface area comes in contact with heat and oxygen. The dried sewage sludge then drops through holes located near the edge of the hearth into the second hearth, where it is raked in the opposite direction. This process is repeated in all subsequent hearths as the sewage sludge particles are dried and burned continuously. The remaining dry ash is discharged through a hole at the periphery of the bottommost hearth, where it is collected for disposal.

Ambient air is blown through the central shaft at its base and rises into the rabble arms, cooling the shaft. A portion, or all, of this air is then recirculated from the top of the shaft back into the lowermost hearth as preheated combustion air. Air that is not recirculated is discharged through the top of the burner into the stack downstream of the APCDs. In addition, ambient air is also injected directly into one of the middle hearths. The air in the combustion chamber flows upward through the drop holes in the hearths, counter-current to the flow of the sewage sludge particles.

The overall sewage sludge incineration process occurs within three basic zones in an MHF. The upper hearths constitute the drying zone, where most of the moisture in the sewage sludge is evaporated. During the drying process, the sewage sludge temperature rises from 427°C to 760°C. Combustion occurs in the middle hearths, or combustion zone, as the temperature is increased to about 815°C to 870°C. The combustion zone can be further subdivided into the upper-middle hearths, where the volatile gases and solids are burned, and the lower-middle hearths, where most of the fixed carbon is combusted. The third zone, comprising the lowermost hearth(s), is the cooling zone. In this zone, the ash is cooled as its heat is transferred to the incoming combustion air.

Under optimal operating conditions in an MHF, 50 to 100 percent "excess air" must be added to ensure complete combustion of the sewage sludge. The theoretical amount of oxygen required for complete combustion is known as the stoichiometric or theoretical oxygen. Specific stoichiometric oxygen requirements are determined by the nature and quantity of the combustible material to be burned. Combustion oxygen usually is obtained from atmospheric air. The additional oxygen (or air) available for combustion over and above the stoichiometric amount is called excess air. Adding excess air enhances contact between the fuel and oxygen in the furnace and compensates for normal variations in both the organic characteristics of the sewage sludge and the feed rate at which the sewage sludge enters the incinerator.

When the amount of oxygen (or air) is less than the stoichiometric amount, it is called starved air, or substoichiometric air. Under starved-air conditions, incomplete combustion occurs, which results in the production of carbon monoxide (CO) and products of incomplete combustion (PICs). The formation of these combustion products is characterized by the release of smoky emissions containing unburned hydrocarbons and volatiles. Too much excess air, on the other hand, results in lower temperatures, consumption of more auxiliary fuel, more entrainment of particulates, and lower efficiency.

The rate at which the dried sewage sludge is fed into the hearths and the sewage sludge moisture content also can affect the performance of multiple-hearth sewage sludge incinerators. A sharp increase in the feed rate generally causes the middle combustion zone to drop to lower hearths, a change that can lead to a decrease in temperature within the combustion zone and high auxiliary fuel usage. Conversely, a sudden decrease in the feed rate to the furnace can cause excessively high temperatures in the furnace with the attendant risk of damage to the refractory and rabble castings. The moisture content of the sewage sludge also must be kept relatively constant for the same reasons. A sharp increase in moisture content can lead to reduced hearth temperatures, while material that is too dry may cause overly high temperatures.

One problem resulting from excessively high temperatures in the combustion zone is the formation of clinkers, or clumps of ash, that can break teeth and rabble arms and increase maintenance requirements. As treatment works move from the use of ferric chloride/lime conditioners to organic polymers, however, clinkers will become less of a problem.

For optimum performance, the temperature profile within the furnace should be controlled by adjusting the firing rate of the burners. Ideally, only those burners located immediately above and below the combustion zone should be used, depending on the number of hearths and the capacities of the available burners. This arrangement allows longer residence times for the sewage sludge in the drying zone and can decrease turbulence in the upper hearths.

2.2.2 Fluidized-Bed Furnaces

In fluidized-bed furnaces (FBFs), air and sewage sludge are introduced from different locations into a bed of sand at the base of a furnace, causing a turbulent mixing, or fluidizing effect. The mixture of air, sewage sludge, and sand acts as a fluid in the furnace, enhancing combustion. Fluidizing the sewage sludge has a number of advantages that help to improve the burning atmosphere within the incinerator. First, the turbulence in the bed facilitates the transfer of heat from the hot sand particles to the sewage sludge. Second, nearly ideal mixing is achieved between the sewage sludge and the combustion air as a result of the greatly increased surface area. Third, the sand provides a relatively uniform source of heat within the bed.

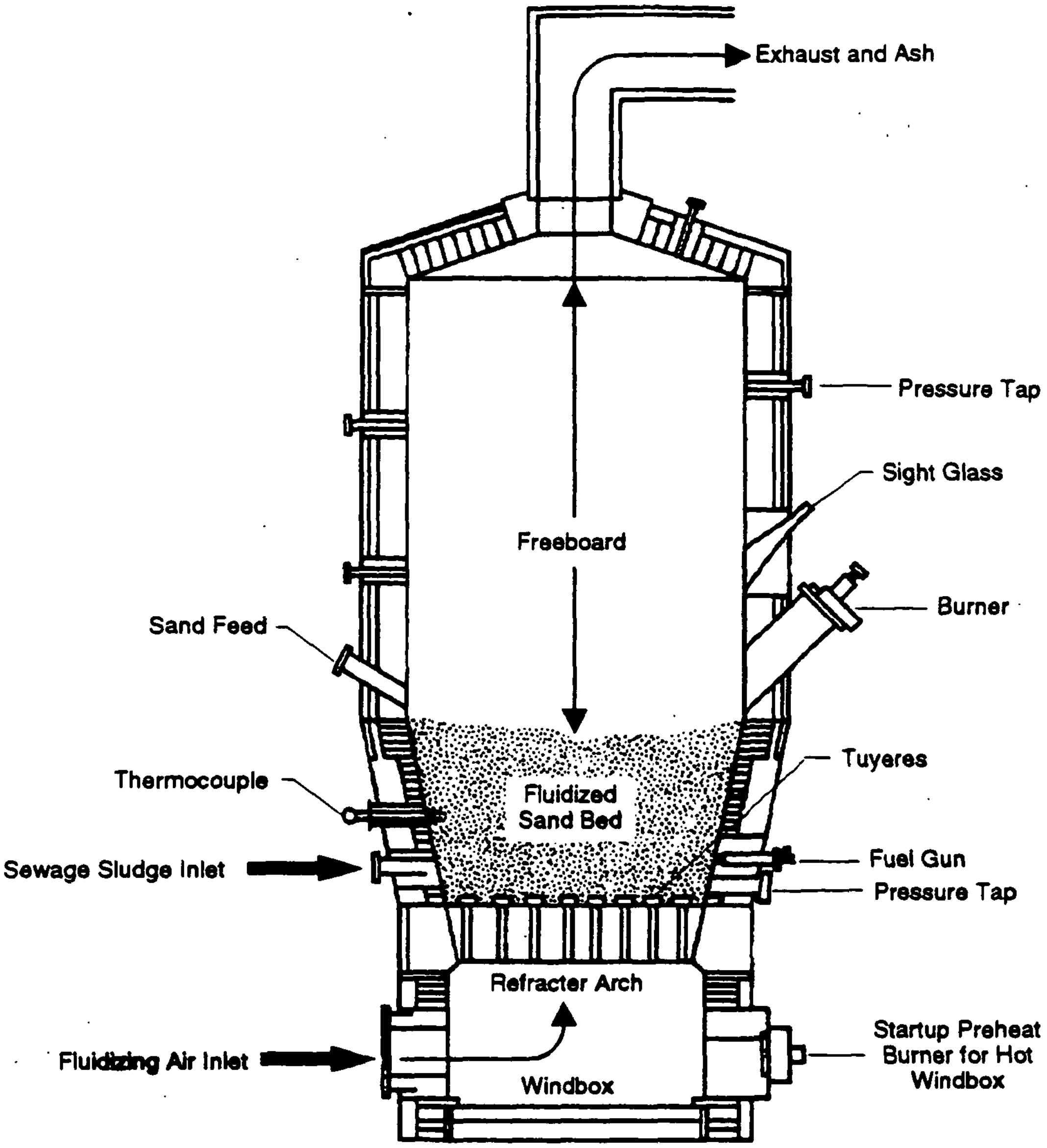
FBFs have been applied to a wide range of industrial processes since its initial development in the oil-refining industry. Coal-drying and calcining operations in the phosphate industry are two other examples of industrial applications of fluidized-bed technology. The first fluidized-bed reactor designed specifically for firing sewage sludge was installed in 1961 in Lynwood, Washington.

2.2.2.1 Design Characteristics

Figure 2-2 depicts a cross-section of a typical FBF. Like multiple-hearth furnaces, FBFs are cylindrically shaped and vertically oriented. The outer shell is constructed of steel and is lined with refractory material. Tuyere nozzles, which blast air into the furnace, are located at the base of the furnace within a refractory-lined arch.

There are two general FBF configurations, each based on the method used to inject the fluidizing air into the furnace. In the "hot-windbox" design (shown in Figure 2-2), air is first

Figure 2-2. Cross-Section of a Fluidized-Bed Furnace



passed through a heat exchanger, where heat is recovered from the hot flue gases. Alternatively, in the "cold-windbox" design, ambient-temperature air is injected directly into the furnace.

The diameter of FBF units is comparable to that for MHFs, ranging from 1.8 to 7.6 meters. FBFs have sewage sludge loading rates ranging from 30 to 60 wet lb/hr/ft^2 of bed and burning capacities ranging from 0.5 to 15 tons/hr of wet sewage sludge.

2.2.2.2 Operating Conditions

Partially dewatered sewage sludge is fed into a bed of hot sand in the lower portion of the furnace. The sand and incoming sewage sludge are simultaneously fluidized by air injected through the tuyere nozzles at pressures ranging from 21 to 34 kilopascals (kPa) (3 to 5 pounds per square inch, lb/in^2) while temperatures of 760°C to 925°C are maintained in the bed. Gas residence times in the freeboard range from 2 to 5 seconds. As the sewage sludge is fired, fine ash particles and minor amounts of sand are carried out through the top of the furnace, where they are captured by a wet scrubbing system. (Refer to Section 2.3.1 for more information on wet scrubbers.)

The overall combustion process in an FBF occurs in two zones. The first zone is within the fluidized bed itself. Here, water evaporation and pyrolysis of organic materials occur almost simultaneously, as the temperature of the sewage sludge is rapidly increased. The freeboard area (see Figure 2-2) is considered to be the second zone, which functions essentially as an afterburner (see Section 2.3.4), where the remaining free carbon and combustible gases are burned.

The most noticeable impact of the improved burning atmosphere provided by an FBF, as compared to the atmosphere provided by other furnace technologies, is the decrease in the amount of excess air required for complete combustion of the sewage sludge. FBFs can achieve complete combustion of sewage sludge with 20 to 50 percent excess air, which is about half the amount of excess air typically required for firing sewage sludge in MHFs. As a result, FBF units generally have lower fuel requirements than MHF units.

The most critical operating variable of FBF units is the rate at which the sewage sludge is fed to the incinerator. The optimal rate of heat transfer achievable for a given quantity of sand is reached when the sewage sludge feed rate is equal to the burning capacity of the sand bed. If the burning capacity is exceeded because of a sewage sludge feed rate that is too high, combustion will not be complete. Similarly, a rapid increase in either the overall furnace load or the total sewage sludge moisture content causes the sewage sludge to coagulate into heavy masses, eliminating the fluidized nature of the bed and halting combustion. To avoid these negative consequences, it is important to ensure that an adequate residence time is maintained so that the sewage sludge burns completely.

Because of excellent mixing characteristics, as well as short sewage sludge residence times, fluidized-bed furnaces are less vulnerable than MHFs are to fluctuations in the sewage sludge feed rate and the total moisture content of the sewage sludge fed to the furnace. Moreover, any disruption of combustion that does occur happens almost immediately and, therefore, can be more easily detected and corrected by the furnace operators.

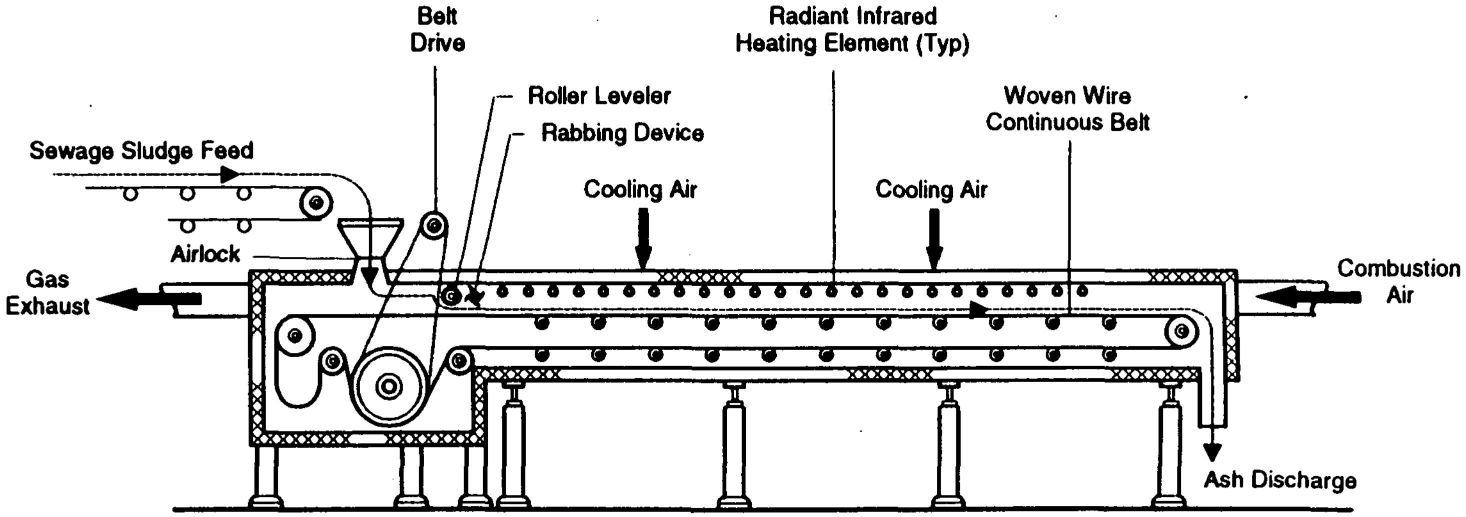
2.2.3 Electric Infrared Furnaces

The electric furnace, which uses infrared radiation as a partial heat source, represents a relatively new technological approach to sewage sludge incineration. The first such unit was put into operation in Richardson, Texas, in 1975. Since that time, a number of installations have been constructed.

2.2.3.1 Design Characteristics

Electric furnaces, unlike the other two furnace designs, are horizontally oriented and consist of insulated enclosures through which sewage sludge is transported on a continuous, woven, wire-mesh conveyor belt (see Figure 2-3). The belt is made of steel alloy and can withstand the 925°C temperatures encountered in the furnaces. The refractory lining in the furnace is composed of ceramic felt, not brick. Because the refractory has a low capacity for

Figure 2-3. Cross-Section of an Electric Infrared Furnace



holding heat, it can be started from a cold condition relatively quickly, as well as shut down quickly.

2.2.3.2 Operating Conditions

In electric furnaces, dewatered sewage sludge is first fed into a holding tank, then into the main unit through a feed hopper and dropped onto the conveyor belt. Here, it is leveled by an internal roller into a layer approximately 1 inch thick, spanning the width of the belt. The sewage sludge layer then moves under infrared heating elements, which sustain the drying and incineration processes. The resulting ash is discharged from the end of the furnace into the ash-handling system.

Combustion air is introduced at the end of the belt as the ash is discharged and is often preheated with an external recuperative-exhaust heat exchanger. The air also picks up heat from the hot burning sewage sludge as the sewage sludge and air travel counter-current to one another.

Because the primary heat-transfer mechanism used in the infrared furnace is radiant transfer, satisfactory combustion rates can be achieved without rabbling or plowing the sewage sludge layer. Thus, compared to MHFs and FBFs, electric furnaces minimize fly ash generation and more easily control particulate emissions.

In addition, complete combustion can be achieved in the electric infrared furnace with excess air levels as low as 10 to 20 percent. This process efficiency is attributed to several factors. First, the furnace is designed so that uncontrolled sources of excess air are eliminated. Second, the flow of combustion air is regulated closely and directed down the channel formed inside the primary combustion chamber between the belt and the heating elements overhead. Third, the addition of supplemental heat does not generate any gaseous by-products, which ordinarily dilute the supply of combustion air. This ability to operate at low excess air levels contributes to a further reduction in the size, complexity, and energy requirements of the exhaust gas scrubbing equipment used with electric infrared furnaces.

The electric furnace is divided into several temperature control zones. These zones are maintained at predetermined temperatures by closed-loop control. Thermocouples sense the temperatures and compare these temperatures with set points. The input power to the infrared heating elements is then adjusted upward or downward, accordingly. Control temperatures range from 760°C in the drying zones to 925°C in the combustion zones.

The flow of air for sewage sludge combustion is also controlled by a closed-loop process. The residual oxygen content in the exhaust stream is sensed continuously and compared with a set point value. In the event that a high-energy sewage sludge is being processed, additional excess air can be used to limit exhaust temperatures to the 650°C to 760°C range. To accommodate different sewage sludge feeds (e.g., sewage sludges with different moisture contents or volatile solids contents), the throughput of the system can be controlled by adjusting the speed of the internal conveyor belt. This adjustment is accomplished from the control panel and is often used to adjust sewage sludge retention time.

To date, infrared furnaces have been used in smaller applications, for which the greater operating flexibility of this type of furnace provides an advantage over traditionally larger multiple-hearth and fluidized-bed furnaces. Because of its ceramic-fiber blanket insulation system, the infrared furnace is well-suited for intermittent operation. This insulation system is not subject to the slow warm-up and cool-down thermal cycling requirements associated with the traditional types of solid refractory materials. Start-up times of 1 to 1-½ hours are normal, and shutdown is accomplished by pressing a single "system stop" button. In addition, the furnace can be left unattended until it is restarted.

2.3 AIR POLLUTION CONTROL DEVICES

Many different methods are used to combust organic pollutants and remove particulates and their associated metals from sewage sludge incinerator exit gas. APCDs used for the removal of metals include wet scrubbers, dry and wet electrostatic precipitators, and fabric filters, while afterburners are usually installed to combust organic vapors. Table 2-1 presents a distribution of the types of APCDs installed on each type of furnace. The data are estimates

TABLE 2-1

AIR POLLUTION CONTROL DEVICES BY FURNACE TYPE

Type of Pollution Control	Electric Furnace	Fluidized Bed	Multiple Hearth	Total Number of Air Pollution Control Devices
Baghouse or Fabric Filter	0	0	2	2
Dry Electrostatic Precipitator	0	0	0	0
Wet Electrostatic Precipitator	0	0	2	2
Dry Cyclone	0	5	19	24
Impinger	0	5	60	65
Spray Chamber	2	26	50	78
Venturi	2	16	37	55
Venturi/Impinger	0	14	49	63
Venturi/Packed Tower	0	7	6	13
Wet Cyclone	0	0	12	12
Wet Cyclone/Impinger	0	2	13	15
Afterburner with Heat Exchanger	0	5	21	26
Afterburner without Heat Exchanger	0	0	22	22
Total Number of Air Pollution Control Devices by Furnace Type	4	80	293	377*

Source: Estimates based on the 1988 National Sewage Sludge Survey, EPA.

*The 377 air pollution control devices listed in this table are installed on an estimated 207 sewage sludge incinerators, which are distributed by the National Sewage Sludge Survey across the following incinerator types: 156 multiple-hearth furnaces, 49 fluidized-bed furnaces, and 2 electric furnaces.

based on the 1988 National Sewage Sludge Survey. This section describes the types of APCDs available for sewage sludge incinerators.

2.3.1 Wet Scrubbers

Historically, wet scrubbers have been the predominant APCD installed in sewage sludge incinerators, as Table 2-1 indicates. One reason for the widespread use of wet scrubbers is that the effluent from a treatment works provides a relatively inexpensive source of scrubber water. Also, a system for treating the scrubber effluent is readily available in that scrubber water can be fed back into the treatment works for solids removal. Another reason for the popularity of wet scrubbers is that they have a long history of success in meeting pollution control standards for particulate matter.

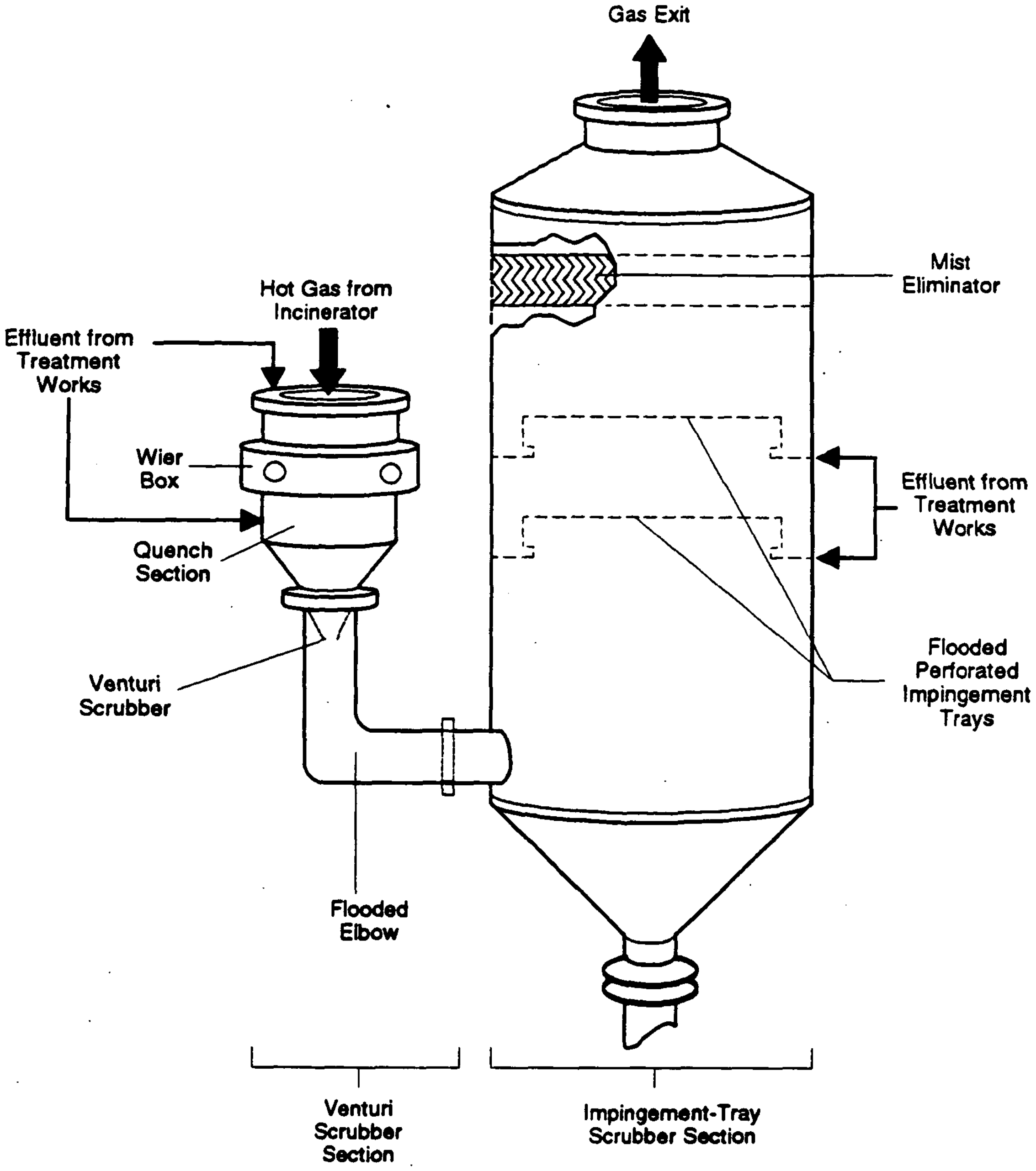
The wet scrubbers listed in Table 2-1 can be grouped into three main categories: venturi scrubbers, spray chambers, and cyclone separators. These scrubbers are most efficient at removing larger particulates. Current air pollution control laws, however, require the removal of finer particulates. These more stringent requirements have increased the interest in, and the application of, electrostatic precipitator and fabric filter technologies.

The wide variety of wet scrubber controls listed in the table range from low-pressure-drop spray chambers and wet cyclones, where the pressure drops range from 995 to 2,240 pascals (4 to 9 inches of water), to higher-pressure-drop venturi scrubbers and venturi/impingement-tray scrubbers, with pressure drops from 2,990 to 9,955 pascals (12 to 40 inches of water). Higher pressure drops will result in more efficient removal of particulate matter.

2.3.1.1 Venturi/Impingement-Tray Scrubbers

Figure 2-4 presents a simplified diagram of a typical venturi/impingement-tray scrubber. As the figure shows, hot gas that exits from the incinerator enters the precooling or quench section of the scrubber. Spray nozzles in the quench section cool the incoming gas with

Figure 2-4. Venturi/Impingement-Tray Scrubber



treatment works effluent. The quenched gas then enters the venturi section of the control device.

Wastewater is usually pumped into the venturi system through an inlet weir above the quencher, entering the scrubber above the throat. This process floods the throat completely to eliminate buildup of solids and reduce abrasion. Turbulence created by high gas velocity in the converging throat section deflects some of the water traveling down the throat into the gas stream.

The venturi breaks up the water into tiny particles. Particulate matter carried along with the gas stream collides with these water particles and the water wall. The particulates become engulfed in the water particles and gain mass. Then, when the scrubber water and flue gas leave the venturi section, they pass into a flooded elbow, where the decreasing velocity of the water and gas stream allows the particulates to settle out.

Most venturi sections come equipped with variable throats. By restricting the throat area within the venturi, the linear gas velocity is increased and, subsequently, the pressure drop is also increased. Up to a certain point, increasing the venturi pressure drop also increases the removal efficiency of the system. Increasing the pressure drop, however, also substantially increases the power requirements of the incinerator fans.

At the base of the flooded elbow, the gas stream passes through a connecting duct to the base of the impingement-tray tower, which usually contains from one to four perforated trays. The gas stream enters the tower and passes upward through the impingement trays. The large diameter of the tower reduces the gas velocity significantly. Effluent from the treatment works usually enters the trays from inlet ports on opposite sides and flows across the tray. As gas passes through each perforation in the tray, it creates a jet that bubbles up through the water and further entrains solid particles. A mist eliminator, located at the top of the tower, reduces the carryover of water droplets in the stack effluent gas.

2.3.1.2 Spray Chamber

The spray chamber scrubber is a round or rectangular chamber into which water is introduced by spray nozzles. There are three different spray chamber configurations by which the water is sprayed onto the sewage sludge: concurrent flow, countercurrent flow, and cross flow. Spray scrubbers can collect both particulate matter and gaseous pollutants, although the collection efficiency for fine particles is low. Figure 2-5 shows a simple countercurrent-flow spray chamber scrubber.

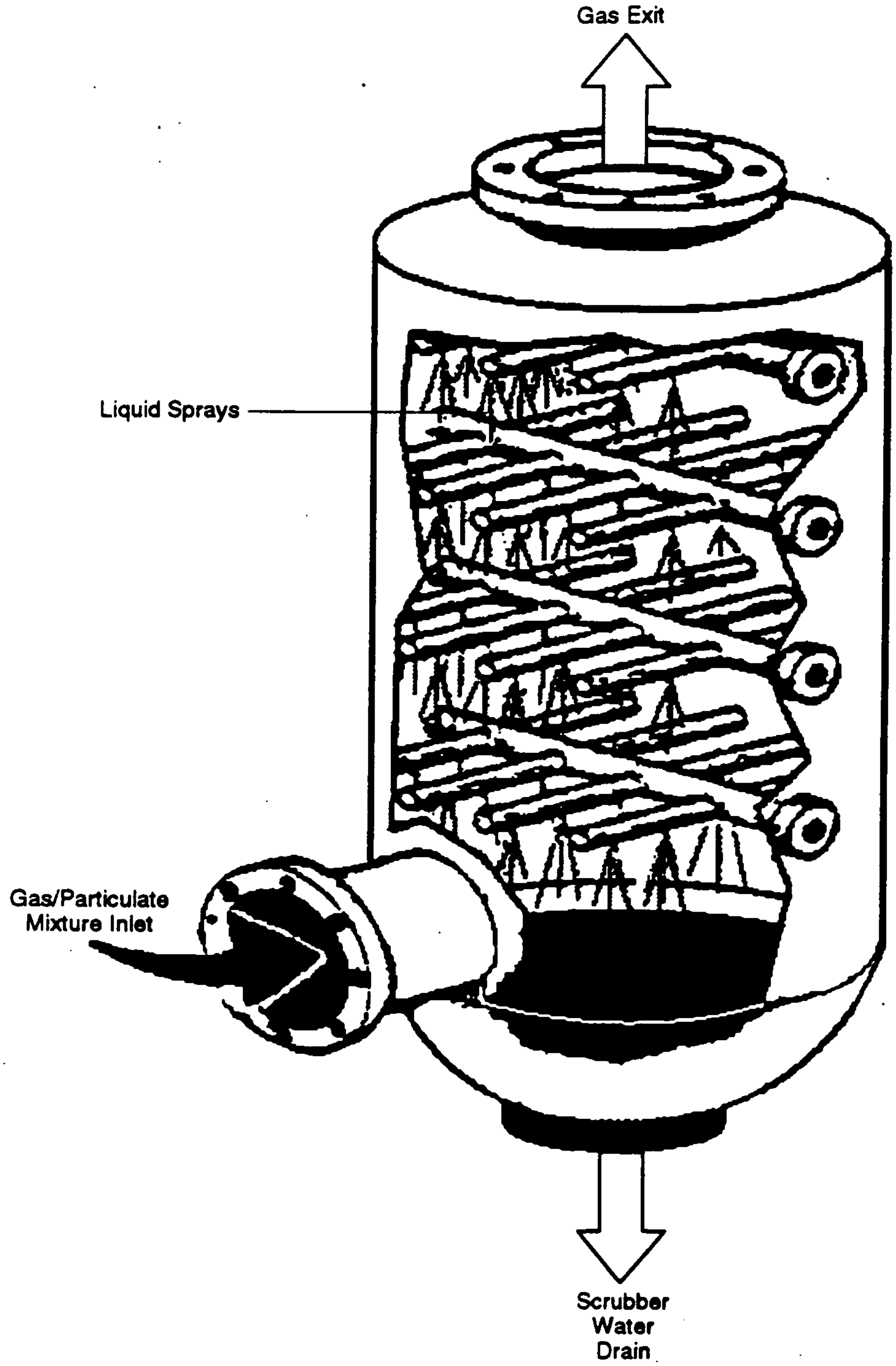
In the spray-tower system, the fluid is sprayed into the enclosure by a series of nozzles located at the top of the chamber, while the gas/particulate mixture enters the bottom of the chamber. As the gas rises, it encounters the falling drops, which remove the particulates by impingement. The scrubber water containing the particulates drains out the bottom of the scrubber.

2.3.1.3 Cyclone Separator

In general, cyclone separators are effective precollectors for removing large-size particulates from effluent gases, especially from fluidized-bed furnaces. Smaller diameter cyclones have better removal efficiencies than those with larger diameters because they spin the gas at a higher velocity. Cyclones are typically combined with other particulate removal devices, such as an electrostatic precipitator or a wet scrubber, which are more effective in eliminating the finer particulates from the system.

A cyclone separator is a vertical cylindrical chamber that takes advantage of the differences in densities of the gas stream and particulate matter. The particulate-laden exhaust gases enter the cyclone tangentially and swirl at high velocity. This high-rotational speed causes centrifugal action to force the particulates to the outside of the chamber where friction with the wall of the cyclone causes them to reduce speed and drop vertically to the discharge area at the

Figure 2-5. Countercurrent-flow Spray Chamber Scrubber



bottom of the chamber. Figure 2-6 depicts the circular path that the particulate matter takes before exiting at the bottom of the cyclone (WPCF 1988).

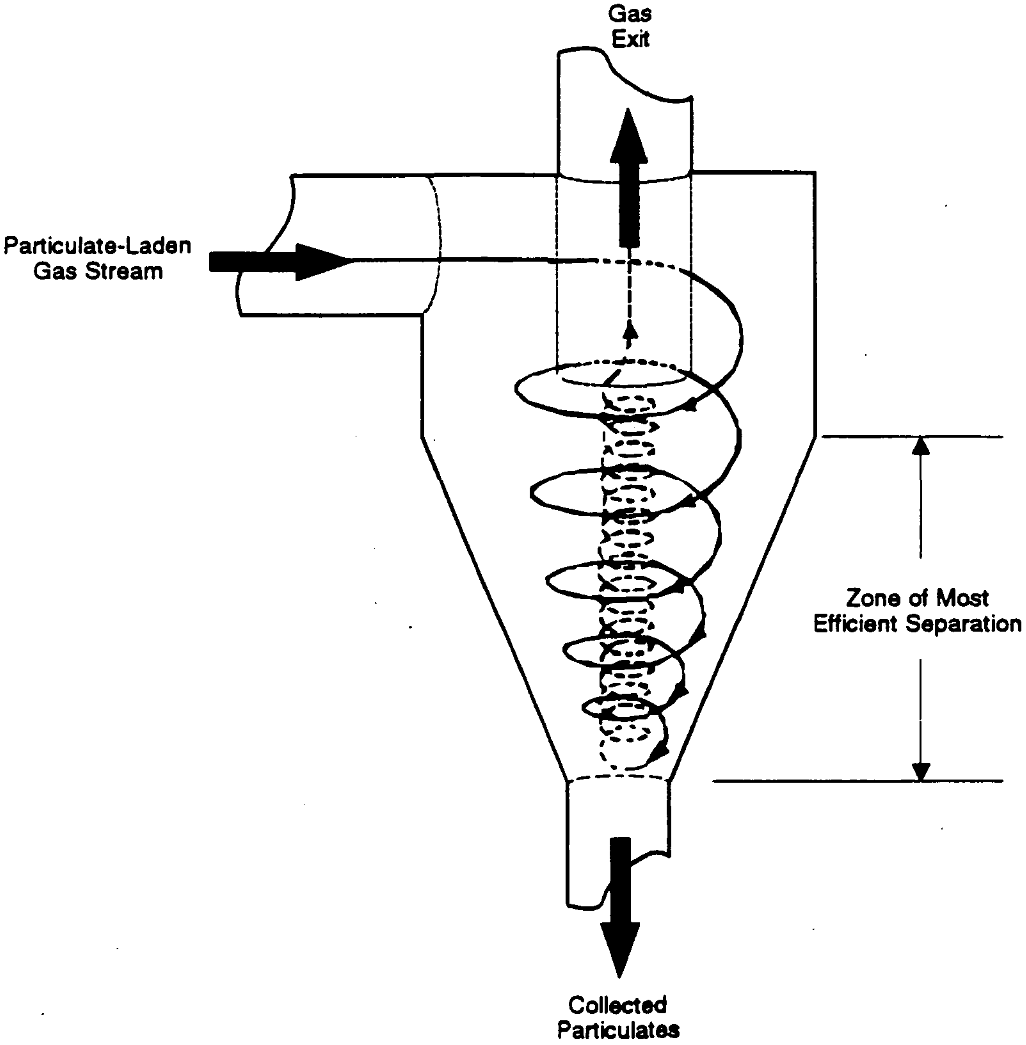
There are basically two types of cyclone separators: large-diameter, low-efficiency cyclones and small-diameter, high-efficiency multitube cyclones. Large cyclones have lower collection efficiencies, especially for particle sizes less than 30 microns (μ), but have a lower initial cost. They usually operate at a pressure drop of 250 to 750 pascals (1 to 3 inches of water). The small-diameter multitube cyclones, however, are capable of eliminating more than 90 percent of particles greater than 10 μ and usually operate at a pressure drop of 750 to 1,250 pascals (3 to 5 inches of water), although the cost of operating this type of system is higher. Historically, smaller diameter systems are also more susceptible to plugging, erosion, and air leakage.

The degree of emission control exhibited by cyclone separators depends on the noncombustible content of the sewage sludge and the sewage sludge incinerator capacity. In general, cyclones have a low efficiency for reducing visible emissions and odors because of their limited capability of removing finer particulates and gaseous contaminants. However, compared to more sophisticated devices that remove similar-sized particulates, cyclone separators require less intensive capital investment.

2.3.2 Electrostatic Precipitators (ESPs)

Electrostatic precipitation is a process by which particles suspended in a gas are electrically charged and separated from the gas stream under the action of an electric field. In this process, negatively charged gas ions are formed between emitting and collecting electrodes by applying a sufficiently high voltage to the emitting electrodes to produce a corona discharge. Suspended particulate matter becomes charged as a result of being bombarded by the gaseous ions, then migrates toward the grounded collecting plates because of electrostatic forces. The particle charge is neutralized at the collecting electrode, where subsequent removal of the particles occurs.

Figure 2-6. Cyclone Separator - Double Vortex Path of the Gas Stream



There are two basic types of electrostatic precipitators (ESPs): dry ESPs and wet ESPs (WESPs). Both types are used with scrubbers to increase the removal of metals bound in the particulates emitted by sewage sludge incinerator units. Whereas scrubbers remove the larger particulates, ESPs remove the finer material.

Because existing sewage sludge incinerators are almost exclusively equipped with wet scrubbers, WESPs are more compatible with the wet environment created by wet scrubbers than are dry ESPs. Dry ESPs tend to develop corrosion problems from the condensation that forms in the system as the air passes from the wet scrubber into the dry ESP. WESPs are also favored for existing sewage sludge incinerators because they are more compact and can be retrofitted easily into an existing system configuration. For newly constructed sewage sludge incinerators, however, dry ESPs might be a preferred option.

2.3.2.1 Dry Electrostatic Precipitators

In the United States, dry ESPs have been used widely in applications such as utility boilers and municipal and industrial incinerators. In some European facilities, they are used on sewage sludge incinerators. In a dry ESP, the exhaust gases pass through a large chamber, where electrodes impart a negative charge to the particulate matter in the exhaust gas stream. Parallel with the flow of gases through the chamber are plates with a positive electrical charge, which attract the negatively charged particulate matter. Periodically, the buildup of particulate matter on the plates is removed by rapping the plates, which causes the particulate matter to fall to the bottom of the chamber, where it is removed (WPCF 1988).

Compared to wet scrubbers, dry ESPs generally provide higher removal efficiencies for particles smaller than one μ in diameter. Also, pressure and temperature drops across dry ESPs are very small compared to those of wet scrubbers, resulting in lower energy demand. The pressure drop across a dry ESP is typically below 249 pascals (1 inch of water), whereas wet scrubbers often operate with pressure drops of up to 14,940 pascals (60 inches of water). Dry ESPs generally can withstand a maximum temperature of 370°C and often are placed downstream of waste heat boilers, where gas temperatures of 250°C to 370°C are encountered.

In dry ESPs, the particulates that cling to the collecting plates are removed by periodically tapping the plates. The collection plates typically carry a static voltage of 30 to 75 kilowatts (kW).

2.3.2.2 Wet Electrostatic Precipitators

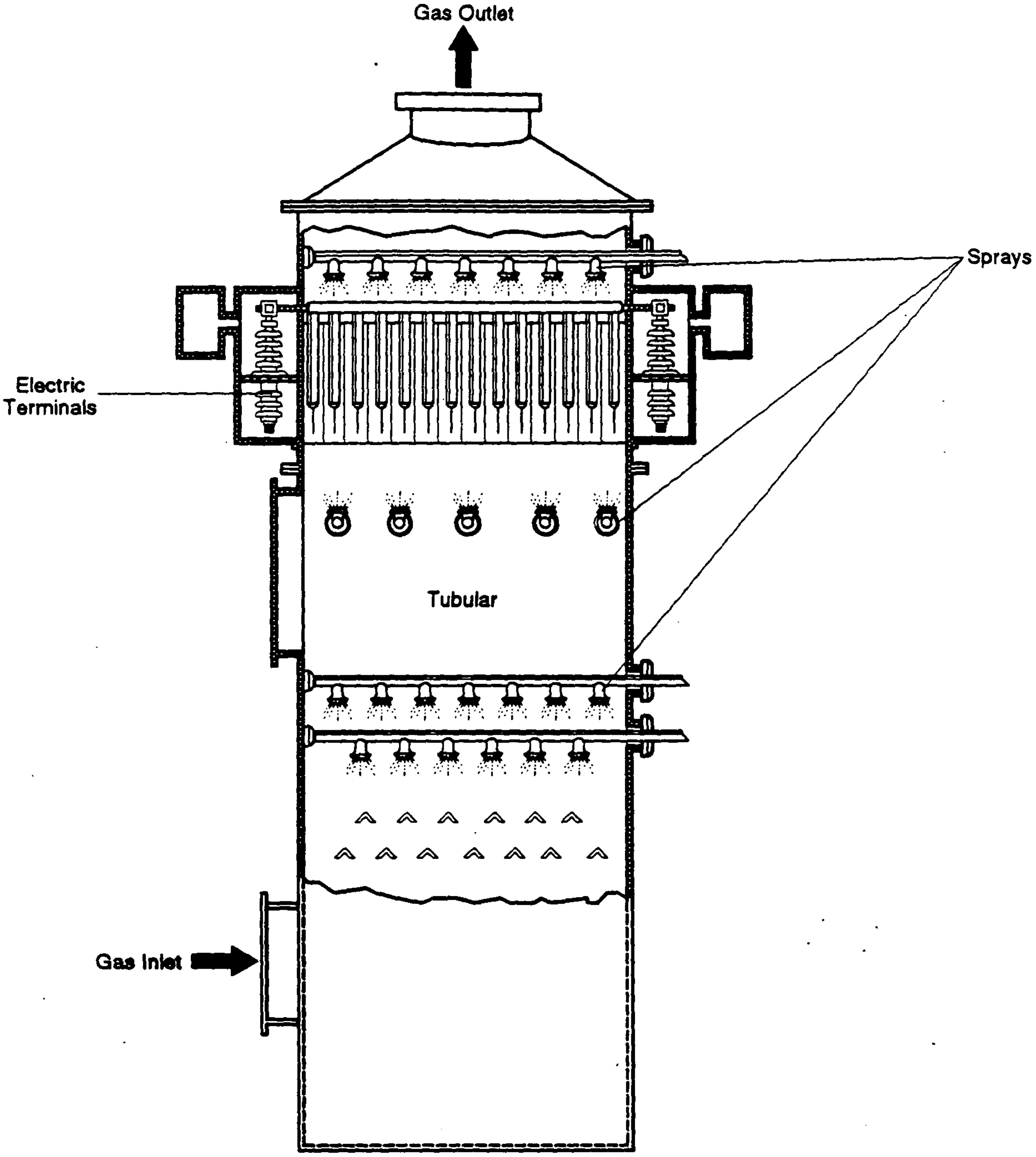
The wet electrostatic precipitator (WESP) is a variation of the dry electrostatic precipitator design and is regarded as a type of wet scrubber system. WESPs are used with metallurgic processes, acid-mist collection, coke-oven gas purification, and other processes where wet conditions prevail or are desired. WESPs are now being installed more frequently in sewage sludge incinerators in the United States because of their effectiveness in removing fine particulates and their compatibility with existing wet scrubbers installed to remove larger particles.

The WESP (see Figure 2-7) operates like the dry ESP in that there are electrodes to charge the incoming gas particles and plates that are positively charged to attract those particles (WPCF 1988). While the collection plates in dry ESPs are tapped to remove the particulates, the plates in WESPs are flooded continuously with water to wash the particles out of the system. Another added feature of a WESP system is that it has a preconditioning step in which inlet water sprays in the entry section are used for cooling, gas absorption, and removal of coarse particles.

Particle collection is achieved by first introducing evenly distributed liquid droplets to the gas stream through sprays located above the electrostatic field sections. The sprays uniformly cover the particulates with water, which renders all particulates the same size and facilitates the induction of an electrical charge. After the particles are charged, they migrate to the charged surfaces. To control the carryover of liquid droplets and mists to the stack plume, the last section of the WESP often operates without sprays and contains baffles to collect the mist.

Because of the uniformity in size of the wetted particles, the operation of the WESP is not influenced by changes in the resistivity of the particles, which is a problem for dry ESPs.

Figure 2-7. Wet Electrostatic Precipitator



Further, since the internal components are washed continuously with liquid, buildup of sticky particles is controlled and there is some capacity for removal of gaseous pollutants.

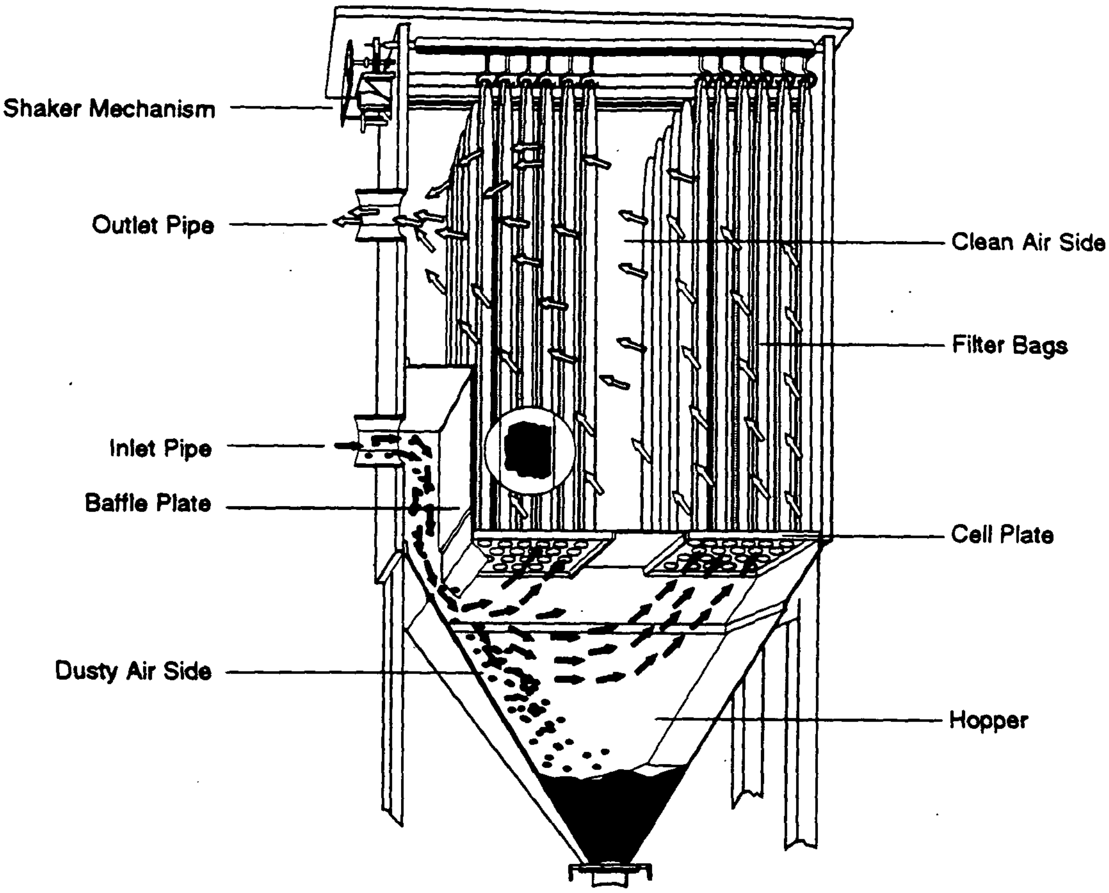
2.3.3 Fabric Filters

Fabric filters, or "baghouses," have achieved very high particle control efficiencies in many applications, including metal operations, power plants, and hazardous waste incinerators. To date, however, fabric filters have not been operated in a full-scale sewage sludge incinerator in the United States. Only one sewage sludge incinerator, in California, is equipped with fabric filters, and it was in the start-up phase in early 1988. While emission problems associated with the baghouse have been reported, testing of different baghouse fabrics is still ongoing.

A baghouse consists of a collection of bags constructed from fabrics, such as nylon, wool, or other material, hung inside a housing (see Figure 2-8). Bag materials must be selected carefully to withstand high flue-gas temperatures and other potentially adverse conditions. The combustion gases are drawn into the housing and pass through the bags, where the particles are retained on the fabric material while the clean gases pass through and are exhausted through a stack. The collected particles and cake buildup typically are removed from the bags by blasts of air, and the removed particles (or flyash) are stored in collection hoppers. Fabric filters are classified by the type of mechanism used to remove particles from the bags: mechanical shaker, reverse air, and pulse jet.

The high-efficiency removal of particulates of all sizes is achieved in fabric filters through a number of different collection mechanisms, with "inertial impaction" being the dominant mechanism. The fabric filter actually is most important as a support for the buildup of a dust cake, which filters particulates carried into the cake. Inertial impaction results when high velocity particles collide with already-deposited particles or collide directly onto the fibers. Electrostatic forces also can play a role in collecting particles because of the difference in electrical charge between the particles and the filter. The effect of electrostatic charges on particulate removal, however, has not been demonstrated fully.

Figure 2-8. Fabric Filter with Mechanical Shaking



Moisture content and acid dew point are important gas composition factors that must be monitored for effective operation of a fabric filter. The temperature of gases passing through the fabric filter must be maintained above the acid dew point to prevent acidic moisture droplets condensing within the filter system. Operating a fabric filter at close to the acid dew point introduces substantial risk of corrosion, especially in localized spots close to hatches, in dead air pockets, in hoppers, or in areas adjacent to heat sinks, such as external supports. Allowing the operating temperature to drop below the water and/or acid dew point, either during startup or during normal operation, will usually cause blinding of the bags.

Fabric filters often are not used alone to filter incinerator flue gas because acid gases attack the fabric and sticky particles "blind" the fabric. Such a condition results when the filter bags become saturated with moisture, allowing a cake to build up so heavily that it cannot be removed. Eventually, the system becomes plugged and air flow is halted. Acids or alkaline materials can also weaken fabric filters and shorten their useful lives, as can trace components, such as fluorine. In addition, baghouse fires have resulted when sparks have been entrained into the flue. ESPs and wet scrubbers have been somewhat less affected by these problems and have generally been used instead of fabric filters.

Technologies are now available for fabric filters, however, that address these problems successfully. These new technologies are equipped with upstream acid gas scrubbers, which alleviate the effect of acid gas on the fabric and sorbent accumulation on fabric materials. Thus, fabric filters are becoming a more attractive choice for particulate control, as well as for control of other pollutants. Even so, for existing sewage sludge incinerators, of which almost all are equipped with wet scrubbers, WESPs are more compatible with the wet scrubber environment than are fabric filters.

Fabric filters combined with either a wet/dry or a dry scrubbing system have demonstrated very high metals collection efficiencies when installed on municipal solid waste combustors. Dry scrubber/fabric filter systems also are being used successfully on a number of hazardous waste incinerators in Europe and the United States. These systems can probably be applied to sewage sludge incinerators if very high (greater than 99 percent) metals removal efficiencies are needed to reduce incinerator metals emissions to acceptable risk levels.

Currently, a fluidized-bed furnace system with a dry scrubber/baghouse system is being built in the United States.

2.3.4 Afterburners

Afterburners are simple combustors that use oxidation to combust organic compounds not combusted in the primary incinerator chamber. The reaction, when complete, produces the nontoxic effluent gases of carbon dioxide, nitrogen, and water vapor. The three types of afterburners described in this section are direct-flame, thermal, and catalytic. Direct-flame and thermal afterburners are similar in that they both raise gas temperature for more complete combustion of organic vapors but differ in the method used to increase the gas temperature. In a direct-flame afterburner, a high percentage of the vapors pass directly through the flame. By contrast, in a thermal unit, the vapors remain in a high-temperature, oxidizing atmosphere long enough for oxidation reactions to take place. The third afterburner type (catalytic) incorporates a catalytic surface to accelerate the oxidation reactions.

Afterburners are fired by either gaseous or liquid fuels. Gaseous fuels permit firing in multiple-jet (or distributed) burners that expose more matter to the fuel, resulting in more effective breakdown of the organics. Oil firing, on the other hand, has the disadvantage of producing sulfur oxides (from sulfur in the oil), and often results in higher nitrogen oxide emissions than gaseous fuels.

2.3.4.1 Direct-Flame Afterburners

Direct-flame afterburners require significant amounts of fuel to operate, resulting in high fuel costs. To improve the economic efficiency of direct-flame afterburners, these units are often operated with a heat-recovery system. Heat is recovered by generating process steam in a waste-heat boiler, which recovers most of the energy produced in the combustion process. Another way to reduce fuel use in direct-flame afterburners is to use a recuperator, or heat-exchange system, that heats the incoming gas stream with the high-temperature exit gas. Figure 2-9 is a simple sketch of a typical direct-flame afterburner.

2.3.4.2 Thermal Afterburners

To ensure destruction of organic vapors, thermal afterburners expose the vapors to a high-temperature, oxidizing atmosphere. Temperatures ranging from 650°C to 1,300°C generally are required for successful operation of these devices. Usually, organic compound levels can be reduced satisfactorily at temperatures of 760°C, but higher temperatures may be required to oxidize carbon monoxide. The following temperatures are often used as oxidation guidelines:

- Hydrocarbons—500° to 650°C (930 to 1,200°F)
- Carbon monoxide—650° to 800°C (1,200 to 1,472°F)

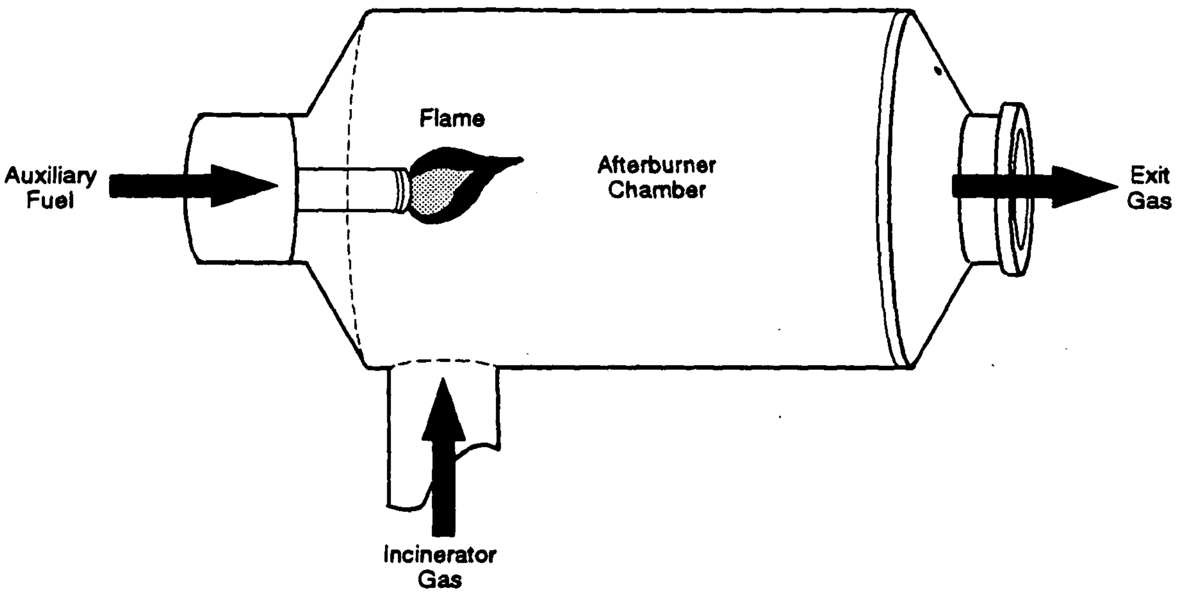
The residence time in most operating thermal afterburner systems is dictated primarily by the chemical kinetic properties of the gases. To ensure good mixing, thermal afterburners are operated at high-velocity gas flows. Gas velocities in thermal afterburners range from 7.6 to 15.2 m/sec. Depending on the type of pollutant in the gas stream, residence times ranging from 0.2 to 6.0 seconds are required for complete combustion.

2.3.4.3 Catalytic Afterburners

Catalytic afterburners usually use noble metals, such as platinum and palladium, as the catalytic agents to destroy gaseous wastes containing low concentrations of combustible materials with air. (Catalysts are materials that promote a chemical reaction without taking part in it. The catalyst does not change, and is not used up. It is, however, subject to contamination and loss of its effectiveness.)

Catalytic afterburners can combust gaseous wastes at relatively low temperatures while achieving high destruction efficiencies, thus minimizing the need for fuel. Most of the

Figure 2-9. Direct-Flame Afterburner



combustion occurs while the gas is flowing through the catalyst bed, which operates at maximum temperatures of 810°C to 870°C. Generally, catalytic afterburners are installed when waste combustion gases contain low hydrocarbon levels. If the waste gas contains a heating value sufficiently high to cause concern about destroying the catalytic agents by overheating, the gas may be diluted by atmospheric air to ensure an operating temperature within the temperature limits of the catalyst.

The residence time for catalytic oxidation typically is about 1 second. Because the combustion reaction occurs on the surface of the catalyst, the catalyst must be physically supported in the hot waste-gas stream by a geometrically configured structure that enables the greatest amount of catalytic surface area to be exposed to the waste gas.

SECTION THREE
RISK ASSESSMENT METHODOLOGY

This chapter discusses current EPA methods and established Agency policy for performing a risk assessment. This process was outlined originally by the National Academy of Sciences (NAS, 1983) and was established as final Risk Assessment Guidelines in the Federal Register (U.S. EPA, 1986b). Five types of guidelines were issued:

- Guidelines for Carcinogen Assessment
- Guidelines for Estimating Exposure
- Guidelines for Mutagenicity Risk Assessment
- Guidelines for Health Effects of Suspect Developmental Toxicants
- Guidelines for Health Risk Assessment of Chemical Mixtures.

The Risk Assessment Methodology consists of four distinct steps: hazard identification, dose-response evaluation, exposure evaluation, and characterization of risks.

3.1 HAZARD IDENTIFICATION

The primary purposes of hazard identification are to determine whether the chemical poses a hazard and whether there is sufficient information to perform a quantitative risk assessment. Hazard identification consists of gathering and evaluating all relevant data that help determine whether a chemical poses a specific hazard, then qualitatively evaluating those data on the basis of the type of health effect produced, the conditions of exposure, and the metabolic processes that govern chemical behavior within the body. Thus, the goals of hazard identification are to determine whether it is appropriate scientifically to infer that effects observed under one set of conditions (e.g., in experimental animals) are likely to occur in other settings (e.g., in human beings), and whether data are adequate to support a quantitative risk assessment.

The first step in hazard identification is gathering information on the toxic properties of chemical substances. The principal methods are animal studies and controlled epidemiological investigations of exposed human populations.

The use of animal toxicity studies is based on the longstanding assumption that effects in human beings can be inferred from effects in animals. There are three categories of animal bioassays: acute exposure tests, subchronic tests, and chronic tests. The usual starting point for such investigations is the study of acute toxicity in experimental animals. Acute exposure tests expose animals to high doses for short periods of time, usually 24 hours or less. The most common measure of acute toxicity is the lethal dose (LD_{50}), the average dose level that is lethal to 50 percent of the test animals. LD_{50} refers to oral doses. LC_{50} designates the inhalation dose at which 50 percent of the animals exposed died. LC_{50} is also used for aquatic toxicity tests and refers to the concentration of the test substance in the water that results in 50 percent mortality in the test species. Substances exhibiting a low LD_{50} (e.g., for sodium cyanide, 6.4 mg/kg) are more acutely toxic than those with higher values (e.g., for sodium chloride, 3,000 mg/kg) (NIOSH, 1979).

Subchronic tests for chemicals involve repeated exposures of test animals for 5 to 90 days, depending on the animal, by exposure routes corresponding to human exposures. These tests are used to determine the No Observed Adverse Effect Level (NOAEL), the Lowest Observed Adverse Effect Level (LOAEL), and the Maximum Tolerated Dose (MTD). The MTD is the largest dose a test animal can receive for most of its lifetime without demonstrating adverse effects other than cancer. In studies of chronic effects of chemicals, test animals receive daily doses of the test agent for approximately 2 to 3 years. The doses are lower than those used in acute and subchronic studies, and the number of animals is larger because these tests are trying to detect effects that will be observed in only a small percentage of animals.

The second method of evaluating health effects uses epidemiology—the study of patterns of disease in human populations and the factors that influence these patterns. In general, scientists view well-conducted epidemiological studies as the most valuable information from which to draw inferences about human health risks. Unlike the other approaches used to evaluate health effects, epidemiological methods evaluate the direct effects of hazardous substances on human beings. These studies also help identify human health hazards without requiring prior knowledge of disease causation, and they complement the information gained from animal studies.

Epidemiological studies compare the health status of a group of persons who have been exposed to a suspected causal agent with that of a comparable nonexposed group. Most epidemiological studies are either case-control studies or cohort studies. In case-control studies, a group of individuals with specific disease is identified (cases) and compared with individuals not having the disease (controls) in an attempt to ascertain commonalities in exposures they may have experienced in the past. Cohort studies start with a group of people (a cohort) considered free of the disease under investigation. The health status of the cohort known to have a common exposure is examined over time to determine whether any specific condition or cause of death occurs more frequently than might be expected from other causes.

Epidemiological studies are well suited to situations in which exposure to the risk agent is relatively high; the adverse health effects are unusual (e.g., rare forms of cancer); the symptoms of exposure are known; the exposed population is clearly defined; the link between the causal risk agent and adverse effects in the affected population is direct and clear; the risk agent is present in the bodies of the affected population; and high levels of the risk agent are present in the environment.

The next step in hazard identification is to combine the pertinent data to ascertain the degree of hazard associated with each chemical. In general, EPA uses different approaches for qualitatively assessing the risk or hazard associated with carcinogenic versus noncarcinogenic effects. For noncarcinogenic health effects (e.g., systemic toxicity), the Agency's hazard identification/weight-of-evidence determination has not been formalized and is based only on a qualitative assessment.

EPA's guidelines for carcinogenic risk assessment (U.S. EPA, 1986a) group all human and animal data reviewed into the following categories based on degree of evidence of carcinogenicity:

- Sufficient evidence
- Limited evidence (e.g., in animals, an increased incidence of benign tumors only)

- Inadequate evidence
- No data available
- No evidence of carcinogenicity.

Human and animal evidence of carcinogenicity in these categories is combined into the following weight-of-evidence classification scheme:

- Group A—Human carcinogen
- Group B—Probable human carcinogen
    - B1—Higher degree of evidence
    - B2—Lower degree of evidence
- Group C—Possible human carcinogen
- Group D—Not classifiable as to human carcinogenicity
- Group E—Evidence of noncarcinogenicity

Group B, probable human carcinogens, is usually divided into two subgroups: B1. chemicals for which there is some limited evidence of carcinogenicity from epidemiology studies; and B2, chemicals for which there is sufficient evidence from animal studies but inadequate evidence from epidemiology studies. EPA treats chemicals classified in categories A and B as suitable for quantitative risk assessment. Chemicals classified as Category C receive varying treatment with respect to dose-response assessment, and they are determined on a case-by-case basis. Chemicals in Groups D and E do not have sufficient evidence to support a quantitative dose-response assessment.

The following factors are evaluated by judging the relevance of the data for a particular chemical:

- Quality of data.
- Resolving power of the studies (significance of the studies as a function of the number of animals or subjects).
- Relevance of route and timing of exposure.
- Appropriateness of dose selection.

- Replication of effects.
- Number of species examined.
- Availability of human epidemiologic study data.
- Relevance of tumors observed (e.g., forestomach, mouse liver, male rat kidney)

Although the information gathered during the course of identifying each chemical hazard is not used to estimate risk quantitatively, hazard identification enables researchers to characterize the body of scientific data in such a way that two questions can be answered: (1) Is a chemical a hazard? and (2) Is a quantitative assessment appropriate? The following two sections discuss how such quantitative assessments are conducted.

3.2 DOSE-RESPONSE EVALUATION

Estimating the dose-response relationships for the chemical under review is the second step in the risk assessment methodology. Evaluating dose-response data involves quantitatively characterizing the connection between exposure to a chemical (measured in terms of quantity and duration) and the extent of toxic injury or disease. Most dose-response relationships are estimated based on results of animal studies, because even good epidemiological studies rarely have reliable information on exposure. Therefore, this discussion focuses primarily on dose-response evaluations based on animal data.

There are two general approaches to dose-response evaluation, depending on whether the health effects are based on threshold or nonthreshold characteristics of the chemical. In this context, **thresholds** refer to exposure levels below which no adverse health effects are assumed to occur. For effects that involve altering genetic material (including carcinogenicity and mutagenicity), the Agency's position is that effects may take place at very low doses, and therefore, they are modeled with no thresholds. For most other biological effects, it is usually (but not always) assumed that "threshold" levels exist.

For nonthreshold effects, the key assumption is that the dose-response curve for such chemicals exhibiting these effects in the human population achieves zero risk only at zero dose. A mathematical model is used to extrapolate response data from doses in the observed (experimental) range to response estimates in the low-dose ranges. Scientists have developed several mathematical models to estimate low-dose risks from high-dose experimental risks. Each model is based on general theories of carcinogenesis rather than on data for specific chemicals. The choice of extrapolation model can have a significant impact on the dose-response estimate. For this reason, the Agency's cancer assessment guidelines recommend the use of the multistage model, which yields estimates of risk that are conservative, representing a plausible upper limit of risk. With this approach, the estimate of risk is not likely to be lower than the true risk (U.S. EPA, 1986a).

The potency value, referred to by the Carcinogenic Assessment Group as q_1^*, is the quantitative expression derived from the linearized multistage model that gives a plausible upper-bound estimate to the slope of the dose-response curve in the low-dose range. The q_1^* is expressed in terms of risk-per-dose, and has units of $(\text{mg/kg}\bullet\text{day})^{-1}$. These values should be used only in dose ranges for which the statistical dose-response extrapolation is appropriate. EPA's q_1^* values can be found in the Integrated Risk Information System (IRIS), accessible through the National Library of Medicine.

Dose-response relationships are assumed to exhibit threshold effects for systemic toxicants or other compounds exhibiting noncarcinogenic, nonmutagenic health effects. Dose-response evaluations for substances exhibiting threshold responses involve calculating what is known as the Reference Dose (oral exposure) or Reference Concentration (inhalation exposure), abbreviated to RfD and RfC, respectively. This measure is used as a threshold level for critical noncancer effects below which a significant risk of adverse effects is not expected. The RfDs and RfCs developed by EPA can be found in IRIS.

The RfD/RfC methodology uses four experimental levels: No Observed Effect Level (NOEL), No Observed Adverse Effect Level (NOAEL), Lowest Observed Effect Level (LOEL), or Lowest Observed Adverse Effect Level (LOAEL). Each level is stated in mg/kg•day, and all the levels are derived from laboratory animal and/or human epidemiology data. When the appropriate level is determined, it is then divided by an appropriate uncertainty (safety) factor. The magnitude of safety factors varies according to the nature and quality of the data from which the NOAEL or LOAEL is derived. The safety factors, ranging from 1 to 10,000, are used to extrapolate from acute to chronic effects, interspecies sensitivity, and variation in sensitivity in human populations. They are also used to extrapolate from a LOAEL to a NOAEL. Ideally, for all threshold effects, a set of route-specific and effect-specific thresholds should be developed. If information is available for only one route of exposure, this value is used in a route-to-route extrapolation to estimate the appropriate threshold. Once these values are derived, the next step is to estimate actual human (or animal) exposure.

3.3 EXPOSURE EVALUATION

Exposure evaluation uses data concerning the nature and size of the population exposed to a substance, the route of exposure (i.e., oral, inhalation, dermal), the extent of exposure (concentration times time), and the circumstances of exposure.

There are two ways of estimating environmental concentrations:

- Directly measuring levels of chemicals (monitoring)
- Using mathematical models to predict concentrations (modeling)

In addition, an analysis of population exposure is necessary.

3.3.1 Monitoring

Monitoring involves collecting and analyzing environmental samples. These data provide the most accurate information about exposure. The two kinds of exposure monitoring are personal monitoring and ambient (or site and location) monitoring.

Most exposure assessments are complicated by the fact that human beings move from place to place and are therefore exposed to different risk agents throughout the day. Some exposure assessments attempt to compensate for this variability by personal monitoring. Personal monitoring uses one or more techniques to measure the actual concentrations of hazardous substances to which individuals are exposed. One technique is sampling air and water. The amount of time spent in various microenvironments (i.e., home, car, or office), may be combined with data on environmental concentrations of risk agents in those microenvironments to estimate exposure.

Personal monitoring may also include the sampling of human body fluids (e.g., blood, urine, or semen). This type of monitoring is often referred to as **biological monitoring** or **biomonitoring**. Biological markers (also called biomarkers) can be classified as markers of exposure, of effect, and of susceptibility. Biological markers of exposure measure exposure either to the exogenous material, its metabolite(s), or to the interaction of the xenobiotic agent with the target cell within an organism. An example of a biomarker of exposure is lead concentration in blood. In contrast, biologic markers of effect measure some biochemical, physiologic, or other alteration within the organism that points to impaired health. (Sometimes the term biomonitoring is also used to refer to the regular sampling of animals, plants, or microorganisms in an ecosystem to determine the presence and accumulation of pollutants, as well as their effects on ecosystem components.)

Ambient monitoring (or site or location monitoring) involves collecting samples from the air, water, soil, or sediments at fixed locations, then analyzing the samples to determine environmental concentrations of hazardous substances at the locations. Exposures can be further evaluated by modeling the fate and transport of the pollutants.

3.3.2 Modeling

Measurements are a direct and preferred source of information for exposure analysis. However, such measurements are expensive and are often limited geographically. The best use of such data is to calibrate mathematical models that can be more widely applied. Estimating concentrations using mathematical models must account not only for physical and chemical properties related to fate and transport, but must also document mathematical properties (e.g., analytical integration vs. statistical approach), spatial properties (e.g., one, two, or three dimensions), and time properties (steady-state vs. nonsteady-state).

Hundreds of models for fate, transport, and dispersion from the source are available for all media. Models can be divided into five general types by media: atmospheric models, surface-water models, ground-water and unsaturated-zone models, multimedia models, and food-chain models. These five types of models are primarily applicable to chemicals or to radioactive materials associated with dusts and other particles.

Selecting a model for a given situation depends on the following criteria: capability of the model to account for important transport, transformation, and transfer mechanisms; fit of the model to site-specific and substance-specific parameters; data requirements of the model, compared to availability and reliability of off-site information; and the form and content of the model output that allow it to address important questions regarding human exposures.

To the extent possible, selection of the appropriate fate and transport model should follow guidelines specified for particular media where available; for example, the Guidelines on Air Quality Models (U.S. EPA, 1986c).

3.3.3 Population Analysis

Population analysis involves describing the size and characteristics (e.g., age/sex distribution), location (e.g., workplace), and habits (e.g., food consumption) of potentially exposed human and nonhuman populations. Census and other survey data often are useful in identifying and describing populations exposed to a chemical.

Integrated exposure analysis involves calculating exposure levels, along with describing the exposed populations. An integrated exposure analysis quantifies the contact of an exposed population to each chemical under investigation via all routes of exposure and all pathways from the sources to the exposed individuals. Finally, uncertainty should be described and quantified to the extent possible.

3.4 RISK CHARACTERIZATION

This final step in the risk assessment methodology involves integrating the information developed in hazard identification, dose-response assessment, and exposure assessment to derive quantitative estimates of risk. Qualitative information should also accompany the numerical risk estimates, including a discussion of uncertainties, limitations, and assumptions. It is useful to distinguish methods used for chemicals exhibiting threshold effects (i.e., most noncarcinogens) from those believed to lack a response threshold (i.e., carcinogens).

For carcinogens, individual risks are generally represented as the probability that an individual will contract cancer in a lifetime as a result of exposure to a particular chemical or group of chemicals. Population risks are usually estimated based on expected or average exposure scenarios (unless information on distributions of exposure is available). The number of persons above a certain risk level, such as 10^{-6}, or above a series of risk levels (10^{-5}, 10^{-4}, etc.), is another useful descriptor of population risks. Thus, individual risks also may be presented using cumulative frequency distributions, where the total number of people exceeding a given risk level is plotted against the individual risk level.

For noncarcinogens, dose-response data above the threshold are usually lacking. Therefore, risks are characterized by comparing the dose or concentration to the threshold level, using a ratio in which the dose is placed in the numerator and the threshold in the denominator. Aggregate population risks for noncarcinogens can be characterized by the number of people exposed above the RfD or RfC. Recall that the hazard identification step for threshold chemicals is addressed qualitatively because no formal Agency weight-of-evidence evaluation is currently available for noncarcinogenic chemicals. The same approach can be used to assess both acute and chronic hazards. For assessing acute effects, the toxicity data and exposure assessment methods must account for the appropriate duration of exposure.

SECTION FOUR

POLLUTANTS OF CONCERN FOR SEWAGE SLUDGE INCINERATION

The number of pollutants regulated under Part 503 depends on the sewage sludge use or disposal practice. Subpart E regulates eight pollutants for sewage sludge fired in a sewage sludge incinerator—arsenic, beryllium, cadmium, chromium, lead, mercury, nickel, and total hydrocarbons (THC). This section describes how the Agency selected these eight pollutants for regulation, and discusses the data bases used to collect information about the pollutants. Since the selection of pollutants to be regulated under all sewage sludge use or disposal practices occurred concurrently, this section discusses the selection process broadly and, where appropriate, focuses on the pollutants found in sewage sludge fired in a sewage sludge incinerator. Those interested in greater detail on the pollutant selection process are encouraged to refer to the following two documents: *The Record of Proceedings on the OWRS Municipal Sewage Sludge Committees*, and *Summary of the Environmental Profiles and Hazard Indices for Constituents of Municipal Sludge* (U.S. EPA, 1983a, 1985h).

4.1 INITIAL LIST OF POLLUTANTS

In the Spring of 1984, EPA enlisted the assistance of federal, state, academic, and private sector experts to determine which pollutants, likely to be found in sewage sludge, should be examined closely as possible candidates for developing numeric limits. These experts screened a list of approximately 200 pollutants in sewage sludge that, when sewage sludge is used or disposed, could cause adverse human health or environmental effects. Many of the pollutants placed on the initial list for consideration came from the Clean Water Act's list of Priority Pollutants and Appendix VIII of the Resource Conservation and Recovery Act. The experts were requested to revise the list, adding or deleting pollutants.

The test for inclusion or exclusion of pollutants involved a qualitative determination of the potential risk to human health and the environment when sewage sludge containing a particular pollutant was applied to the land, placed on a surface disposal site, incinerated, or disposed in the ocean.[1] The Agency also requested that the experts identify the most likely pathway by which a pollutant could travel to reach target organisms, whether human, plant, or wild or domestic animals. For sewage sludge fired in a sewage sludge incinerator, inhalation was chosen as the most likely route of exposure.

Based on the qualitative assessments of each of the approximately 200 initial pollutants, the committee of experts recommended that the Agency gather additional environmental information on approximately 50 pollutants (see Table 4-1). For each pollutant, EPA developed an "environmental profile" and a "hazard index" to evaluate further and rank the degree of hazard each of the 50 pollutants posed. The environmental profiles consisted of data on toxicity, occurrence, and fate and effects of each pollutant. The profiles also contained a series of indices for evaluating the pollutant's hazard relative to the major exposure pathway(s) for each use or disposal practice (U.S. EPA 1985a-h). The other 150 pollutants were not included on the list because the committee judged them not likely to cause adverse human health or environmental effects if used or disposed properly.

Of the 50 pollutants selected for further consideration, 29 were considered a potential risk if sewage sludge was fired in a sewage sludge incinerator. Not every pollutant was considered a potential risk under each use or disposal practice because different use or disposal practices may result in different exposure levels for the same pollutant. For example, although iron was considered a possible risk to human health and the environment when sewage sludge is applied to land, this pollutant was not considered very likely to result in a significant risk if the sewage sludge was fired in a sewage sludge incinerator or placed on a surface disposal site.

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[1] The final Part 503 rule regulates three use or disposal practices: land application, surface disposal, and incineration (see Appendix A for definitions). Included in the land application category is the distribution and marketing of sewage sludge (which was a separate category in the Part 503 proposal), and included in the surface disposal category is the disposal of sewage sludge in a surface disposal site or sewage sludge-only landfill, which also was a separate category in the proposal.

TABLE 4-1

POLLUTANTS SELECTED FOR ENVIRONMENTAL PROFILES/HAZARD INDICES*

Pollutants	Land Application	Surface Disposal Site (formerly Landfill)	Incineration
Aldrin/Dieldrin	X		X
Arsenic	X	X	X
Benzene		X	X
Benzo(a)anthracene	X		X
Benzo(a)pyrene	X	X	X
Beryllium			X
Bis(2-ethylhexyl) phthalate	X	X	X
Cadmium	X	X	X
Carbon tetrachloride			X
Chlordane	X	X	X
Chlorinated dibenzodioxins			X
Chlorinated dibenzofurans			X
Chloroform			X
Chromium	X	X	X
Cobalt	X	X	
Copper	X	X	X
Cyanide		X	
DDT/DDD/DDE	X	X	X
2,4-Dichlorophenoxy-acetic acid		X	
Fluoride	X		
Heptachlor	X		X
Hexachlorobenzene	X		
Hexachlorobutadiene	X		

TABLE 4-1 (continued)

Pollutants	Land Application	Surface Disposal Site (formerly Landfill)	Incineration
Iron	X		
Lead	X	X	X
Lindane	X	X	X
Malathion		X	
Mercury	X	X	X
Methylene bis (2-chloroaniline)	X		
Methylene chloride	X	X	X
Methylethyl ketone		X	
Molybdenum	X	X	
N-nitrosodimethylamine	X	X	
Nickel	X	X	X
PCBs	X	X	X
Pentachlorophenol	X		
Phenanthrene		X	X
Phenol		X	
Selenium	X	X	X
Tetrachloroethylene			X
Toxaphene	X	X	X
Trichloroethylene	X	X	
Tricresyl phosphate	X		
Vinyl chloride			X
Zinc	X	X	X

[*] Excludes pollutants selected for environmental profiles and hazard indices for the ocean disposal of sewage sludge.

4.2 ENVIRONMENTAL PROFILES

During 1984 and 1985, the Agency collected data and information from published scientific reports on the list of 50 pollutants of concern, including toxicity and persistence information and information on the pathways by which the pollutants travel through the environment to a receptor organism (plant, animal, or human); the mechanisms that transport or bind the pollutants; and the effects of the pollutants on the target organism. EPA also analyzed data on the relative frequencies and concentrations of sewage sludge pollutants as part of an Agency study of 45 POTWs in 40 cities. The study was officially called the "Fate of Priority Pollutants in Publicly Owned Treatment Works," but was better known as the "40 City Study" (U.S. EPA, 1982). The 40 City Study contained data on the concentrations of 40 pollutants in the sewage sludge (12 metals, 6 base neutral organic compounds, 6 volatile organic compounds, 9 pesticides, and 7 polychlorinated biphenyls [PCBs]).

EPA used the data collected on the 50 pollutants to assess the likelihood of each pollutant to affect human health or the environment adversely. For this analysis, EPA relied on rudimentary risk assessments to predict at what concentration a pollutant would occur in surface or ground water, soil, air, or food. EPA then compared the predicted pollutant concentration with an Agency human health criterion to determine whether, at that concentration, the pollutant could be expected to have an adverse effect.

For carcinogens, if the calculated risk using the predicted concentration was lower than an allowable cancer risk level of 1×10^{-6} (1 person in 1,000,000),[2] the pollutant was not considered to have an adverse effect. For noncarcinogens, adverse impact hinged on whether the pollutant concentration exceeded an existing standard, such as the National Emission Standard for Hazardous Air Pollutants (NESHAPs) for beryllium and mercury, in the case of sewage

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[2] In the initial phase of the pollutant selection process, EPA chose the 1×10^{-6} risk level as being protective of human health for a most sensitive individual exposed under a hypothetical worst-case scenario. As discussed in Section 5.3, later EPA analyses for the proposed Part 503 rule used a 1×10^{-5} risk level for sewage sludge incineration and a 1×10^{-4} risk level for the other use or disposal practices, while the final rule uses a risk level of 1×10^{-4} for all use or disposal practices. The 1×10^{-6} risk level used at the outset of the pollutant selection process was more inclusive of the number of pollutants selected for further, more extensive analysis.

sludge fired in a sewage sludge incinerator. To determine the human health impact of the pollutants of concern, EPA assumed worst-case conditions that would maximize the pollutant exposure.

The Agency used the rudimentary risk assessments to score and rank each pollutant, screening out those pollutants not expected to have an adverse human health impact before proceeding with more thorough, detailed modeling for pollutants considered to be of concern. EPA excluded two categories of pollutants from further evaluation. First, EPA excluded pollutants that, when compared to the "hazard index," presented no risk to human health at the highest concentration found in the 40 City Study or in other available data bases for each particular use or disposal practice. Hazard indices were developed for each pollutant and for each use or disposal practice and used to compare a pollutant's risk to the 1 x 10^{-6} risk level for carcinogens or to a threshold level index for noncarcinogens. Table 4-2 identifies the pollutants excluded under this category by use or disposal practice. Some of the pollutants excluded for one use or disposal practice were determined to present a risk for a different use or disposal practice. For example, even though copper was found to present no risk for sewage sludge fired in a sewage sludge incinerator, it is regulated under the Part 503 regulation for land application. The second category of pollutants deferred from consideration were those for which no EPA human health criteria were available or for which there were insufficient data to conduct a risk assessment (see Table 4-3).

Of the 29 pollutants for which environmental profiles and hazard indices were developed, 11 were dropped from further consideration and are found in either Table 4-2 or Table 4-3. Of the 18 remaining pollutants, 7 are being regulated as individual pollutants under Part 503, while the other 11 are being regulated under Part 503 under the category of total hydrocarbons (THC) (see Section 6.1). The THC category covers other hydrocarbon compounds as well, including five found either in Table 4-2 or Table 4-3. Table 4-4 lists the 16 organic compounds from the list of 29 pollutants for which environmental profiles and hazard indices were developed that are being regulated under the Part 503 incineration regulation through the operational standard on THC.

TABLE 4-2

POLLUTANTS EVALUATED AND FOUND NOT TO CAUSE AN ADVERSE EFFECT ON HUMAN HEALTH FOR SEWAGE SLUDGE FIRED IN A SEWAGE SLUDGE INCINERATOR

- Benzene
- Copper
- Heptachlor
- Mercury[*]
- Methylene chloride
- Selenium
- Tetrachloroethylene
- Zinc

[*] Regulated under Part 503 through the National Emission Standards for Hazardous Air Pollutants

TABLE 4-3

POLLUTANTS DEFERRED BECAUSE OF INSUFFICIENT DATA TO CONDUCT A RISK ASSESSMENT FOR SEWAGE SLUDGE FIRED IN A SEWAGE SLUDGE INCINERATOR

- Benzo(a)anthracene
- Phenanthrene
- Vinyl chloride

TABLE 4-4

POLLUTANTS SELECTED FOR ENVIRONMENTAL PROFILES/ HAZARD INDICES THAT ARE REGULATED UNDER PART 503 THROUGH THE TOTAL HYDROCARBONS STANDARD

- Aldrin/Dieldrin
- Benzene
- Benzo(a)pyrene
- Bis(2-ethylhexyl) phthalate
- Carbon tetrachloride
- Chlordane
- Chlorinated dibenzodioxins
- Chlorinated dibenzofurans
- Chloroform
- DDT/DDD/DDE
- Heptachlor
- Lindane
- Methylene chloride
- PCBs
- Tetrachloroethylene
- Toxaphene

Listed in Table 4-5 are the eight pollutants regulated under the Part 503 rule when sewage sludge is fired in a sewage sludge incinerator. While EPA believed that the 40 City Study data were the appropriate data on which to base the February 6, 1989, proposed Part 503 regulation, the Agency concluded that the data needed to be replaced or, at a minimum, supplemented to support the final regulation. EPA therefore undertook the National Sewage Sludge Survey (NSSS)[3] to obtain a current and reliable data base for evaluating the impacts of the final Part 503 rule. Based on the NSSS, the pollutants of concern for sewage sludge incineration regulated in the final rule did not change from the pollutants of concern identified for the proposed regulation using data from the 40 City Study.

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[3] The National Sewage Sludge Survey data collection effort began in August 1988 and was completed in September 1989. EPA collected sewage sludge samples at 180 publicly owned treatment works (POTWs) with either secondary or advanced treatment processes and analyzed them for more than 400 pollutants. In addition, through the use of detailed questionnaires, the survey collected information on sewage sludge use or disposal practices from 475 POTWs with at least secondary treatment of wastewater.

TABLE 4-5

POLLUTANTS REGULATED UNDER PART 503 FOR SEWAGE SLUDGE FIRED IN A SEWAGE SLUDGE INCINERATOR

- Arsenic
- Beryllium*
- Cadmium
- Chromium
- Lead
- Mercury*
- Nickel
- Total Hydrocarbons

*Controlled through the existing National Emission Standards for Hazardous Air Pollutants (40 CFR Part 61).

SECTION FIVE

DEVELOPMENT OF LIMITS FOR INORGANIC POLLUTANTS

Through Subpart E of Part 503, EPA regulates eight pollutants in sewage sludge fired in a sewage sludge incinerator or in the exit gas from the stack. The seven inorganic pollutants regulated, all of which are metals, are arsenic, beryllium, cadmium, chromium, lead, mercury, and nickel, while the organics are represented and regulated through total hydrocarbons (THC).

EPA regulates five of the metals—arsenic, cadmium, chromium, lead, and nickel—by limiting the concentration of these pollutants in sewage sludge fed to a sewage sludge incinerator on a site-specific basis. For beryllium and mercury, however, limits are not site-specific but have been incorporated into Subpart E by reference to the NESHAP for Beryllium in Subpart C of 40 CFR Part 61 and the NESHAP for Mercury in Subpart E of 40 CFR Part 61. The regulation also requires that THC be monitored in the stack gas and that THC emissions not exceed a prescribed operational standard. The next section provides an overview of the Subpart E pollutant limits and operational standard for sewage sludge fired in a sewage sludge incinerator.

5.1 OVERVIEW OF SUBPART E POLLUTANT LIMITS AND OPERATIONAL STANDARD

The Subpart E pollutant limits and operational standard are based on the following:

- Risk-specific Concentrations (arsenic, cadmium, chromium, nickel)
- National Ambient Air Quality Standard (lead)
- Technology-based Operational Standard (total hydrocarbons)
- National Emission Standards for Hazardous Air Pollutants (beryllium and mercury)

Of the pollutants listed above, the limits for only four of them are derived through a risk-based equation developed specifically for the Part 503 standard. This equation is used to calculate a "risk-specific concentration" (RSC) for arsenic, cadmium, chromium, and nickel. An

RSC is the allowable increase in the average daily ground-level ambient air concentration for a pollutant above background levels that results from the firing of sewage sludge in a sewage sludge incinerator.

The RSC is equivalent to the amount of pollutant that a person living near the sewage sludge incinerator site can inhale daily with a probability of 1 in 10,000 (10^{-4}) that the person will contract cancer as a result of inhaling the pollutant. The probability of contracting cancer is a theoretical upper bound estimate, and the probability can be as low as zero. RSC values are calculated independently from background levels and pertain only to the concentration of the pollutant emitted from the sewage sludge incinerator. RSCs for arsenic, cadmium, chromium, and nickel are factored into a second equation, along with site-specific characteristics of the sewage sludge incinerator, to develop limits on the concentration of these four pollutants in sewage sludge.

The pollutant limit for lead is based on a percentage of the National Ambient Air Quality Standard (NAAQS) for lead, not on a calculated RSC value. EPA allows sewage sludge incinerators to increase the lead concentration in the ambient air around the incinerator site by up to 10 percent of the NAAQS. This allowable ambient lead concentration substitutes for an RSC value and is factored into an equation similar to that used for the four metals to calculate a site-specific concentration limit for lead in sewage sludge.

In contrast to the pollutant limits based on RSCs or the NAAQS, the requirement for THC is a technology-based operational standard, not a risk-based limit, because a methodology for developing a site-specific risk-based approach for THC is not well established. This operational standard is based on an approach that regulates all organic pollutants through one THC emission value. The operational standard is based on the THC emission levels achievable by multiple-hearth furnaces and was determined by an analysis of data on operations and THC emissions from several sewage sludge incinerators. EPA used risk assessment methodology to evaluate whether the THC operational standard protects public health from the reasonably anticipated adverse effects of organic pollutants in the exit gas from a sewage sludge incinerator stack. In the judgment of EPA, the THC operational standard is protective of public health.

(See Section 6.6 for a further discussion of how risk assessment was used to judge that the THC operational standard is protective of human health.)

According to the NESHAPs, beryllium and mercury are regulated as limits to air emissions either by monitoring the exit gas from the sewage sludge incinerator stack or the ambient air around the incinerator, or by monitoring the sewage sludge. Depending on the pollutant, the monitoring methods are either listed in NESHAPs or are set by the permitting authority. Although the proposed Part 503 rule, published February 6, 1989, recommended that the NESHAPs values for beryllium and mercury be used in equations to calculate allowable concentrations of beryllium and mercury in sewage sludge, the final Part 503 rule uses the NESHAPs values as the pollutant limits. The frequency of monitoring requirement for both pollutants is specified by the permitting authority.

The remainder of Section Five explains the development of the inorganic pollutant limits. Section 5.2 presents the equation EPA developed through risk assessment methodology that is used to derive the RSCs for arsenic, cadmium, chromium, and nickel. This section also describes the two other equations into which either an RSC or a percentage of the NAAQS for lead is factored to calculate pollutant limits for the five metals. Section 5.3 discusses the factors EPA used to develop the risk assessment methodology. Section 5.4 provides an explanation as to how RSC values were calculated, while Section 5.5 explains the use of a percentage of the NAAQS for lead to calculate the allowable limit on the concentration of lead in sewage sludge.

In Section 5.6, detailed explanations are given for the site-specific characteristics of a sewage sludge incinerator unit that are used to calculate limits on the concentration of arsenic, cadmium, chromium, lead, and nickel. Sample calculations derive limits for arsenic and lead at a hypothetical POTW. The final section, Section 5.7, discusses EPA's policy decision to use the NESHAPs for beryllium and mercury as the pollutant requirements of Subpart E.

5.2 RISK-SPECIFIC CONCENTRATIONS AND THE EQUATIONS FOR DERIVING LIMITS FOR INORGANIC POLLUTANTS IN SEWAGE SLUDGE

As mentioned in Section 5.1, EPA used risk assessment methodology to develop risk-specific concentrations (RSCs), which are then used to calculate limits on the concentration of arsenic, cadmium, chromium, and nickel in the sewage sludge. In Subpart E, RSCs are provided for these four metals, all of which are carcinogens. These RSCs were calculated using Equation 1 below, which contains four risk-related factors—risk level (RL), body weight (BW), cancer potency (q_1^*), and inhalation rate (I_a). The only factor in this equation that is different for each pollutant is the cancer potency value (q_1^*), which EPA previously has calculated for three of the four metals (U.S. EPA, 1992a). The RSC is determined by the following equation:

$$\mathbf{RSC} = \frac{\mathbf{RL \times BW}}{\mathbf{q_1^* \times I_a}} \times 10^3 \qquad (1)$$

where:

RSC = risk-specific concentration ($\mu g/m^3$) for arsenic, cadmium, chromium, and nickel

RL = risk level, or the probability of developing cancer, unitless

BW = body weight, in kilograms (kg)

q_1^* = cancer potency value for each carcinogenic metal, in milligrams per kilogram-day $(mg/kg\text{-}day)^{-1}$

I_a = inhalation rate, in cubic meters per day (m^3/day)

10^3 = conversion factor from milligrams to micrograms (1000 $\mu g/mg$)

The **RSC** for arsenic, cadmium, chromium, or nickel is input into a second equation that includes three other variables, each of which relate to site-specific characteristics of the sewage sludge incinerator unit. Equation 2 below presents the relationship among the four factors used to calculate limits on the average daily concentrations (C) of the four metals in sewage sludge:

$$\mathbf{C = (RSC \times 86{,}400)/(DF \times [1\text{-}CE] \times SF)} \qquad (2)$$

where:

C = the allowable average daily concentration of arsenic, cadmium, chromium, or nickel in the sewage sludge, in milligrams per kilogram of total solids, dry weight basis (mg/kg)

RSC = the risk-specific concentration, in micrograms per cubic meter ($\mu g/m^3$)

DF = dispersion factor (the ratio of the increase in ground-level air concentration at or beyond the property line to the mass emission rate for the pollutant from the stack), in micrograms per cubic meter, per gram, per second ($\mu g/m^3/g/sec$)

CE = the sewage sludge incinerator control efficiency for arsenic, cadmium, chromium, or nickel, in hundredths

SF = the sewage sludge feed rate, in metric tons per day, dry weight basis (dmt/day)

86,400 = a conversion factor from seconds to days (86,400 sec/day)

The dispersion factor is calculated using an EPA-approved air dispersion model (U.S. EPA, 1990b; 1986d), which accounts for such factors as stack height, stack diameter, stack gas temperature, exit velocity, and surrounding terrain. In most cases, the actual stack height of the sewage sludge incinerator is used in the model. If the stack height exceeds 65 meters, however, a "creditable" stack height is used in the model based on "good engineering practice" (GEP) (see Section 5.6.1.3).

The control efficiency regarding the percent removal of each metal pollutant is determined by undertaking a performance test of the sewage sludge incinerator (see Section 5.6.2). During the performance test, the sewage sludge feed rate is either the average daily amount of sewage sludge incinerated in all sewage sludge incinerators within the property line of the site for the number of days the incinerators operate during the year or the average daily design capacity for all sewage sludge incinerators within the site. For sites with more than one sewage sludge incinerator, the feed rate is the average daily amount of sewage sludge for all incinerators at the site. This rate is determined by dividing the sum of the amounts of sewage sludge fed into each incinerator at the site during the calendar month by the total number of days that all incinerators operated during that month.

For lead, EPA did not develop an RSC value. Instead, the Agency chose an allowable increase in the ambient air concentration for lead resulting from sewage sludge incineration and expressed it in terms of a percentage of the NAAQS for lead. EPA concluded that a sewage sludge incinerator can increase the lead concentration in the ambient air surrounding the incinerator site by up to 10 percent of the NAAQS. Equation 3 shows how 10 percent of the NAAQS for lead is used in place of an RSC to calculate the sewage sludge limit for lead:

$$\mathbf{C = (.10)(NAAQS) \times 86{,}400/(DF \times [1\text{-}CE] \times SF)} \quad (3)$$

where:

C = the allowable average daily concentration of lead in the sewage sludge, in milligrams per kilogram of total solids, dry weight basis (mg/kg)

.10 = the percentage of the NAAQS for lead that sewage sludge incinerators are allowed to add to the lead concentration in the ambient air around the incinerator site.

NAAQS = National Ambient Air Quality Standard for lead, in micrograms per cubic meter ($\mu g/m^3$)

DF = dispersion factor (the ratio of the increase in ground-level air concentration of the pollutant at or beyond the property line to the mass emission rate for the pollutant from the stack), in micrograms per cubic meter, per gram, per second ($\mu g/m^3/g/sec$)

CE = the sewage sludge incinerator control efficiency for lead, in hundredths

SF = the sewage sludge feed rate, in metric tons per day, dry weight basis (dmt/day)

86,400 = a conversion factor from seconds to days (86,400 sec/day)

5.3 EPA PART 503 RISK ASSESSMENT FOR INCINERATION

This section discusses the human exposure pathway assessed for sewage sludge incineration and the factors EPA used to calculate RSCs. It also describes the concept of the highly exposed individual that EPA used to ensure public health protection. In addition, this section explains the way in which EPA applied its risk assessment methodology to the development of pollutant limits for Subpart E of the sewage sludge regulation.

5.3.1 Inhalation Pathway

To develop the Part 503 rule for sewage sludge fired in a sewage sludge incinerator, EPA evaluated exposure only through direct inhalation of air emissions (U.S. EPA, 1988b).

5.3.2 The Highly Exposed Individual

The risk-based equations developed for the Part 503 regulation were designed to limit potential exposure of a highly exposed individual (HEI) to the pollutants of concern. The HEI is an individual who remains for an extended period of time at the point of maximum ambient ground-level pollutant concentration. For sewage sludge fired in a sewage sludge incinerator, total concentration is limited so that the increased risk attributable to each carcinogenic pollutant being emitted does not exceed an additional lifetime risk (70 years) of 1×10^{-4} (1 in 10,000) to the HEI.

The 1989 proposed Part 503 rule considered the exposed individual to be a "most exposed individual" (MEI). EPA changed the terminology for the final rule based on a revised exposure assessment analysis. The assessment for the final Part 503 regulation incorporates assumptions that the Agency has concluded present a more realistic characterization of the potential for reasonably anticipated adverse effects on public health. These assumptions are designed to limit the potential exposure to a highly exposed individual (HEI) rather than to an MEI.

EPA's HEI exposure assessment analysis and the numerical pollutant limits developed from that analysis are designed to address the risk to individuals and populations that may face a greater risk than the general population from exposure to pollutants in sewage sludge. The analysis attempts to evaluate realistic risk by using variables that are reflective of likely experience. This approach does not evaluate the risk associated with a combination of unlikely occurrences, as did the MEI approach. EPA concluded that the HEI approach is consistent with its statutory duty to develop regulations that are "adequate to protect public health and the environment from any reasonably anticipated adverse effects." In the case of sewage sludge fired in a sewage sludge incinerator, the assumptions used in the risk assessment methodology did not change as a result of the change in terminology from the MEI to the HEI.

In developing Subpart E of the rule, EPA used the HEI to estimate the potential cancer risk from direct inhalation of carcinogenic pollutants emitted from a sewage sludge incinerator. The HEI is the person assumed to reside at the point of maximum, off-site, ground-level concentration, with the point of maximum concentration being determined by air dispersion modeling. EPA assumes that people do not routinely reside inside the facility boundary. For a person firing sewage sludge from more than one sewage sludge incinerator unit, the point of maximum exposure, and thus the location of the HEI, is determined by taking the sum of the actual or projected emissions from the individual units at each receptor location.

5.3.3 Factors Used to Calculate Risk-Specific Concentrations

This section discusses the values chosen for the risk-based equation (Equation 1 from Section 5.2) used to calculate RSCs.

$$\mathrm{RSC} = \frac{\mathrm{RL} \times \mathrm{BW}}{q_1^* \times I_a} \times 10^3$$

where:

RSC = risk-specific concentration ($\mu g/m^3$) for arsenic, cadmium, chromium, and nickel

RL = risk level: 1×10^{-4}, or 1 chance in 10,000 of developing cancer

BW = body weight: 70 kg

q_1^* = cancer potency value for each carcinogenic metal, measured in $(mg/kg\text{-}day)^{-1}$

I_a = inhalation rate: 20 m^3/day

10^3 = conversion factor (1000 μg/mg)

5.3.3.1 Risk Level

EPA's regulations are designed to achieve risk levels of between $1x10^{-4}$ and $1x10^{-7}$ in a number of regulatory applications, depending on the statute, surrounding issues, uncertainties, and available data bases. For the Part 503 proposal, EPA chose the $1x10^{-5}$ risk level, or the probability of 1 cancer case in 100,000 individuals, for sewage sludge fired in a sewage sludge incinerator. Additional data provided by the NSSS, the scientific peer review committees, and the public were incorporated into an aggregate effects assessment for the final rule, which considers the health effects on the HEI and the population as a whole. This assessment showed minimal risk from current sewage sludge use or disposal practices. Because sewage sludge incinerators exhibited low baseline risk, the Agency chose to regulate sewage sludge incinerator units such that each carcinogen in the emissions does not exceed an incremental unit risk of 1 x 10^{-4} to the HEI. The incremental risk is considered as that which is caused only by emissions from a sewage sludge incinerator unit and not from other sources, natural or manmade.

5.3.3.2 Body Weight

As defined by EPA, lifetime inhalation exposures are estimated for a 70 kg man (154 pounds), which is considered the standard body weight of an adult male (U.S. EPA, 1990a).

5.3.3.3 Cancer Potency

The cancer potency value (q_1^*) represents the relationship between a specified carcinogenic dose and its associated degree of risk. The q_1^* is based on continual exposure of an individual to a specified concentration over a period of 70 years. Established EPA methodology for determining cancer potency values assumes that any degree of exposure to a carcinogen produces a measurable risk. The q_1^* value is expressed in terms of risk per dose and is measured in reciprocal units of milligrams of pollutant per kilogram of body weight and per day of exposure $(mg/kg\text{-}day)^{-1}$. For example, the q_1^* value for arsenic is 15 $(mg/kg\text{-}day)^{-1}$. The arsenic q_1^* of 15 $(mg/kg\text{-}day)^{-1}$ is then factored into the RSC equation to obtain an allowable increase in the ambient air concentration of arsenic resulting from sewage sludge incineration.

EPA previously has calculated cancer potency estimates for arsenic, cadmium, and chromium, which appear in the Agency's Integrated Risk Information System (IRIS) database (U.S. EPA, 1992a), and are shown in Table 5-1. The cancer potency for chromium is shown for its carcinogenic form, hexavalent chromium. RSCs for arsenic, cadmium, and chromium are based in part on their cancer potency values. The RSC for nickel subsulfide (the carcinogenic form of nickel) was taken directly from the IRIS database. EPA also compiles scientific data on the observed health effects from exposure to a large number of pollutants in its IRIS database. The "most sensitive endpoint" for humans exposed to the four carcinogens regulated in Subpart E are listed in IRIS as follows: arsenic (lung, skin, and gastrointestinal cancers); cadmium (lung, tracheal, and bronchial cancer); hexavalent chromium (lung cancer and cancers in other organs); and nickel subsulfide (lung and nasal cancer) (U.S. EPA, 1992a).

5.3.3.4 Inhalation Rate

EPA uses 20 m^3/day as the amount of air inhaled long-term by the HEI. The Agency regards this value as the standard inhalation rate of an adult male during a normal day (U.S. EPA, 1990a).

TABLE 5-1

CANCER POTENCY VALUES (q_1^*) FOR METALS

METALS	q_1^* $(mg/kg\text{-}day)^{-1}$
Arsenic	15.0
Cadmium	6.1
Hexavalent Chromium	41.0

Source: U.S. EPA Integrated Risk Information System, 1992a.

5.4 DERIVATION OF RISK-SPECIFIC CONCENTRATIONS FOR THE CARCINOGENIC METALS

Subpart E of the Part 503 rule provides RSC values for arsenic, cadmium, chromium, and nickel that can be used to calculate allowable pollutant concentrations in sewage sludge given the site-specific variables associated with each sewage sludge incinerator. These RSCs are shown in Table 5-2. The RSC for chromium depends on the type of sewage sludge incinerator unit and air pollution control equipment used. Optionally, treatment works staff can calculate a site-specific RSC value for chromium based on the percentage of hexavalent chromium to total chromium in the emissions from the sewage sludge incinerator. The RSC for nickel was based on the detection limit for the percentage of nickel subsulfide to total nickel analyzed in the stack gas from several sewage sludge incinerators.

TABLE 5-2

RISK-SPECIFIC CONCENTRATIONS FOR METALS

METAL	RISK-SPECIFIC CONCENTRATION ($\mu g/m^3$)
Arsenic	0.023
Cadmium	0.057
Chromium	
Fluidized-bed with scrubber	0.65
Fluidized-bed with wet scrubber and wet electrostatic precipitator	0.23
Other types with wet scrubber	0.064
Other types with wet scrubber and wet electrostatic precipitator	0.016
Nickel	2.0

Source: 40 CFR Part 503, Subpart E.

5.4.1 RSC Calculations for Arsenic and Cadmium

The RSCs for arsenic and cadmium are calculated below, using Equation 1 from Section 5.2 and the standard values for risk level, body weight, and inhalation rate, and the cancer potency value for each metal from Table 5-1. Following these RSC calculations are discussions of the standard and site-specific RSCs for chromium, including calculations for each of the four standard chromium RSCs, and of the RSC for nickel, including the calculation for the nickel RSC.

$$\mathbf{RSC} = \frac{\mathbf{RL \times BW}}{\mathbf{q_1^* \times I_a}} \times \mathbf{10^3}$$

where:

RSC = risk-specific concentration ($\mu g/m^3$) for arsenic, cadmium, or chromium

RL = risk level: 1×10^{-4}

BW = body weight: 70 kg

q_1^* = cancer potency value for each carcinogenic metal (listed in Table 5-1), in $(mg/kg\text{-}day)^{-1}$

I_a = inhalation rate: 20 m^3/day

10^3 = conversion factor: 1000 $\mu g/mg$

$$\textbf{RSC (arsenic)} = \frac{0.0001 \times 70\ kg}{15.0\ (mg/kg\text{-}day)^{-1} \times 20\ m^3/day} \times 1{,}000\ \mu g/mg$$

$$= 0.023\ \mu g/m^3$$

$$\textbf{RSC (cadmium)} = \frac{0.0001 \times 70\ kg}{6.1\ (mg/kg\text{-}day)^{-1} \times 20\ m^3/day} \times 1{,}000\ \mu g/mg$$

$$= 0.057\ \mu g/m^3$$

5.4.2 RSC Calculation for Chromium

Chromium is emitted from sewage sludge incinerators either in the noncarcinogenic trivalent state (Cr^{+3}), or in the highly carcinogenic, hexavalent state (Cr^{+6}). Trivalent chromium is toxic only at levels higher than those normally found in sewage sludge or emitted from sewage sludge incinerators. For the Part 503 proposal, EPA estimated that one percent of the chromium emitted from a sewage sludge incinerator was in its most toxic form, hexavalent chromium. This estimate was based on limited EPA chromium emission data.

After the Part 503 proposal was published, EPA conducted a series of tests at three sewage sludge incinerators to determine more accurately the percentage of chromium converted during combustion to the hexavalent state (U.S. EPA, 1991a; 1991b; 1991c). The three sewage sludge incinerator units were equipped with the following incinerator and APCDs: (1) a multiple-hearth furnace with a venturi scrubber system; (2) a fluidized-bed furnace with a venturi scrubber and a pilot-scale wet electrostatic precipitator (WESP); and (3) a multiple-hearth furnace with a venturi scrubber and a WESP.

These tests for chromium conversion were made possible because of the recent development of a sophisticated stack sampling method (U.S. EPA, 1992b) that minimizes the conversion of hexavalent chromium back to the trivalent state in the sampling and analysis process (Steinsberger et al., 1992). Overall, the EPA tests determined that most of the chromium is emitted in the trivalent state because hexavalent chromium is more highly reactive, and thus reacts with reducing agents to form the more stable and less toxic trivalent chromium.

Based on the EPA tests of the three sewage sludge incinerators, the Agency also concluded that the conversion to hexavalent chromium varies with the type of sewage sludge incinerator and air pollution controls. First, the fluidized-bed furnace produced a lower degree of conversion of chromium to hexavalent chromium than the multiple-hearth furnaces. Second, the use of a WESP tends to increase the percentage of hexavalent chromium measured at the outlet of the WESP as a result of a higher collection efficiency of trivalent chromium by the WESP (U.S. EPA, 1991d; U.S. EPA, 1992c; Steinsberger et al., 1992).

Based on the results of the above tests, EPA derived different RSC values for four combinations of sewage sludge incinerator and APCD technologies. To develop chromium concentration limits in the sewage sludge, the RSC value for the appropriate technologies at the incinerator should be used. The four RSCs for chromium for the various technologies are listed in Table 5-2. Chromium RSCs are highest for fluidized-bed furnaces with a wet scrubber and no WESP and lowest for other furnace types with a wet scrubber and a WESP. The lower the RSC value, the lower will be the calculated chromium concentration limit.

EPA used Equation 4 below to calculate the standard chromium RSCs based on the percentage of hexavalent chromium in the total chromium concentration emitted during the emission tests at the three sewage sludge incinerators. The 0.0085 value in Equation 4 is the RSC for 100 percent hexavalent chromium. Shown below are Equation 4 and the calculation for the 0.0085 value, which is based on the q_1^* for hexavalent chromium.

$$\mathbf{RSC = 0.0085/r} \qquad \textbf{(4)}$$

where:

RSC = RSC for chromium, in micrograms per cubic meter ($\mu g/m^3$)

r = decimal fraction of hexavalent chromium in the total chromium concentration, in hundredths

$$\textbf{RSC (100\% hexavalent chromium)} = \frac{0.0001 \text{ x } 70 \text{ kg}}{41.0 \text{ (mg/kg-day)}^{-1} \text{ x } 20 \text{ m}^3\text{/day}} \text{ x } 1{,}000 \ \mu g/mg$$

$$= 0.0085 \ \mu g/m^3$$

Table 5-3 shows the percentage of hexavalent chromium to total chromium by furnace type and APCD. The percentages are based on the 95th percentile values derived from the

TABLE 5-3

PERCENTAGE OF HEXAVALENT CHROMIUM TO TOTAL CHROMIUM BY FURNACE TYPE AND AIR POLLUTION CONTROL DEVICE

	POLLUTION CONTROL DEVICE	
FURNACE TYPE	**Scrubber**	**Scrubber Plus WESP**
Fluidized Bed	1.3 %	3.7 %
Multiple Hearth	13.2 %	50.9 %

Source: U.S. EPA, 1991d.

EPA tests on the three sewage sludge incinerators (U.S. EPA, 1991d). Data from the EPA tests on which the chromium RSCs in Table 5-2 are based are presented in Appendix C, along with a discussion of the test results. Presented below are the calculations for the four RSCs for chromium using Equation 4 and the percentages of hexavalent chromium from Table 5-3, expressed in hundredths.

$$\mathbf{RSC = 0.0085/r}$$

(a) $\text{RSC} = 0.0085/.013 = 0.65$

(c) $\text{RSC} = 0.0085/.132 = 0.064$

(b) $\text{RSC} = 0.0085/.037 = 0.23$

(d) $\text{RSC} = 0.0085/.509 = 0.016$

Since the RSC values for chromium developed by the Agency are estimates based on the 95th percentile values for the percentage of hexavalent chromium in sewage sludge incinerator emissions, treatment works staff also can decide to calculate a site-specific RSC based on the percentage of hexavalent chromium to total chromium in the stack emissions (see EPA-approved test methodology (U.S. EPA, 1992b)). This calculation, shown below, uses the same equation as that used to calculate the four standard chromium RSCs.

$$RSCsp = 0.0085/r \qquad (5)$$

where:

RSCsp = site-specific RSC for chromium, in micrograms per cubic meter ($\mu g/m^3$)

r = decimal fraction of hexavalent chromium in the total chromium concentration, in hundredths

5.4.3 RSC Calculation for Nickel

In the proposed Part 503 regulation, EPA assumed that 100 percent of the nickel emitted from a sewage sludge incinerator unit was in the carcinogenic form, nickel subsulfide. To obtain more accurate data on nickel emissions for the final regulation, EPA conducted nickel speciation tests at the same two multiple-hearth furnaces and one fluidized-bed furnace at which chromium tests were conducted (U.S. EPA, 1991a; 1991b; 1991c). These tests were based on both new and established testing and sampling techniques. EPA contractors used two analytical methods: a wet chemical speciation technique to measure the nickel species and two instrumental techniques using atomic absorption spectroscopy to confirm the presence or absence of the different nickel species (Steinsberger et al., 1992).

The nickel speciation samples were taken at three locations within the sewage sludge incinerator: at the inlet to the air pollution control device from the furnace; at the outlet from the air pollution control device; and at the midpoint between the scrubber and wet electrostatic precipitator, when both of these air pollution control devices were present. The results of the nickel speciation analysis (see Appendix D) revealed that nickel subsulfide is not emitted from sewage sludge incinerators above the level of detection for both analytical techniques. For multiple-hearth furnaces, the detection limit is 12 percent for the inlet emissions and 10 percent for the outlet emissions, and for the fluidized-bed furnace, the detection limit is 2 percent in the inlet emissions and 1 percent in the midpoint emissions. To be conservative, EPA based the standard RSC value for nickel on the higher of the two detection limits for nickel subsulfide (10 percent) measured at the outlet from the APCD. The RSC derivation below uses the RSC for nickel subsulfide obtained from IRIS and revises the RSC for 10 percent nickel subsulfide.

$$\text{RSC nickel} = \frac{0.20\ \mu g/m^3}{0.10} \text{ (100 percent nickel subsulfide)}$$

$$= 2.0\ \mu g/m^3 \text{ (10 percent nickel subsulfide)}$$

5.5 USE OF A PERCENTAGE OF THE NATIONAL AMBIENT AIR QUALITY STANDARD FOR LEAD

While pollutant limits for the carcinogenic metals are calculated using RSC values, the lead limit is calculated using a percentage of the existing National Ambient Air Quality Standard (NAAQS) for lead, which currently is 1.5 $\mu g/m^3$ (40 CFR Part 50.12). While lead is now classified as a "probable" human carcinogen, the Clean Air Scientific Advisory Committee of the Science Advisory Board recommended that the NAAQS for lead be based on noncarcinogenic health effects. EPA considers developmental neurotoxity to be the most sensitive endpoint for lead exposure (U.S. EPA, 1986c).

For the Part 503 proposal, EPA considered two alternatives for the percentage of the NAAQS to use to represent the allowable increase in ambient air concentration for lead: 10 percent and 25 percent. The final rule allows a sewage sludge incinerator to increase the lead concentration in the ambient air around the incinerator site by up to 10 percent of the NAAQS. EPA concluded that this lower fraction is warranted due to concern about overexposure of the public to lead. It also appears that almost every sewage sludge incinerator currently can restrict lead emissions so that the resulting increase in the ground-level ambient air concentration of lead is no greater than 10 percent of the NAAQS.

5.6 DERIVATION OF THE LIMITS ON THE CONCENTRATION OF ARSENIC, CADMIUM, CHROMIUM, LEAD, AND NICKEL IN SEWAGE SLUDGE

Subpart E requires that limits be calculated for the five metals using either Equation 2 or Equation 3, from Section 5.2. These equations factor in values for the dispersion factor (DF), control efficiency (CE), and sewage sludge feed rate (SF) that are specific to each sewage sludge incinerator, along with an RSC for arsenic, cadmium, chromium, or nickel, or a percentage of the NAAQS for lead.

In the Part 503 proposal, pollutant limits for the incineration of sewage sludge were to be determined in one of three ways. At the first and simplest level, the dispersion factors and control efficiencies provided in the proposed regulation, which are based on a simplified air dispersion analysis technique, could be used to calculate the limits. If the allowable sewage sludge concentrations could not be met, a site-specific value for the dispersion factor and a control efficiency value provided in the regulation could be used to calculate the limits. If compliance still could not be demonstrated at this second level, site-specific tests for dispersion factors and control efficiencies could both be used. This third level required performance tests and stack sampling of emissions to compute control efficiencies.

The final rule requires that the metals limits be based on site-specific conditions. Dispersion factors and control efficiencies are not provided in the regulation.

The dispersion factor, control efficiency, and sewage sludge feed rate have be derived independently and site-specifically. These factors, however, are also interdependent. For example, in deriving the metals limits, either the average daily design capacity of the sewage sludge incinerator or the average daily amount of sewage sludge fed to the incinerator could be used. Choosing the capacity feed rate results in a lower allowable metal concentration in the sewage sludge. On the other hand, using the average daily amount, which is often a lower feed rate, will increase the allowable metal concentration. Another factor that effects the calculated metal concentration limit is the control efficiency of the APCD(s). Installation of an additional APCD may tend to increase the allowable metal concentration limit in the sewage sludge. The three site-specific factors that are used to determine the metals concentration limits in the sewage sludge are described below.

5.6.1 Dispersion Factor

The dispersion factor correlates the emission rate for a pollutant with the resulting increase in the ambient ground-level pollutant concentration in the air around the sewage sludge incinerator and is expressed in the following manner:

$$\text{Dispersion Factor} = \frac{\text{increase in ambient ground-level pollutant concentration } (\mu g/m^3)}{\text{emission rate (g/sec)}}$$

The dispersion factor is determined through the use of air dispersion models. Site-specific air dispersion modeling conducted for the purpose of establishing pollutant limits under Part 503 can be based on procedures in the *Guidelines on Air Quality Models (GAQM) (Revised)* (U.S. EPA, 1990b; 1986d) if approved by the permitting authority. The GAQM is the principal source of information on the proper selection and regulatory application of air dispersion models. It also provides recommendations on the relevant databases and requirements for modeling ambient air concentrations.

This section summarizes procedures contained in the GAQM. Successful performance of a detailed air dispersion modeling analysis requires a knowledgeable air quality modeler, adequate computer resources, and the ability to assemble the meteorological and source parameter data required for model input.

5.6.1.1 Model Selection

The model selected for deriving the dispersion factor should be the one that most accurately represents atmospheric transport and dispersion in the area around the sewage sludge incinerator. Atmospheric dispersion models have been developed for both simple and complex terrain and for rural and urban applications. The topography and land use in the area surrounding the incinerator must be evaluated to determine the type of model that applies to the specific situation.

Terrain Type. One of the initial determinations to make in model selection regards the type of terrain surrounding the incinerator. If all the terrain in the surrounding area is below the incinerator's lowest stack elevation, incinerator impacts can be adequately addressed with a simple terrain model. If terrain elevations above the lowest stack elevation are identified, use of a complex terrain model is required. Receptors with terrain elevations between the stack height and the plume height (intermediate terrain receptors) must be modeled with both a simple and a complex terrain model.

Urban/Rural Classification. Aside from terrain type, the second major determination to make in model selection regards the urban/rural classification for the area. This determination is typically based on the land use in the area surrounding the emission source. The GAQM provides guidance on acceptable land use classification procedures. Sources located in an urban area should be modeled using urban plume dispersion coefficients, while sources located in a rural area should be modeled using rural plume coefficients. Some models incorporate both urban and rural dispersion coefficients. Other models, particularly those addressing complex terrain, generally accommodate one land use classification or the other.

Simple Terrain. The GAQM identifies both simple and complex terrain models. Simple terrain is defined as terrain elevation below the incinerator's stack elevation. The simple or "noncomplex" terrain model recommended for this situation is the Industrial Source Complex Long-Term model (ISCLT2). The ISCLT2 model is intended for rural or urban areas where terrain elevations do not exceed the stack height. For details on the ISCLT2 model execution and input requirements, consult the *User's Guide for the Industrial Source Complex (ISC2) Dispersion Models - Volumes I, II, III* (U.S. EPA, 1992d) and the *Sludge Incineration Modeling (SIM) System User's Guide* (U.S. EPA, 1990c).

Complex Terrain. The air dispersion models most often recommended for use in complex terrain, where terrain elevations exceed the sewage sludge incinerator stack height, are

the LONGZ and COMPLEX I models. LONGZ is intended for complex urban terrain, wh
COMPLEX I is intended for complex rural terrain.

5.6.1.2 *Source Parameters*

Certain source parameters are required for input to air dispersion models. The stack ga flow rate and the gas exit velocity used as inputs to these models must be confirmed in the field. The input variables typical for sewage sludge incinerator stacks include:

- Stack height above ground level
- Inside stack diameter
- Gas velocity at stack exit*
- Gas flow rate*
- Gas temperature at stack exit*
- Stack-base elevation
- Dimensions of nearby buildings
- Stack coordinates (based on distance from grid origin)
- Emission rate of pollutant*
- Fenceline coordinates (based on distance from grid origin to points along the fenceline)

*these variables are determined from or during a performance test

5.6.1.3 *Good Engineering Practice Stack Height*

Good Engineering Practice (GEP) stack height standards were developed by the Agency to avoid the construction of tall stacks built for the sole purpose of reducing excessive ground-level ambient air concentrations by dilution. Such a practice may not reduce, and may even increase, the cancer potential to the aggregate population. The GEP stack height plays an integral role in determining the impact that sewage sludge incinerator emissions have on ambient air quality. The physical stack height input for modeling cannot be greater than the GEP stack height. If the physical stack height is found to exceed the GEP stack height, the GEP value must be used.

For incinerators with stacks shorter than 65 meters, the actual stack height should be used in the air dispersion model. Most sewage sludge incinerators that are currently operating have stacks shorter than 65 meters. For sewage sludge incinerators with stack heights in excess of 65 meters, Equation 6 presented below must be used to determine the GEP stack height for modeling purposes, as cited in 40 CFR 51.100(ii).

$$H_g = H + 1.5L \qquad (6)$$

where:

H_g = good engineering practice stack height, measured from the ground-level elevation at the base of the stack

H = height of nearby structure(s) measured from the ground-level elevation at the base of the stack

L = lesser dimension, height or projected width, of nearby structure(s)

The requirement to meet the equation above applies to all sewage sludge incinerators with a stack height in excess of 65 meters built <u>after</u> January 12, 1979:

> "...provided that the EPA, State or local control agency may require the use of a field study or fluid model to verify GEP stack height for the source; or the height demonstrated by a fluid model or a field study approved by the EPA, State or local control agency, which ensures that the emissions from a stack do not result in excessive concentrations of any air pollutant as a result of atmospheric downwash, wakes, or eddy effects created by the source itself, nearby structures or nearby terrain features" [40 CFR 51.1(ii)].

Sewage sludge incinerators with stack heights in excess of 65 meters and which were in existence on January 12, 1979, were required to use a second formula to determine the effective stack height. However, because no sewage sludge incinerators in the United States had stack heights in excess of 65 meters prior to January 12, 1979, this other formula does not apply. Sewage sludge incinerator units in existence on December 31, 1970, are not subject to this regulation. The actual stack height at these facilities is considered to be the GEP height in the modeling calculations.

5.6.1.4 Building Downwash Factor

Most sewage sludge incinerators have short stacks that are not much higher than the buildings on which they are located. As a result, the incinerator plumes are impacted by the wake effect created by the buildings and are deflected onto the ground in the area surrounding the building. Because of this aerodynamic building downwash effect, the highest ground-level concentrations of pollutants usually are found close to the incinerator. According to the GAQM, the ISCLT model is the only EPA-accepted model that considers the effect of building downwash in computing ground-level air concentrations of pollutants that occur close to the incinerator.

Building downwash should be included in the modeling analysis for all stacks with heights less than the GEP height. The ISCLT model contains algorithms for determining building downwash. Methods and procedures for determining the appropriate inputs to account for downwash are discussed in the user's guide for ISCLT and the *Guideline for Determination of Good Engineering Practice Stack Height (Technical Support Document for the Stack Height Regulations - Revised)* (U.S. EPA, 1985i).

5.6.1.5 Meteorological Data

Meteorological data used as input data to an air quality dispersion model should be spatially and temporally representative of the area of interest. These data are typically collected by the National Weather Service (NWS) or as part of an on-site measurement program. Other sources of meteorological data may include local universities, the Federal Aviation Administration (FAA), military stations, or pollution control agencies. The NWS and military station data may be purchased from the National Climatic Data Center in Asheville, North Carolina. NWS data are also available on the Support Center for Regulatory Air Model's (SCRAM) Electronic Bulletin Board System (BBS), managed by EPA's Office of Air Quality

Planning and Standards (OAQPS) Source Receptor Analysis Branch of the Technical Support Division.

Guidance on determining representative meteorological data and recommendations for the collection and use of on-site meteorological data are provided in the GAQM, *On-Site Meteorological Program Guidance for Regulatory Modeling Applications* (U.S. EPA, 1987a), and *Ambient Monitoring Guidelines for Prevention of Significant Deterioration (PSD)* (U.S. EPA, 1987b). Further information on meteorological data collection is provided in the *Quality Assurance Handbook for Air Pollution Measurement Systems: Volume IV, Meteorological Measurements* (U.S. EPA, 1983b). Determinations of the appropriate nature of meteorological data is made on a case-by-case basis in consultation with the state or regional air quality meteorologist.

In terms of meteorological data application, some models use hourly weather observations and twice-daily mixing height data, which are preprocessed into a format suitable for model execution. Models designed to predict long-term averages, such as ISCLT2, commonly use Stability Array (STAR) summaries, which are joint frequency distributions of wind speed, wind direction, and Pasquill-Gifford atmospheric stability class.

5.6.1.6 Model Availability

Source code or executable code for the dispersion models can be purchased from the National Technical Information Service (NTIS) or obtained without charge from the SCRAM BBS. Other sources of model code include private vendors. Private vendors frequently supply interactive or menu-driven data entry programs that can considerably simplify the modeling effort. Modelers should verify that they are using the most up-to-date version of the model, particularly when purchasing models through NTIS or private vendors.

5.6.2 Control Efficiency

The control efficiency parameter is determined by site-specific performance tests that measure the degree to which the sewage sludge incinerator and associated APCDs remove a given pollutant from the stack emissions. The control efficiency for a sewage sludge incinerator directly relates the quantity of a pollutant in the sewage sludge that is fed into an incinerator to the quantity of the pollutant emitted from the stack. Thus, for example, if a quantity of sewage sludge being fed to the incinerator contains 100 grams of lead and only 1 gram of lead is emitted, the incinerator has a 99-percent control efficiency for lead. Performance tests also are required because they will generate data on which to base the operating ranges that will be used for an incinerator's permit conditions.

EPA has prepared guidance on the performance test needed to develop the control efficiency for a sewage sludge incinerator. This document is entitled, *POTW Sludge Sampling and Analysis Guidance Document (Volume II)* (U.S. EPA, 1992e), which replaces the document entitled, *Guidance Document for Testing and Permitting Sewage Sludge Incinerators* (MRI, 1990).

There are three major elements of a stack test conducted to derive the control efficiency for a sewage sludge incinerator:

- Sampling and analysis of the sewage sludge for five metals (arsenic, cadmium, chromium, lead, and nickel)
- Sampling and analysis of stack emissions for the five metals
- Monitoring and documentation of operating conditions during the test (including temperature(s), oxygen, and sewage sludge feed rate)

For a list of general guidelines appropriate for conducting a performance test, see Appendix E.

Specific EPA methods for sampling and analysis of metal emissions for the derivation of control efficiency values for sewage sludge incinerators include Method 12 for lead (40 CFR Part 60, Appendix A) and Method 108 for arsenic (40 CFR Part 61, Appendix B). A new sampling and analytical method for hexavalent chromium has recently been validated by EPA (U.S. EPA, 1992b). These methods may be applicable to sewage sludge incinerators in cases where only one metal is being investigated. However, a method has been finalized for the emissions sampling and analysis for multiple metal analytes. It is entitled, "Methodology for the Determination of Metals Emissions in Exhaust Gases From Hazardous Waste Incineration and Similar Combustion Processes." The method can be applied to 16 analytes, making the Multiple Metals Method highly appropriate for the sampling and analysis of the five metals as they are emitted in the exit gas from a sewage sludge incinerator. The Multiple Metals Method, however, only measures total chromium and does not distinguish between total chromium and hexavalent chromium. A copy of this final method can be found in the *Methods Manual for Compliance with the BIF Regulation* (U.S. EPA, 1991e) and in the *POTW Sludge Sampling and Analysis Guidance Document (Volume II)* (U.S. EPA, 1992e). This latter document also recommends a quality assurance/quality control (QA/QC) plan for sewage sludge sampling and analysis. A QA/QC plan is recommended to ensure that the field sampling and laboratory analysis will provide data of sufficient quality for regulatory compliance.

5.6.3 Sewage Sludge Feed Rate

During the performance test, a sewage sludge feed rate is selected that is either the average daily amount of sewage sludge fired in all sewage sludge incinerators within the property line of the site for the number of days in a 365 day period that each sewage sludge incinerator operates or the average daily design capacity for all sewage sludge incinerators within the property line of the site. The sewage sludge feed rate will be determined as part of a permit strategy once the actual concentration of the pollutants of concern in the sewage sludge is known and the control efficiency and dispersion factor are calculated. In general, the higher the feed rate, the "cleaner" the sewage sludge quality must be to meet the pollutant concentration limit.

5.6.4 Example of Calculation for the Arsenic Limit

As required by Subpart E, site-specific limits are calculated for five metals in the sewage sludge. These calculated limits become part of the treatment works permit requirements. This section includes an example of a calculation for the limit on arsenic using values for the dispersion factor, control efficiency, and sewage sludge feed rate that are representative of a typical sewage sludge incinerator.[1] For the arsenic limit, the RSC for arsenic provided in Subpart E is used. Equation 2 from Section 5.2 is used below to calculate the pollutant limit for arsenic:

$$C = (RSC \times 86{,}400)/(DF \times [1\text{-}CE] \times SF)$$

where:

C = the allowable average daily concentration of arsenic in the sewage sludge (mg/kg)

RSC = risk-specific concentration for arsenic: 0.023 $\mu g/m^3$

DF = dispersion factor: 3.4 ($\mu g/m^3/g/sec$)

CE = the sewage sludge incinerator control efficiency: 0.975

SF = the sewage sludge feed rate: 12.86 dmt/day

86,400 = conversion factor: 86,400 sec/day

$$C_{arsenic} = (0.023\ \mu g/m^3 \times 86{,}400\ sec/day)/(3.4(\mu g/m^3/g/sec) \times [1\text{-}0.975] \times 12.86\ dmt/day)$$

$$C_{arsenic} = 1{,}818\ mg/kg$$

5.6.5 Example of Calculation for the Lead Limit

The following calculations derive the limit on the concentration of lead using Equation 3 from Section 5.2:

$$C = (.10)(NAAQS) \times 86{,}400/(DF \times [1\text{-}CE] \times SF)$$

---

[1] The values for the dispersion factor and the sewage sludge feed rate are from POTW 353 listed in the National Sewage Sludge Survey. POTW 353 is a representative multiple-hearth furnace. The values for the control efficiency for arsenic and lead emissions represent the median control efficiency observed at multiple-hearth furnaces from the National Sewage Sludge Survey.

where:

C = the allowable average daily concentration of lead in the sewage sludge, in milligrams per kilogram of total solids, dry weight basis (mg/kg)

.10 = the percentage of the NAAQS for lead that sewage sludge incinerators are allowed to add to the lead concentration in the ambient air around the incinerator site.

NAAQS = National Ambient Air Quality Standard for lead: 1.5 $\mu g/m^3$

DF = dispersion factor: 3.4 ($\mu g/m^3/g/sec$)

CE = sewage sludge incinerator control efficiency: 0.916

SF = sewage sludge feed rate: 12.86 dmt/day

86,400 = conversion factor: 86,400 sec/day

C_{lead} = 1.5 $\mu g/m^3$ x 8,640/(3.4($\mu g/m^3/g/sec$) x [1-0.916] x 12.86 dmt/day)

C_{lead} = 3,529 mg/kg

5.7 POLLUTANT LIMITS FOR BERYLLIUM AND MERCURY

Beryllium and mercury are regulated under the NESHAPs, 40 CFR Part 61, Subpart C and Subpart E, respectively. Subpart E of Part 503 requires that the NESHAPs for these two metals, which are health-based, not be violated. The beryllium NESHAP, however, only applies to a person firing sewage sludge who receives beryllium-bearing waste at the treatment works. Because only a few facilities fall into this category, beryllium is most often not required to be monitored. For a treatment works that knows it receives beryllium-bearing waste, it must test for beryllium as part of the performance test to determine permit conditions. From this test, the permitting authority will determine whether beryllium monitoring limits will be required as a permit condition. The beryllium NESHAPS requires that, during the performance test, beryllium be analyzed in emissions and in the sewage sludge and that all operating conditions be documented.

In the proposed Part 503 rule, beryllium and mercury were to be regulated in the sewage sludge along with the other metals. The Part 503 proposal contained an equation for calculating the beryllium and mercury limits in the sewage sludge that was developed specifically for these two metals. The final Part 503 rule uses the NESHAPs for each metal as the regulated limits. The appropriate methods for analysis are listed in 40 CFR Part 61, Subpart C and E, respectively. *The POTW Sludge Sampling and Analysis Guidance Document (Volume II)* recommends a sewage sludge analysis method for beryllium, if necessary.

The NESHAPs for beryllium emissions from sewage sludge incinerators is stated either as a limit on the rate of emissions from the stack (10 g/day) or as a limit on the ambient air concentration of beryllium in the vicinity of the sewage sludge incinerator (0.01 $\mu g/m^3$, averaged over a 30-day period). The beryllium NESHAPs also contains requirements for stack sampling and air sampling, as well as a provision that the permitting authority may approve an alternative method (40 CFR Part 61.13(h)(1)(ii)).

The NESHAPs for mercury emissions from sewage sludge incinerators is a limit on the rate of emissions from the stack (3,200 g/day). However, a sewage sludge incinerator can show compliance by either monitoring the air emissions or the sewage sludge for mercury. The NESHAPs provides an equation that relates sewage sludge concentration to emissions and factors in the sewage sludge feed rate and the weight fraction of solids in the sewage sludge. If the mercury concentration in the sewage sludge is monitored, Method 105 in Appendix B of the NESHAPs must be used. The mercury NESHAPs contains additional requirements for stack sampling and sewage sludge sampling.

Although beryllium currently is considered a carcinogen, it was considered a noncarcinogen at the time the NESHAP for beryllium was established in 1973. Therefore, the NESHAPS limit was considered to protect against noncarcinogenic health effects from beryllium exposure. The most sensitive endpoint for exposure to beryllium through the inhalation pathway is inflammation and granulomatous lesion of the lung (Cullen, 1987) and that for mercury, also considered a noncarcinogen at the time the NESHAP was established, is irreversible damage to the central nervous system (U.S. EPA, 1984).

SECTION SIX

DEVELOPMENT OF THE OPERATIONAL STANDARD FOR TOTAL HYDROCARBONS

EPA regulates organic compounds emitted from sewage sludge incinerators by limiting emissions of total hydrocarbons (THC). The THC standard of 100 ppm, measured by use of a THC monitor with a "hot" sampling line and corrected to 7-percent oxygen and for zero-percent moisture is measured at the stack. The THC operational standard is based on THC emissions data from several sewage sludge incinerators and represents what is achievable with available technology at a sewage sludge incinerator. To judge whether this THC operational standard is also protective of public health to the 1 x 10^{-4} risk level, EPA used risk assessment methodology and based its calculations on data from the National Sewage Sludge Survey.

This section first explains EPA's decision to use THC as a surrogate for organic emissions from sewage sludge incinerators. Section 6.2 discusses the statutory basis for regulating THC through a technology-based operational standard instead of by setting a risk-based limit. Section 6.3 provides the basis for setting the operational standard at 100 ppm measured with the previously mentioned monitoring device and corrected for oxygen and moisture content. Section 6.4 outlines the THC emission excursion policy, while Section 6.5 explains the correction factors for oxygen and moisture content. In Section 6.6, the risk-based analysis of the THC operational standard is provided. This section presents the equations used to determine the degree of risk posed by the operational standard and discusses the factors used in these equations, such as the dispersion factor, the gas flow rate, and the weighted q_1^*, to derive site-specific, risk-specific concentrations (RSCs) and risk levels for THC.

6.1 THC AS A SURROGATE FOR ORGANIC EMISSIONS

EPA regulates the emission of organic pollutants from sewage sludge incinerators by setting a limit on the concentration of total hydrocarbons (THC) measured in the stack gas.

Organic pollutants are chemical compounds that contain one or more carbon atoms. Hydrocarbons are the simplest organic compounds and contain only carbon and hydrogen atoms.

There are several difficulties in monitoring organic emissions. Most important is that sampling and analysis techniques are not available to identify or quantify all potential organic compounds emitted from sewage sludge incinerators, nor are toxicity data available for all compounds. At present, only a few tests have been conducted to identify and quantify organic emissions from sewage sludge incinerators. These tests are both complex and expensive. In addition, these measurements are conducted on a noncontinuous basis, which does not allow the sewage sludge incinerator operator to make timely corrections to management practices when emissions exceed regulatory levels.

EPA determined, however, that organic emissions could be controlled by monitoring for THC instead of monitoring the total emissions of individual organic compounds. EPA tests at four sewage sludge incinerators (U.S. EPA, 1991f; 1991g; 1991h; 1991i) showed a significant correlation between the THC concentration measured continuously using a flame ionization detector and the sum of the concentrations of 21 volatile and semivolatile organic compounds sampled and analyzed for in each sampling run (see Table 6-1). This relationship is illustrated in Figure 6-1, where the THC concentration in stack gas is plotted against the sum of the concentrations of the 21 organic compounds detected in each sample. The full data set on which Table 6-1 and Figure 6-1 are based appears in Appendix F.

Analysis of the data revealed a strong correlation between THC and total organics, as measured by the Spearman rank correlation coefficient. A correlation coefficient based on rank was chosen because a linear relationship between THC and total organics is not required to determine the strength of the correlation. The results of the analysis show a Spearman correlation coefficient of 0.85, indicating that changes in THC concentrations are highly significantly correlated with changes in the sum of the concentrations of the 21 organics.

Furthermore, a regression analysis of the data reveals an R^2 of 0.81 (see Figure 6-1). This figure indicates that 81 percent of the change in the THC concentration is accounted for by the change in the summation of the volatiles and semivolatiles in the emissions. EPA concluded

TABLE 6-1

CORRELATION BETWEEN THC AND TOTAL ORGANICS—SUMMARY EMISSIONS DATA FROM FOUR SEWAGE SLUDGE INCINERATOR UNITS

Site	Run	THC (ppm)	Total Organics ($\mu g/m^3$)
1	1	9.00	3,171.8
1	2	16.00	3,918.2
1	3	9.00	3,230.4
1	4	7.50	2,343.8
1	5	8.00	4,242.0
2	1	21.10	4,591.1
2	2	21.00	3,726.0
2	3	34.00	6,950.3
2	4		7,558.8
2	5		7,423.8
2	6		14,265.0
3	1	0.90	13,930.4
3	2		850.6
3	3	2.00	236.8
4	1		12,403.9
4	2	21.30	3,842.7
4	3	182.00	13,930.4
4	4	1.01	828.5
4	5	1.72	236.8
4	6	0.91	95.9
4	7	12.60	776.9
4	8	12.60	931.4
4	9	28.20	4,963.5

Source: U.S. EPA, 1991f; 1991g; 1991h; 1991i.

TABLE 6-1

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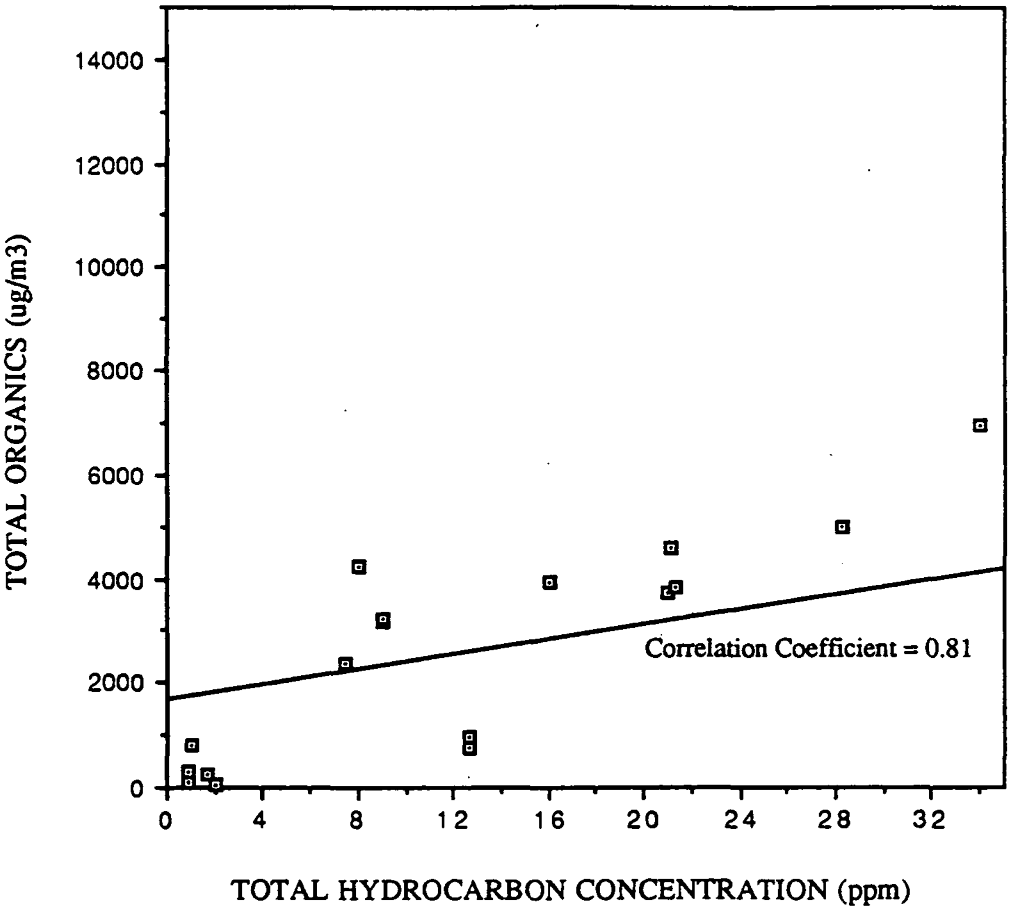
2	2	21.00	3,726.0
2	3	34.00	6,950.3
2	4		7,558.8
2	5		7,423.8
2	6		14,265.0
3	1	0.90	13,930.4
3	2		850.6
3	3	2.00	236.8
4	1		12,403.9
4	2	21.30	3,842.7
4	3	182.00	13,930.4
4	4	1.01	828.5
4	5	1.72	236.8
4	6	0.91	95.9
4	7	12.60	776.9
4	8	12.60	931.4
4	9	28.20	4,963.5

Source: U.S. EPA, 1991f; 1991g; 1991h; 1991i.

FIGURE 6-1

TOTAL HYDROCARBON CONCENTRATION (THC) VS. TOTAL ORGANICS CONCENTRATION OF VOLATILES AND SEMIVOLATILES DETECTED IN FOUR SEWAGE SLUDGE INCINERATORS



Source: U.S.EPA, 1991f; 1991g; 1991h; 1991i.

that the correlation of THC to the sum of the concentration of volatile and semi-volatile organics in sewage sludge incinerator emissions is sufficiently high to support the use of THC as a basis for a regulatory control of organic emissions.

THC is a good surrogate for organics not only because of the significance of the correlation but also because it is easier and less expensive (excluding capital expenditures) to monitor for a subset of simple organic compounds than to monitor for total organics, which include complex compounds. In addition, THC monitoring can be performed continuously with a flame-ionization detector, which enhances the ability of a sewage sludge incinerator operator to correct management practices and incinerator operational conditions when THC emissions exceed regulatory levels. EPA uses carbon monoxide (CO) and THC emissions as a surrogate for organic emissions in its hazardous waste program. For the case of sewage sludge incinerators, however, THC is a more appropriate surrogate for organics than CO.

A THC monitor can detect hydrocarbons present in the vapor phase. Unheated (cold) THC monitors, however, can occasionally fail to detect the higher molecular weight compounds with low vapor pressure because these compounds condense in the sample line of the monitoring device, therefore providing an inaccurate measure of the total organic mass emission rate of a combustion gas. Using a heated monitoring device, which maintains stack outlet temperature, makes it less likely that those compounds with low volatility will condense in the sampling line and more likely that they will reach the monitor. Because of this advantage of a heated sampling line, Subpart E of the sewage sludge regulation requires that THC measurements be taken "hot." (Section 7.1 discusses in more detail the rationale behind the use of a hot THC monitoring device.)

EPA test data also indicate that it is impossible to regulate total organics by setting limits on the concentration of these pollutants in the sewage sludge. To derive an allowable concentration of organics in sewage sludge would require that a "destruction and removal efficiency" be established for the organics, similar to the control efficiency derived for the five metals for which pollutant limits are calculated. This destruction and removal efficiency approach to controlling organics fails to account directly for emissions of products of incomplete combustion (PICs), which can be as toxic as, or more toxic than, the principal organic hazardous constituents. The data also indicate that, although most organic constituents in the sewage sludge are readily transformed into nonhazardous substances during the combustion process, organics in the drying zone of multiple-hearth sewage sludge incinerators are volatilized directly into the exhaust gases and bypass combustion. For these reasons, a destruction and removal efficiency approach is not feasible for regulating organics in the sewage sludge. Instead, EPA decided to use THC as a surrogate for organics and monitor for THC in the stack gas.

6.2 STATUTORY BASIS FOR USING AN OPERATIONAL STANDARD

Section 405 (d) of the Clean Water Act requires EPA to develop regulations for the use or disposal of sewage sludge that are protective of public health from any reasonably anticipated adverse effects of the pollutants. In the case of THC, the potential adverse health effects from excessive exposure to certain organic pollutants may be various forms of cancer and noncancerous effects.

EPA's original approach to regulating THC, as outlined in the proposed rule, was to establish a site-specific limit on THC emissions that varied according to the characteristics of the sewage sludge incinerator and site conditions. EPA derived a standard RSC value for THC from a THC cancer potency value that was weighted to account for the different cancer potencies of each carcinogen detected or suspected to be in sewage sludge incinerator emissions.

Comments received on the proposed regulation (U.S. EPA, 1989) suggested that such a risk-based methodology might produce unrealistic risk estimates and that EPA could not conclude with certainty that such emission limits calculated from such a methodology were protective of public health. The Agency concurred with these comments and decided to replace its proposed THC approach with an operational standard that is technology-based.

The CWA specifically provides for alternatives to numeric limitations for sewage sludge use or disposal in certain circumstances:

> "Alternative standards—For purposes of this subsection, if, in the judgment of the Administrator, it is not feasible to prescribe or enforce a numeric limitation for a pollutant identified under paragraph (2), the Administrator may instead promulgate a design, equipment, management practice, or operational standard (emphasis added), or combination thereof, which in the Administrator's judgment is adequate to protect public health and the environment from any reasonably anticipated adverse effect of such pollutant." [Clean Water Act, Section 405 (d)(3)]

EPA has selected a regulatory limit for sewage sludge incinerators of 100 ppm THC measured with a hot sampling line monitor for three main reasons: (1) it is within the range of values reported in the Agency's data base for sewage sludge incinerators; (2) based on aggregate effects risk assessment, there are minimal pollutant effects from current sewage sludge incineration practices; and (3) based on existing data, the Agency concluded that the limit is protective of public health at a risk level of 1×10^{-4} to an HEI.

6.3 BASIS FOR THC OPERATIONAL STANDARD

Part 503 requires that THC in the stack gas not exceed the 100 ppm THC limit, as measured with a hot sampling line monitoring device and corrected to 7-percent oxygen and for zero-percent moisture. Compliance with the monthly average THC operational standard of 100 ppm is determined by calculating the arithmetic mean of the hourly averages for the hours a sewage sludge incinerator operates during the calendar month. An hourly average is the arithmetic mean of all THC measurements taken during each operating hour with a minimum of two measurements taken during the hour. EPA does not require monitoring of organic pollutants in the sewage sludge, as is required for the metals limits, because organic pollutant emissions are determined more by the operational characteristics of a sewage sludge incinerator unit (e.g., combustion temperature, percent excess air) than by their presence in sewage sludge.

EPA based the THC operational standard of 100 ppm on extensive testing at three sewage sludge incinerators—two multiple-hearth furnaces (MHFs) and one fluidized-bed furnace (FBF). One of the MHFs (Site 6) was outfitted with a scrubber but no electrostatic precipitator (ESP) while the other MHF (Site 9) had both a Venturi scrubber and a full-scale wet ESP (WESP). The FBF (Site 8) was outfitted with a Venturi scrubber and a pilot-scale WESP. The

MHFs were run under normal operating conditions and improved conditions (e.g., higher combustion temperatures, optimizing excess air requirements, firing sewage sludge with a lower water content), and the FBF was run under normal conditions only (U.S. EPA, 1991a; 1991b; 1991c).

The operational standard is based on actual data from the three sites and is not based on parametric statistical models from which inferences were made. The data for these sites are summarized in Table 6-2. Measurements performed at all three sewage sludge incinerators were taken with an unheated ("cold") sampling line monitoring device. At the MHF with a WESP, the measurements were taken at the outlet from the scrubber, whereas measurements from the MHF and FBF with WESPs were taken at the outlet from the WESPs.

These data show that for the two MHFs, there is a dramatic difference between the data obtained under improved operating conditions and those obtained under normal conditions. For example, at Site 6 under normal operations, the cold sampling line monitor measured 20 ppm (equivalent to 30-ppm measured with a hot sampling line) or less only 3.9 percent of the time (3.9th percentile), whereas under improved conditions, emissions of THC remained under 20 ppm 98.6 percent of the time (98.6th percentile). At Site 9, a nearly identical result was obtained.

Data obtained from the FBF unit (Site 8) show that much lower THC emission levels can be expected from this type of sewage sludge incinerator. At the 99th percentile, under normal operating conditions, the THC emission level was 8.3 ppm measured with a cold sampling line (U.S. EPA, 1992f). For a discussion of these test results see Appendix G.

After evaluating the aggregate impact analysis, which showed that there are minimal health effects from current sewage sludge incineration practices, along with the site data on THC emissions, EPA decided to set the THC operational standard at 100 ppm measured with a hot sampling line. EPA believes that the 100 ppm standard can reasonably be met by most sewage sludge incinerators without modifying any equipment or operations.

TABLE 6-2

SUMMARY OF TOTAL HYDROCARBONS EMISSIONS MEASURED WITH A "COLD" MONITOR AND ADJUSTED TO 7-PERCENT OXYGEN*

Site	Incinerator Type	Operating Conditions**	Number of Data Points	PERCENTILE FOR			ppm AT PERCENTILE		
				20 ppm	25 ppm	30 ppm	90%	95%	99%
Site 6	MHF[1]	Normal	909	3.9%	10.7%	24.0%	63.0	98.0	193.0
		Improved	655	98.6%	100.0%	100.0%	17.7	18.5	21.0
Site 8	FBF[2]	Normal	769	100.0%	100.0%	100.0%	4.6	5.1	8.3
Site 9	MHF[3]	Normal	1395	1.1%	4.7%	8.0%	390.0	503.0	1,194.0
		Improved	1512	98.8%	99.3%	99.7%	15.9	17.2	20.3

*Data do not include measurements that have an event flag, such as "plant not operating" or "monitor failure."

**Improved operating conditions includes higher combustion temperatures, optimizing excess requirements, and firing sewage sludge with a lower water content.

[1] MHF with scrubber and no electrostatic precipitator
[2] FBF with Venturi scrubber and pilot-scale wet electrostatic precipitator
[3] MHF with Venturi scrubber and full-scale wet electrostatic precipitator

(U.S. EPA, 1992f)

TABLE 6-2

SUMMARY OF TOTAL HYDROCARBONS EMISSIONS MEASURED WITH A "COLD" MONITOR AND ADJUSTED TO 7-PERCENT OXYGEN*

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				20 ppm	25 ppm	30 ppm	90%	95%	99%
Site 6	MHF[1]	Normal	909	3.9%	10.7%	24.0%	63.0	98.0	193.0
		Improved	655	98.6%	100.0%	100.0%	17.7	18.5	21.0
Site 8	FBF[2]	Normal	769	100.0%	100.0%	100.0%	4.6	5.1	8.3
Site 9	MHF[3]	Normal	1395	1.1%	4.7%	8.0%	390.0	503.0	1,194.0
		Improved	1512	98.8%	99.3%	99.7%	15.9	17.2	20.3

*Data do not include measurements that have an event flag, such as "plant not operating" or "monitor failure."

**Improved operating conditions includes higher combustion temperatures, optimizing excess requirements, and firing sewage sludge with a lower water content.

[1] MHF with scrubber and no electrostatic precipitator
[2] FBF with Venturi scrubber and pilot-scale wet electrostatic precipitator
[3] MHF with Venturi scrubber and full-scale wet electrostatic precipitator

(U.S. EPA, 1992f)

As noted earlier, Subpart E of the sewage sludge regulation requires that THC be monitored using a heated sampling monitoring device. Because measurements at the three sewage sludge incinerators were taken using an unheated (cold) sampling line technique, further tests were conducted to develop a conversion factor. Based on extensive data from a fourth MHF (Site 4), where emissions were measured using both a heated and unheated (cold) sampling line THC analyzer, EPA determined that the difference between measurements conducted using a hot sampling line analyzer and those measured with a cold sampling line monitor was 10 ppm at the 90th percentile (U.S. EPA, 1992g).

Emission samples were taken using both hot and cold sampling line THC analyzers at the inlet to the Venturi scrubber after the gas exited the afterburner. EPA developed two basic criteria by which to choose data to use in developing the conversion factor between hot and cold THC analyzer measurements. First, the THC measurements had to be performed simultaneously using hot and cold sampling line analyzers. Second, the measurements had to be for emissions near or below the regulatory level of 100 ppm hot. The data meeting these criteria were used to develop the conversion factor.

In general, hot and cold sampling line THC measurements taken when emissions are near the regulatory level (100 ppm hot) differ less than those taken at higher emission levels. This result occurs because unheated sample lines condense a fraction of the volatile organics. Thus, the absolute difference between THC measured hot and cold will increase as the emission level increases. For a discussion of these test results, see Appendix H.

6.4 CORRECTION FACTORS FOR OXYGEN AND MOISTURE CONTENT AND A SAMPLE CALCULATION FOR THC CONCENTRATION

Subpart E requires that measurements of THC emissions from a sewage sludge incinerator be corrected to account for the actual moisture content and amount of oxygen present in the combustion gases. Stoichiometric air is the amount of air that contains the amount of oxygen needed to completely combust the organic fraction in the combustion chamber (see Section 2.2.1). "Excess air" is the amount of air in the combustion chamber in excess of the stoichiometric air requirement. The introduction of extra oxygen, or excess air, into the combustion chamber enhances the combustion process. The use of excess air is also a management practice employed by sewage sludge incinerator operators to account for variations in the system, including the sewage sludge feed rate and the sewage sludge moisture content.

The Subpart E requirement that THC measurements be corrected to 7-percent oxygen stipulates that the measurements be calculated assuming that 7 percent more oxygen is being introduced into the combustion chamber than is needed to fully combust the organic material. The 7-percent oxygen value is the standard amount of oxygen used to reference measurements required for pollutant limits expressed as a concentration (i.e., ppm) rather than as an emission rate (i.e., $\mu g/m^3$), and 7-percent oxygen in the combustion gas is equivalent to 50-percent excess air. It is also the amount of oxygen used by most efficient combustion processes to enhance combustion. However, any percentage of oxygen could have been chosen as long as all THC measurements were corrected to that value.

If the THC measurement were not corrected to 7-percent oxygen or some other standard, sewage sludge incinerators could lower the THC concentration detected without reducing the actual emission rate of THC simply by adding higher rates of air to the incinerator. High oxygen rates dilute the THC concentration detected by the flame-ionization detector and could allow an incinerator to appear to be meeting the THC standard, when actually the THC emissions are in excess of those set by the standard.

Subpart E also requires that THC measurements be based on zero-percent moisture for a similar reason as that for the 7-percent oxygen requirement. Moisture can dilute THC measurements similar to excess air. Since most sewage sludges are composed of a significant percentage of water, the THC measurement must be based on an unchanging moisture content. THC is measured conventionally in terms of a dry-volumetric basis, so zero percent is used for the moisture content.

Subpart E requires that both the moisture content and the oxygen concentration in stack gas be corrected so that THC emissions can be compared to an operational standard. As discussed in Section 7.1, THC emissions are initially measured using a flame ionization detector.

This THC reading will contain a certain percentage of moisture. Equation 1 below corrects this THC_{wet} concentration to zero-percent moisture (THC_{dry}). The percent moisture concentration in the stack gas is determined in two ways depending on whether the THC measurements are taken in saturated conditions (100 percent relative humidity) or non-saturated conditions (see Section 7.3).

$$\mathbf{THC_{dry} = THC_{wet}/1 - X} \qquad (1)$$

where:

THC_{dry} = ppm THC corrected to zero-percent moisture

THC_{wet} = ppm THC measured with a flame ionization detector

X = percent moisture content, in hundredths (volume/volume)

The THC_{dry} calculation from Equation 1 is input into Equation 2 below, along with the percent oxygen concentration, to determine the THC concentration at 7-percent oxygen and zero-percent moisture. The percentage of oxygen in the stack gas is measured by an oxygen monitor (see Section 7.2).

$$\mathbf{THC_{corrected} = THC_{dry} \times 14/21 - Y} \qquad (2)$$

where:

$THC_{corrected}$ = ppm THC corrected to zero-percent moisture and 7-percent oxygen

THC_{dry} = ppm THC corrected to zero-percent moisture

21 = the percent of oxygen in air, rounded

14 = the difference between the percent of oxygen in air (21 percent) and 7 percent oxygen

Y = percent oxygen concentration in the sewage sludge incinerator stack exit gas (dry volume/dry volume)

The sample calculation below uses hypothetical data in Equations 1 and 2 to derive a $THC_{corrected}$ value that would be compared to the 100 ppm THC standard to determine compliance. The assumptions below are for THC measurements taken in the stack gas exiting a wet scrubber, where saturated conditions are assumed to be present (see Section 7.3).

Sample Calculation Assumptions:

THC_{wet} = 40 ppm
stack gas temperature = 120°F (49°C).
percent moisture = .12 (in hundredths)
percent oxygen = 10 (actual percent)

$$\begin{aligned} THC_{dry} &= THC_{wet}/1 - X \\ &= 40 \text{ ppm}/1 - .12 \\ &= 45.5 \text{ ppm} \end{aligned}$$

$$\begin{aligned} THC_{corrected} &= THC_{dry} \text{ X } 14/21 - \\ &= 45.5 \text{ ppm X } 14/21 - 10 \\ &= 58 \text{ ppm} \end{aligned}$$

6.5 RISK POSED BY THE THC OPERATIONAL STANDARD

As mentioned in Sections 6.2 and 6.3, EPA based the 100 ppm THC standard on sewage sludge incinerator technology and not risk assessment methodology. Even so, EPA assessed the THC operational standard for risk to judge whether the THC operational standard is protective of public health at a 10^{-4} risk level to an HEI. EPA performed its risk assessment using the 100 ppm THC emission standard and data on 23 POTWs operating sewage sludge incinerators obtained from the National Sewage Sludge Survey (NSSS). The results of the analysis showed that the risk associated with emissions at a 100 ppm THC level at all 23 plants were calculated to be lower than the 10^{-4} risk level, which is at the upper end of the Agency's allowable risk. The remainder of this section describes how EPA used risk assessment methodology to judge the risk to an HEI posed by the THC operational standard.

6.5.1 Equations Used to Determine the Degree of Risk

To evaluate the risk posed by the THC operational standard, EPA used two equations, the first of which (Equation 2) calculates an RSC value for THC based on the 100 ppm emission standard, two site-specific variables pertaining to characteristics of a sewage sludge incinerator, and a conversion factor. The RSC is then input into a second equation (Equation 3) used to conduct a risk assessment to determine the degree of risk posed by the THC emission standard under the site-specific conditions. Twenty-three risk assessments were conducted, one for each POTW operating sewage sludge incinerators for which complete data were available in the NSSS data base. Table 6-3 lists each of the 23 sewage sludge incinerators in the NSSS along with the calculated dispersion factor, gas flow rate (see Section 6.6.2), and risk level. In no case did the risk level exceed 10^{-4}. (For more information on how the dispersion factors were calculated, see U.S. EPA, 1992h; Hughes 1991.) These POTWs are statistically representative of all POTWs operating sewage sludge incinerators nationwide. The risk level calculated for each incinerator was compared to the 10^{-4} risk level. Equations 2 and 3 are presented below:

$$RSC_{sp} = \frac{THC \times DF \times GF}{3.24 \times 10^9} \qquad (2)$$

where:

RSC_{sp} = site-specific risk-specific concentration for THC, in micrograms per cubic meter ($\mu g/m^3$).

THC = operational standard for THC in the sewage sludge incinerator emissions, in parts per million, on a volumetric basis, corrected for 7-percent oxygen and zero-percent moisture (dry basis) (ppm).

DF = dispersion factor (the ratio of the increase in ground-level air concentration at or beyond the property line to the mass emission rate for the pollutant from the stack), in micrograms per cubic meter, per gram, per second ($\mu g/m^3/g/sec$).

GF = maximum combustion gas flow rate from the sewage sludge incinerator, in gram-moles per day (g-moles/day).

3.24×10^9 = combination of conversion factors that express the RSC value as a volumetric concentration.

TABLE 6-3

RISK LEVELS AND OTHER DATA FOR 23 SEWAGE SLUDGE INCINERATORS CALCULATED FROM DATA PROVIDED BY THE 1988 NATIONAL SEWAGE SLUDGE SURVEY

(Based on 100 ppm THC)

Site	Incinerator Type	Air Pollution Controls	Dispersion Factor ($\mu g/m^3/g/sec)^{-1}$	Gas Flow Rate (g-moles/day)	Risk-Specific Concentration ($\mu g/m^3$)	Risk Level
212	MHF	Scrubber	0.42	191,785,257	2.49	8.52E-06
221	MHF	Scrubber, Afterburner w/Heat Exch.	1.37	137,339,818	5.81	1.99E-05
317	MHF	Scrubber, Afterburner w/Heat Exch.	4.02	31,690,611	3.93	1.35E-05
319	MHF	Scrubber	14.27	25,594,905	11.27	3.86E-05
351	MHF	Scrubber, Afterburner w/Heat Exch.	0.30	29,090,531	0.27	9.34E-07
011	MHF	Scrubber, Afterburner	9.19	16,606,051	4.71	1.61E-05
040	MHF	Scrubber	6.89	6,493,943	1.38	4.73E-06
051	MHF	Scrubber	3.26	7,979,586	0.80	2.75E-06
072	EF	Scrubber	23.43	19,360	0.01	4.80E-08
076	MHF	Scrubber	0.79	19,579,456	0.48	1.64E-06
157	MHF	Scrubber, Afterburner w/Heat Exch.	1.26	4,908,786	0.19	6.55E-07
172	MHF	Scrubber	6.92	4,781,872	1.02	3.50E-06
181	MHF	Scrubber	0.76	17,727,979	0.42	1.43E-06
209	FBF	Scrubber	23.80	3,747,667	2.75	9.44E-06
210	MHF	Scrubber, Afterburner	1.26	3,002,822	0.12	4.00E-07
214	MHF	Scrubber	2.66	31,297,383	2.57	8.81E-06
244	MHF	Scrubber	8.86	1,853,342	0.51	1.74E-06
287	MHF	Scrubber, Afterburner	3.27	8,327,339	0.84	2.88E-06

$$RL_{sp} = \frac{RSC_{sp} \times q_1{*} \times Ia}{BW \times 10^3} \quad (3)$$

where:

RL_{sp} = site-specific risk level, or the probability of developing cancer, unitless

RSC_{sp} = site-specific risk-specific concentration for THC, in micrograms per cubic meter ($\mu g/m^3$)

$q_1{*}$ = weighted cancer potency value for THC, in milligrams per kilogram-day $(mg/kg\text{-}day)^{-1}$

I_a = inhalation rate, in cubic meters per day (m^3/day)

BW = body weight, in kilograms (kg)

10^3 = conversion factor from micrograms to milligrams (1,000 $\mu g/mg$)

6.5.2 Derivation of Estimated Site-Specific RSC Values for THC

Unlike the pollutant limit calculations for the five metals that use a risk-based equation, the THC risk assessments require that site-specific RSC values be calculated for each sewage sludge incinerator (which may include one or more sewage sludge incinerator units). RSCs are then used to calculate site-specific risk levels. As Equation 2 shows, these THC RSC values are based on four factors: the THC operational standard, the dispersion factor, the gas flow rate, and a conversion factor. The derivation of the THC operational standard of 100 ppm measured with a heated monitor was described in Section 6.3. This section describes the derivation of the site-specific calculations for the dispersion factor and the gas flow rate and provides an explanation for the conversion factor.

TABLE 6-3 (cont.)

Site	Incinerator Type	Air Pollution Controls	Dispersion Factor ($\mu g/m^3/g/sec)^{-1}$	Gas Flow Rate (g-moles/day)	Risk-Specific Concentration ($\mu g/m^3$)	Risk Level
314	MHF	Scrubber	31.20	3,073,146	2.92	1.00E-05
447	MHF	Scrubber	2.29	14,983,785	1.29	4.42E-06
084	FBF	Scrubber	26.58	7,916,493	6.49	2.23E-05
353	MHF	Scrubber	3.41	1,746,395	0.18	6.30E-07
149	FBF	Scrubber	8.80	4,695,776	1.28	4.37E-06

Note: EF = Electric Furnace
FBF = Fluidized Bed Furnace
MHF = Multiple Hearth Furnace

Source: ERG estimates based on 1988 National Sewage Sludge Survey, EPA.

The derivation of the annual average daily fuel usage rate (FR) involves an extensive calculation. The formula for this calculation, including related assumptions and data, can be found in Appendix J.

To derive the fuel constant for #2 fuel oil (FC), the following factors were used:

$FC_{\#2\text{ oil}}$ = 18,300 Btu/lb x 7.5 lb/air/10,000 Btu x 1.50 x 1 g-mole air/28.84 g air x 453.6 g-mole /lb-mole

$FC_{\#2\text{ oil}}$ = 323.80

where:

18,300 = average heating value of #2 fuel oil, in Btu/lb

$\frac{\text{7.5 lb/air}}{\text{10,000 Btu}}$ = stoichiometric air requirement for combustion of fuel oil

1.50 = 50 percent excess air rate (7-percent oxygen)

28.84 = molecular weight of air

453.6 = conversion from lb-moles gas to g-moles gas

The equations above are based on standard combustion parameters, data on the sewage sludge, and data on the amount of auxiliary fuel used. The calculation provides an estimate of the total gas flow on a dry weight basis at 7-percent oxygen, the same amount of excess air as is required in the regulation. The gas flow rates have been calculated for the 23 sewage sludge incinerators in the NSSS and appear in Table 6-3.

6.5.2.3 Conversion Factor

The THC emission value is converted to a volumetric basis for consistency with the THC analyzer that also monitors on a volumetric basis. To convert the THC concentration into an emission rate, a series of conversion factors were required. The following factors have been combined to form the conversion factor of 3.24×10^9:

$$RL_{sp} = \frac{RSC_{sp} \times q_1{*} \times Ia}{BW \times 10^3} \qquad (3)$$

where:

RL_{sp} = site-specific risk level, or the probability of developing cancer, unitless

RSC_{sp} = site-specific risk-specific concentration for THC, in micrograms per cubic meter ($\mu g/m^3$)

$q_1{*}$ = weighted cancer potency value for THC, in milligrams per kilogram-day $(mg/kg\text{-}day)^{-1}$

I_a = inhalation rate, in cubic meters per day (m^3/day)

BW = body weight, in kilograms (kg)

10^3 = conversion factor from micrograms to milligrams (1,000 $\mu g/mg$)

6.5.2 Derivation of Estimated Site-Specific RSC Values for THC

Unlike the pollutant limit calculations for the five metals that use a risk-based equation, the THC risk assessments require that site-specific RSC values be calculated for each sewage sludge incinerator (which may include one or more sewage sludge incinerator units). RSCs are then used to calculate site-specific risk levels. As Equation 2 shows, these THC RSC values are based on four factors: the THC operational standard, the dispersion factor, the gas flow rate, and a conversion factor. The derivation of the THC operational standard of 100 ppm measured with a heated monitor was described in Section 6.3. This section describes the derivation of the site-specific calculations for the dispersion factor and the gas flow rate and provides an explanation for the conversion factor.

6.5.2.1 Dispersion Factor

EPA calculated dispersion factors for the 23 sewage sludge incinerators in the NSSS data base based on site-specific factors. The air dispersion model used to calculate the dispersion factors was the Industrial Source Complex Long-Term (ISCLT2) model (see Section 5.6.1).

6.5.2.2 Gas Flow Rate

The flame-ionization detector (FID) measures THC emissions in terms of a gas concentration (ppm, volume) (ppmv). To obtain an RSC value for THC, which is measured as a ground-level air concentration, an allowable emission rate must be calculated. To make the conversion, the total gas flow in the sewage sludge incinerator stack must also be calculated. Once the gas flow rate is known, the mass emission rate can be calculated. The dispersion factor is then used to convert the THC mass emission rate to a ground-level ambient-air concentration (the RSC). The equation used to calculate the gas flow rate is:

$$GF = SGF + FGF \tag{4}$$

where:

GF = maximum combustion gas flow rate from the sewage sludge incinerator, in gram moles per day (g-moles/day)

SGF = maximum combustion gas flow rate attributable to the combustible portion of the sewage sludge, in gram moles per day (g-moles/day)

FGF = fuel combustion gas flow rate, in gram moles per day (g-moles/day)

Calculating the maximum combustion gas flow rate from the sewage sludge incinerator is a two-step process. Listed below are the factors used to calculate the two parts of the gas-flow-rate equation. In each step, the factors are explained and the units in which the factor is expressed are presented. Included in the explanation is whether, for the purposes of these calculations, the factor was assumed to be a certain value or whether the data were site-specific and obtained from the NSSS.

Step 1 — Calculate the maximum combustion gas flow rate for the sewage sludge incinerator attributable to the combustible portion of the sewage sludge using Equation 5:

$$SGF = SF \times VF \times VEHC \times 70{,}100 \tag{5}$$

where:

SGF = maximum combustion gas flow rate attributable to the combustible portion of the sewage sludge, in gram moles per day (g-moles/day).

SF = average daily sewage sludge feed rate, in metric tons per day (dry weight basis) (dmt/day) (megagrams, Mg); obtained from the NSSS.

VF = annual average volatile solids fraction of the sewage sludge solids (dimensionless, less than 1.0); from the NSSS.

VEHC = annual average heat value of the volatile solids in sewage sludge, in kilocalories per gram of volatile solids in sewage sludge; assumed to be 5.54 kcal/g.

70,100 = a combination of constants
= (1,348 g/air)/1,000 kcal x (1 x 10^6 g/Mg) x 1.50 (excess air) x (1 g-mole air)/28.84 g air

Step 2 — Calculate the gas flow rates from the combustion of all auxiliary fuels in the sewage sludge incinerator using Equation 6:

$$FGF = FR \times FC \tag{6}$$

where:

FGF = fuel combustion gas flow rate, in gram moles per day (g-moles/day).

FR = annual average daily fuel usage rate, in either pounds per day or cubic feet per day (lb/day, or ft^3/day); calculated from a combination of data from the NSSS and assumptions.

FC = fuel constant; assumed to be #2 fuel oil.

The derivation of the annual average daily fuel usage rate (FR) involves an extensive calculation. The formula for this calculation, including related assumptions and data, can be found in Appendix J.

To derive the fuel constant for #2 fuel oil (FC), the following factors were used:

$FC_{\#2\ oil}$ = 18,300 Btu/lb x 7.5 lb/air/10,000 Btu x 1.50 x 1 g-mole air/28.84 g air x 453.6 g-mole /lb-mole

$FC_{\#2\ oil}$ = 323.80

where:

18,300 = average heating value of #2 fuel oil, in Btu/lb

$\frac{7.5\ \text{lb/air}}{10{,}000\ \text{Btu}}$ = stoichiometric air requirement for combustion of fuel oil

1.50 = 50 percent excess air rate (7-percent oxygen)

28.84 = molecular weight of air

453.6 = conversion from lb-moles gas to g-moles gas

The equations above are based on standard combustion parameters, data on the sewage sludge, and data on the amount of auxiliary fuel used. The calculation provides an estimate of the total gas flow on a dry weight basis at 7-percent oxygen, the same amount of excess air as is required in the regulation. The gas flow rates have been calculated for the 23 sewage sludge incinerators in the NSSS and appear in Table 6-3.

6.5.2.3 Conversion Factor

The THC emission value is converted to a volumetric basis for consistency with the THC analyzer that also monitors on a volumetric basis. To convert the THC concentration into an emission rate, a series of conversion factors were required. The following factors have been combined to form the conversion factor of 3.24×10^9:

$$\frac{86{,}400 \times 0.75 \times 1.7 \times (1 \times 10^6)}{34} = 3.24 \times 10^9 \qquad (7)$$

where:

86,400 = conversion from seconds to days (86,400 sec/day)

0.75 = factor to adjust for the estimated loss of heavy organics in the sampling system (dimensionless)

1.7 = ratio of the FID response factor of propane (3.0) to the weighted average FID response of the list of compounds (1.8) used to determine the weighted cancer potency (q_1*) for THC (see Section 6.6.3.1)

1×10^6 = conversion of concentration to ppm

34.0 = sum of the weighted molecular weight of the THC compounds used to develop the q_1* (g-moles)

The response factor accounts for the response of the FID monitor to the substance it is monitoring. The FID measures the number of chemical bonds per molecule being broken. Because each organic compound has a different set of chemical bonds, the response factor is different for each compound. To correct for the varying responses, each measurement is referenced to propane, which has a standard response factor of 3.0. The response factor of 1.8 is the weighted average response factor for total organics used to develop the weighted q_1*, which is discussed in Section 6.6.3.1. The 1.7 constant is the ratio of the FID response factor of propane (3.0) to the average response factor for total organics (1.8). For a complete list of the response factors for the q_1* organics, see Appendix I.

The 34.0 g-moles represents the average molecular weight of the organic compounds used to develop the q_1* for THC. These values also are listed in Appendix I.

6.5.2.4 Example of a Calculation to Derive a Site-Specific RSC Value

The following is a simplified calculation to obtain the site-specific RSC value for THC using data from one of the 23 sewage sludge incinerators listed in the NSSS (POTW 317). For the full calculations using data for all 23 POTWs, see Appendix I.

$$RSC_{sp} = \frac{THC \times DF \times GF}{3.24 \times 10^9} \qquad (8)$$

where:

RSC_{sp} = site-specific risk-specific concentration for THC, in $\mu g/m^3$

THC = operational standard for THC in the sewage sludge incinerator emissions, in parts per million, on a volumetric basis, corrected for seven percent oxygen (dry basis) = 100 ppm.

DF = dispersion factor = 4.02 ($\mu g/m^3/g/sec$)

GF = maximum combustion gas flow rate = 31,690,610 g-moles/day

3.24×10^9 = combination of conversion factors that express the RSC value as a volumetric concentration

The actual calculation then is:

$$RSC_{sp} = (100 \text{ ppm}) \times (4.02\ (\mu g/m^3/g/sec)) \times (31{,}690{,}610 \text{ g-moles/day})/3.24 \times 10^9$$

$$= 3.93\ \mu g/m^3$$

6.5.3 Estimate of Public Health Protection Regarding the THC Operational Standard

As described earlier in this section, the RSC for THC was developed solely to judge whether the 100 ppm operational standard for THC measured at the stack was protective of public health to the 10^{-4} risk level. The RSC was not used to develop the technology-based 100 ppm standard. The equation used to judge the risk posed by the THC standard was presented earlier in Section 6.6.1 (Equation 3). The only factor in this equation that has not been explained is the cancer potency value (q_1*). The derivation of a weighted q_1* value for THC is described below.

6.5.3.1 Derivation of a Weighted Cancer Potency Value for THC

The THC cancer potency value (q_1^*) is representative of all organic compounds emitted from a sewage sludge incinerator that have the potential to create an adverse health effect. EPA considers two types of compounds that create adverse health effects—carcinogens and noncarcinogens. For carcinogens, the level of exposure determines the anticipated cancerous effect. For toxic compounds not known to have carcinogenic properties, EPA sets a threshold concentration below which no adverse health effects are known to occur. To protect against the adverse health effects of a noncarcinogen, the concentration should be kept below the threshold dose.

The q_1* value for THC was calculated using data on 21 compounds detected in tests at eight sewage sludge incinerators, as well as on data for numerous organics that were potentially present but not detected in the tests. The complete list of organics used to develop the q_1* value for THC is presented in Appendix K. The list of organics includes the following compounds:

- 21 carcinogenic and noncarcinogenic compounds detected in tests at 8 sewage sludge incinerators (U.S. EPA, 1991a-c,f-j)
- All carcinogens and noncarcinogens for which inhalation health effects data are found in EPA's Integrated Risk Information System (IRIS), but which were not detected in the sewage sludge incinerator tests. (IRIS is EPA's database of chemical risk assessment information.)
- Formaldehyde, which has been detected in the emissions of municipal waste incinerators, and chloromethane, detected in hazardous waste incinerators, but which were not measured during the sewage sludge incinerator emissions tests.
- Methane (C_1) and ethane, ethylene, and acetylene (C_2), which are known to be emitted in significant quantities from all combustion sources, but which were not measured during the sewage sludge incinerator tests.

Each organic chemical listed in Appendix K has a corresponding q_1*, an emission concentration, a weighted fraction based on the emission concentration, and a weighted q_1* value. The q_1* for THC is derived by adding the weighted q_1* values for each compound on the list. For carcinogens, the individual q_1* values are obtained directly from the IRIS database. Noncarcinogens, however, have zero carcinogenic potency and thus are represented by zeros in the first column of Appendix K (U.S. EPA, 1991k).

For the noncarcinogens, EPA has identified exposure thresholds below which adverse health effects usually do not occur. Therefore, protection against the adverse health effects of a noncarcinogen is likely to be achieved by preventing total exposure levels from exceeding the threshold dose. EPA uses these threshold values to calculate reference air concentrations (RACs) for noncarcinogenic compounds much as cancer potency values are used to develop RSCs for carcinogens. RACs are defined in terms of a fixed fraction of the estimated threshold concentration. To develop the q_1* for THC, EPA has assumed that the actual maximum ambient air concentrations for each compound will not exceed the RACs and, therefore, would not cause adverse health effects. EPA makes this assumption because all noncarcinogenic compounds detected in the sewage sludge incinerator tests were below the threshold levels. EPA, therefore, assumed that those noncarcinogenic compounds not detected were at the detection limit for the monitoring equipment, which is also below the threshold levels for each compound. Although noncarcinogens do not affect the q_1* value for THC, these compounds are listed in Appendix K to account for their contribution to the total mass of organic emissions.

The second column in Appendix K lists each compound's emission concentration. For each of the 21 detected compounds, EPA used the 95th percentile concentration to develop the q_1* value. If a compound was only detected once, the single-point concentration was used. The available data used to obtain the emission concentrations for the 21 detected compounds can be found in Appendix L. For the nondetected organics taken from the IRIS database, EPA used an assumed detection limit of 0.1 $\mu g/m^3$. Although these compounds were not detected in emissions from the sewage sludge incinerators tested, they have been detected during a variety of other EPA combustion tests. Concentrations for formaldehyde and chloromethane are based on data from tests of municipal solid waste and hazardous waste incinerators, respectively. In addition, to account for the presence of the C_1 compound (methane) and the C_2 compounds (ethane, ethylene, and acetylene) known to be emitted in stack gases, EPA used combustion data from fossil-fueled boilers, furnaces, and other sources. The Agency used the 95th percentile concentrations of the C_1 and C_2 fractions in the q_1^* calculation. These 95th percentile concentrations are shown at the end of Appendix K.

The third column in Appendix K is the weighted fractional concentration for each compound based on the compound's detected or assumed concentration. The last column, the weighted q_1^*, is derived by multiplying the q_1^* value for each compound (zero for noncarcinogens) by its weighted fractional concentration. The q_1^* for THC, which is the result of the addition of these weighted q_1^* values, is calculated to be 1.2×10^{-2} (U.S. EPA, 1991k).

6.5.3.2 *Example of a Calculation Used to Evaluate the Risk Level for the THC Operational Standard*

The following is an example of a calculation used to evaluate risk level for THC emissions using data from one of the 23 sewage sludge incinerators listed in the NSSS (POTW 317) and the 100 ppm THC operational standard, measured with a hot sampling line and corrected to 7-percent oxygen. The risk levels for all 23 POTWs appear in Appendix J. The results of the calculations show that the risk levels for all 23 POTWs are at or lower than the 10^{-4} risk level established in Subpart E of the Part 503 rule to protect public health. Based on these results, in the Administrator's judgment, the THC operational standard is protective of public health to the 10^{-4} risk level. Below is the sample calculation:

$$RL_{sp} = \frac{RSC_{sp} \times q_1{*} \times Ia}{BW \times 10^3}$$

where:

RL_{sp} = site-specific risk level, or the probability of developing cancer, unitless

RSC_{sp} = site-specific risk-specific concentration for THC = 3.93 $\mu g/m^3$

q_1^* = weighted cancer potency value for THC = 1.2×10^{-2} $(mg/kg\text{-}day)^{-1}$

I_a = inhalation rate = 20 m^3/day

BW = body weight = 70 kg

10^3 = conversion factor = 1,000 μg/mg

The actual calculation then is:

$$\mathbf{RL = \frac{(3.93\ mg/m^3)\ x\ (1.2\ x\ 10^{-}2\ (mg/kg\text{-}day)^{-}1)\ x\ (20\ m^3/day)}{70\ kg\ x\ 1{,}000\ mg/mg}}$$

$$\mathbf{= 1.35\ x\ 10^{-5}}$$

SECTION SEVEN

MANAGEMENT PRACTICES

Under Subpart E, data must be measured and recorded to determine compliance with the pollutant limits and operational standard. Key operating parameters for sewage sludge incinerators are monitored continuously to indicate that adequate combustion conditions are being maintained in the incinerator and to minimize metal and THC emissions. The regulation requires the use of four instruments to continuously measure and record the following data for each sewage sludge incinerator: the THC concentration in the stack exit gas; the oxygen concentration in the stack gas; information used to determine the moisture content in the stack gas; and combustion temperature. The management practices specify that the four monitoring instruments be installed, calibrated, operated, and maintained, as specified by the permitting authority. (See the text of the rule in Appendix A.)

7.1 INSTRUMENT FOR MEASURING TOTAL HYDROCARBONS IN STACK GAS

THC is monitored continuously in a sewage sludge incinerator as an indirect indicator of combustion efficiency for organic compounds in sewage sludge. Subpart E requires that the instrument measuring THC employ a flame ionization detector (FID). The FID detects hydrocarbon emissions in the stack gas and reports the results as a concentration of THC. The instrument reads out in parts per million of THC by volume. Thus, as described in Section 6.6.2.3, the THC emission rate in grams per second must be converted to a volumetric basis for consistency with the output of the FID. While THC sampling and detection are continuous, the data readout can either be on a continuous basis or computer averaged over an established interval.

The FID is a hydrogen-oxygen flame into which a small sample of exhaust gases from an incinerator is introduced. If any hydrocarbon compounds are present in the sample, they will be burned in the flame. When carbon-carbon (C-C) or carbon-hydrogen (C-H) bonds are broken and oxidized in the flame, an ion is released and an electrical detection system senses the release of the ion. The electrical signal strength is thus a direct measure of the number of C-C and C-H bonds being oxidized in the flame. By using a series of calibration gases of known hydrocarbon concentration that are periodically introduced into the sample stream, the direct readout of this signal can be calibrated to indicate the THC concentration in the sample stream.

An FID detector that determines the THC concentration in a stack exit gas can also be viewed as an auxiliary incinerator (afterburner). If there are few THCs in the sampled gas from the sewage sludge incinerator that burn in the detector, the incinerator is an efficient combustor. A high level indicates that the incinerator is operating inefficiently.

One problem in interpreting the FID response to an organic compound is that the FID only measures and "counts" the number of chemical bonds being broken. Thus, a molecule with a total of 12 C-C and C-H bonds, for example, will respond differently from a molecule that contains 16 C-C and C-H bonds. A given mass of benzene, in other words, will respond differently from the same mass of 2,3,7,8-TCPD (tetrachlorinated paradioxin). The FID therefore provides no direct information about the chemical nature of the molecule being burned. Rather, it provides information only about the number of the bonds.

The differing FID responses to organic compounds is expressed as a series of response factors. Subpart E requires that the output from a detector be expressed as an equivalent ppm of propane as the calibration gas and that the response factor be referenced to a particular gas equivalent. The regulation requires that the THC monitor be calibrated at least once every 24 hours and be referenced to propane. As an example, published response factors range from 10 percent for carbon tetrachloride to 225 percent for acetylene when referenced to methane, set at 100 percent. Thus carbon tetrachloride provides a response one-tenth that of methane, and acetylene produces a response over two times that of methane.

To account for this varying response by the FID, the Agency has calculated a weighted-average response factor (see Section 6.6.2.3) similar to the way the cancer potency weighted average q_i^* was developed for THCs (see Section 6.6.3.1). The FID response factor is used to correct the reading from the FID to account for the same mix of organics used to determine the q_i^*.

Subpart E also requires that the sampling line to the THC monitor be maintained at a temperature of 150°C. Heated sample lines produce a better correlation between the concentration of THC and the total organic compounds in the stack gas than do unheated (cold) sample lines. Cold sampling line monitors condense a fraction of the organics in the sampling system before they can pass by the FID and, thus, this system does not detect as many compounds as do the heated devices.

7.2 INSTRUMENT FOR MEASURING OXYGEN CONCENTRATION IN STACK GAS

7.2.1 Excess Air Rate

Oxygen in the exit gas is monitored continuously in a sewage sludge incinerator and is used to correct the THC emissions measured with an FID to 7-percent oxygen (see Section 6.5). It is also an indirect indicator of gas velocity in the incinerator and is directly related to excess air. The excess air rate in a sewage sludge incinerator affects the level of metal emissions. A high excess air rate, measured as a high percentage of oxygen in the combustion gas, indicates that more air is being introduced into the combustion than is needed to achieve complete combustion. This extra air increases the volume of gas passing through the combustion zone, which increases the velocity of combustion gas as it comes in contact with burning sewage sludge. The higher gas velocity tends to carry larger quantities of partially burned sewage sludge particles and ash particles out of the incinerator and into the APCD. The extra load of combustion gas, with increased amounts of sewage sludge and ash particles, produces greater post-APCD emissions.

Conversely, an excess air rate that is too low can cause incomplete combustion of the organic constituents in the sewage sludge because of insufficient oxygen in parts of the combustion zone. Continuously monitoring THCs in the stack and limiting the THC concentration to 100 ppm, however, precludes the need to specify a minimum excess air level to ensure complete combustion. If a sewage sludge incinerator is operated at an excess air level too low to obtain complete combustion, then the THC concentration will exceed the operational standard and the operator will be forced to increase the excess air to lower the THC level to the 100 ppm limit specified in the permit.

7.2.2 Oxygen Monitors

Oxygen monitors are of two types: in situ and extractive. In situ monitors are in direct contact with the gas stream. In an extractive system, the gas sample is continuously withdrawn (extracted) from the gas stream and directed to an analyzer, which may be located several feet or several hundred feet away.

Extractive analyzers include a conditioning system to remove dust and moisture from the gas sample; thus, the oxygen concentration measurement is on a dry basis. In situ analyzers, on the other hand, do not include a conditioning system, and the oxygen concentration measurement is on a "wet basis." For the same gas stream, the oxygen measurement obtained with an in situ analyzer will be slightly lower than that obtained with an extractive analyzer. For example, a typical combustion gas stream that contains 10 percent water vapor will yield a reading of 8 percent oxygen using an in situ analyzer and a reading of 10 percent oxygen using an extractive analyzer. The oxygen values for sewage sludge incinerators must be reported on a dry basis.

Oxygen analyzers are accurate to +/- 1 percent as long as the actual gas to be sampled reaches the analyzer (no pluggage or in-leakage of air); the conditioning system (if one is present) is operating properly; and the instrument is calibrated. Electrocatalytic in situ monitors have rapid response time (i.e., seconds). The response times for polarographic and paramagnetic extractive analyzers are slower (several seconds to a minute). Extractive systems inherently involve longer response times, usually on the order of 1 to 2 minutes, depending on the sampling rate and the volume of the sampling line and conditioning system.

Problems with oxygen analyzer systems may be difficult to diagnose since they commonly are associated with slowly developing pluggage in the system or small air in-leaks. The extractive systems should be checked daily by the operators and maintained and calibrated on a weekly basis by the sewage sludge incinerator instrument personnel.

7.3 MEASURING MOISTURE CONTENT IN STACK GAS

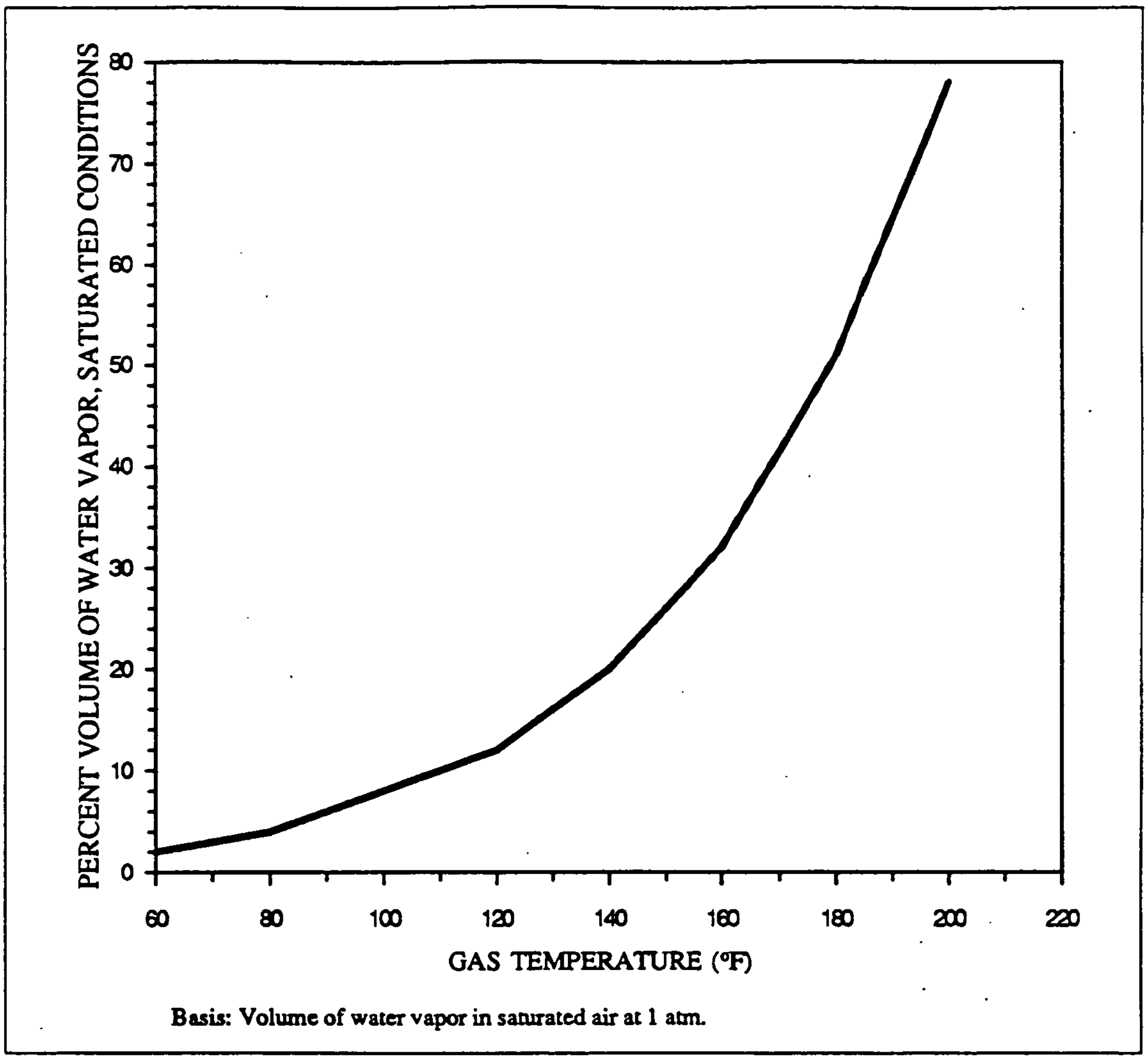
The moisture content of the sewage sludge incinerator stack gas is measured for much the same reason that the percentage of oxygen is determined. Just as excess air, or oxygen, can dilute a pollutant concentration in a given volume of gas, excess moisture also has a dilutory effect. For this reason, the moisture content is corrected for all sewage sludge incinerators.

Subpart E requires that the permitting authority specify the appropriate instrument to continuously measure and record information used to determine the moisture content in the stack gas, and that an instrument be installed, calibrated, operated, and maintained for each sewage sludge incinerator.

Where saturated conditions are known to exist, such as in gas exiting a wet ESP or wet scrubber, the simplest method to determine moisture content is to use a new or existing thermocouple to measure stack gas temperature. This temperature reading is assumed to correspond to 100 percent relative humidity because of the wet environment. The stack gas temperature is then correlated to the moisture content of the stack gas by using a standard conversion graph (see Figure 7-1). The temperature of most exit gases in typical wet scrubber systems will be between 110°F and 170°F (43°C and 77°C) which corresponds to a moisture content of between 10 percent and 40 percent on a volumetric basis. (For a discussion of how the percent moisture content is used to correct the THC measurement, see Section 6.5.)

Where non-saturated conditions exist, such as where the gas exits a baghouse or dry ESP, the simplest method to obtain the stack gas moisture content is to use a dewpoint detector (also called a wet bulb/dry bulb detector). Such an instrument detects the stack gas temperature in a simulated saturated gas condition. The instrument automatically calculates the stack gas

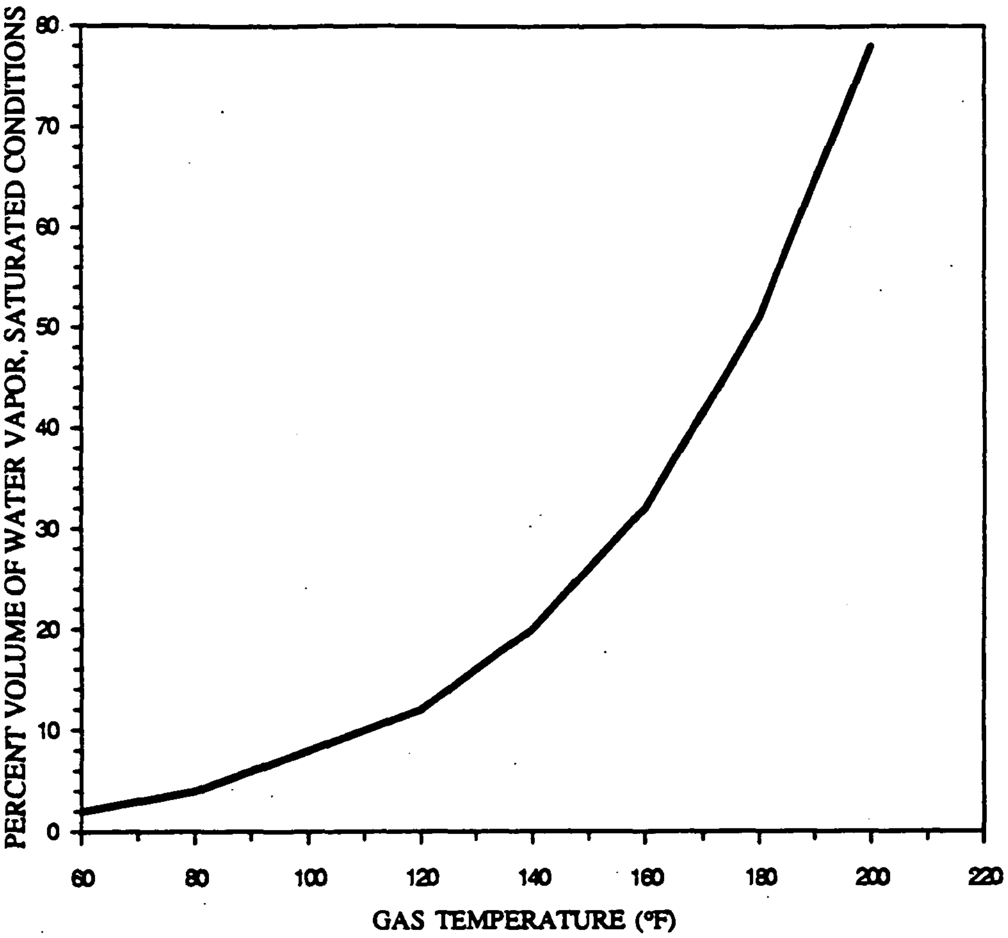
FIGURE 7-1
SATURATED WATER VAPOR CONTENT OF FLUE GAS



Source: MITRE, 1983.

FIGURE 7-1

SATURATED WATER VAPOR CONTENT OF FLUE GAS



Basis: Volume of water vapor in saturated air at 1 atm.

Source: MITRE, 1983.

moisture content from the "dewpoint temperature" in much the same way as the table was used to determine moisture content where saturated conditions are present.

7.4 COMBUSTION TEMPERATURE

Temperatures in sewage sludge incinerators affect the emissions of both organic compounds and metals. The regulation requires the maximum combustion temperature for the sewage sludge incinerator to be consistent with values determined through a performance test. Excess temperatures increase the volatilization of the metal pollutants from the sewage sludge solids and increase their emission. Excessively high temperatures also damage equipment and result in increased maintenance costs. Combustion temperatures that are too low cause incomplete combustion of organic compounds and promote the formation of products of incomplete combustion (PICs), both of which are emitted with the combustion gas. There is no requirement, however, for a minimum combustion temperature because an adequate minimum temperature must be maintained to meet the THC operational standard.

Temperatures within a sewage sludge incinerator are typically monitored by thermocouples located at various points within the system. The thermocouples are always enclosed in a thermowell to protect the small thermocouple wires and the critical thermocouple "hot" junction from direct exposure to the combustion gases and entrained dust particles. Thermocouples are usually located near the exit of the combustion chamber to provide a representative temperature reading away from the flame zone, which can otherwise cause erratic temperature readings as well as damage to the thermocouple. Thermowells may extend several inches past the inner wall of the refractory into the gas stream or may extend only to the depth of the refractory. Thermowells that extend past the refractory provide a more accurate measure of the gas temperature and respond more quickly to temperature changes. This type, however, also may be subject to dust and slag buildup, which can slow response to temperature changes. Thermocouples may also be located upstream of the APCD to provide a warning or control mechanism for high temperature excursions that could damage control equipment.

Thermocouples are available in a variety of types, with each type constructed of specific metals or alloys. The temperature ranges and reported accuracy vary by type. The environment for which the thermocouple is suited also varies. Periodic replacement of thermocouples and checking the physical integrity of the thermowell and any outer dust buildup is the best maintenance procedure. Because it is not practical to perform a high temperature calibration of the thermocouple, only periodic replacement ensures that a properly operating thermocouple is in place.

7.5 OPERATING PARAMETERS FOR AIR POLLUTION CONTROL DEVICES

Subpart E requires that the operating parameters for the APCDs be consistent with the values determined through a performance test. Conditions are placed on the operating conditions of the APCD to ensure that the system is functioning properly and that there are no excess pollutant emissions. Permits for sewage sludge incinerators will include continuous monitoring requirements for selected parameters that indicate adequate performance of the APCDs. Such requirements will be developed on a case-by-case basis, depending on the APCD used and facility-specific issues. A list of performance indicator parameters for various APCD technologies is presented in Appendix M, along with the common measuring devices for the respective parameters.

The performance indicator parameters include technology-specific parameters, as well as universal parameters. Examples of APCD technology-specific parameters include pressure drop and liquid flow for wet scrubbers, and secondary voltage and secondary current for wet electrostatic precipitators (WESPs). Because the performance of all APCDs is influenced by gas flow rate and gas temperature, these two parameters are considered to be universal APCD parameters and are included in the performance for each APCD technology. Systems such as wet scrubbers, fabric filters (baghouses), wet and dry electrostatic precipitators, and semidry and dry scrubbing systems may be required on some sewage sludge incinerators to meet the emission levels proposed in the standards. Fired afterburners may also be required on some multiple-hearth furnaces to meet the THC operational standard of the regulation.

Due to the potential variety of APCDs, the Part 503 regulation requires that values for the operating parameters of the APCD be determined during a performance test, and to establish these parameters as permit conditions. The performance test is conducted to establish an acceptable control efficiency for metal emissions.

7.6 THREATENED OR ENDANGERED SPECIES

Subpart E prohibits the firing of sewage sludge in a sewage sludge incinerator if it would adversely affect a threatened or endangered species listed under Section 4 of the Endangered Species Act or its designated critical habitat. EPA will develop guidance to carry out this provision consistent with the Endangered Species Act.

SECTION EIGHT

FREQUENCY OF MONITORING, RECORDKEEPING, AND REPORTING

8.1 FREQUENCY OF MONITORING

The frequency of monitoring for arsenic, cadmium, chromium, lead, and nickel is set by the regulation according to the amount of sewage sludge fired in a sewage sludge incinerator during a 365-day period, and ranges from once per year to once per month (see Table 8-1). The calculations used to develop the different amounts of sewage sludge on which the monitoring frequency is based are shown in Appendix N. The calculations are based on treatment works with flow rates of 1 million gallons per day (1 MGD, corresponding to 290 dry metric tons per year for use or disposal), 5 MGD (corresponding to 1,500 dry metric tons per year), and 50 MGD (corresponding to 15,000 dry metric tons per year). The regulation also allows the permitting authority to modify the frequency of monitoring for these five pollutants after the sewage sludge is monitored for two years in accordance with the frequency set forth in Subpart E, as long as the frequency of monitoring is at least once per year.

The frequency of monitoring for beryllium and mercury is to be specified by the permitting authority. In addition, the regulation requires the continuous monitoring of the exit gas for THC, oxygen concentration, and information used to determine moisture content, as well as combustion temperature. The operating parameters for the sewage sludge incinerator APCD(s) are to be monitored as specified by the permitting authority.

8.2 RECORDKEEPING

Any person who fires sewage sludge in a sewage sludge incinerator must retain certain data for 5 years. This information is needed to show that the Part 503 requirements are being met. The required data include the following:

TABLE 8-1

FREQUENCY OF MONITORING—INCINERATION

Amount of Sewage Sludge[a] **(Metric Tons per 365-Day Period)**	**Frequency**
Greater than zero but less than 290	Once per year
Equal to or greater than 290 but less than 1,500	Once per quarter (four times per year)
Equal to or greater than 1,500 but less than 15,000	Once per 60 days (six times per year)
Equal to or greater than 15,000	Once per month (twelve times per year)

[a] Amount of sewage sludge fired in a sewage sludge incinerator—dry weight basis.

- Concentration of arsenic, cadmium, chromium, nickel, and lead in the sewage sludge.
- The concentration of THC in the exit gas.
- Information that indicates the NESHAPs requirements for beryllium, if required, and mercury are met.
- The oxygen concentration and information used to measure moisture content in the exit gas.
- Sewage sludge feed rate for each sewage sludge incinerator unit, on a dry weight basis.
- The stack height for the sewage sludge incinerator.
- The dispersion factor for the site where the sewage sludge incinerator is located.
- The control efficiency for arsenic, cadmium, chromium, nickel, and lead for each sewage sludge incinerator unit.
- The risk-specific concentration for chromium calculated using the site-specific equation for chromium presented in Section 5.4.2, if applicable.
- A calibration and maintenance log for instruments used to measure the THC concentration, oxygen concentration, combustion temperature, and information needed to determine the moisture content in the exit gas from the sewage sludge incinerator stack.
- The combustion temperatures, including the maximum combustion temperature.
- Values for the APCD operating parameters.

8.3 REPORTING

The reporting requirements under Subpart E pertain to Class I sewage sludge management facilities and treatment works with a flow rate equal to or greater than one MGD or that serve a population of 10,000 people or greater. All treatment works operating sewage sludge incinerators are classified as Class I sewage sludge management facilities. Those treatment works are required, therefore, to report yearly, except as specified in a permit issued by the permitting authority.

SECTION NINE

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U.S. EPA. 1991j. Emissions of Metals, Chromium and Nickel Species, and Organics from Municipal Wastewater Sludge Incinerators. Volume : Site 10 Emission Test Report. Risk Reduction Engineering Laboratory, Office of Research and Development. Cincinnati, OH.

U.S. EPA. 1991k. Background Information on the Risk of Organic Emissions from Sewage Sludge Incinerators. Prepared by Midwest Research Institute for the EPA. MRI project no. 9102-L(36). Office of Water. Washington, DC.

U.S. EPA. 1992a. Integrated Risk Information System (IRIS). [Current file; updated as necessary.] Washington, DC. Available through the National Library of Medicine.

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U.S. EPA. 1992c. Emissions of Metals, Chromium and Nickel Species, and Organics from Municipal Wastewater Sludge Incinerators. Risk Reduction Engineering Laboratory. Cincinnati, OH. EPA/600/SR-92/003.

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APPENDIX A

STANDARDS FOR THE USE OR DISPOSAL OF SEWAGE SLUDGE

Subpart A—General Provisions

Subpart E—Incineration

Pollutant	Use or disposal practice			
	LA	(SD)		I
		Unlined[1]	Lined[2]	
Chromium			[3]100	
Copper		[3]46	[3]100	1400
DDD, DDE, DDT (Total)	1.2	2000	2000	
2.4 Dichlorophenoxy-acetic acid		7	7	
Fluoride	730			
Heptachlor	7.4			
Hexachlorobenzene	29			
Hexachlorobutadiene	600			
Iron	[3]78			
Lead		[3]100	[3]100	
Lindane	84	[3]28	[3]28	
Malathion		0.63	0.63	
Mercury		[3]100	[3]100	
Molybdenum		40	40	
Nickel			[3]100	
N-Nitrosodimethylamine	2.1	0.088	0.088	
Pentachlorophenol	30			
Phenol		82	82	
Polychlorinated biphenyls	4.6	<50	<50	
Selenium		4.8	4.8	4.8
Toxaphene	10	[3]26	[3]26	
Trichloroethylene	[3]10	9500	[3]10	
Zinc		4500	4500	4500

Key: LA—land application, SD—surface disposal, I—incineration.

[1] Sewage sludge unit without a liner and leachate collection system.

[2] Sewage sludge unit with a liner and leachate collection system.

[3] Value expressed in grams per kilogram—dry weight basis.

Subchapter O in chapter I of title 40 of the Code of Federal Regulations is amended by adding part 503, which reads as follows:

SUBCHAPTER O—SEWAGE SLUDGE

PART 503—STANDARDS FOR THE USE OR DISPOSAL OF SEWAGE SLUDGE

Subpart A—General Provisions

Subpart B—Land Application

Subpart C—Surface Disposal

Subpart D—Pathogens and Vector Attraction Reduction

Subpart E—Incineration

Appendix A to Part 503—Procedure to Determine the Annual Whole Sludge Application Rate for a Sewage Sludge

Appendix B to Part 503—Pathogen Treatment Processes

Authority: Sections 405 (d) and (e) of the Clean Water Act, as amended by Pub. L. 95–217, Sec. 54(d), 91 Stat. 1591 (33 U.S.C. 1345 (d) and (e)); and Pub. L. 100–4, Title IV, Sec. 406 (a), (b), 101 Stat., 71, 72 (33 U.S.C. 1251 *et seq.*).

Subpart A—General Provisions

§ 503.1 Purpose and applicability.

(a) *Purpose.* (1) This part establishes standards, which consist of general requirements, pollutant limits, management practices, and operational standards, for the final use or disposal of sewage sludge generated during the treatment of domestic sewage in a treatment works. Standards are included in this part for sewage sludge applied to the land, placed on a surface disposal site, or fired in a sewage sludge incinerator. Also included in this part are pathogen and alternative vector attraction reduction requirements for sewage sludge applied to the land or placed on a surface disposal site.

(2) In addition, the standards in this part include the frequency of monitoring and recordkeeping requirements when sewage sludge is applied to the land, placed on a surface disposal site, or fired in a sewage sludge incinerator. Also included in this part are reporting requirements for Class I sludge management facilities, publicly owned treatment works (POTWs) with a design flow rate equal to or greater than one million gallons per day, and POTWs that serve 10,000 people or more.

(b) *Applicability.* (1) This part applies to any person who prepares sewage sludge, applies sewage sludge to the land, or fires sewage sludge in a sewage sludge incinerator and to the owner/operator of a surface disposal site.

(2) This part applies to sewage sludge applied to the land, placed on a surface disposal site, or fired in a sewage sludge incinerator.

(3) This part applies to the exit gas from a sewage sludge incinerator stack.

(4) This part applies to land where sewage sludge is applied, to a surface disposal site, and to a sewage sludge incinerator.

§ 503.2 Compliance period.

(a) Compliance with the standards in this part shall be achieved as expeditiously as practicable, but in no case later than February 19, 1994. When compliance with the standards requires construction of new pollution control facilities, compliance with the standards shall be achieved as expeditiously as practicable, but in no case later than February 19, 1995.

(b) The requirements for frequency of monitoring, recordkeeping, and reporting in this part for total hydrocarbons in the exit gas from a sewage sludge incinerator are effective February 19, 1994 or, if compliance with the operational standard for total hydrocarbons in this part requires the construction of new pollution control facilities, February 19, 1995.

(c) All other requirements for frequency of monitoring, recordkeeping, and reporting in this part are effective on July 20, 1993.

§ 503.3 Permits and direct enforceability.

(a) Permits. The requirements in this part may be implemented through a permit:

(1) Issued to a "treatment works treating domestic sewage", as defined in 40 CFR 122.2, in accordance with 40 CFR parts 122 and 124 by EPA or by a State that has a State sludge management program approved by EPA in accordance with 40 CFR part 123 or 40 CFR part 501 or

(2) Issued under subtitle C of the Solid Waste Disposal Act; part C of the Safe Drinking Water Act; the Marine Protection, Research, and Sanctuaries Act of 1972; or the Clean Air Act. "Treatment works treating domestic sewage" shall submit a permit application in accordance with either 40 CFR 122.21 or an approved State program.

(b) Direct enforceability. No person shall use or dispose of sewage sludge through any practice for which requirements are established in this part except in accordance with such requirements.

§ 503.4 Relationship to other regulations.

Disposal of sewage sludge in a municipal solid waste landfill unit, as defined in 40 CFR 258.2, that complies with the requirements in 40 CFR part 258 constitutes compliance with section 405(d) of the CWA. Any person who prepares sewage sludge that is disposed in a municipal solid waste landfill unit shall ensure that the sewage sludge meets the requirements in 40 CFR part 258 concerning the quality of materials disposed in a municipal solid waste landfill unit.

§ 503.5 Additional or more stringent requirements.

(a) On a case-by-case basis, the permitting authority may impose requirements for the use or disposal of sewage sludge in addition to or more stringent than the requirements in this part when necessary to protect public health and the environment from any adverse effect of a pollutant in the sewage sludge.

(b) Nothing in this part precludes a State or political subdivision thereof or interstate agency from imposing requirements for the use or disposal of sewage sludge more stringent than the requirements in this part or from imposing additional requirements for the use or disposal of sewage sludge.

§ 503.6 Exclusions.

(a) *Treatment processes.* This part does not establish requirements for processes used to treat domestic sewage or for processes used to treat sewage sludge prior to final use or disposal, except as provided in § 503.32 and § 503.33.

(b) *Selection of a use or disposal practice.* This part does not require the selection of a sewage sludge use or disposal practice. The determination of the manner in which sewage sludge is used or disposed is a local determination.

(c) *Co-firing of sewage sludge.* This part does not establish requirements for sewage sludge co-fired in an incinerator with other wastes or for the incinerator in which sewage sludge and other wastes are co-fired. Other wastes do not include auxiliary fuel, as defined in 40 CFR 503.41(b), fired in a sewage sludge incinerator.

(d) *Sludge generated at an industrial facility.* This part does not establish requirements for the use or disposal of sludge generated at an industrial facility during the treatment of industrial wastewater, including sewage sludge generated during the treatment of industrial wastewater combined with domestic sewage.

(e) *Hazardous sewage sludge.* This part does not establish requirements for the use or disposal of sewage sludge determined to be hazardous in accordance with 40 CFR part 261.

(f) *Sewage sludge with high PCB concentration.* This part does not establish requirements for the use or disposal of sewage sludge with a concentration of polychlorinated biphenyls (PCBs) equal to or greater than 50 milligrams per kilogram of total solids (dry weight basis).

(g) *Incinerator ash.* This part does not establish requirements for the use or disposal of ash generated during the firing of sewage sludge in a sewage sludge incinerator.

(h) *Grit and screenings.* This part does not establish requirements for the use or disposal of grit (e.g., sand, gravel, cinders, or other materials with a high specific gravity) or screenings (e.g., relatively large materials such as rags) generated during preliminary treatment of domestic sewage in a treatment works.

(i) *Drinking water treatment sludge.* This part does not establish requirements for the use or disposal of sludge generated during the treatment of either surface water or ground water used for drinking water.

(j) *Commercial and industrial septage.* This part does not establish requirements for the use or disposal of commercial septage, industrial septage, a mixture of domestic septage and commercial septage, or a mixture of domestic septage and industrial septage.

§ 503.7 Requirement for a person who prepares sewage sludge.

Any person who prepares sewage sludge shall ensure that the applicable requirements in this part are met when the sewage sludge is applied to the land, placed on a surface disposal site, or fired in a sewage sludge incinerator.

§ 503.8 Sampling and analysis.

(a) *Sampling.* Representative samples of sewage sludge that is applied to the land, placed on a surface disposal site, or fired in a sewage sludge incinerator shall be collected and analyzed.

(b) *Methods.* The materials listed below are incorporated by reference in this part. These incorporations by reference were approved by the Director of the Federal Register in accordance with 5 U.S.C. 552(a) and 1 CFR part 51. The materials are incorporated as they exist on the date of approval, and notice of any change in these materials will be published in the Federal Register. They are available for inspection at the Office of the Federal Register, 7th Floor, suite 700, 800 North Capitol Street, NW., Washington, DC, and at the Office of Water Docket, room L–102, U.S. Environmental Protection Agency, 401 M Street, SW., Washington, DC. Copies may be obtained from the standard producer or publisher listed in the regulation. Methods in the materials listed below shall be used to analyze samples of sewage sludge.

(1) *Enteric viruses.* ASTM Designation: D 4994–89, "Standard Practice for Recovery of Viruses From Wastewater Sludges", 1992 Annual Book of ASTM Standards: Section 11—Water and Environmental Technology, ASTM, 1916 Race Street, Philadelphia, PA 19103–1187.

(2) *Fecal coliform.* Part 9221 E. or Part 9222 D., "Standard Methods for the Examination of Water and Wastewater", 18th Edition, 1992, American Public Health Association, 1015 15th Street, NW., Washington, DC 20005.

(3) *Helminth ova.* Yanko, W.A., "Occurrence of Pathogens in Distribution and Marketing Municipal Sludges", EPA 600/1–87–014, 1987. National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161 (PB 88–154273/AS).

(4) *Inorganic pollutants:* "Test Methods for Evaluating Solid Waste, Physical/Chemical Methods", EPA Publication SW–846, Second Edition (1982) with Updates I (April 1984) and II (April 1985) and Third Edition (November 1986) with Revision I (December 1987). Second Edition and Updates I and II are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161 (PB–87–120–291). Third Edition and Revision I are available from Superintendent of Documents, Government Printing Office, 941 North Capitol Street, NE., Washington, DC 20002 (Document Number 955–001–00000–1).

(5) *Salmonella sp. bacteria.* Part 9260 D., "Standard Methods for the Examination of Water and Wastewater", 18th Edition, 1992, American Public Health Association, 1015 15th Street, NW., Washington, DC 20005; or

Kenner, B.A. and H.P. Clark, "Detection and enumeration of *Salmonella* and *Pseudomonas aeruginosa*", Journal of the Water Pollution Control Federation, Vol. 46, no. 9, September 1974, pp. 2163–2171. Water Environment Federation, 601 Wythe Street, Alexandria, Virginia 22314.

(6) *Specific oxygen uptake rate.* Part 2710 B., "Standard Methods for the Examination of Water and Wastewater", 18th Edition, 1992, American Public Health Association, 1015 15th Street, NW., Washington, DC 20005.

(7) *Total, fixed, and volatile solids.* Part 2540 G., "Standard Methods for the Examination of Water and Wastewater", 18th Edition, 1992, American Public Health Association, 1015 15th Street, NW., Washington, DC 20005.

§ 503.9 General definitions.

(a) *Apply sewage sludge or sewage sludge applied to the land* means land application of sewage sludge.

(b) *Base flood* is a flood that has a one percent chance of occurring in any given year (i.e., a flood with a magnitude equalled once in 100 years).

(c) *Class I sludge management facility* is any publicly owned treatment works (POTW), as defined in 40 CFR 501.2, required to have an approved pretreatment program under 40 CFR 403.8(a) (including any POTW located in a State that has elected to assume local program responsibilities pursuant to 40 CFR 403.10(e)) and any treatment works treating domestic sewage, as defined in 40 CFR 122.2, classified as a Class I sludge management facility by the EPA Regional Administrator, or, in the case of approved State programs, the Regional Administrator in conjunction with the State Director, because of the potential for its sewage sludge use or disposal practice to affect public health and the environment adversely.

(d) *Cover crop* is a small grain crop, such as oats, wheat, or barley, not grown for harvest.

(e) *CWA* means the Clean Water Act (formerly referred to as either the Federal Water Pollution Act or the Federal Water Pollution Control Act Amendments of 1972), Public Law 92–500, as amended by Public Law 95–217, Public Law 95–576, Public Law 96–483, Public Law 97–117, and Public Law 100–4.

(f) *Domestic septage* is either liquid or solid material removed from a septic tank, cesspool, portable toilet, Type III marine sanitation device, or similar treatment works that receives only domestic sewage. Domestic septage does not include liquid or solid material removed from a septic tank, cesspool, or similar treatment works that receives either commercial wastewater or industrial wastewater and does not include grease removed from a grease trap at a restaurant.

(g) *Domestic sewage* is waste and wastewater from humans or household operations that is discharged to or otherwise enters a treatment works.

(h) *Dry weight basis* means calculated on the basis of having been dried at 105 degrees Celsius until reaching a constant mass (i.e., essentially 100 percent solids content).

(i) *EPA* means the United States Environmental Protection Agency.

(j) *Feed crops* are crops produced primarily for consumption by animals.

(k) *Fiber crops* are crops such as flax and cotton.

(l) *Food crops* are crops consumed by humans. These include, but are not limited to, fruits, vegetables, and tobacco.

(m) *Ground water* is water below the land surface in the saturated zone.

(n) *Industrial wastewater* is wastewater generated in a commercial or industrial process.

(o) *Municipality* means a city, town, borough, county, parish, district, association, or other public body (including an intermunicipal Agency of two or more of the foregoing entities) created by or under State law; an Indian tribe or an authorized Indian tribal organization having jurisdiction over sewage sludge management; or a designated and approved management Agency under section 208 of the CWA, as amended. The definition includes a special district created under State law, such as a water district, sewer district, sanitary district, utility district, drainage district, or similar entity, or an integrated waste management facility as defined in section 201(e) of the CWA, as amended, that has as one of its principal responsibilities the treatment, transport, use, or disposal of sewage sludge.

(p) *Permitting authority* is either EPA or a State with an EPA-approved sludge management program.

(q) *Person* is an individual, association, partnership, corporation, municipality, State or Federal agency, or an agent or employee thereof.

(r) *Person who prepares sewage sludge* is either the person who generates sewage sludge during the treatment of domestic sewage in a treatment works or the person who derives a material from sewage sludge.

(s) *Place sewage sludge or sewage sludge placed* means disposal of sewage sludge on a surface disposal site.

(t) *Pollutant* is an organic substance, an inorganic substance, a combination of organic and inorganic substances, or a pathogenic organism that, after discharge and upon exposure, ingestion, inhalation, or assimilation into an organism either directly from the environment or indirectly by ingestion through the food chain, could, on the basis of information available to the Administrator of EPA, cause death, disease, behavioral abnormalities, cancer, genetic mutations, physiological malfunctions (including malfunction in reproduction), or physical deformations in either organisms or offspring of the organisms.

(u) *Pollutant limit* is a numerical value that describes the amount of a pollutant allowed per unit amount of sewage sludge (e.g., milligrams per kilogram of total solids); the amount of a pollutant that can be applied to a unit area of land (e.g., kilograms per hectare); or the volume of a material that can be applied to a unit area of land (e.g., gallons per acre).

(v) *Runoff* is rainwater, leachate, or other liquid that drains overland on any part of a land surface and runs off of the land surface.

(w) *Sewage sludge* is solid, semi-solid, or liquid residue generated during the treatment of domestic sewage in a treatment works. Sewage sludge includes, but is not limited to, domestic septage; scum or solids removed in primary, secondary, or advanced wastewater treatment processes; and a material derived from sewage sludge. Sewage sludge does not include ash generated during the firing of sewage sludge in a sewage sludge incinerator or grit and screenings generated during preliminary treatment of domestic sewage in a treatment works.

(x) *State* is one of the United States of America, the District of Columbia, the Commonwealth of Puerto Rico, the Virgin Islands, Guam, American Samoa, the Trust Territory of the Pacific Islands, the Commonwealth of the Northern Mariana Islands, and an Indian Tribe eligible for treatment as a State pursuant to regulations promulgated under the authority of section 518(e) of the CWA.

(y) *Store or storage of sewage sludge* is the placement of sewage sludge on land on which the sewage sludge remains for two years or less. This does not include the placement of sewage sludge on land for treatment.

(z) *Treat or treatment of sewage sludge* is the preparation of sewage sludge for final use or disposal. This includes, but is not limited to, thickening, stabilization, and dewatering of sewage sludge. This does not include storage of sewage sludge.

(aa) *Treatment works* is either a federally owned, publicly owned, or privately owned device or system used to treat (including recycle and reclaim) either domestic sewage or a combination of domestic sewage and industrial waste of a liquid nature.

(bb) *Wetlands* means those areas that are inundated or saturated by surface water or ground water at a frequency and duration to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.

Subpart B—Land Application

§ 503.10 Applicability.

(a) This subpart applies to any person who prepares sewage sludge that is applied to the land, to any person who applies sewage sludge to the land, to sewage sludge applied to the land, and to the land on which sewage sludge is applied.

(b)(1) *Bulk sewage sludge*. The general requirements in § 503.12 and the management practices in § 503.14 do not apply when bulk sewage sludge is applied to the land if the bulk sewage sludge meets the pollutant concentrations in § 503.13(b)(3), the Class A pathogen requirements in § 503.32(a), and one of the vector attraction reduction requirements in § 503.33 (b)(1) through (b)(8).

(2) The Regional Administrator of EPA or, in the case of a State with an approved sludge management program, the State Director, may apply any or all of the general requirements in § 503.12 and the management practices in § 503.14 to the bulk sewage sludge in § 503.10(b)(1) on a case-by-case basis after determining that the general requirements or management practices are needed to protect public health and the environment from any reasonably anticipated adverse effect that may occur from any pollutant in the bulk sewage sludge.

(c)(1) The general requirements in § 503.12 and the management practices in § 503.14 do not apply when a bulk material derived from sewage sludge is applied to the land if the derived bulk material meets the pollutant concentrations in § 503.13(b)(3), the Class A pathogen requirements in § 503.32(a), and one of the vector attraction reduction requirements in § 503.33 (b)(1) through (b)(8).

(2) The Regional Administrator of EPA or, in the case of a State with an approved sludge management program, the State Director, may apply any or all of the general requirements in § 503.12 or the management practices in § 503.14 to the bulk material in § 503.10(c)(1) on a case-by-case basis after determining that the general requirements or management practices are needed to protect public health and the environment from any reasonably anticipated adverse effect that may occur from any pollutant in the bulk sewage sludge.

(d) The requirements in this subpart do not apply when a bulk material derived from sewage sludge is applied to the land if the sewage sludge from which the bulk material is derived meets the pollutant concentrations in § 503.13(b)(3), the Class A pathogen requirements in § 503.32(a), and one of the vector attraction reduction requirements in § 503.33 (b)(1) through (b)(8).

(e) *Sewage sludge sold or given away in a bag or other container for application to the land*. The general requirements in § 503.12 and the management practices in § 503.14 do not apply when sewage sludge is sold or given away in a bag or other container for application to the land if the sewage sludge sold or given away in a bag or other container for application to the land meets the pollutant concentrations in § 503.13(b)(3), the Class A pathogen requirements in § 503.32(a), and one of the vector attraction reduction requirements in § 503.33 (b)(1) through (b)(8).

(f) The general requirements in § 503.12 and the management practices in § 503.14 do not apply when a material derived from sewage sludge is sold or given away in a bag or other container for application to the land if the derived material meets the pollutant concentrations in § 503.13(b)(3), the Class A pathogen requirements in § 503.32(a), and one of the vector attraction reduction requirements in § 503.33 (b)(1) through (b)(8).

(g) The requirements in this subpart do not apply when a material derived from sewage sludge is sold or given away in a bag or other container for application to the land if the sewage sludge from which the material is derived meets the pollutant concentrations in § 503.13(b)(3), the Class A pathogen requirements in § 503.32(a), and one of the vector attraction reduction requirements in § 503.33 (b)(1) through (b)(8).

§ 503.11 Special definitions.

(a) *Agricultural land* is land on which a food crop, a feed crop, or a fiber crop is grown. This includes range land and land used as pasture.

(b) *Agronomic rate* is the whole sludge application rate (dry weight basis) designed:

(1) To provide the amount of nitrogen needed by the food crop, feed crop, fiber crop, cover crop, or vegetation grown on the land; and

(2) To minimize the amount of nitrogen in the sewage sludge that passes below the root zone of the crop or vegetation grown on the land to the ground water.

(c) *Annual pollutant loading rate* is the maximum amount of a pollutant that can be applied to a unit area of land during a 365 day period.

(d) *Annual whole sludge application rate* is the maximum amount of sewage sludge (dry weight basis) that can be applied to a unit area of land during a 365 day period.

(e) *Bulk sewage sludge* is sewage sludge that is not sold or given away in a bag or other container for application to the land.

septage) is placed on an active sewage sludge unit.

(5) One of the vector attraction reduction requirements in § 503.33 (b)(9), (b)(10), or (b)(12) shall be met when domestic septage is applied to agricultural land, forest, or a reclamation site and one of the vector attraction reduction requirements in § 503.33 (b)(9) through (b)(12) shall be met when domestic septage is placed on an active sewage sludge unit.

(b)(1) The mass of volatile solids in the sewage sludge shall be reduced by a minimum of 38 percent (see calculation procedures in "Environmental Regulations and Technology—Control of Pathogens and Vector Attraction in Sewage Sludge", *EPA–625/R–92/013*, 1992, *U.S.* Environmental Protection Agency, Cincinnati, Ohio 45268).

(2) When the 38 percent volatile solids reduction requirement in § 503.33(b)(1) cannot be met for an anaerobically digested sewage sludge, vector attraction reduction can be demonstrated by digesting a portion of the previously digested sewage sludge anaerobically in the laboratory in a bench-scale unit for 40 additional days at a temperature between 30 and 37 degrees Celsius. When at the end of the 40 days, the volatile solids in the sewage sludge at the beginning of that period is reduced by less than 17 percent, vector attraction reduction is achieved.

(3) When the 38 percent volatile solids reduction requirement in § 503.33(b)(1) cannot be met for an aerobically digested sewage sludge, vector attraction reduction can be demonstrated by digesting a portion of the previously digested sewage sludge that has a percent solids of two percent or less aerobically in the laboratory in a bench-scale unit for 30 additional days at 20 degrees Celsius. When at the end of the 30 days, the volatile solids in the sewage sludge at the beginning of that period is reduced by less than 15 percent, vector attraction reduction is achieved.

(4) The specific oxygen uptake rate (SOUR) for sewage sludge treated in an aerobic process shall be equal to or less than 1.5 milligrams of oxygen per hour per gram of total solids (dry weight basis) at a temperature of 20 degrees Celsius.

(5) Sewage sludge shall be treated in an aerobic process for 14 days or longer. During that time, the temperature of the sewage sludge shall be higher than 40 degrees Celsius and the average temperature of the sewage sludge shall be higher than 45 degrees Celsius.

(6) The pH of sewage sludge shall be raised to 12 or higher by alkali addition and, without the addition of more alkali, shall remain at 12 or higher for two hours and then at 11.5 or higher for an additional 22 hours.

(7) The percent solids of sewage sludge that does not contain unstabilized solids generated in a primary wastewater treatment process shall be equal to or greater than 75 percent based on the moisture content and total solids prior to mixing with other materials.

(8) The percent solids of sewage sludge that contains unstabilized solids generated in a primary wastewater treatment process shall be equal to or greater than 90 percent based on the moisture content and total solids prior to mixing with other materials.

(9)(i) Sewage sludge shall be injected below the surface of the land.

(ii) No significant amount of the sewage sludge shall be present on the land surface within one hour after the sewage sludge is injected.

(iii) When the sewage sludge that is injected below the surface of the land is Class A with respect to pathogens, the sewage sludge shall be injected below the land surface within eight hours after being discharged from the pathogen treatment process.

(10)(i) Sewage sludge applied to the land surface or placed on a surface disposal site shall be incorporated into the soil within six hours after application to or placement on the land.

(ii) When sewage sludge that is incorporated into the soil is Class A with respect to pathogens, the sewage sludge shall be applied to or placed on the land within eight hours after being discharged from the pathogen treatment process.

(11) Sewage sludge placed on an active sewage sludge unit shall be covered with soil or other material at the end of each operating day.

(12) The pH of domestic septage shall be raised to 12 or higher by alkali addition and, without the addition of more alkali, shall remain at 12 or higher for 30 minutes.

Subpart E—Incineration

§ 503.40 Applicability.

(a) This subpart applies to a person who fires sewage sludge in a sewage sludge incinerator, to a sewage sludge incinerator, and to sewage sludge fired in a sewage sludge incinerator.

(b) This subpart applies to the exit gas from a sewage sludge incinerator stack.

§ 503.41 Special definitions.

(a) *Air pollution control device* is one or more processes used to treat the exit gas from a sewage sludge incinerator stack.

(b) *Auxiliary fuel* is fuel used to augment the fuel value of sewage sludge. This includes, but is not limited to, natural gas, fuel oil, coal, gas generated during anaerobic digestion of sewage sludge, and municipal solid waste (not to exceed 30 percent of the dry weight of sewage sludge and auxiliary fuel together). Hazardous wastes are not auxiliary fuel.

(c) *Control efficiency* is the mass of a pollutant in the sewage sludge fed to an incinerator minus the mass of that pollutant in the exit gas from the incinerator stack divided by the mass of the pollutant in the sewage sludge fed to the incinerator.

(d) *Dispersion factor* is the ratio of the increase in the ground level ambient air concentration for a pollutant at or beyond the property line of the site where the sewage sludge incinerator is located to the mass emission rate for the pollutant from the incinerator stack.

(e) *Fluidized bed incinerator* is an enclosed device in which organic matter and inorganic matter in sewage sludge are combusted in a bed of particles suspended in the combustion chamber gas.

(f) *Hourly average* is the arithmetic mean of all measurements, taken during an hour. At least two measurements must be taken during the hour.

(g) *Incineration* is the combustion of organic matter and inorganic matter in sewage sludge by high temperatures in an enclosed device.

(h) *Monthly average* is the arithmetic mean of the hourly averages for the hours a sewage sludge incinerator operates during the month.

(i) *Risk specific concentration* is the allowable increase in the average daily ground level ambient air concentration for a pollutant from the incineration of sewage sludge at or beyond the property line of the site where the sewage sludge incinerator is located.

(j) *Sewage sludge feed rate* is either the average daily amount of sewage sludge fired in all sewage sludge incinerators within the property line of the site where the sewage sludge incinerators are located for the number of days in a 365 day period that each sewage sludge incinerator operates, or the average daily design capacity for all sewage sludge incinerators within the property line of the site where the sewage sludge incinerators are located.

(k) *Sewage sludge incinerator* is an enclosed device in which only sewage sludge and auxiliary fuel are fired.

(l) *Stack height* is the difference between the elevation of the top of a sewage sludge incinerator stack and the elevation of the ground at the base of the stack when the difference is equal to or less than 65 meters. When the difference is greater than 65 meters, stack height is the creditable stack height determined in accordance with 40 CFR 51.100 (ii).

(m) *Total hydrocarbons* means the organic compounds in the exit gas from a sewage sludge incinerator stack measured using a flame ionization detection instrument referenced to propane.

(n) *Wet electrostatic precipitator* is an air pollution control device that uses both electrical forces and water to remove pollutants in the exit gas from a sewage sludge incinerator stack.

(o) *Wet scrubber* is an air pollution control device that uses water to remove pollutants in the exit gas from a sewage sludge incinerator stack.

§ 503.42 General requirements.

No person shall fire sewage sludge in a sewage sludge incinerator except in compliance with the requirements in this subpart.

§ 503.43 Pollutant limits.

(a) Firing of sewage sludge in a sewage sludge incinerator shall not violate the requirements in the National Emission Standard for Beryllium in subpart C of 40 CFR part 61.

(b) Firing of sewage sludge in a sewage sludge incinerator shall not violate the requirements in the National Emission Standard for Mercury in subpart E of 40 CFR part 61.

(c) *Pollutant limit—lead.*

(1) The daily concentration of lead in sewage sludge fed to a sewage sludge incinerator shall not exceed the concentration calculated using Equation (4).

$$C = \frac{0.1 \times NAAQS \times 86{,}400}{DF \times (1 - CE) \times SF} \qquad \text{Eq. (4)}$$

Where:

C=Daily concentration of lead in sewage sludge in milligrams per kilogram of total solids (dry weight basis).

NAAQS=National Ambient Air Quality Standard for lead in micrograms per cubic meter.

DF=Dispersion factor in micrograms per cubic meter per gram per second.

CE=Sewage sludge incinerator control efficiency for lead in hundredths.

SF=Sewage sludge feed rate in metric tons per day (dry weight basis).

(2)(i) When the sewage sludge stack height is 65 meters or less, the actual sewage sludge incinerator stack height shall be used in an air dispersion model specified by the permitting authority to determine the dispersion factor (DF) in equation (4).

(ii) When the sewage sludge incinerator stack height exceeds 65 meters, the creditable stack height shall be determined in accordance with 40 CFR 51.100(ii) and the creditable stack height shall be used in an air dispersion model specified by the permitting authority to determine the dispersion factor (DF) in equation (4).

(3) The control efficiency (CE) in equation (5) shall be determined from a performance test of the sewage sludge incinerator, as specified by the permitting authority.

(d) Pollutant limit—arsenic, cadmium, chromium, and nickel.

(1) The daily concentration for arsenic, cadmium, chromium, and nickel in sewage sludge fed to a sewage sludge incinerator each shall not exceed the concentration calculated using equation (5).

$$C = \frac{RSC \times 86{,}400}{DF \times (1 - CE) \times SF} \qquad \text{Eq. (5)}$$

Where:

C=Daily concentration of arsenic, cadmium, chromium, or nickel in sewage sludge in milligrams per kilogram of total solids (dry weight basis).

CE=Sewage sludge incinerator control efficiency for arsenic, cadmium, chromium, or nickel in hundredths.

DF=Dispersion factor in micrograms per cubic meter per gram per second.

RSC=Risk specific concentration in micrograms per cubic meter. S

F=Sewage sludge feed rate in metric tons per day (dry weight basis).

(2) The risk specific concentrations for arsenic, cadmium, and nickel used in equation (6) shall be obtained from Table 1 of § 503 .43.

TABLE 1 OF § 503.43.—RISK SPECIFIC CONCENTRATION ARSENIC, CADMIUM, AND NICKEL

Pollutant	Risk specific concentration (micrograms per cubic meter)
Arsenic	0.023
Cadmium	0.057
Nickel	2.0

(3) The risk specific concentration for chromium used in equation (5) shall be obtained from Table 2 of § 503.43 or shall be calculated using equation (6), as specified by the permitting authority.

TABLE 2 OF § 503.43.—RISK SPECIFIC CONCENTRATION—CHROMIUM

Type of incinerator	Risk specific concentration (micrograms per cubic meter)
Fluidized bed with wet scrubber	0.65
Fluidized bed with wet scrubber and wet electrostatic precipitator	0.23
Other types with wet scrubber	0.064
Other types with wet scrubber and wet electrostatic precipitator	0.016

$$RSC = \frac{0.0085}{r} \qquad \text{Eq. (6)}$$

Where:

RSC=risk specific concentration for chromium in micrograms per cubic meter used in equation (5).

r=decimal fraction of the hexavalent chromium concentration in the total chromium concentration measured in the exit gas from the sewage sludge incinerator stack in hundredths.

(4)(i) When the sewage sludge incinerator stack height is equal to or less than 65 meters, the actual sewage sludge incinerator stack height shall be used in an air dispersion model, as specified by the permitting authority, to determine the dispersion factor (DF) in equation (5).

(ii) When the sewage sludge incinerator stack height is greater than 65 meters, the creditable stack height shall be determined in accordance with 40 CFR 51.100(ii) and the creditable stack height shall be used in an air dispersion model, as specified by the permitting authority, to determine the dispersion factor (DF) in equation (5).

(5) The control efficiency (CE) in equation (5) shall be determined from a performance test of the sewage sludge incinerator, as specified by the permitting authority.

§ 503.44 Operational standard—total hydrocarbons.

(a) The total hydrocarbons concentration in the exit gas from a sewage sludge incinerator shall be corrected for zero percent moisture by multiplying the measured total hydrocarbons concentration by the correction factor calculated using equation (7).

$$\text{Correction factor (percent moisture)} = \frac{1}{(1 - X)} \qquad \text{Eq. (7)}$$

Where:

X=decimal fraction of the percent moisture in the sewage sludge incinerator exit gas in hundredths.

(b) The total hydrocarbons concentration in the exit gas from a sewage sludge incinerator shall be corrected to seven percent oxygen by multiplying the measured total hydrocarbons concentration by the correction factor calculated using equation (8).

$$\text{Correction factor (oxygen)} = \frac{14}{(21-Y)} \quad \text{Eq. (8)}$$

Where:

Y=Percent oxygen concentration in the sewage sludge incinerator stack exit gas (dry volume/dry volume).

(c) The monthly average concentration for total hydrocarbons in the exit gas from a sewage sludge incinerator stack, corrected for zero percent moisture using the correction factor from equation (7) and to seven percent oxygen using the correction factor from equation (8), shall not exceed 100 parts per million on a volumetric basis when measured using the instrument required by § 503.45(a).

§ 503.45 Management practices.

(a)(1) An instrument that measures and records the total hydrocarbons concentration in the sewage sludge incinerator stack exit gas continuously shall be installed, calibrated, operated, and maintained for each sewage sludge incinerator, as specified by the permitting authority.

(2) The total hydrocarbons instrument shall employ a flame ionization detector; shall have a heated sampling line maintained at a temperature of 150 degrees Celsius or higher at all times; and shall be calibrated at least once every 24-hour operating period using propane.

(b) An instrument that measures and records the oxygen concentration in the sewage sludge incinerator stack exit gas continuously shall be installed, calibrated, operated, and maintained for each sewage sludge incinerator, as specified by the permitting authority.

(c) An instrument that measures and records information used to determine the moisture content in the sewage sludge incinerator stack exit gas continuously shall be installed, calibrated, operated, and maintained for each sewage sludge incinerator, as specified by the permitting authority.

(d) An instrument that measures and records combustion temperatures continuously shall be installed, calibrated, operated, and maintained for each sewage sludge incinerator, as specified by the permitting authority.

(e) The maximum combustion temperature for a sewage sludge incinerator shall be specified by the permitting authority and shall be based on information obtained during the performance test of the sewage sludge incinerator to determine pollutant control efficiencies.

(f) The values for the operating parameters for the sewage sludge incinerator air pollution control device shall be specified by the permitting authority and shall be based on information obtained during the performance test of the sewage sludge incinerator to determine pollutant control efficiencies.

(g) Sewage sludge shall not be fired in a sewage sludge incinerator if it is likely to adversely affect a threatened or endangered species listed under section 4 of the Endangered Species Act or its designated critical habitat.

§ 503.46 Frequency of monitoring.

(a) *Sewage sludge.*

(1) The frequency of monitoring for beryllium and mercury shall be specified by the permitting authority.

(2) The frequency of monitoring for arsenic, cadmium, chromium, lead, and nickel in sewage sludge fed to a sewage sludge incinerator shall be the frequency in Table 1 of § 503.46.

TABLE 1 OF § 503.46.—FREQUENCY OF MONITORING—INCINERATION

Amount of sewage sludge[1] (metric tons per 365 day period)	Frequency
Greater than zero but less than 290.	Once per year.
Equal to or greater than 290 but less than 1,500.	Once per quarter (four times per year).
Equal to or greater than 1,500 but less than 15,000.	Once per 60 days (six times per year).
Equal to or greater than 15,000	Once per month (12 times per year).

[1] Amount of sewage sludge fired in a sewage sludge incinerator (dry weight basis).

(3) After the sewage sludge has been monitored for two years at the frequency in Table 1 of § 503.46, the permitting authority may reduce the frequency of monitoring for arsenic, cadmium, chromium, lead, and nickel, but in no case shall the frequency of monitoring be less than once per year when sewage sludge is fired in a sewage sludge incinerator.

(b) Total hydrocarbons, oxygen concentration, information to determine moisture content, and combustion temperatures.

The total hydrocarbons concentration and oxygen concentration in the exit gas from a sewage sludge incinerator stack, the information used to measure moisture content in the exit gas, and th combustion temperatures for the sewage sludge incinerator shall be monitored continuously.

(c) Air pollution control device operating parameters.

The frequency of monitoring for the sewage sludge incinerator air pollution control device operating parameters shall be specified by the permitting authority.

(Approved by the Office of Management and Budget under control number 2040–0157)

§ 503.47 Recordkeeping.

(a) The person who fires sewage sludge in a sewage sludge incinerator shall develop the information in § 503.47(b) through § 503.47(n) and shall retain that information for five years.

(b) The concentration of lead, arsenic, cadmium, chromium, and nickel in the sewage sludge fed to the sewage sludge incinerator.

(c) The total hydrocarbons concentrations in the exit gas from the sewage sludge incinerator stack.

(d) Information that indicates the requirements in the National Emission Standard for beryllium in subpart C of 40 CFR part 61 are met.

(e) Information that indicates the requirements in the National Emission Standard for mercury in subpart E of 40 CFR part 61 are met.

(f) The combustion temperatures, including the maximum combustion temperature, for the sewage sludge incinerator.

(g) Values for the air pollution control device operating parameters.

(h) The oxygen concentration and information used to measure moisture content in the exit gas from the sewage sludge incinerator stack.

(i) The sewage sludge feed rate.

(j) The stack height for the sewage sludge incinerator.

(k) The dispersion factor for the site where the sewage sludge incinerator is located.

(l) The control efficiency for lead, arsenic, cadmium, chromium, and nickel for each sewage sludge incinerator.

(m) The risk specific concentration for chromium calculated using equation (6), if applicable.

(n) A calibration and maintenance log for the instruments used to measure the total hydrocarbons concentration and oxygen concentration in the exit gas from the sewage sludge incinerator stack, the information needed to determine moisture content in the exit gas, and the combustion temperatures

(Approved by the Office of Management and Budget under control number 2040–0157)

§ 503.48 Reporting.

Class I sludge management facilities, POTWs (as defined in 40 CFR 501.2) with a design flow rate equal to or greater than one million gallons per day, and POTWs that serve a population of 10,000 people or greater shall submit the information in § 503.47(b) through § 503.47(h) to the permitting authority on February 19 of each year.

(Approved by the Office of Management and Budget under control number 2040–0157)

Appendix A to Part 503—Procedure to Determine the Annual Whole Sludge Application Rate for a Sewage Sludge

Section 503.13(a)(4)(ii) requires that the product of the concentration for each pollutant listed in Table 4 of § 503.13 in sewage sludge sold or given away in a bag or other container for application to the land and the annual whole sludge application rate (AWSAR) for the sewage sludge not cause the annual pollutant loading rate for the pollutant in Table 4 of § 503.13 to be exceeded. This appendix contains the procedure used to determine the AWSAR for a sewage sludge that does not cause the annual pollutant loading rates in Table 4 of § 503.13 to be exceeded.

The relationship between the annual pollutant loading rate (APLR) for a pollutant and the annual whole sludge application rate (AWSAR) for 1a sewage sludge is shown in equation (1).

$$APLR = C \times AWSAR \times 0.001 \tag{1}$$

Where:

APLR=Annual pollutant loading rate in kilograms per hectare per 365 day period.

C=Pollutant concentration in milligrams, per kilogram of total solids (dry weight basis).

AWSAR=Annual whole sludge application rate in metric tons per hectare per 365 day period (dry weight basis).

0.001=A conversion factor.

To determine the AWSAR, equation (1) is rearranged into equation (2):

$$AWSAR = \frac{APLR}{C \times 0.001} \tag{2}$$

The procedure used to determine the AWSAR for a sewage sludge is presented below.

Procedure:

1. Analyze a sample of the sewage sludge to determine the concentration for each of the pollutants listed in Table 4 of § 503.13 in the sewage sludge.
2. Using the pollutant concentrations from Step 1 and the APLRs from Table 4 of § 503.13, calculate an AWSAR for each pollutant using equation (2) above.
3. The AWSAR for the sewage sludge is the lowest AWSAR calculated in Step 2.

Appendix B to Part 503—Pathogen Treatment Processes

A. Processes to Significantly Reduce Pathogens (PSRP)

1. Aerobic digestion—Sewage sludge is agitated with air or oxygen to maintain aerobic conditions for a specific mean cell residence time at a specific temperature. Values for the mean cell residence time and temperature shall be between 40 days at 20 degrees Celsius and 60 days at 15 degrees Celsius.

2. Air drying—Sewage sludge is dried on sand beds or on paved or unpaved basins. The sewage sludge dries for a minimum of three months. During two of the three months, the ambient average daily temperature is above zero degrees Celsius.

3. Anaerobic digestion—Sewage sludge is treated in the absence of air for a specific mean cell residence time at a specific temperature. Values for the mean cell residence time and temperature shall be between 15 days at 35 to 55 degrees Celsius and 60 days at 20 degrees Celsius.

4. Composting—Using either the within-vessel, static aerated pile, or windrow composting methods, the temperature of the sewage sludge is raised to 40 degrees Celsius or higher and remains at 40 degrees Celsius or higher for five days. For four hours during the five days, the temperature in the compost pile exceeds 55 degrees Celsius.

5. Lime stabilization—Sufficient lime is added to the sewage sludge to raise the pH of the sewage sludge to 12 after two hours of contact.

B. Processes to Further Reduce Pathogens (PFRP)

1. Composting—Using either the within-vessel composting method or the static aerated pile composting method, the temperature of the sewage sludge is maintained at 55 degrees Celsius or higher for three days.

Using the windrow composting method, the temperature of the sewage sludge is maintained at 55 degrees or higher for 15 days or longer. During the period when the compost is maintained at 55 degrees or higher, there shall be a minimum of five turnings of the windrow.

2. Heat drying—Sewage sludge is dried by direct or indirect contact with hot gases to reduce the moisture content of the sewage sludge to 10 percent or lower. Either the temperature of the sewage sludge particles exceeds 80 degrees Celsius or the wet bulb temperature of the gas in contact with the sewage sludge as the sewage sludge leaves the dryer exceeds 80 degrees Celsius.

3. Heat treatment—Liquid sewage sludge is heated to a temperature of 180 degrees Celsius or higher for 30 minutes.

4. Thermophilic aerobic digestion—Liquid sewage sludge is agitated with air or oxygen to maintain aerobic conditions and the mean cell residence time of the sewage sludge is 10 days at 55 to 60 degrees Celsius.

5. Beta ray irradiation—Sewage sludge is irradiated with beta rays from an accelerator at dosages of at least 1.0 megarad at room temperature (ca. 20 degrees Celsius).

6. Gamma ray irradiation—Sewage sludge is irradiated with gamma rays from certain isotopes, such as Cobalt 60 and Cesium 137, at room temperature (ca. 20 degrees Celsius).

7. Pasteurization—The temperature of the sewage sludge is maintained at 70 degrees Celsius or higher for 30 minutes or longer.

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BILLING CODE [illegible]

ENVIRONMENTAL PROTECTION AGENCY

40 CFR Parts 122, 123, and 501

[FRL–4515–7]

National Pollutant Discharge Elimination System Sewage Sludge Permit Regulations; State Sludge Management Program Requirements

AGENCY: Environmental Protection Agency.

ACTION: Final rule; technical amendment.

SUMMARY: Under existing regulations that establish sewage sludge permitting and State sewage sludge program requirements, approximately 20,000 publicly owned treatment works and other treatment works treating domestic sewage are required to submit permit applications within 120 days after the promulgation of standards applicable to their sewage sludge use or disposal practice(s). The final sewage sludge use and disposal standards will be published in the Federal Register on or near the same date as this final rule. To facilitate the management of these applications, on May 27, 1992, EPA proposed to revise these rules to stagger the submission of permit applications. Additionally, EPA proposed to extend the time period during which the initial set of applications must be submitted from 120 days to 180 days after promulgation of the technical standards. In response to comments received on the May 27, 1992, proposal, EPA is issuing a final rule which requires permit applications in phases and extends the time period in which the initial applications are due following the publication of the final use or disposal standards.

On July 28, 1986, EPA promulgated final regulations for application requirements for facilities that discharge only non-process wastewater, which resulted in internal recodification of § 122.21. Conforming changes were not made to § 123.25(a)(4) which refers to the relevant portions of section 122. These technical corrections are being made as part of this rule.

EFFECTIVE DATE: The effective date of this final rule is March 22, 1993.

APPENDIX B

SEWAGE SLUDGE INCINERATORS SUBJECT TO PART 503
(as of October 27, 1992)

SEWAGE SLUDGE INCINERATORS SUBJECT TO PART 503 AS OF 10/27/92

STATE	CITY	FACILITY NAME	NPDES#	STATE COUNT	REG
CT	STAMFORD	STAMFORD STP	CT0101087	1	01
CT	NEW CANAAN	NEW CANAAN STP	CT0101273	2	01
CT	HARTFORD	THE METROPOLITAN DIST.	CT0100251	3	01
CT	NEW HAVEN	NEW HAVEN EAST SHORE STP	CT0100366	4	01
CT	NORWALK	NORWALK STP	CT0101249	5	01
CT	VERNON	VERNON WPCF	CT0100609	6	01
CT	NEW LONDON	NEW LONDON/STP	CT0100382	7	01
CT	WATERBURY	WATERBURY STP	CT0100625	8	01
CT	NAUGATUCK	NAUGATUCK SEWAGE TREATMENT	CT0100641	9	01
CT	CROMWELL	MATTABASSETT DISTR. COMMISSION	CT0100307	10	01
MA	FITCHBURG	EAST FITCHBURG W W T F	MA010098	1	01
MA	MILLBURY	UPPER BLACKSTONE W P A D	MA010236	2	01
MA	NEW BEDFORD	NEW BEDFORD W T P	MA010078	3	01
MA	FALL RIVER	FALL RIVER S T P	MA010038	4	01
MA	N. ANDOVER,	GREATER LAWRENCE SD WWTP	MA010044	5	01
MA	CHICOPEE	CHICOPEE W P C	MA010150	6	01
NH	WEST LEBANON	LEBANON W W T F	NH0100366	1	01
NH	MANCHESTER	MANCHESTER W W T F	NH0100447	2	01
RI	CRANSTON	CRANSTON WWTF	RI0100013	1	01
NJ	BRIDGEWATER	SOMERSET RARITAN VALLEY S A	NJ0024864	1	02
NJ	ATLANTIC CITY	ATLANTIC COUNTY UTILITIES	NJ0024473	2	02
NJ	PARSIPPANY	PARSIPPANY TROY HILLS	NJ0024970	3	02
NJ	WAYNE	MOUNTAIN VIEW STP	NJ0028002	4	02
NJ	FAIRFIELD	TWO BRIDGES SA-PEQUANNOCK LIN	NJ0029386	5	02
NJ	THOROFARE	GLOUCESTER COUNTY UA	NJ0024686	6	02
NJ	PRINCETON	STONY BROOK REGIONAL SA	NJ0031119	7	02
NJ	CAMDEN	CAMDEN COUNTY MUA **	NJ0026468	8	02
NJ	WALDWICK	NORTHWEST BERGEN COUNTY UA	NJ0024813	9	02
NJ	UNION BEACH	BAYSHORE REGIONAL SA	NJ0024708	10	02
NY	NEW ROCHELLE	NEW ROCHELLE S.D.-WESCHESTER C	NY0026697	1	02
NY	POUGHKEEPSIE	ARLINGTON STP-POUGHKEEPSIE	NY0026271	2	02
NY	BUFFALO	ERIE CO/SOUTHTOWNS SEW TRT	NY0095401	3	02
NY	BUFFALO	BUFFALO BIRD ISLAND WWTP	NY0028410	4	02
NY	ROCHESTER	MONROE CO-GATES-CHILI-OGDEN S.	NY0028045	5	02
NY	HILTON	MUNROE CO-NORTHWEST QUAD.PUR	NY0028231	6	02
NY	AUBURN	AUBURN (C) STP	NY0021903	7	02
NY	MECHANICVILLE	SARATOGA CO SD# 1 WWTP	NY0028240	8	02
NY	BEACON	BEACON (C) WTP	NY0025976	9	02
NY	ALBANY	ALBANY CO SD NORTH WWTP	NY0026875	10	02

SEWAGE SLUDGE INCINERATORS SUBJECT TO PART 503 AS OF 10/27/92

STATE	CITY	FACILITY NAME	NPDES#	STATE COUNT	REG
NY	ALBANY	ALBANY CO SD SOUTH WWTP	NY0026867	11	02
NY	PORT WASHINGTO	PORT WASHINGTON WPCP	NY0026778	12	02
NY	ORANGETOWN	ORANGETOWN (T) SD#2 STP	NY0026051	13	02
NY	OSSINING	WESTCHESTER CO-OSSINING SD WW	NY0108324	14	02
NY	WATERTOWN	WATERTOWN (C) WPCP	NY0025984	15	02
NY	ROCHESTER	ROCHESTER-FRANK E. VAN LARE ST	NY0028339	16	02
NY	SCHENECTADY	SCHENECTADY (C) WPC FACILITY	NY0020516	17	02
NY	PORT CHESTER	PORT CHESTER SANITARY SD WWTP-	NY0026786	18	02
NY	NEW WINDSOR	NEW WINDSOR (T) STP	NY0022446	19	02
NY	UTICA	ONEIDA COUNTY WPCP	NY0025780	20	02
NY	WEST BABYLON	SUFFOLK COUNTY SD#3-SOUTHWEST	NY0104809	21	02
NY	OSWEGO (C)	OSWEGO (C) EAST SIDE STP	NY0029114	22	02
NY	GLEN COVE	GLEN COVE (C) WTP	NY0026620	23	02
NY	OSWEGO	OSWEGO WEST SIDE STP	NY0029106	24	02
NY	DUNKIRK	DUNKIRK (C) WWTP	NY0027961	25	02
NY	LITTLE FALLS	LITTLE FALLS (C) WWTP	NY0022403	26	02
IL	NORTHBROOK *	UTIL OF MD-MARLBORO MEADOWS S	MD002278	1	03
MD	BALTIMORE	PATAPSCO WWTP	MD002160	2	03
MD	SNOW HILL	OCEAN CITY WTP, WORCESTER CO.	MD002004	3	03
PA	PITTSBURGH	ALLEGHENY COUNTY SANITARY	PA0025984	1	03
PA	CHESTER	DELAWARE CTY. REGL. WATER	PA0027103	2	03
PA	LEECHBURG	KISKI VALLEY WATER POLLUTION	PA0027626	3	03
PA	DAUPHIN COUNTY	SWATARA TWP AUTH	PA0026735	4	03
PA	HAZELTON	GREATER HAZELTON SEWAGE TREA	PA0026921	5	03
PA	WILKES BARRE	WYOMING VALLEY STP	PA0026107	6	03
PA	JOHNSTOWN,	JOHNSTOWN CITY	PA0026034	7	03
PA	NORTH WALES	UPPER GWYNEDD TOWNSHIP AUTHO	PA0023256	8	03
PA	WILLOW GROVE	UPPER MORELAND-HATBORO SEWAG	PA0025976	9	03
PA	DAUPHIN COUNTY	DERRY TOWNSHIP MUN. AUTH.	PA0026484	10	03
PA	COLMAR	HATFIELD TWP. MUN. AUTH.	PA0026247	11	03
PA	YORK_COUNTY	YORK CITY WASTEWATER TMT PLAN	PA0026263	12	03
PA	BLAIR COUNTY	TYRONE BOROUGH SEWER AUTH-STP	PA0026727	13	03
PA	DURYEA	LOWER LACKAWANNA VALLEY SAN.	PA0026361	14	03
PA	NORRISTOWN	EAST NORRITON-PLYMOUTH - STP	PA0026816	15	03
PA	ERIE	ERIE WASTEWATER TREATMENT	PA0026301	16	03
VA	VIRGINIA BEACH	WILLIAMSBURG	VA0025267	1	03
VA	NEWPORT NEWS	HRSD - BOAT HARBOR STP	VA0025283	2	03
VA	ARLINGTON	ARLINGTON STP	VA0025143	3	03
VA	FAIRFAX	LOWER POTOMAC STP	VA0025364	4	03
VA	HOPEWELL	HOPEWELL STP CITY OF	VA0066630	5	03
VA	BLACKSBURG	BLACKBURG-VPI SANITATION AUTH	VA0060844	6	03

SEWAGE SLUDGE INCINERATORS SUBJECT TO PART 503 AS OF 10/27/92

STATE	CITY	FACILITY NAME	NPDES#	STATE COUNT	REG
VA	WILLIAMSBURG	WILLIAMSBURG WFP CITY OF	VA0056537	7	03
VA	PRINCE WILLIAM	MOONEY STP	VA0025101	8	03
WV	HUNTINGTON	CITY OF HUNTINGTON	WV002315	1	03
WV	CLARKSBURG	CLARKSBURG SANITARY BOARD	WV002330	2	03
FL	JACKSONVILLE	JAX BUCKMAN ST STP #1	FL0026000	1	04
FL	PENSACOLA	ESCAMBIA CNTY-MAIN STREET WTP	FL0021440	2	04
GA	ATLANTA	ATLANTA-R M CLAYTON WPCP	GA0021482	1	04
GA	ATLANTA	ATLANTA- UTOY CREEK WPCP	GA0021458	2	04
GA	MARIETTA	COBB CO.-SO. COBB WPCP	GA0026158	3	04
GA	GAINESVILLE	GAINESVILLE FLAT CR WPCP	GA0021156	4	04
GA	SAVANNAH	SAVANNAH PRESIDENT ST. WPCP	GA0025348	5	04
GA	MARIETTA	COBB CO - NOONDAY CREEK WPCP	GA0024988	6	04
GA	MARIETTA	COBB CO-SUTTON WPCP	GA0026140	7	04
GA	STONE MOUNTAIN	DEKALB CO-SNAPFINGER CR WPCP	GA0024147	8	04
NC	ROCKY MOUNT	ROCKY MOUNT (TAR RIVER WWTP)	NC0030317	1	04
NC	GREENSBORO	GREENSBORO T. Z. OSBORNE WWTF	NC0047384	2	04
NC	SHELBY	SHELBY WWTP, CITY OF	NC0024538	3	04
SC	COLUMBIA	COLUMBIA/METRO PLANT	SC0020940	1	04
SC	CHARLESTON	CHARLESTON/PLUM ISLAND PLANT	SC0021229	2	04
TN	NASHVILLE	NASHVILLE CENTRAL STP	TN0020575	1	04
TN	NEWPORT	NEWPORT STP	TN0020702	2	04
TN	MARYVILLE	MARYVILLE STP	TN0020079	3	04
TN	BRISTOL	BRISTOL STP #2	TN0023531	4	04
IN	INDIANAPOLIS	INDIANAPOLIS-BELMONT MUN. STP	IN0023183	1	05
MI	WYANDOTTE	WAYNE CO-WYANDOTTE WWTP	MI0021156	1	05
MI	PORT HURON	PORT HURON WWTP	MI0023833	2	05
MI	LANSING	LANSING WWTP	MI0023400	3	05
MI	GRAND RAPIDS	GRAND RAPIDS WWTP	MI0026069	4	05
MI	FLINT	FLINT WWTP	MI0022926	5	05
MI	YPSILANTI	YCUA REGIONAL WWTP	MI0042676	6	05
MI	EAST LANSING	EAST LANSING WWTP	MI0022853	7	05
MI	TRENTON	TRENTON WWTP	MI0021164	8	05
MI	ANN ARBOR	ANN ARBOR WWTP	MI0022217	9	05
MI	WARREN	WARREN WWTP	MI0024295	10	05
MI	DETROIT	DETROIT WWTP	MI0022802	11	05
MI	BAY CITY	BAY CITY WWTP	MI0022284	12	05

SEWAGE SLUDGE INCINERATORS SUBJECT TO PART 503 AS OF 10/27/92

STATE	CITY	FACILITY NAME	NPDES#	STATE COUNT	REG
MI	KALAMAZOO	KALAMAZOO WWTP	MI0023299	13	05
MI	PONTIAC	PONTIAC WWTP	MI0023825	14	05
MN	SAINT PAUL	MWCC/MC-SENECA	MN003000	1	05
MN	DULUTH	WESTERN LAKE SSD	MN004978	2	05
MN	SAINT PAUL	MWCC/MC-METROPOLITAN	MN002981	3	05
OH	EUCLID	EUCLID, CITY OF	OH0031062	1	05
OH	CINCINNATI	HAMILTON CO. MILL CREEK	OH0025461	2	05
OH	CLEVELAND	NEORSD - WESTERLY	OH0024660	3	05
OH	WILLOUGHBY	WILLOUGHBY, CITY OF	OH0028126	4	05
OH	CINCINNATI	HAMILTON CO.-MUDDY CREEK	OH0025470	5	05
OH	YOUNGSTOWN	YOUNGSTOWN, CITY OF	OH0028223	6	05
OH	CLEVELAND	NEORSD - SOUTHERLY	OH0024651	7	05
OH	CANTON	CANTON, CITY OF	OH0024350	8	05
OH	COLUMBUS	COLUMBUS, CITY OF-JACKSON	OH0024732	9	05
OH	COLUMBUS	COLUMBUS, CITY OF - SOUTHERLY	OH0024741	10	05
OH	YOUNGSTOWN	MAHONING CO. BD. OF COMM.	OH0045721	11	05
OH	AKRON	AKRON, CITY OF	OH0023833	12	05
WI	GREEN BAY	GREEN BAY METROPOLITAN SEWERA	WI0020991	1	05
WI	DE PERE	DE PERE CITY	WI0023787	2	05
AR	LITTLE ROCK	CITY OF LITTLE ROCK-FOURCHE WW	AR0040177	1	06
LA	NEW ORLEANS	NEW ORLEANS -EASTBANK STP	LA0038091	1	06
LA	LAKE CHARLES	CITY OF LAKE CHARLES B PLANT	LA0036358	2	06
LA	LAKE CHARLES	CITY OF LAKE CHARLES C PLANT	LA0036366	3	06
LA	NEW ORLEANS	NEW ORLEANS -WESTBANK STP	LA0038105	4	06
IA	DAVENPORT	DAVENPORT CITY OF STP	IA0043052	1	07
IA	DUBUQUE	DUBUQUE CITY OF STP	IA0044458	2	07
IA	CEDAR RAPIDS	CEDAR RAPIDS CITY OF STP	IA0042641	3	07
KS	SHAWNEE MISSION	JOHNSON CO UWWD MISSION/TURK	KS0055492	1	07
KS	KANSAS CITY	KANSAS CITY KS PLANT #20	KS0038547	2	07
KS	KANSAS CITY	KC MUNIC WWTP #1-KAW POINT	KS0038563	3	07
MO	ST LOUIS	ST LOUIS MSD, BISSELL POI	MO002517	1	07
MO	INDEPENDENCE	INDEPENDENCE-ROCK CREEK WTP	MO008968	2	07
MO	KANSAS CITY	KC, BLUE RIVER	MO002491	3	07
MO	ST. LOUIS	ST. LOUIS MSD - LEMAY	MO002515	4	07
NE	OMAHA	OMAHA PAPILLION CREEK WWTF	NE0112810	1	07

SEWAGE SLUDGE INCINERATORS SUBJECT TO PART 503 AS OF 10/27/92

STATE	CITY	FACILITY NAME	NPDES#	STATE COUNT	REG
CA	BARSTOW	BARSTOW, CA	CA	1	09
CA	SOUTH LAKE TAH	SOUTH TAHOE P.U.D.	CA0102709	2	09
CA	REDWOOD CITY	SOUTH BAYSIDE SYSTEM	CA0038369	3	09
CA	LAGUNA HILLS	S.E.R.R.A.	CA0107417	4	09
CA	PALO ALTO	PALO ALTO STP	CA0037834	5	09
CA	MARTINEZ	CENTRAL CONTRA COSTA	CA0037648	6	09
CA	SAN MATEO	SAN MATEO, CITY OF	CA0037541	7	09
HI	HONOLULU	HONOLULU, CITY AND COUNTY OF	HI0020117	1	09
NV	ZEPHYR COVE	DOUGLAS CO. SEWER	NV0020052	1	09
AK	WRANGELL	WRANGELL, CITY OF	AK0021466	1	10
AK	ANCHORAGE	ANCHORAGE, PORT OF	AK0021636	2	10
WA	EDMONDS	EDMONDS, CITY OF	WA002405	1	10
WA	LYNNWOOD	LYNNWOOD, CITY OF	WA002403	2	10
WA	VANCOUVER	VANCOUVER, CITY OF	WA002435	3	10
WA	BELLINGHAM	BELLINGHAM, CITY OF	WA002374	4	10

ACTIVE NON EXPIRED	118
ACTIVE SLUDGE ONLY	1
EXPIRED PERMITS	47

TOTAL # ACTIVE INCINERATORS	166
INACTIVES	12

TOTAL # INCINERATORS	178

APPENDIX C

RATIO OF HEXAVALENT TO TOTAL CHROMIUM INCINERATION EMISSION

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

JUN 28 1991

OFFICE OF WATER

MEMORANDUM

SUBJECT: Ratio of Hexavalent to Total Chromium Incineration Emission

FROM: Helen Jacobs, Statistician, H.J.
Statistics Section, EAD (WH-552)

TO: Alan Rubin, Chief
Sludge Risk Assessment Branch, HECD (WH-586)

THRU: Henry Kahn, Chief HK
Statistics Section, EAD (WH-552)

Purpose:

A statistical analysis of incinerator performance data was conducted. The numerical values developed from this analysis will be used as a basis for recommending limits for the maximum proportion of hexavalent chromium in total chromium emitted during the incineration of sludge.

Data:

Measurements of the emission levels of hexavalent and total chromium were obtained from samples of three incinerators. At each incinerator, sampling runs were conducted on several different days. For a particular run, samples were taken at one or more of the following locations in the incinerator: exiting the furnace, exiting the scrubber and exiting the electrostatic precipitator (ESP). At each location two to four sampling trains located at the same height in the stack but at different points in its circumference were run simultaneously. The results from these trains were averaged and this average was considered a single observation. The results from sampling trains which did not meet QA/QC standards were excluded from the average.

The sites, incinerator types and the location in the stack where the samples were taken are as follows:

Site	Incinerator Type	Location of Sample
Site 6	Multiple earth	Exiting scrubber
Site 8	Fluidized bed	Exiting furnace Exiting scrubber Exiting ESP
Site 9	Multiple hearth	Exiting scrubber Exiting ESP

Six sets of data were created - one for each site and sample location.

Statistical Analysis:

The beta distribution was selected as the model for the proportion of hexavalent chromium in total chromium. This distribution is defined over the closed interval 0<=y<=1 and as such is often used as the model for proportions. The beta distribution is capable of modeling a wide range of variation since its shape will change markedly depending on the value of its two parameters, alpha and beta.

The probability density function for the beta distribution is

$$f(y/\alpha,\beta) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} y^{\alpha-1}(1-y)^{\beta-1}, \qquad \alpha,\beta>0;\ 0\le y\le 1$$

$$= 0 \ \textit{elsewhere}.$$

where

$$y = \textit{hexavalent chromium/totalchromium}$$

The corresponding likelihood function, L, is

$$L(\alpha,\beta/y_1,\ldots,y_n) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} \prod_{i=1}^{n} y_i^{\alpha-1}(1-y_i)^{\beta-1}$$

The maximum likelihood procedure was used to estimate the parameters, alpha and beta, for each set of data. These maximum likelihood estimates were computed using a software routine that utilizes the Simplex method to maximize the likelihood, L. The software was provided by Bill Smith of EPA's Office of Policy, Planning and Evaluation.

The estimates of the means and standard deviations of the beta distributions were calculated using the following formulas:

$$\mu = \frac{a}{a+b}$$

$$\partial = \sqrt{\frac{ab}{(a+b+1)\,(a+b)^2}}$$

where

a, *b* = *maximum likelihood estimates of* α and β, *respectively.*

The maximum limit was set equal to the 95th upper percentile value of the distributions. The pth percentile of the beta distribution denoted by $\hat{X}_p$, is calculated by solving the following equation for $\hat{X}_p$.

$$p = \int_0^{\hat{x}_p} \frac{t^{a-1}(1-t)^{b-1}}{\beta(a,b)}\,dt$$

where

$$\beta(a,b) = \frac{\Gamma(a)\Gamma(b)}{\Gamma(a+b)}$$

and

a, *b* = *maximum likelihood estimates of* α and β, *respectively.*

The percentiles were calculated using Statails, a software program written by Bill Smith.

Limits were defined for each of the four combinations of furnace types (fluidized bed or multiple hearth) and pollution control devices (scrubber or scrubber plus ESP). The limit for the multiple hearth/scrubber combination represents the average values for sites 6 and 9.

Table 1: Descriptive Statistics on the Ratio of Hexavalent Chromium to Total Chromium in Incinerator Emissions

Site	Location	N	$\bar{X}$	SD	$\hat{\mu}$	$\hat{\sigma}$	Min	Max	.50	.95
6	Scrubber	5	0.0446	0.0336	0.0445	0.0354	0.0100	0.0958	0.036	0.114
8	Furnace	3	0.0010	0.0011	0.0001	0.0012	0.0001	0.0026	0.001	0.003
8	Scrubber	3	0.0103	0.0018	0.0103	0.0003	0.0082	0.0125	0.010	0.013
8	ESP	3	0.0208	0.0077	0.0208	0.0087	0.0100	0.0273	0.020	0.037
9	Scrubber	4	0.1002	0.0282	0.1002	0.0280	0.0642	0.1433	0.098	0.150
9	ESP	4	0.3689	0.0808	0.3681	0.0829	0.2347	0.4464	0.365	0.509

N = Number of observations
$\bar{X}$ = Arithmetic mean of observations
SD = Standard deviation of observations
$\hat{\mu}$ = Mean of beta distribution
$\hat{\sigma}$ = Standard deviation of beta distribution
Min = Smallest observed value
Max = Largest observed value
.50 = Median (50th percentile) of beta distribution
.95 = 95th percentile of beta distribution

Results:

Six sets of data were available for analysis - one for each site and sampling location. Appendix A contains tables of the contents of each of these data sets. Appendix B contains the original tables of measurements taken at the three sites from which the 6 data sets were abstracted.

Measurements of the amounts of total chromium produced by 3 of the sampling trains were deleted from the analysis as outliers. Site 6 had one such outlier for the scrubber exit location and site 9 had two - one at a scrubber exit and one at a ESP exit. The determination that these results were outliers was based on the professional judgement of a chemist employed by Entropy, one of the contractors responsible for conducting the sampling and analysis.

The number of observations in the six sets of data ranged from 3 to 5. The site 6 scrubber exit had 5 observations; the site 8 furnace, scrubber and ESP exit locations had 3 observations each; and the site 9 scrubber and ESP exit locations had 4 observations each.

Estimates of the beta distribution parameters, alpha and beta, were produced for each of the sets of data. Appendix C contains a table of these parameter estimates.

Table I provides descriptive statistics for the proportion of hexavalent chromium in total chromium for each sampling location and site. Among the incinerators tested, site 9, which has a multiple hearth furnace, showed the highest median percent of hexavalent chromium in emissions. The median percent of hexavalent chromium at site 9 was 9.8% exiting the scrubber and 36.5% exiting the ESP. At site 6, also a multiple hearth incinerator, the median percent of hexavalent chromium exiting the scrubber was 3.6%. The third incinerator, site 8, is a fluidized bed incinerator. Results from this site were mostly non-detection for hexavalent chromium and, thus, the true values are less than or equal to the reported values. The medians based on the reported values for site 8 were 1.3% exiting the scrubber and 2.0% exiting the ESP.

Table II provides the proposed maximum limits for hexavalent chromium in total chromium emitted during sludge incineration by furnace type and pollution control device. These limits are based on the 95th percentile of the beta distribution. For a fluidized bed furnace with a scrubber the limit is 1.3% and with the addition of an ESP the limit is 3.7%. For a multiple hearth with a scrubber the limit is 13.2% and with the addition of an ESP the limit is 50.9%.

Table 2: Proposed Emission Limitations for the Percent of Hexavalent Chromium in Total Chromium		
	Pollution Control Device	
Furnace Type	Scrubber	Scrubber Plus ESP
Fluidized Bed	1.3%	3.7%
Multiple Hearth	13.2%	50.9%

Conclusions:

There are substantial differences with regard to the percent of hexavalent chromium in total chromium emitted during the incineration of sludge among different furnace types and pollution control devices. The fluidized bed furnace had lower percents of hexavalent chromium than the multiple hearth furnaces. And, the emissions leaving the scrubber had lower percents of hexavalent chromium than the emissions exiting the ESP. Given these differences the need for separate limits for each combination of scrubber and pollution control device appears justified.

cc: Neil Patel
Gene Crumpler

Attachment

Sampling Results for Hexavalent and Total Chromium

Site 6

Location of Sample - Exiting the Scrubber

Sample Run	Cr+6 (ug/dscm)	Total Cr (ug/dscm)	Ratio of Cr+6 to Total Cr
3	0.15	5.6	0.0268
3	0.06	8.6	0.0070
3	0.03	4.3	0.0070
3	0.005	6.1	0.0008
Average	0.06	6.15	0.0100
7	0.17	4.1	0.0415
7	0.15	3.9	0.0385
7	0.16	4.4	0.0364
7	0.10	13.7 *	0.0073
Average	0.15	4.1333	0.0351
9	0.18	3.1	0.0581
9	0.29	3.6	0.0806
Average	0.24	3.35	0.0701
11	0.31	3.8	0.0816
11	0.38	3.4	0.1118
Average	0.35	3.6	0.0958
13	0.04	2.7	0.0148
13	0.02	2.3	0.0087
Average	0.03	2.5	0.0120

* Outlier not included in average.

Sampling Results for Hexavalent and Total Chromium

Site 8

Location of Sample - Exiting Furnace

Run	Cr+6 (ug/dscm)	Total Cr (ug/dscm)	Ratio of Cr+6 to Total Cr
4	11.00	96500	0.0001
	11.00	72100	0.0002
Average	11.00	84300	0.0001
6	7.48	31200	0.0002
Average	7.48	31200	0.0002
8	9.92	3800	0.0026
Average	9.92	3800	0.0026

Sampling Results for Hexavalent and Total Chromium

Site 8

Location of Sample - Exiting Scrubber

Sample Run	Cr+6 (ug/dscm)	Total Cr (ug/dscm)	Ratio of Cr+6 to Total Cr
4	0.02	3.0	0.0067
	0.01	1.4	0.0071
	0.02	1.7	0.0118
Average	0.02	2.03	0.0082
6	0.02	1.5	0.0133
	0.02	2.9	0.0069
	0.02	1.5	0.0133
Average	0.02	1.97	0.0102
8	0.02	1.2	0.0167
	0.02	1.5	0.0133
	0.01	1.3	0.0077
Average	0.02	1.33	0.0125

Sampling Results for Hexavalent and Total Chromium

Site 8

Site of Sample - Exiting WESP

Run	Cr+6 (ug/dscm)	Total Cr (ug/dscm)	Ratio of Cr+6 to Total Cr
4	0.03	1.1	0.0273
Average	0.03	1.1	0.0273
6	0.02	0.8	0.0250
Average	0.02	0.8	0.0250
8	0.01	1.0	0.0100
Average	0.01	1.0	0.0100

Sampling Results for Hexavelant and Total Chromium

Site 9

Location of Sample - Exiting Scrubber

Sample Run	Cr+6 (ug/dscm)	Total Cr (ug/dscm)	Ratio of Cr+6 to Total Cr
3	1.4	11.8	0.1186
3	1.3	10.7	0.1215
3	2.3	12.4	0.1855
Average	1.67	11.63	0.1433
5	2.5	17.2	0.1453
5	0.6	15.2	0.0395
5	1.4	15.3	0.0915
Average	1.5	15.9	0.0943
8	1.0	17.5	0.0571
8	1.3	18.3	0.0710
8	0.9	4.2 *	0.2143
Average	1.15	17.9	0.0642
10	1.2	14.5	0.0828
10	1.8	15.3	0.1176
10	1.4	14.6	0.0959
Average	1.47	14.80	0.0991

* Outlier not included in average.

Sampling Results for Hexavelant and Total Chromium

Site 9

Location of Sample - Exiting WESP

Sample Run	Cr+6 (ug/dscm)	Total Cr (ug/dscm)	Ratio of Cr+6 to Total Cr	Print File
3	0.8	2.6	0.3077	0.2347
3	0.8	4.0	0.2000	0.4133
3	0.7	3.2	0.2187	0.4464
				0.3810
Average	0.77	3.27	0.2347	
5	1.0	33.9 *	0.0295	
5	1.6	3.6	0.4444	
5	1.5	3.9	0.3846	
Average	1.55	3.75	0.4133	
8	0.4	1.6	0.2500	
8	0.6	1.8	0.3333	
8	1.5	2.2	0.6818	
Average	0.83	1.87	0.4464	
10	0.8	2.3	0.3478	
10	0.8	2.1	0.3810	
10	0.8	1.9	0.4211	
Average	0.8	2.1	0.3810	

* Outlier not included in average.

N	4
Mean	0.3689
Minimum	0.2347
Maximum	0.4464
Std. dev.	0.0808

Alpha	12.10092
Beta	20.77726
Mean	0.368053
Variance	0.006865
Std. dev.	0.082858

* Outlier not included in average.

Estimated Beta Distribution Parameters			
Site	Location	Alpha	Beta
Site 6	**Exiting Scrubber**	1.46205	31.38569
Site 8	**Exiting Furnace**	0.69174	707.59162
	Exiting Scrubber	33.6712	3239.0905
	Exiting ESP	5.59566	263.97016
Site 9	**Exiting Scrubber**	11.40484	102.38166
	Exiting ESP	12.10092	20.77726

Estimated Beta Distribution Parameters

Site	Location	Alpha	Beta
Site 6	Exiting Scrubber	1.46205	31.38569
Site 8	Exiting Furnace	0.69174	707.59162
	Exiting Scrubber	33.6712	3239.0905
	Exiting ESP	5.59566	263.97016
Site 9	Exiting Scrubber	11.40484	102.38166
	Exiting ESP	12.10092	20.77726

APPENDIX D

SUMMARY OF NICKEL SPECIATION EMISSION TESTS AT THREE SEWAGE SLUDGE INCINERATORS

SUMMARY OF NICKEL SPECIATION IN SEWAGE SLUDGE INCINERATOR EMISSIONS

Run No.	Soluble		Sulfidic*		Oxidic		Total
	µg/m3	%	µg/m3	%	µg/m3	%	µg/m3
Outlet - Site 6							
Run 5	1.6	58	<0.15	< 5	1.2	42	2.8
Run 6	0.9	42	<0.18	< 8	1.3	58	2.2
Run 10	1.1	60	<0.18	<10	0.7	40	1.8
Run 12	0.7	39	<0.20	<11	1.1	61	1.8
Inlet - Site 6							
Run 5	65	41	<18	<12	92	59	157
Run 6	98	41	<28	<12	140	59	238
Run 8	18	21	< 6	< 7	66	79	84
Run 10	65	41	19	12	74	47	158
Run 12	64	77	<13	<15	19	23	83
Midpoint - Site 8							
Run 5	0.32	52.6	<0.065	<10.5	0.29	47.4	0.61
Run 10	0.17	35.7	<0.069	<14.3	0.31	64.3	0.52
Inlet - Site 8							
Run 8	555	12.0	<370	<9.0	3546	88.0	4101
Run 10	301	4.0	<301	<3.9	7377	96.0	7678
Midpoint - Site 9							
Run 4C	10.0	51.1	2.2	11.4	7.3	37.5	19.6
Run 9C	22.7	92.2	<0.1	<0.5	1.9	7.8	24.6
Run 11C	24.2	91.4	<0.1	<0.4	2.3	8.6	26.4
Run 12C	30.7	95.5	<0.1	<0.3	1.4	4.5	32.1
Run 13C	24.6	95.5	<0.1	<0.4	1.2	4.5	25.8
Inlet - Site 9							
Run 4C	77.0	18.1	<9.1	<2.1	330.6	77.8	425.1
Run 9C	201.0	19.2	<11.2	<1.1	826.4	78.7	1050
Run 11C	449.1	20.5	<26.4	<1.2	1691	77.1	2193
Run 12C	415.6	30.4	<18.5	<1.4	914.3	66.9	1367
Run 13C	358.5	55.8	10.5	1.6	263.6	41.0	643.1

*The sulfidic nickel is a combination of nickel sulfide and nickel subsulfide.

Site 6 and Site 9 are multiple-hearth furnaces; Site 8 is a fluidized-bed furnace. Outlet samples had insufficent particulate matter to attempt an analysis

Source: Steinsberger, et al., 1992.

APPENDIX E

GENERAL GUIDELINES FOR CONDUCTING A PERFORMANCE TEST AT A SEWAGE SLUDGE INCINERATOR TO DETERMINE THE CONTROL EFFICIENCY

STACK GAS SAMPLING

This section describes testing activities used in determining facility-specific control efficiency values for toxic metals emissions. These efficiency values are used to calculate the maximum allowable concentration of toxic metals in the sludge feed and the maximum allowable sludge feed rate to the incinerator based upon the equations provided in the proposed rule. The test data will also be used to determine facility-specific limits for temperature, oxygen, and air pollution control conditions.

1. Test Design:

The stack test must be designed to gather all needed information in an acceptable manner. Major elements of the testing are:

- Sampling and analysis of sludge feed for metals.
- Sampling and analysis of stack emissions for metals.
- Monitoring and documentation of operating conditions during the test (including temperature(s), oxygen, total hydrocarbon, sludge feed rate, and air pollution control devices).

A few general guidelines are appropriate:

- The test should be conducted at worst case conditions (i.e., with the highest expected feed rate of sludge, at the highest temperature, etc.) for metals emissions in order to obtain the most flexible permit conditions. However, the system must be operated within its design specifications to demonstrate adequate performance in controlling metals emissions.

Source: MRI, 1990

- All testing and monitoring must be conducted concurrently (or phased to account for material lag time). Sludge feed samples must be collected and analyzed to calculate an input loading rate for each investigated toxic metal for comparison with outlet emission rates.

- Three replicate test runs are requested for each specific set of operating conditions. This provides added assurance that the incinerator is operating in a consistent manner. Operating conditions should be maintained as consistently as possible for the three test runs.

- Measurements of temperature, oxygen, THC, sludge feed rate, and air pollution control indicators should be recorded continuously, or, at a minimum, every 60 sec.

- All monitoring instruments should be recalibrated immediately prior to and after the test. Documentation of calibrations should be included in the test report.

- Sludge feed samples should be collected at least every 15 min during each stack sampling test period. Individual samples can be composited into one sample analyzed per test run.

- Sampling should not begin until the incinerator has reached a steady state on sludge feed. A minimum of 60 min (or 120 min for a multiple hearth) of operation feeding sludge is recommended prior to sampling.

- Minimum stack sampling time for each run (actual sampling time not including time for port changes, etc.) should be 1 hr.

- Custody procedures should be used for handling all samples. Full chain-of-custody procedures are typically much more labor-intensive but may be used at the applicant's option.

- Results should be reported in a format which includes all information and data necessary to calculate final results and verify quality assurance objectives. Results should be presented in as clear and succinct a format as possible.

APPENDIX F

EMISSIONS DATA FOR THC, CO, AND 21 ORGANICS FROM FOUR SEWAGE SLUDGE INCINERATORS

Emissions Data for the THC, CO, and 21 Organics from Four Sewage Sludge Incinerators

SITE	RUN	THC (ppm)	CO (ppm)	B,2,6,PH (ug/M3)	1,2,DICHLOROBENZENE (ug/M3)	1,3,DICHLOROBENZENE (ug/M3)	1,4,DICHLORO BENZENE (ug/M3)	2-NITRO PHENOL (ug/M3)	PHENOL (ug/M3)
1	1	9	320	2.5			22		
1	2	16	450						
1	3	9	450	22.1	15.6				
1	4	7.5	360				25.9		
1	5	8	325	14.2		11.5	43.8		
2	1	21.1	821	191	34	0	50.7	89.4	173
2	2	21	821	35.8	15.8	0	24.7	42.6	107
2	3	34	1490	36.4	36.4	0	41.7	91	208
2	4		1563	15	13.5	0	16.6	0	61.7
2	5		1037	7.2	35.4	3.1	29.7	91.5	153
2	6		888	7.3	25.8	2.2	36.2	112	50.1
3	1	0.9	168	5.2	0	0	0	0	0
3	2		71	30.5	0	0	0	0	0
3	3	2	132	10.1	0	0	0	0	0
4	1		256						3.6
4	2	21.3	1503						6.9
4	3	182	1841						8.8
4	4	1.01	250						
4	5	1.72	98						
4	6	0.91	221						
4	7	12.6	1230						
4	8	12.6	1230						
4	9	28.2	2838						

Source: U.S. EPA, 1991f; 1991g; 1991h; 1991i.

Appendix F (continued)

SITE	RUN	NAPHTHAL. (ug/M3)	ACRYLONITRIL (ug/M3)	BENZENE (ug/M3)	CCL4 (ug/M3)	CHLORO BENZENE (ug/M3)	CHLOROFORM (ug/M3)	1,2 DICHL OROETHANE (ug/M3)
1	1		454	883	8.1	50.7	218	0.6
1	2		884	948	5.6	75.5	214	0.2
1	3		574	774	3.1	47.6	276	0.5
1	4		439	528	3.4	27	226	0.9
1	5		1073	1287	6.8	69.4	325	4.6
2	1	65.6	2159	507	0.4	29	0.34	0
2	2	124	1892	283	0.31	18	0.38	0
2	3	85.3	3159	511	0.44	19.5	1.1	0
2	4	0	2594	573	0.46	53.8	0.49	0
2	5	282	3351	730	0.1	43.3	0	0
2	6	62.6	3869	4191	0	33.3	0	0
3	1	0	0	37	0	0.29	244	0
3	2	0	0	62	0	0.6	745	0
3	3	0	0	7.4	1.1	0	4.1	0
4	1	1.3	8737	902	0	255	0	0
4	2	3.4	2429	433	4.41	102	11.4	0
4	3	3.6	8566	2224	5.02	324	25.1	0
4	4		504	142	2.16	5.91	5.84	0
4	5		145	57.8	0.242	2.63	0.617	0
4	6		0	54.9	0.384	0	1.6	0
4	7		693	52.7	0.92	7.11	0.823	0
4	8		816	68.2	0	6.35	3.7	0
4	9		4555	307	7.18	16.3	13.1	0

Appendix F (continued)

SITE	RUN	TRANS 1,2 DICHL OROETHANE (ug/M3)	ETHYL BENZENE (ug/M3)	METHYLENE CHLORIDE (ug/M3)	TETRA CHLORO ETHENE (ug/M3)	TOLUENE (ug/M3)	1,1,1 TRICH LOROETHANE (ug/M3)	TRICHLORO ETHENE (ug/M3)	VINYL CHLORIDE (ug/M3)	DIOXIN EQUIVALENTS (ug/M3)
1	1	7.2	34.1	82.4	898	232	10.1	44.1	225	
1	2	7.3	31	108.2	962	252	14.4	81	335	
1	3	12.8	249.6	176.8	572	201	15.6	78.7	211	
1	4	11.3	37.1	154.9	450	193	25.5	46.8	175	
1	5	14	69.3	43.4	300	441	7.9	101.1	430	
2	1	0.74	10.5	0	23.6	341	0	2.8	913	
2	2	0.77	0.79	2.7	16.1	241	0	3	918	
2	3	1.1	29.8	0.14	22.4	2005	0.27	8.7	693	
2	4	0.36	91.7	323	27.9	2389	0.59	8.7	1389	
2	5	0.46	34.1	181	54.3	1322	0	4.6	1101	
2	6	0.77	11.6	29.5	114	4437	0	9.6	1273	
3	1	0	0.49	11	0	2.2	5	0.62	0	
3	2	0	0	6.9	0	2.7	2.9	0	0	
3	3	0	3.3	1.9	3.9	11.3	3.7	1.2	0	
4	1	0	579	20.1	174	744	4.62	37.3	944	
4	2	0	61.3	4.96	73.5	193	1.66	7.19	511	
4	3	0	444	33.5	350	1316	24.4	141	465	
4	4	0	27.4	2.73	0.263	136	1.33	0.836	0	0.983
4	5	0	3.84	0	0.174	25.2	1.13	0.191	0	1.214
4	6	0	5.83	0	0.503	31.9	0.39	0.377	0	0.995
4	7	0	0	1	6.59	2.38	2.96	9.45	0	0.271
4	8	0	0	5.32	11.1	1.54	9.94	9.21	0	1.148
4	9	0	0	0.44	7.6	29.5	5.44	1.87	20.1	

NOTE: DIOXIN SAMPLES TAKEN AFTER THE AFTER-BURNER

APPENDIX G

STATISTICAL SUPPORT FOR THE PROPOSED REGULATORY LEVEL ON TOTAL HYDROCARBON EMISSIONS FROM THE INCINERATION OF SEWAGE SLUDGE

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF
WATER

MEMORANDUM: NOV 10 [illegible]

SUBJECT: Statistical Support for the Proposed Regulatory Level on Total Hydrocarbon Emissions from the Incineration of Sewage Sludge

FROM: George Zipf, Statistician GWZ
Statistical Analysis Section (WH-552)

THRU: Henry D. Kahn, Chief HDK
Statistical Analysis Section (WH-552)

TO: Al Rubin, Chief
Sludge Risk Assessment Branch (WH-585)

Summary

At your request the Statistics Section has studied the data measuring Total Hydrocarbon Emissions Adjusted to 7% Oxygen (THC7) resulting from the incineration of sewage sludge in order to recommend a statistically defensible operational standard for THC7 emissions. This standard is determined to be the 99th percentile of the THC7 emissions distributions based on data from the two best multiple hearth sites under improved operating conditions. For sites that use the unheated sample line measurement method we recommend that the operational standard of THC7 emissions be set at 21 ppm. To account for the difference in measurement methods, we recommend that sites using the heated sample line measurement method have an operational standard of 31 ppm.

Data

Data were collected at nine sludge incineration sites. All sludge incineration sites are multiple hearth except Site 3 and Site 8, which are fluidized bed. Total hydrocarbons were not measured at Site 5 and no THC7 data exist for this site.

Total hydrocarbon measurements are multiplied by a correction factor to account for the level of oxygen in the combustion chamber. The correction factor is $14/(21\text{-}O_2)$ where the O_2 is the percentage oxygen concentration at the stack outlet. Thus when the percentage oxygen concentration is seven, the correction factor is 14/(21-7), or 1. Correction for the level of oxygen ensures that incinerators can not lower their THC concentration simply by increasing air flow.

I. Data Measurement

The multiple hearth sites studied were operated in three different states: normal operations, improved operations, and operation with afterburners. A multiple hearth site under normal operations has no special engineering supervision or additional pollution control equipment beyond a wet scrubber. Under improved operations, professional engineers monitor the equipment carefully, but no additional pollution control equipment is added. However, when afterburners are added as additional pollution control equipment, the site is otherwise operated under normal conditions, that is, without special engineering supervision.

The reason for testing emissions under improved operating conditions is that expensive capital improvements such as afterburners may not be necessary if significant improvements can be made through employee training. The use of afterburners tests whether THC7 emissions are significantly reduced without changes in the multiple hearth site operations.

Samples were taken at the inlet, which is before the air pollution control system (APCS), or at the stack outlet, which is after the APCS. However, samples taken at inlet do not represent THC7 emissions to the air. This is because the hydrocarbons at inlet have not been through the APCS, so that the emission levels at inlet are higher than the final emissions at outlet. **For the purposes of determining the operational standard, only outlet data were used to support the regulation.**

Sample lines carry the sample from a probe inserted in an emission stream for measurement at a monitor. The sample lines are either heated to the temperature of the emission stream or chilled to ambient temperature. These sample lines are called hot and cold accordingly. Heating the sample lines prevents high boiling point organics from condensing before measurement at the monitor. Consequently a heated sample line provides a more direct measurement than an unheated sample line.

The proposed regulation will mandate heated sample lines. However, the available data used to develop the proposed regulation were measured cold. Therefore it was necessary to estimate the difference between a sample measured hot and the same sample measured cold. This estimation was based on samples that were taken simultaneously with two sample lines at the same site, one hot and one cold. We recommend that THC7 hot be estimated at 10 ppm greater than THC7 cold. The statistical support for this figure is in a companion memorandum to Al Rubin from George Zipf, titled "A statistically defensible estimate of the difference between a sample of total hydrocarbons measured with heated sample lines and the same sample measured with unheated sample lines." What is important here is that THC7 measured cold may be used to support a proposed regulation for THC7 measured hot because the difference between simultaneous hot and cold samples can be estimated.

II. Data Which Supports the Proposed Regulation

For data to support the proposed regulation, it <u>must</u> be measured at the APCS outlet. Ideally, the data are also measured hot. Only data from sites 6, 7, 8, and 9 are measured at the outlet. Of this data, only Site 7 has hot measurements. However, cold outlet measurements can be used to support an operational standard based on the estimated difference as described above.

Each sample must be classifiable in only one operating condition and not be qualified in any way. Samples taken in a transition period between different operating conditions or qualified with event flags such as "plant not operating" or "monitor failure," were discarded.

Thus data may be grouped for analysis if they are site-specific, operations-specific, location-specific, and sample line-specific. Table 1 below summarizes the data by site, by operation, by location, and by sample line. The table includes the percentiles corresponding to 20 ppm, 25 ppm, and 30 ppm and the THC7 emissions levels corresponding to the 90th, 95th, and 99th percentiles.

<u>Methodology</u>

No distributional assumptions are made about the data in any site-specific operations-specific category. This is because each site-specific operations-specific group has at least 439 data points, which should be sufficiently large to approximate the true cumulative density function. **The 99th percentile of the best distribution(s) of site-specific operations-specific data is selected as the statistically supportable operational standard of THC7 emissions.** The best distribution is simply defined as having the lowest THC7 measurements, and is not based on any engineering review. This also assumes that the proposed regulation will specify compliance on the basis of samples measured in the same way as the supporting data.

TABLE 1: SUMMARY OF TOTAL HYDROCARBON EMISSIONS ADJUSTED TO 7% OXYGEN
BY SITE AND OPERATING CONDITIONS: SAMPLE SIZES AND EMPIRICAL PERCENTILES

ALL SITES ARE MULTIPLE HEARTH UNLESS OTHERWISE SPECIFIED IN THE OPERATING CONDITIONS COLUMN.
DATA DOES NOT INCLUDE SAMPLES THAT ARE QUALIFIED.

SITE	OPERATING CONDITIONS	SAMPLE LINES AND LOCATION	N	Percentile for			ppm at Percentile		
				20 ppm	25 ppm	30 ppm	90%	95%	99%
SITE 1	NORMAL	HOT INLET	2625	69.6%	83.5%	91.9%	28.5	32.7	48.9
SITE 2	NORMAL	HOT INLET	972	35.6%	43.3%	52.9%	78.4	84.8	109
SITE 3	FLUIDIZED BED	HOT INLET	1017	97.7%	97.9%	98.4%	6.1	8.1	54.6
SITE 4	NORMAL Sample=1,2,5,6,7,9	COLD INLET	2444	16.6%	19.3%	21.4%	730	833	933
	NORMAL Sample=1,2,5	HOT INLET	1197	31.8%	35.3%	37.9%	303	448	709
	IMPROVED Sample=8	COLD INLET	381	73.0%	79.0%	86.1%	34.8	41.8	66.8
	AFTERBURNER Sample=3,4	COLD INLET	899	72.1%	73.0%	74.7%	74.1	125	326
		HOT INLET	899	69.3%	71.5%	73.4%	82.6	127	378
SITE 6	NORMAL Sample=1,2,5	COLD OUTLET	909	3.9%	10.7%	24.0%	63	98	193
	IMPROVED Sample=3,4	COLD OUTLET	655	98.6%	100.0%	100.0%	17.7	18.5	21
SITE 7	NORMAL	COLD OUTLET	439	0.0%	0.0%	0.0%	205	244	327
		HOT OUTLET	439	0.0%	0.0%	0.0%	217	266	351
SITE 8	FLUIDIZED BED	COLD OUTLET	769	100.0%	100.0%	100.0%	4.6	5.1	8.3
SITE 9	NORMAL Sample=1,2,3,4,5	COLD OUTLET	1395	1.1%	4.7%	8.0%	390	503	1194
	IMPROVED Sample=6,7,8	COLD OUTLET	1512	98.8%	99.3%	99.7%	15.9	17.2	20.3

Results

As can be seen from Table 1 above, the 99th percentile for Site 6 under improved conditions is 21 ppm cold, and for Site 9 under improved conditions is 20.3 ppm cold. Thus at two different multiple hearth sites it is possible to keep THC7 emissions down to 21 ppm cold 99% of the time, without additional pollution control equipment. These levels are dramatically lower than the same sites under normal operations.

It should also be noted that the fluidized bed incineration site (Site 8), easily passes the 21 ppm level. In fact, the maximum outlet THC7 emissions measurement for the 769 Site 8 observations is 9.2 ppm.

Conclusions

We recommend an operational standard of 21 ppm for THC7 when measured cold from outlet. This figure should be raised to 31 ppm for THC7 emissions measured hot. This is based on data for multiple hearth incineration sites. Fluidized bed sites should easily achieve the proposed regulation limits.

cc: Neil Patel
Bob Southworth

APPENDIX H

A STATISTICALLY DEFENSIBLE ESTIMATE OF THE DIFFERENCE BETWEEN A SAMPLE OF TOTAL HYDROCARBON EMISSIONS MEASURED WITH HEATED SAMPLE LINES AND THE SAME SAMPLE MEASURED WITH UNHEATED SAMPLE LINES

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF
WATER

MEMORANDUM NOV 10 1992

SUBJECT: A statistically defensible estimate of the difference between a sample of total hydrocarbon emissions measured with heated sample lines and the same sample measured with unheated sample lines

FROM: George Zipf, Statistician GWZ
Statistical Analysis Section (WH-552)

THRU: Henry D. Kahn, Chief HDK
Statistical Analysis Section (WH-552)

TO: Al Rubin, Chief
Sludge Risk Assessment Branch (WH-585)

Summary

At your request the Statistics Section has studied the data measuring Total Hydrocarbon Emissions Adjusted to 7% Oxygen (THC7) resulting from the incineration of sludge when the emissions are simultaneously measured with heated sample lines (hot) and with unheated sample lines (cold) in order to estimate a statistically defensible difference between the two. Statistical support for the proposed regulation requires estimation of (Hot THC7 - Cold THC7) because the proposed regulation specifically mandates heated sample lines, while the available data used to support an operational standard are measured cold. We recommend that the difference between a sample of hydrocarbon emissions adjusted to 7% O_2 measured hot and the same sample measured cold, (Hot THC7 - Cold THC7) be estimated at 10 ppm.

Background

A sample is taken by a probe inserted into an emissions stream and carried by sample lines to a monitor. The sample lines are either heated to the temperature of the probe location or chilled to ambient temperature. The probe is inserted either at the inlet to the air pollution control system or the incineration stack outlet.

In theory, a THC7 sample measured hot is always greater than one measured cold because heating the sample lines prevents high boiling point organics from condensing before measurement at the monitor. Thus a heated sample line provides a more direct measurement than an unheated sample line. Furthermore, because the cold system condenses a fraction of the hydrocarbons, the absolute difference between a THC7 sample measured hot and the same sample measured cold should increase as the true emissions level increases. Thus the difference in measurement between hot and cold samples is expected to be less at regulatory levels than when a plant is in violation.

In practice, measurement variability, sampling variability, and random error affect the recorded value of THC7, which in turn affects the difference between hot and cold samples. In fact, many of the observed sample differences are negative, which is theoretically impossible. **We therefore recommend that the estimate of (Hot THC7 - Cold THC7) be conservative. That is, that the estimate of (Hot THC7 - Cold THC7) have a high probability of exceeding the actual difference.**

Data

Simultaneous hot and cold measurements exist for the first five sampling days at Site 4 and all sampling days for Site 7. Site 4 is inlet data and Site 7 is outlet data.

It was judged that inlet and outlet data should not be combined in the analysis because scrubbers might preferentially remove semi- and non-volatile organics. Thus the difference between hot and cold measurements is likely to be greater at inlet than at outlet, although the available data do not support estimation of this difference. It was also judged that data should not be combined across operating conditions, as differences might be greater or lesser depending on operating efficiency. Thus the data was grouped into: Site 4 Normal Operations (sample days 1, 2, and 5), Site 4 Afterburners (sample days 3 and 4), and Site 7.

The lowest emission readings are at Site 4 Afterburners, with roughly 70% of both the hot measurements and the cold measurements less than 20 ppm. Since the best estimate for the difference in the measurements at regulatory level should be based on data in or near the regulatory range, only Site 4 Afterburners are used in this analysis. The emissions levels from Site 4 Normal Operations and from Site 7 are too high to accurately estimate the difference between hot and cold THC7 at regulatory levels. It is true that the Site 4 Afterburners data are measured at inlet. However it is judged preferable to use inlet data in and near the regulatory range than outlet data at high emission levels. There are 899 measurements for sample days three and four at Site 4.

Methodology

The difference between hot and cold measurements is estimated with two different methodologies. The first methodology uses percentiles of the empirical distribution of the data. The second methodology uses linear regression analysis with confidence intervals. The data used in both methodologies are the 899 measurements from Site 4 Afterburners.

Methodology 1: Using the 90th Percentile of $(\text{Hot THC7})_i - (\text{Cold THC7})_i$

A variable D_i is created such that $D_i = (\text{Hot THC7})_i - (\text{Cold THC7})_i$, where i is the ith paired observation. No distributional assumptions are made about D_i because 899 observations should be sufficient for the sample density function to approximate the true cumulative distribution function.

Because the estimate of the difference between a sample measured hot and the same sample measured cold should be conservative, the issue then is to choose a sufficiently high percentile so that the actual difference has a high likelihood of being less. The 90th percentile of D_i is chosen as this level. At this level, ninety percent of the differences between simultaneous hot and cold measurements are expected to be less.

Results for Methodology 1

The 90th percentile is 10 ppm. That is, a sample measured hot will be up to 10 ppm greater than the same sample measured cold 90% of the time.

The table below gives several percentiles.

The Frequency Distribution for (Hot THC7 - Cold THC7)

Percentiles	1%	25%	50%	75%	90%	95%	99%
ppm	-13	-1	0.5	5	10	16	38

Methodology 2: Regression Analysis of THC7 Hot against THC7 Cold

A plot of THC7 Hot against THC7 Cold for the 899 Site 4 observations suggests a linear relationship where THC7 Hot is generally slightly greater than THC7 Cold (see plots below). This is consistent with the theory that THC7 Hot should always be greater than THC7 Cold. The variance appears constant up to THC7 (Hot or Cold) equals 100 ppm, and then increases.

For the regression analysis, the 72 observations where THC7 Hot and/or THC7 Cold are greater than 100 ppm were excluded from the data set because they introduce non-constant variance and are well above the regulatory range of 20 ppm. This leaves 827 observations containing both hot and cold THC7 measurements.

The regression equation gives the best linear unbiased estimator for THC7 Hot for a given THC7 Cold within the appropriate range. Furthermore, regression analysis allows for confidence intervals on the estimate of THC7 Hot, for a given level of THC7 Cold. The methodology then is to choose as a statistically supportable level of THC7 Hot the upper limit of the range which has a 90% chance of containing the true THC7 Hot, given THC7 Cold equals 20 ppm. The range is chosen such that there is only a 10% chance that the true THC7 Hot is greater.

Results for Methodology 2

The regression model is estimated as:

$$\text{THC7 Hot}_i = -0.1802 + 1.1218*(\text{THC7 Cold})_i + \epsilon_i$$

The F-test for the regression is highly significant and $r^2 = 0.9672$. The regression model fits the data well.

At THC7 Cold equals 20 ppm, the regression estimate for THC7 Hot is 22.3 ppm. Then 27.9 ppm is the upper limit of the range defined in the methodology. That is, there is a 90% chance that the true THC7 Hot is below 27.9 ppm.

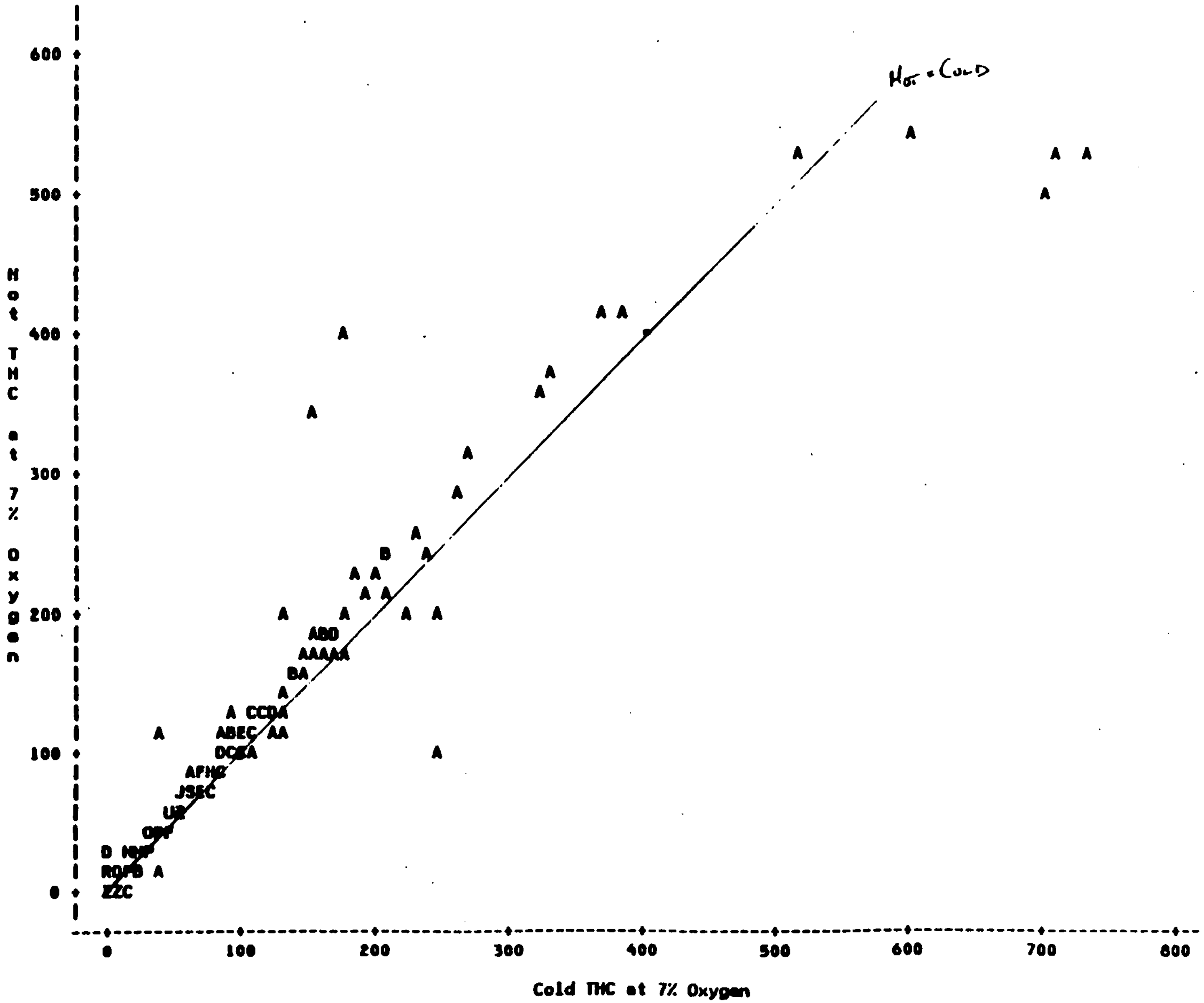
Conclusion

Both methodologies support an operational standard of 30 ppm for THC7 Hot. As both methodologies are designed so that the true THC7 Hot is not likely to be higher, this estimate is conservative.

cc: Neil Patel
Bob Southworth

Site 4 - THC7 (Hot & Cold) 14:31 Thursday, July 30, 1992 1

Plot of THC7HOT*THC7. Legend: A = 1 obs, B = 2 obs, etc.

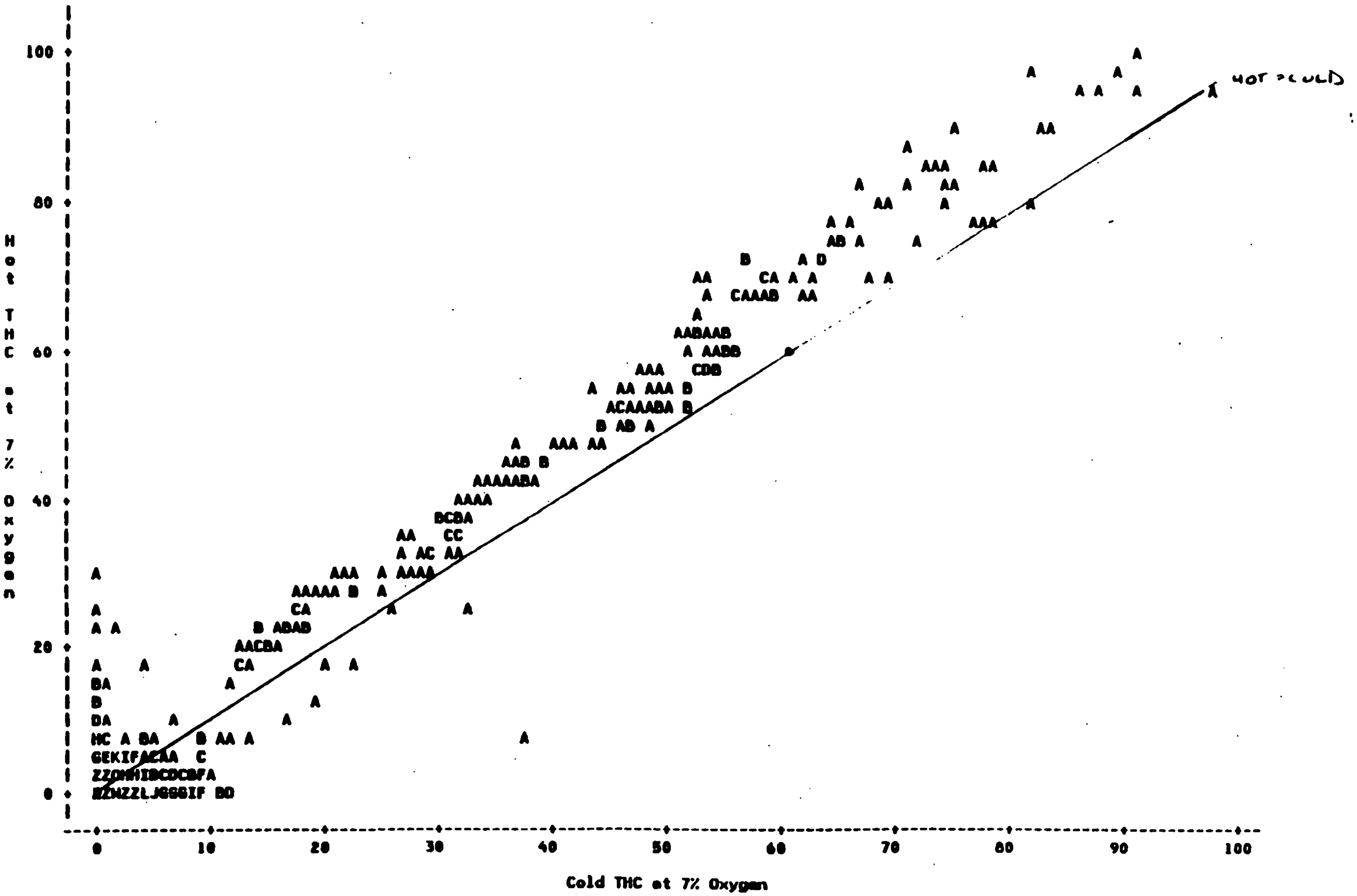


NOTE: 537 obs hidden.

Site 4 - THC7 (HOT & COLD) < 100 ppm 14:31 Thursday, July 30, 1992 3

Plot of THC7HOT*THC7. Legend: A = 1 obs, B = 2 obs, etc.

H-6



NOTE: 228 obs hidden.

APPENDIX I

MOLECULAR WEIGHTS AND RESPONSE FACTORS FOR ORGANIC COMPOUNDS USED TO DEVELOP A q_1* FOR THC

Average MW and Average Response Factor

Carcinogens	MW	95% Emission Concentration (ng/L)	Fraction Present	Average MW	Response Factor	Average Response Factor
Acrylamide	71.08	0.1	1.77E-06	1.26E-04	1.30	2.30E-06
Acrylonitrile	53.06	341050.0	1.82E-02	9.64E-01	1.93	3.51E-02
Aldrin	364.93	0.1	1.77E-06	6.47E-04	11.76	2.08E-05
Aniline	93.12	0.1	1.77E-06	1.65E-04	5.40	9.57E-06
Benzene	78.11	427500.0	5.49E-03	4.29E-01	6.00	3.30E-02
Benzidine	184.23	0.1	1.77E-06	3.27E-04	10.80	1.91E-05
Benzo(a)pyrene	252.3	17.49	3.10E-04	7.82E-02	20.00	6.20E-03
Bis(2-chloroethyl)ether	143.02	0.1	1.77E-06	2.53E-04	3.00	5.32E-06
Bis(2-chloromethyl)ether	114.97	0.1	1.77E-07	2.04E-04	1.00	1.77E-06
Bis(2-ethylhexyl) phthalate	390.54	27550.0	8.35E-04	3.26E-01	1.83	1.53E-03
1,3-Butadiene	54.09	0.1	1.77E-06	9.59E-05	3.80	6.73E-06
Carbon tetrachloride	153.84	139.65	3.30E-05	5.07E-03	0.64	2.11E-05
Chlordane	409.8	0.1	1.77E-06	7.26E-04	9.76	1.73E-05
Chloroform	119.39	6260.5	3.75E-03	4.48E-01	0.85	3.19E-03
Chloromethane	50.49	450	7.98E-03	4.03E-01	0.95	7.58E-03
Chloromethyl methyl ether	80.51	0.1	1.77E-06	1.43E-04	1.00	1.77E-06
DDD	320.05	0.1	1.77E-06	5.67E-04	13.86	2.46E-05
DDE	316	0.1	1.77E-06	5.60E-04	13.86	2.46E-05
DDT	354.5	0.1	1.77E-06	6.28E-04	13.64	2.42E-05
1,2-Dibromo-3-chloropropane	236.36	0.1	1.77E-06	4.19E-04	3.00	5.32E-06
1,2-Dibromoethane	187.88	0.1	1.77E-06	3.33E-04	2.00	3.54E-06
1,2-Dichloroethane	98.97	61.18	2.25E-05	2.23E-03	1.60	3.60E-05
1,1-Dichloroethylene	96.95	1.03	1.83E-05	1.77E-03	1.90	3.47E-05
Dieldrin	380.93	156.0	1.77E-06	6.75E-04	10.76	1.91E-05
Diethylstilbestrol	268.34	0.1	1.77E-06	4.76E-04	15.30	2.71E-05
Dioxane	88.1	0.1	1.77E-06	1.56E-04	2.00	3.54E-06
1,2-Diphenylhydrazine	184.23	0.1	1.77E-06	3.27E-04	10.50	1.86E-05
Epichlorohydrin	92.53	0.1	1.77E-06	1.64E-04	2.00	3.54E-06
Ethylene oxide	44.05	0.1	1.77E-06	7.81E-05	1.00	1.77E-06
Formaldehyde	30.03	780	1.38E-02	4.15E-01	0.00	0.00E+00
Heptachlor	373.35	0.1	1.77E-06	6.62E-04	9.76	1.73E-05
Heptachlor epoxide	389.4	0.1	1.77E-06	6.90E-04	8.76	1.55E-05
2,3,7,8-Heptachlorodibenzo-p-dioxin	425.5	.000491	9.22E-09	3.92E-06	11.50	1.06E-07
other-Heptachlorodibenzo-p-dioxin	425.5	0.14	1.06E-08	4.52E-06	11.50	1.22E-07
Hexachlorobutadiene	260.76	0.1	1.77E-06	4.62E-04	4.30	7.62E-06
alpha-Hexachlorocyclohexane	290.85	0.1	1.77E-06	5.15E-04	6.00	1.06E-05
beta-Hexachlorocyclohexane	290.85	0.1	1.77E-06	5.15E-04	6.00	1.06E-05

(continued)

Source: U.S. EPA, 1991k.

Average MW and Average Response Factor

Carcinogens	MW	95% Emission Concentration (ng/L)	Fraction Present	Average MW	Response Factor	Average Response Factor
gamma-Hexachlorocyclohexane	290.85	0.1	1.77E-06	5.15E-04	6.00	1.06E-05
Hexachlorocyclohexane, technical	290.85	0.1	1.77E-06	5.15E-04	6.00	1.06E-05
2,3,7,8-Hexachlorodibenzo-p-dioxin	391	0.00048	9.04E-09	3.53E-06	11.50	1.04E-07
other-Hexachlorodibenzo-p-dioxin	391	0.062	3.90E-08	1.52E-05	11.50	4.48E-07
Hexachloroethane	236.74	0.77	1.36E-05	3.23E-03	1.28	1.75E-05
3-Methylchlolanthrene	268.34	0.1	1.77E-06	4.76E-04	21.00	3.72E-05
Methylene chloride	84.94	83.75	1.48E-03	1.26E-01	0.90	1.34E-03
4,4-Methylene-bis-2-chloroaniline	267.16	0.1	1.77E-06	4.73E-04	11.80	2.09E-05
Methyl hydrazine	46.07	0.1	1.77E-06	8.17E-05	0.40	7.09E-07
2-Nitropropane	89.09	0.1	1.77E-06	1.58E-04	3.00	5.32E-06
N-Nitrosodi-N-butylamine	158.24	0.1	1.77E-06	2.80E-04	7.25	1.28E-05
N-Nitrosodi-N-propylamine	146.24	0.1	1.77E-06	2.59E-04	6.25	1.11E-05
N-Nitrosodiethylamine	102.14	0.1	1.77E-06	1.81E-04	2.65	4.70E-06
N-Nitrosodimethylamine	74.08	0.1	1.77E-06	1.31E-04	1.25	2.22E-06
N-Nitrosopyrrolidine	96.09	0.1	1.77E-06	1.70E-04	3.25	5.76E-06
PCBs	292	234.65	3.54E-06	1.04E-03	12.00	4.25E-05
2,3,7,8-pentachlorodibenzo-p-dioxin	356.5	0.000136	2.48E-09	8.85E-07	11.50	2.85E-08
other-pentachlorodibenzo-p-dioxin	356.5	0.00319	6.03E-08	2.15E-05	11.50	6.93E-07
Pentachloronitrobenzene	295.36	0.1	1.77E-06	5.23E-04	5.00	8.86E-06
Pronamide	256.13	0.1	4.54E-04	4.54E-04	10.95	1.94E-05
Reserpine	608.7	0.1	1.77E-06	1.08E-03	30.25	5.36E-05
2,3,7,8-Tetrachlorodibenzofuran	306	0.0037	6.56E-08	2.01E-05	11.75	7.71E-07
2,3,7,8-Tetrachlorodibenzo-p-dioxin	322	0.0000762	1.42E-09	4.57E-07	11.50	1.63E-08
other-Tetrachlorodibenzo-p-dioxin	322	0.00716	1.33E-07	4.28E-05	11.50	1.53E-06
1,1,2,2-Tetrachloroethane	167.86	0.1	1.77E-06	2.98E-04	1.20	2.13E-06
Tetrachloroethylene	165.85	228.77	4.05E-03	6.72E-01	1.10	4.46E-03
Thiourea	76.12	0.1	1.77E-06	1.35E-04	0.40	7.09E-07
Toxaphene	413.81	0.1	1.77E-06	7.33E-04		0.00E+00
1,1,2-Trichloroethane	133.42	0.1	1.77E-06	2.36E-04	1.50	2.66E-06
Trichloroethylene	131.4	120.21	2.13E-03	2.80E-01	1.50	3.20E-03
2,4,6-Trichlorophenol	197.46	0.1	1.77E-06	3.50E-04	5.40	9.57E-06
<u>Non-carcinogens</u>						
Acetonitrile	41.05	281.0	5.25E-03	2.16E-01	1.30	6.83E-03
Acetophenone	120.15	0.1	1.77E-06	2.13E-04	7.00	1.24E-05
Allyl alcohol	58.08	0.1	1.77E-06	1.03E-04	2.30	4.08E-06
Bromodichloromethane	163.83	0.1	1.77E-06	2.90E-04	0.76	1.35E-06
Bromoform	252.77	0.1	1.77E-06	4.48E-04	1.00	1.77E-06

(continued)

Average MW and Average Response Factor

Non - Carcinogens	MW	95% Emission Concentration (ng/L)	Fraction Present	Average MW	Response Factor	Average Response Factor
Bromomethane	94.95	0.1	1.77E-06	1.68E-04	0.95	1.68E-06
2-chloro-1,3-butadiene	88.54	0.1	1.77E-06	1.57E-04	3.60	6.38E-06
Cresols	108.13	0.1	1.77E-06	1.92E-04	6.40	1.13E-05
Di-n-butyl phthalate	278.34	0.1	1.77E-06	4.93E-04	13.50	2.39E-05
Dibromochloromethane	208.289	0.1	1.77E-06	3.69E-04	0.88	1.56E-06
Dichlorodifluoromethane	120.92	0.1	1.77E-06	2.14E-04	0.60	1.06E-06
2,4-Dichlorophenol	162	43.03	7.09E-04	1.15E-01	1.83	1.30E-03
1,3-Dichloropropene	110.98	0.095	1.77E-06	1.97E-04	2.90	5.14E-06
Diethyl phthalate	222.23	0.1	1.77E-06	3.94E-04	1.83	3.24E-06
Dimethoate	229.28	0.1	1.77E-06	4.06E-04	3.25	5.76E-06
2,4-Dinitrophenol	184.11	260.95	4.62E-03	8.51E-01	5.40	2.50E-02
Diphenylamine	169.22	0.1	1.77E-06	3.00E-04	11.25	1.99E-05
Endosulfan	406.95	0.1	1.77E-06	7.21E-04	8.76	1.55E-05
Endrin	380.93	0.1	1.77E-06	6.75E-04	10.76	1.91E-05
Ethylbenzene	94.16	95.0	8.60E-04	8.10E-02	8.00	6.88E-03
Formic acid	46.02	0.1	1.77E-06	8.16E-05	0.00	0.00E+00
Hexachlorocyclopentadiene	272.77	0.1	1.77E-06	4.83E-04	5.00	8.86E-06
Hydrogen cyanamide	42.04	0.1	1.77E-06	7.45E-05	0.30	5.32E-07
Isobutyl alcohol	74.12	0.1	1.77E-06	1.31E-04	3.75	6.65E-06
Isophorone	138.2	0.1	1.77E-06	2.45E-04	8.00	1.42E-05
Methomyl	162.2	0.1	1.77E-06	2.87E-04	7.75	1.37E-05
Methoxychlor	345.65	0.1	1.77E-06	6.13E-04	13.64	2.42E-05
Methyl ethyl ketone	72.1	165.0	3.08E-03	2.22E-01	1.83	5.63E-03
Methyl parathion	263.23	0.1	1.77E-06	4.67E-04	8.00	1.42E-05
Nitrobenzene	123.11	3.04	5.62E-05	6.92E-03	6.00	3.37E-04
Pentachlorobenzene	250.34	0.1	1.77E-06	4.44E-04	6.00	1.06E-05
Pentachlorophenol	266.35	77.37	1.37E-03	3.65E-01	1.83	2.51E-03
Phenol	94.11	839.0	2.11E-03	1.99E-01	1.83	3.87E-03
N-phenylenediamine	108.14	0.1	1.77E-06	1.92E-04	5.25	9.30E-06
Phenylmercuric acetate	336.75	0.1	1.77E-06	5.97E-04	6.00	1.06E-05
Pyridine	79.1	0.1	1.77E-06	1.40E-04	5.00	8.86E-06
Selenourea	123.02	0.1	1.77E-06	2.18E-04	0.40	7.09E-07
Strychnine	334.4	0.1	1.77E-06	5.93E-04	20.50	3.63E-05
1,2,3,4,5-Tetrachlorobenzene	215.89	0.1	1.77E-06	3.83E-04	6.00	1.06E-05
2,3,4,6-Tetrachlorophenol	231.89	0.1	1.77E-06	4.11E-04	5.40	9.57E-06
Tetraethyl lead	323.45	0.1	1.77E-06	5.73E-04	4.00	7.09E-06
Toluene	92.13	215.02	3.81E-03	3.51E-03	7.00	2.67E-02

(continued)

Average MW and Average Response Factor

Non-Carcinogens	MW	95% Emission Concentration (ng/L)	Fraction Present	Average MW	Response Factor	Average Response Factor
1,2,4-Trichlorobenzene	181.46	333.0	5.29E-04	9.60E-02	1.83	9.68E-04
1,1,1 Trichloroethane	133.39	11100.0	1.73E-03	2.30E-01	1.64	2.83E-03
Trichlorofluoromethane	137.38	0.1	1.77E-06	2.43E-04	0.64	1.13E-06
2,4,5-Trichlorophenol	197.45	0.1	1.77E-06	3.50E-04	1.83	3.24E-06
C1 Hydrocarbons	16	17575	3.11E-01	4.98E+00	1.00	3.11E-01
C2 Hydrocarbons	30	34200	6.06E-01	1.82E+01	2.00	1.21E+00
				34.0g-moles		1.8E+00

Note: Methane was assumed for C1 Hydrocarbons
Ethane was assumed for C2 Hydrocarbons
Tetra CB was assured for PCBs

APPENDIX J

CALCULATIONS TO DERIVE SITE-SPECIFIC RISK-SPECIFIC CONCENTRATIONS AND RISK LEVELS AT THE 23 SEWAGE SLUDGE INCINERATORS IN THE NATIONAL SEWAGE SLUDGE SURVEY

Appendix J

Calculations to Derive Site-Specific Risk-Specific Concentrations and Risk Levels at the 23 Sewage Sludge Incinerators in the Analytical Survey of the 1988 NSSS

Variable	Title	Units	Formula/Assumption	POTW 13-23-212 City Detroit	13-24-221 St. Paul
DF	Dispersion Factor	ug/m^3/g/sec	Abt Associates calculations	0.42	1.37
DQ16C	Annual Throughput	dry USton/yr	From NSSS Part D	141,565.00	66,000.00 (a)
DQ16E	Number of Days Operated, 1988	days	From NSSS Part D	2,203.00	NA
DAILYTP	Daily Throughput	dry UStons/day	DQ16C / DQ16E	626.88	540.00
DQ16F	Percent Volatile Solids	unitless	From NSSS Part D	65.00	72.00
SOLIDS	Reported/Calculated Percent Solids	unitless	From NSSS: SAIC's dataset DISPOSAL(DRYWT)	24.00	33.00
PCTWET (b)	Reported/Assumed Percent Moisture Content	unitless	100 - SOLIDS	76.00	67.00
X00	Wet Feed	wet lb/hr	(DQ16C * 2000 lb/ton) / ((DQ16E * 24 hrs op/day)*(1-(DQ16G/10	217,666.20	136,363.64
X01	Moisture Fraction	unitless	DQ16G / 100	0.76	0.67
X02	Ash Solids Fraction	unitless	1 - Volatile Solids / 100	0.35	0.28
X03	Heat Value of Combustibles	BTU/lb	Assume 10,000 BTU/lb	10,000.00	10,000.00
X04	Total Air Fraction, Sludge Combustion	unitless	Assume MH = 2.50, FB = 1.50	2.50	2.50
X05	Cooling Air Wasted	lb/hr	Assume 0 wasted air	0.00	0.00
X06	Desired Outlet Temp	deg F	Assume MH = 900 degrees F, FB = 1400 degrees F	900.00	900.00
X25	Radiation Loss Fraction	unitless	Assume 5 % loss : 0.05	0.05	0.05
X08	Solids (Dry Feed Rate)	lb/hr	X00 - X01 * X00	52,239.89	45,000.00
X09	Combustible Inlet	BTU/hr	X08 * X03 * (1 - X02)	339,559,265.58	324,000,000.00
X19	Dry Gas From Sludge	lb/hr	X09 * 0.0007494	254,465.71	242,805.60
X10	Moisture from Sludge Combustion	lb/hr	X09 * 0.0000568	19,286.97	18,403.20
X12	Stoichiometric Combustion Air	lb/hr	X10 + X00 * X01 + X19 + X08 * X02 - X00	239,796.75	228,808.80
X13	Total Air, Sludge Combustion	lb/hr	X12 * X04	599,491.88	572,022.00
X17	Moisture Produced Without Fuel Oil	lb/hr	X13 * 0.01 + X10 + X00 * X01	190,708.19	115,487.06
X11	Heat Losses	BTU/hr	X09 * X25 + X08 * X02 * 130 + X05 * 94 + X13 *970 *0.01	25,169,949.41	23,386,613.40
X23	Incinerator Outlet Without Fuel Oil	BTU/hr	X09 - X11	314,389,316.17	300,613,386.60
X26	Dry Gas Plus Excess Air	lb/hr	X13 - X12 + X19	614,160.84	586,018.80
X29	Incinerator Outlet Without Fuel Oil	deg F	(X26 * 22- 1010 * X17 + X09 - X11)/(0.26 * X26 +0.5 * X17)	530.46	936.96
X20	Enthalpy, Dry Gas at Incin. Outlet	BTU/lb	X06 * 0.26 - 22	212.00	212.00
X21	Enthalpy, Moisture at Incin. Outlet	BTU/lb	X06 * 0.5 + 1010	1,460.00	1,460.00
X18	Fuel Oil Required	gal/hr	MAX (0 , (X21 * X17 + X20 * X26 - X23) / (135084 - X06 * 37.5	930.06	0.00
THC	Max. Allowable Concentration of THC in emissions	ppm	Assume 30 ppm	100.00	100.00
DF	Dispersion Factor	ug/m^3/g/sec	Abt Associates Calculations	0.42	1.37
GF	Maximum Combustion Gas Flow Rate	g-moles/day	GF = SGF + FGF	191,785,256.88	137,339,818.04
SGF	Maximum Sewage Sludge Combustion Gas Flow Ra	g-moles/day	SGF = SF * VF * VEHC * 70,100	143,935,209.10	137,339,818.04
SF	Annual Average Daily Sludge Feed Rate	dmt/day	Dry feed in dmt/day	569.89	490.91
VF	Annual Average Volatile Solids Fraction	unitless	DQ16F / 100	0.65	0.72
VEHC	Annual Average Heat Value of Volatiles	kcal/g	10,000 BTU/lb * 0.0005543 to get kcal/g	5.54	5.54
FGF	Fuel Combustion Gas Flow Rate	g-moles/day	FGF = FR * FC	47,850,047.79	0.00
FR	Average Annual Daily Fuel Usage Rate	lb/day	FR = X18 Converted to lb/d [X18 gal/hr * 24 hrs/day * 6.6 lb/gal]	147,321.58	0.00
FC	Fuel Constant	g-moles/lb	Assume #2 Fuel Oil : 324.8	324.80	324.80
RSC	Risk Specific Concentration	ug/m^3	RSC = (THC * DF * GF / 3,240,000,000)	2.49	5.81
BW	Body Weight	kg	Assume 70 kg	70.00	70.00
q1star	Cancer Potency	(mg/kg bw/day)^-1	Assume 1.2 * 10^-2	0.01	0.01
Ia	Inhalation rate	m^3/day	Assume 20 cu meters/day	20.00	20.00
RL	Risk Level	unitless	RL = RSC * q1star * Ia / (BW * 10^3)	8.52E-06	1.99E-05

(a) The total throughput for POTW 221 is taken from its calculated dry weight fired in sewage sludge incinerators and is not caluculated from its annual throughput value DQ16C.

(b) Moisture Content (PCTWET) is determined by the percent solids reported by the POTW or calculated by SAIC during its data consistency checks.

Source: ERG estimates based on 1988 National Sewage Sludge Survey, EPA.

Calculations to Derive Site-Specific Risk-Specific Concentrations and Risk Levels at the 23 Sewage Sludge Incinerators in the Analytical Survey of the 1988 NSSS

Title	13-36-317 Cuyahoga	13-36-319 Cincinnati	13-39-351 Pittsburgh	23-05-011 Martinez	23-07-040 Waterbury	23-10-051 Pensacola	23-11-072 Decatur Electric Furnace	23-11-076 Atlanta
Dispersion Factor	4.02	14.27	0.30	9.19	6.89	3.26	23.43	0.79
Annual Throughput	44,056.00	28,766.00	24,250.00	12,950.00	5,580.00	6,705.00	40.00	17,986.00
Number of Days Operated, 1988	1,100.00	1,102.00	464.00	366.00	301.00	340.00	365.00	600.00
Daily Throughput	160.20	104.28	96.81	69.25	18.54	19.72	0.11	59.95
Percent Volatile Solids	56.00	55.00	68.00	24.00	78.00	73.00	35.00	55.00
Reported/Calculated Percent Solids	44.00	29.00	25.00	24.00	22.00	18.00	35.00	21.00
Reported/Assumed Percent Moisture Content	56.00	71.00	75.00	76.00	78.00	82.00	65.00	79.00
Wet Feed	30,341.60	29,966.80	32,271.21	24,043.48	7,022.05	9,129.90	26.09	23,791.01
Moisture Fraction	0.56	0.71	0.75	0.76	0.78	0.82	0.65	0.79
Ash Solids Fraction	0.44	0.45	0.32	0.76	0.22	0.27	0.65	0.45
Heat Value of Combustibles	10,000.00	10,000.00	10,000.00	10,000.00	10,000.00	10,000.00	10,000.00	10,000.00
Total Air Fraction, Sludge Combustion	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50
Cooling Air Wasted	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Desired Outlet Temp	900.00	900.00	900.00	900.00	900.00	900.00	900.00	900.00
Radiation Loss Fraction	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Solids (Dry Feed Rate)	13,350.30	8,690.37	8,067.80	5,770.44	1,544.85	1,643.38	9.13	4,996.11
Combustible Inlet	74,761,696.97	47,797,044.77	54,861,049.11	13,849,044.83	12,049,833.89	11,996,691.18	31,963.47	27,478,611.11
Dry Gas From Sludge	56,026.42	35,819.11	41,112.87	10,378.47	9,030.15	8,990.32	23.95	20,592.47
Moisture from Sludge Combustion	4,246.46	2,714.87	3,116.11	786.63	684.43	681.41	1.82	1,560.79
Stoichiometric Combustion Air	52,796.71	33,754.27	38,742.87	9,780.20	8,509.59	8,472.06	22.57	19,405.40
Total Air, Sludge Combustion	131,991.78	84,385.68	96,857.18	24,450.49	21,273.98	21,180.16	56.43	48,513.49
Moisture Produced Without Fuel Oil	22,557.68	24,835.16	28,288.08	19,304.18	6,374.37	8,379.73	19.34	20,840.81
Heat Losses	5,782,042.41	3,716,780.11	4,018,187.66	1,499,740.99	853,032.04	862,964.81	2,917.25	2,136,783.89
Incinerator Outlet Without Fuel Oil	68,979,654.56	44,080,264.66	50,842,861.45	12,349,303.84	11,196,801.85	11,133,726.36	29,046.22	25,341,827.22
Dry Gas Plus Excess Air	135,221.48	86,450.51	99,227.18	25,048.77	21,794.53	21,698.42	57.81	49,700.56
Incinerator Outlet Without Fuel Oil	1,058.89	598.91	612.24	(408.10)	591.63	320.15	436.60	230.74
Enthalpy, Dry Gas at Incin. Outlet	212.00	212.00	212.00	212.00	212.00	212.00	212.00	212.00
Enthalpy, Moisture at Incin. Outlet	1,460.00	1,460.00	1,460.00	1,460.00	1,460.00	1,460.00	1,460.00	1,460.00
Fuel Oil Required	0.00	103.68	113.43	208.67	26.94	56.26	0.11	154.17
Max. Allowable Concentration of THC in emissions	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Dispersion Factor	4.02	14.27	0.30	9.19	6.89	3.26	23.43	0.79
Maximum Combustion Gas Flow Rate	31,690,610.67	25,594,905.08	29,090,531.49	16,606,050.52	6,493,942.93	7,979,586.20	19,360.43	19,579,456.17
Maximum Sewage Sludge Combustion Gas Flow Ra	31,690,610.67	20,260,609.35	23,254,958.34	5,870,448.45	5,107,783.93	5,085,257.36	13,548.94	11,647,862.50
Annual Average Daily Sludge Feed Rate	145.64	94.80	88.01	62.95	16.85	17.93	0.10	54.50
Annual Average Volatile Solids Fraction	0.56	0.55	0.68	0.24	0.78	0.73	0.35	0.55
Annual Average Heat Value of Volatiles	5.54	5.54	5.54	5.54	5.54	5.54	5.54	5.54
Fuel Combustion Gas Flow Rate	0.00	5,334,295.72	5,835,573.15	10,735,602.07	1,386,159.00	2,894,328.85	5,811.49	7,931,593.67
Average Annual Daily Fuel Usage Rate	0.00	16,423.32	17,966.67	33,052.96	4,267.73	8,911.11	17.89	24,419.93
Fuel Constant	324.80	324.80	324.80	324.80	324.80	324.80	324.80	324.80
Risk Specific Concentration	3.93	11.27	0.27	4.71	1.38	0.80	0.01	0.48
Body Weight	70.00	70.00	70.00	70.00	70.00	70.00	70.00	70.00
Cancer Potency	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Inhalation rate	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Risk Level	1.35E-05	3.86E-05	9.34E-07	1.61E-05	4.73E-06	2.75E-06	4.80E-08	1.64E-06

Calculations to Derive Site-Specific Risk-Specific Concentrations and Risk Levels at the 23 Sewage Sludge Incinerators in the Analytical Survey of the 1988 NSSS

Title	23-20-157 Fall River	23-20-172 Fitchburg	23-21-181 Baltimore	23-23-209 Port Huron Fluidized Bed Incin.	23-23-210 Ann Arbor	23-23-214 Wyandotte	23-28-244 Rocky Mount	23-35-287 Hilton
Dispersion Factor	1.26	6.92	0.76	23.80	1.26	2.66	8.86	3.27
Annual Throughput	4,288.00	2,080.00	13,394.00	641.00	4,853.00	14,960.00	2,500.00	4,600.00
Number of Days Operated, 1988	306.00	130.00	730.00	84.00	333.00	766.00	365.00	200.00
Daily Throughput	14.01	16.00	55.04	7.63	14.57	78.12	6.85	23.00
Percent Volatile Solids	78.00	67.00	75.00	70.00	50.00	58.00	75.00	77.00
Reported/Calculated Percent Solids	22.00	25.00	24.00	18.00	34.00	17.00	30.00	21.00
Reported/Assumed Percent Moisture Content	78.00	75.00	76.00	82.00	66.00	83.00	70.00	79.00
Wet Feed	5,307.98	5,333.33	19,112.81	3,532.85	3,571.95	38,294.50	1,902.59	9,126.98
Moisture Fraction	0.78	0.75	0.76	0.82	0.66	0.83	0.70	0.79
Ash Solids Fraction	0.22	0.33	0.25	0.30	0.50	0.42	0.25	0.23
Heat Value of Combustibles	10,000.00	10,000.00	10,000.00	10,000.00	10,000.00	10,000.00	10,000.00	10,000.00
Total Air Fraction, Sludge Combustion	2.50	2.50	2.50	1.50	2.50	2.50	2.50	2.50
Cooling Air Wasted	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Desired Outlet Temp	900.00	900.00	900.00	1,400.00	900.00	900.00	900.00	900.00
Radiation Loss Fraction	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Solids (Dry Feed Rate)	1,167.76	1,333.33	4,587.07	635.91	1,214.46	6,510.07	570.78	1,916.67
Combustible Inlet	9,108,496.73	8,933,333.33	34,403,052.49	4,451,388.89	6,072,322.32	37,758,377.88	4,280,821.92	14,758,333.33
Dry Gas From Sludge	6,825.91	6,694.64	25,781.65	3,335.87	4,550.60	28,296.13	3,208.05	11,059.89
Moisture from Sludge Combustion	517.36	507.41	1,954.09	252.84	344.91	2,144.68	243.15	838.27
Stoichiometric Combustion Air	6,432.42	6,308.72	24,295.44	3,143.57	4,288.27	26,664.97	3,023.12	10,422.33
Total Air, Sludge Combustion	16,081.05	15,771.80	60,738.59	4,715.36	10,720.69	66,662.42	7,557.79	26,055.84
Moisture Produced Without Fuel Oil	4,818.40	4,665.13	17,087.21	3,196.93	2,809.60	34,595.74	1,650.54	8,309.15
Heat Losses	644,808.85	656,853.13	2,458,396.83	293,109.00	486,546.95	2,889,993.89	305,901.90	1,047,966.62
Incinerator Outlet Without Fuel Oil	8,463,687.88	8,276,480.21	31,944,655.65	4,158,279.89	5,585,775.37	34,868,383.99	3,974,920.02	13,710,366.71
Dry Gas Plus Excess Air	16,474.54	16,157.72	62,224.80	4,907.66	10,983.01	68,293.58	7,742.72	26,693.40
Incinerator Outlet Without Fuel Oil	591.63	600.00	649.44	360.89	701.74	40.77	873.11	532.26
Enthalpy, Dry Gas at Incin. Outlet	212.00	212.00	212.00	342.00	212.00	212.00	212.00	212.00
Enthalpy, Moisture at Incin. Outlet	1,460.00	1,460.00	1,460.00	1,710.00	1,460.00	1,460.00	1,460.00	1,460.00
Fuel Oil Required	20.37	19.34	61.13	36.17	8.34	297.23	0.75	40.26
Max. Allowable Concentration of THC in emissions	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Dispersion Factor	1.26	6.92	0.76	23.80	1.26	2.66	8.86	3.27
Maximum Combustion Gas Flow Rate	4,908,786.17	4,781,872.46	17,727,979.05	3,747,666.81	3,002,821.73	31,297,382.73	1,853,341.62	8,327,339.04
Maximum Sewage Sludge Combustion Gas Flow Ra	3,860,985.44	3,786,735.72	14,583,052.37	1,886,891.79	2,573,986.55	16,005,335.64	1,814,590.44	6,255,885.23
Annual Average Daily Sludge Feed Rate	12.74	14.55	50.04	6.94	13.25	71.02	6.23	20.91
Annual Average Volatile Solids Fraction	0.78	0.67	0.75	0.70	0.50	0.58	0.75	0.77
Annual Average Heat Value of Volatiles	5.54	5.54	5.54	5.54	5.54	5.54	5.54	5.54
Fuel Combustion Gas Flow Rate	1,047,800.73	995,136.74	3,144,926.68	1,860,775.02	428,835.17	15,292,047.09	38,751.18	2,071,453.81
Average Annual Daily Fuel Usage Rate	3,225.99	3,063.84	9,682.66	5,728.99	1,320.31	47,081.43	119.31	6,377.63
Fuel Constant	324.80	324.80	324.80	324.80	324.80	324.80	324.80	324.80
Risk Specific Concentration	0.19	1.02	0.42	2.75	0.12	2.57	0.51	0.84
Body Weight	70.00	70.00	70.00	70.00	70.00	70.00	70.00	70.00
Cancer Potency	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Inhalation rate	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Risk Level	6.55E-07	3.50E-06	1.43E-06	9.44E-06	4.00E-07	8.81E-06	1.74E-06	2.88E-06

Calculations to Derive Site-Specific Risk-Specific Concentrations and Risk Levels at the 23 Sewage Sludge Incinerators in the Analytical Survey of the 1988 NSSS

Title	23-36-314 Euclid	23-47-447 Virginia Beach	33-13-084 Dubuque Fluidized Bed Incin.	33-39-353 Allegheny	35-07-038 Rocky Hill Offsite Incinerator	35-19-149 Natchiotches Fluidized Bed Incin.	35-20-164 Billerica Offsite Incinerator	45-32-274 Oxford Offsite Incinerator
Dispersion Factor	31.20	2.79	26.58	3.41	0.83	8.80		3.30
Annual Throughput	3,647.00	7,473.00	3,072.00	860.00	14,690.00	NA	NA	NA
Number of Days Operated, 1988	330.00	377.00	225.00	218.00	571.00	NA	NA	NA
Daily Throughput	11.05	39.10	27.48	3.94	77.16	13.09		
Percent Volatile Solids	60.00	81.00	65.00	70.00	78.00	75.00		
Reported/Calculated Percent Solids	26.00	20.00	30.00	16.00	18.00	25.00	4.00	5.00
Reported/Assumed Percent Moisture Content	74.00	80.00	70.00	84.00	82.00	75.00	NA	NA
Wet Feed	3,542.15	16,291.68	7,632.17	2,054.66	35,723.68	4,363.33	0.00	0.00
Moisture Fraction	0.74	0.80	0.70	0.84	0.82	0.75	0.00	0.00
Ash Solids Fraction	0.40	0.19	0.35	0.30	0.22	0.25	1.00	1.00
Heat Value of Combustibles	10,000.00	10,000.00	10,000.00	10,000.00	10,000.00	10,000.00	10,000.00	10,000.00
Total Air Fraction, Sludge Combustion	2.50	2.50	1.50	2.50	2.50	1.50	2.50	2.50
Cooling Air Wasted	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Desired Outlet Temp	900.00	900.00	1,400.00	900.00	900.00	1,400.00	900.00	900.00
Radiation Loss Fraction	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Solids (Dry Feed Rate)	920.96	3,258.34	2,289.65	328.75	6,430.26	1,090.83	0.00	0.00
Combustible Inlet	5,525,757.58	26,392,528.02	14,882,728.49	2,301,223.24	50,156,048.91	8,181,250.00	0.00	0.00
Dry Gas From Sludge	4,141.00	19,778.56	11,153.12	1,724.54	37,586.94	6,131.03	0.00	0.00
Moisture from Sludge Combustion	313.86	1,499.10	845.34	130.71	2,848.86	464.70	0.00	0.00
Stoichiometric Combustion Air	3,902.29	18,638.40	10,510.18	1,625.12	35,420.20	5,777.60	0.00	0.00
Total Air, Sludge Combustion	9,755.73	46,596.01	15,765.27	4,062.81	88,550.50	8,666.40	0.00	0.00
Moisture Produced Without Fuel Oil	3,032.61	14,998.40	6,345.51	1,897.26	33,027.79	3,823.86	0.00	0.00
Heat Losses	418,808.31	1,852,088.60	1,001,238.68	167,291.52	3,550,647.85	528,578.65	0.00	0.00
Incinerator Outlet Without Fuel Oil	5,106,949.27	24,540,439.42	13,881,489.81	2,133,931.73	46,605,401.06	7,652,671.35	0.00	0.00
Dry Gas Plus Excess Air	9,994.44	47,736.17	16,408.21	4,162.22	90,717.25	9,019.83	0.00	0.00
Incinerator Outlet Without Fuel Oil	550.17	524.46	1,053.05	152.29	380.12	937.03	ERR	ERR
Enthalpy, Dry Gas at Incin. Outlet	212.00	212.00	342.00	212.00	212.00	342.00	212.00	212.00
Enthalpy, Moisture at Incin. Outlet	1,460.00	1,460.00	1,710.00	1,460.00	1,460.00	1,710.00	1,460.00	1,460.00
Fuel Oil Required	14.21	73.79	31.25	14.98	205.73	23.87	0.00	0.00
Max. Allowable Concentration of THC in emissions	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Dispersion Factor	31.20	2.79	26.58	3.41	0.83	8.80	0.00	3.30
Maximum Combustion Gas Flow Rate	3,073,146.31	14,983,784.98	7,916,492.55	1,746,395.33	31,844,915.33	4,695,776.43	0.00	0.00
Maximum Sewage Sludge Combustion Gas Flow Ra	2,342,304.14	11,187,484.55	6,308,614.89	975,461.67	21,260,563.67	3,467,936.38	0.00	0.00
Annual Average Daily Sludge Feed Rate	10.05	35.55	24.98	3.59	70.15	11,90	0.00	0.00
Annual Average Volatile Solids Fraction	0.60	0.81	0.65	0.70	0.78	0.75	0.00	0.00
Annual Average Heat Value of Volatiles	5.54	5.54	5.54	5.54	5.54	5.54	5.54	5.54
Fuel Combustion Gas Flow Rate	730,842.18	3,796,300.42	1,607,877.66	770,933.66	10,584,351.66	1,227,840.05	0.00	0.00
Average Annual Daily Fuel Usage Rate	2,250.13	11,688.12	4,950.36	2,373.56	32,587.29	3,780.30	0.00	0.00
Fuel Constant	324.80	324.80	324.80	324.80	324.80	324.80	324.80	324.80
Risk Specific Concentration	2.96	1.29	6.49	0.18	0.82	1.28	0.00	0.00
Body Weight	70.00	70.00	70.00	70.00	70.00	70.00	70.00	70.00
Cancer Potency	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Inhalation rate	20.00	20.00	20.00	20.00	20.00	20.00	20.00	20.00
Risk Level	1.01E-05	4.42E-06	2.23E-05	6.30E-07	2.81E-06	4.37E-06	NA	NA

APPENDIX K

WEIGHTED CANCER POTENCY RISK FACTOR FOR THC

WEIGHTED CANCER POTENCY RISK FACTOR FOR THC

Compounds	Q* (day-kg/mg)	95% Emission concentration (ng/L) or 0.1 detection limit	Weight fraction	Weighted Q* (day-kg/mg)
Carcinogens				
Acrylamide	2.4E-0.1	0.1	1.8E-06	4.3E-07
Acrylonitrile	1.8E-01	341,050.9	1.8E-02	3.2E-03
Aldrin	1.8E+0.1	0.1	1.8E-06	3.1E-05
Aniline	2.5E-02	0.1	1.8E-06	4.4E-08
Benzene	2.9E-02	427,500.0	5.5E-03	1.6E-04
Benzidine	2.3E+02	0.1	1.8E-06	4.1E-04
Benzo[a]pyrene	1.2E+01	17.49	3.1E-04	3.6E-03
Bis(2-chloroethyl) ether	1.2E+00	0.1	1.8E-06	2.1E-06
Bis(chloromethyl) ether	2.2E+02	0.1	1.8E-06	3.9E-04
Bis(2-ethylhexyl) phthalate	8.4E-04	27,500.0	8.3E-04	7.0E-07
1,3-Butadiene	9.7E-01	0.1	1.8E-06	1.7E-06
Carbon tetrachloride	1.3E-01	139.6	3.3E-05	4.3E-06
Chlordane	1.3E+00	0.1	1.8E-06	2.3E-06
Chloroform	8.1E-02	6,260.5	3.8E-03	3.1E-04
Chloromethane	1.2E-02	450	8.0E-03	9.3E-05
Chloromethyl methyl ether	9.5E+00	0.1	1.8E-06	1.7E-05
DDD	2.4E-01	0.1	1.8E-06	4.3E-07
DDE	3.4E-01	0.1	1.8E-06	6.0E-07

Source: U.S. EPA, 1991k.

(continued)

Appendix K (continued)

Compounds	Q* (day-kg/mg)	95% Emission concentration (ng/L) or 0.1 detection limit	Weight fraction	Weighted Q* (day-kg/mg)
Carcinogens (continued)				
DDT	3.4E-01	0.1	1.8E-06	6.0E-07
1,2-Dibromo-3-chloropropane	2.2E+01	0.1	1.8E-06	3.9E-05
1,2-Dibromoethane	7.8E-01	0.1	1.8E-06	1.4E-06
1,2-Dichloroethane	9.1E-02	61.18	2.3E-05	2.0E-06
1,1-Dichloroethylene	1.2E+00	1.03	1.8E-05	2.1E-05
Dieldrin	1.6E+01	345.65	1.8E-06	2.8E-05
Diethylstilbestrol	4.9E+02	0.1	1.8E-06	8.7E-04
Dioxane	4.9E-03	0.1	1.8E-06	8.7E-09
1,2-Diphenylhydrazine	8.0E-01	0.1	1.8E-06	1.4E-06
Epichlorohydrin	4.2E-03	0.1	1.8E-06	7.5E-09
Ethylene oxide	3.5E-01	0.1	1.8E-06	6.2E-07
Formaldehyde	4.4E-02	780	1.4E-02	6.0E-04
Heptachlor	4.5E+00	0.1	1.8E-06	8.1E-06
Heptachlor epoxide	9.1E+00	0.1	1.8E-06	1.6E-05
2,3,7,8-Heptachlorodibenzo-*p*-dioxin	1.8E+02	0.00049	9.2E-09	1.6E-06
other-Heptachlorodibenzo-*p*-dioxin	1.8E+00	0.14	1.1E-08	1.9E-08
Hexachlorobutadiene	7.8E-02	0.1	1.8E-06	1.4E-07
α-Hexachlorocyclohexane	6.3E+00	0.1	1.8E-06	1.1E-05

(continued)

Appendix K (continued)

Compounds	Q* (day-kg/mg)	95% Emission concentration (ng/L) or 0.1 detection limit	Weight fraction	Weighted Q* (day-kg/mg)
Carcinogens (continued)				
beta-Hexachlorocyclohexane	1.8E+00	0.1	1.8E-06	3.3E-06
gamma-Hexachlorocyclohexane	1.3E-01	0.1	1.8E-06	2.3E-07
Hexachlorocyclohexane, technical	1.8E+00	0.1	1.8E-06	3.1E-06
2,3,7,8-Hexachlorodibenzo-*p*-dioxin	6.2E+03	0.00048	9.0E-09	5.6E-05
other-Hexachlorodibenzo-*p*-dioxin	7.0E+01	0.062	3.9E-08	2.7E-06
Hexachloroethane	1.4E-02	0.77	1.4E-05	1.9E-07
3-Methylcholanthrene	9.5E+00	0.1	1.8E-06	1.7E-05
Methylene chloride	1.5E-02	11,495	1.5E-03	2.2E-05
4,4-Methylene-bis-2-chloroaniline	1.7E-01	0.1	1.8E-06	3.0E-07
Methyl hydrazine	1.2E+00	0.1	1.8E-06	2.1E-06
2-Nitropropane	2.0E+02	0.1	1.8E-06	3.5E-04
N-Nitrosodi-*n*-butylamine	5.6E+00	0.1	1.8E-06	9.8E-06
N-Nitrosodi-*n*-propylamine	7.0E+00	0.1	1.8E-06	1.3E-05
N-Nitrosodiethylamine	1.5E+02	0.1	1.8E-06	2.7E-04
N-Nitrosodimethylamine	4.9E+01	0.1	1.8E-06	8.7E-05
N-Nitrosopyrrolidine	2.2E-00	0.1	1.8E-06	3.9E-06
PCBs	7.0E+00	0.2	3.5E-06	2.5E-05
2,3,7,8-Pentachlorodibenzo-*p*-dioxin	8.8E+04	0.00013	2.5E-09	2.2E-04

(continued)

Appendix K (continued)

Compounds	Q* (day-kg/mg)	95% Emission concentration (ng/L) or 0.1 detection limit	Weight fraction	Weighted Q* (day-kg/mg)
<u>Carcinogens</u> (continued)				
other-Pentachlorodibenzo-p-dioxin	8.8E+02	0.0032	6.0E-08	5.3E-05
Pentachloronitrobenzene	2.5E-02	0.1	1.8E-06	4.4E-08
Pronamide	1.6E-02	0.1	1.8E-06	2.8E-08
Reserpine	1.1E+01	0.1	1.8E-06	1.9E-05
2,3,7,8-Tetrachlorodibenzofuran	1.8E+04	0.00370	6.6E-08	1.1E-03
2,3,7,8-Tetrachlorodibenzo-p-dioxin	1.8E+05	0.000076	1.4E-09	2.5E-04
other-Tetrachlorodibenzo-p-dioxin	1.8E+03	0.0072	1.3E-07	2.3E-04
1,1,2,2-Tetrachloroethane	2.1E-01	0.1	1.8E-06	3.6E-07
Tetrachloroethylene	1.7E-03	228.77	4.1E-03	6.8E-06
Thiourea	1.9E+00	0.1	1.8E-06	3.4E-06
Toxaphene	1.1E+00	0.1	1.8E-06	2.0E-06
1,1,2-Trichloroethane	5.76-02	0.1	1.8E-06	1.0E-07
Trichloroethylene	1.3E-02	120.21	2.1E-03	2.8E-05
2,4,6-Trichlorophenol	2.0E-02	0.1	1.8E-06	3.5E-08
<u>Noncarcinogens</u>				
Acetonitrile	0.0E+00	281.2	5.3E-03	0
Acetophenone	0.0E+00	0.1	1.8E-06	0

(continued)

Appendix K (continued)

Compounds	Q* (day-kg/mg)	95% Emission concentration (ng/L) or 0.1 detection limit	Weight fraction	Weighted Q* (day-kg/mg)
Noncarcinogens (continued)				
Allyl alcohol	0.0E+00	0.1	1.8E-06	0
Bromodichloromethane	0.0E+00	0.1	1.8E-06	0
Bromoform	0.0E+00	0.1	1.8E-06	0
Bromomethane	0.0E+00	0.1	1.8E-06	0
2-Chloro-1,3-butadiene	0.0E+00	0.1	1.8E-06	0
Cresols	0.0E+00	0.1	1.8E-06	0
Di-n-butyl phthalate	0.0E+00	0.1	1.8E-06	0
Dibromochloromethane	0.0E+00	0.1	1.8E-06	0
Dichlorodifluoromethane	0.0E+00	0.1	1.8E-06	0
2,4-Dichlorophenol	0.0E+00	40.03	7.1E-04	0
1,3-Dichloropropene	0.0E+00	0.1	1.8E-06	0
Diethyl phthalate	0.0E+00	0.1	1.8E-06	0
Dimethoate	0.0E+00	0.1	1.8E-06	0
2,4-Dinitrophenol	0.0E+00	260.95	4.6E-03	0
Diphenylamine	0.0E+00	0.1	1.8E-06	0
Endosulfan	0.0E+00	0.1	1.8E-06	0
Endrin	0.0E+00	0.1	1.8E-06	0
Ethylbenzene	0.0E+00	95.0	8.6E-04	0

(continued)

Appendix K (continued)

Compounds	Q* (day-kg/mg)	95% Emission concentration (ng/L) or 0.1 detection limit	Weight fraction	Weighted Q* (day-kg/mg)
Noncarcinogens (continued)				
Formic acid	0.0E+00	0.1	1.8E-06	0
Hexachlorocyclopentadiene	0.0E+00	0.1	1.8E-06	0
Hydrogen cyanamide	0.0E+00	0.1	1.8E-06	0
Isobutyl alcohol	0.0E+00	0.1	1.8E-06	0
Isophorone	0.0E+00	0.1	1.8E-06	0
Methomyl	0.0E+00	0.1	1.8E-06	0
Methoxychlor	0.0E+00	0.1	1.8E-06	0
Methyl ethyl ketone	0.0E+00	165.3	3.1E-03	0
Methyl parathion	0.0E+00	0.1	1.8E-06	0
Nitrobenzene	0.0E+00	3.17	5.6E-05	0
Pentachlorobenzene	0.0E+00	0.1	1.8E-06	0
Pentachlorophenol	0.0E+00	77.37	1.4E-03	0
Phenol	0.0E+00	8,388.5	2.1E-03	0
N-Phenylenediamine	0.0E+00	0.1	1.8E-06	0
Phenylmurcuric acetate	0.0E+00	0.1	1.8E-06	0
Pyridine	0.0E+00	0.1	1.8E-06	0
Selenourea	0.0E+00	0.1	1.8E-06	0
Strychnine	0.0E+00	0.1	1.8E-06	0

(continued)

Appendix K (continued)

Compounds	Q* (day-kg/mg)	95% Emission concentration (ng/L) or 0.1 detection limit	Weight fraction	Weighted Q* (day-kg/mg)
<u>Noncarcinogens</u> (continued)				
1,2,4,5-Tetrachlorobenzene	0.0E+00	0.1	1.8E-06	0
2,3,4,6-Tetrachlorophenol	0.0E+00	0.1	1.8E-06	0
Tetraethyl lead	0.0E+00	0.1	1.8E-06	0
Toluene	0.0E+00	215.02	3.8E-03	0
1,2,4-Trichlorobenzene	0.0E+00	332.5	5.3E-04	0
1,1,1-Trichloroethane	0.0E+00	11,115.0	1.7E-03	0
Trichlorofluoromethane	0.0E+00	0.1	1.8E-06	0
2,4,5-Trichlorophenol	0.0E+00	0.1	1.8E-06	0
C_1 Hydrocarbons	0.0E+00	17,575	3.1E-01	0
C_2 Hydrocarbons	0.0E+00	34,200	6.1E-01	0
TOTAL		888,645.43		1.2E-02

APPENDIX L

EMISSIONS DATA FOR ORGANIC COMPOUNDS USED TO DERIVE q_1* FOR THC

Emission Rate (ng/L)**

Municipal Sludge Incinerators	Test No.	Acrylonitrile	Acetonitrile	Benzene	MEK	Carbon Tet	Chloroform
Site 1	1	1.47E+02		2.71E+02		2.60E+00	7.10E+01
	2	3.83E+02		4.11E+02		2.40E+00	9.25E+01
	3	2.30E+02		3.10E+02		1.20E+00	1.10E+02
	4	1.57E+02		1.89E+02		1.20E+00	8.10E+01
	5	3.78E+02		4.50E+02		2.40E+00	1.14E+02
	Average:	2.59E+02		3.26E+02		1.96E+00	9.37E+01
Site 2 (Values from the control device outlet)	1	8.60E-01		2.10E-02		3.20E-02	1.60E-02
	2	8.50E-01		2.10E-02		3.20E-02	1.60E-02
	3	8.60E-01		2.20E-02		3.20E-02	1.60E-02
	4	8.40E-01		2.11E-02		3.20E-02	1.60E-02
	5	8.22E-01		2.06E-02		3.10E-02	1.50E-02
	6	8.30E-01		2.10E-02		3.10E-02	1.60E-02
	Average:	8.44E-01		2.11E+00		3.17E+00	1.58E+00
Site 3	1	1.80E+00 *		1.90E+01		2.50E-01 *	1.26E+02
	2	1.83E+00 *		4.50E+01		2.60E-01 *	5.40E+02
	3	1.90E+00 *		5.50E+00		8.00E-01	3.00E+00
	Average:	1.84E+00 *		2.32E+01		4.37E-01 *	2.23E+02
Site 4 (Values from the control device outlet)	1	2.64E+03		6.67E+02	1.03E+03	2.98E-01	1.73E+01
	2	4.07E+02	1.89E+02	1.23E+02	6.70E+00	9.70E-01	2.74E+01
	3	3.33E+03	1.15E+03	4.96E+02	0.00E+00	1.56E+00	3.19E+01
	4	2.64E+01	3.84E+01	1.97E+01	3.79E+00	1.10E+00	3.44E+01
	5	2.37E+01	3.66E+01	6.13E+00	2.16E+00	3.74E-01	2.72E+01
	6	4.54E+01	7.43E+01	8.02E+00	4.03E+00	3.01E-01	3.71E+01
	Average:	1.08E+03	2.98E+02	2.20E+02	1.74E+02	7.67E-01	2.92E+01
Site 5	1						4.50E+00
	2						4.60E+00
	3					3.00E-01	6.60E+00
	Average:					3.00E-01	5.23E+00
Site 8 (Values from the control device outlet)	1			4.52E+00			1.17E+01
	2			9.06E+00			1.41E+01
	3			4.96E+00			2.46E+01
	Average			6.18E+00			1.68E+01
Site 9 (Values from the control device outlet)	1	1.40E+03		1.04E+04			2.40E+01
	2	1.11E+03		5.09E+03			2.38E+01
	3	6.70E+02		3.67E+03			2.44E+01
	Average	1.06E+03		6.39E+03			2.41E+01
Site 10	1	7.00E+02		3.30E+03		9.90E+02	2.73E+03
	2	2.63E+05		1.07E+06		3.30E+02	1.66E+03
	3	4.60E+03		1.21E+04		0.00E+00	0.00E+00
	4	2.06E+04		3.77E+04		0.00E+00	4.80E+02
	5	1.01E+08		1.50E+06		0.00E+00	9.48E+03
	6	2.06E+06		5.52E+06		0.00E+00	2.38E+04
	7	6.40E+06		1.23E+08		0.00E+00	3.17E+03
	8	6.06E+06		1.04E+08		0.00E+00	1.13E+04
	9	5.83E+06		9.23E+06		0.00E+00	6.71E+03
	Average	3.59E+06		4.50E+06		1.47E+02	6.59E+03
SITE AVERAGE - MIN		8.44E-01	0.00E+00	2.11E+00	0.00E+00	3.20E-02	1.58E+00
SITE AVERAGE - MAX		3.59E+06	2.98E+02	4.50E+06	1.74E+02	1.47E+02	6.59E+03
SITE AVERAGE - 95TH		3.41E+06	2.98E+02	4.28E+06	1.74E+02	1.40E+02	6.26E+03

* Detection Limits

** Reported as ug/dscm,
Dioxins/furan were reported in ng/dscm
and converted to ng/L

Source: U.S. EPA, 1991k.

Emission Rate (ng/L) *

Municipal Sludge Incinerators	Test No.	1,2-Dichloroethane	Methylene Chloride	Tetrachloro ethene	Toluene	Trichloro ethene	Vinyl Chloride	Bis (2-Ethyl hexyl) phthalate	1,2-Dichloro benzene
Site 1	1	1.90E-01	2.68E+01	2.92E+02	7.54E+01	1.43E+01	7.32E+01	7.80E+00	1.73E+01 *
	2	1.00E-01	4.69E+01	4.17E+02	1.09E+02	3.51E+01	1.48E+02		
	3	1.90E-01	7.07E+01	2.29E+02	8.04E+01	3.15E+01	8.46E+01	6.52E+01	3.90E+01
	4	3.30E-01	5.56E+01	1.61E+02	6.90E+01	1.67E+01	6.27E+01	5.06E+01 *	4.34E+01 *
	5	1.60E+00	1.52E+01	1.06E+02	1.54E+02	3.54E+01	1.50E+02	4.26E+01	2.93E+01 *
	Average:	4.82E-01	4.30E+01	2.41E+02	9.76E+01	2.66E+01	1.03E+02	3.91E+01 *	3.23E+01
Site 2	1	3.20E-02	5.40E-02	1.60E-01	1.10E-01	1.60E-01	4.80E-01	1.91E+02	3.40E+01
(Values from the control	2	3.20E-02	5.30E-02	1.60E-01	1.10E-01	1.60E-01	4.80E-01	3.58E+01	1.58E+01
device outlet)	3	3.20E-02	5.40E-02	1.60E-01	1.10E-01	1.60E-01	4.90E-01	3.64E+01	3.64E+01
	4	3.20E-02	6.00E-02	1.60E-01	1.10E-01	1.60E-01	4.80E-01	1.50E+01	1.36E+01
	5	3.10E-02	5.10E-02	1.50E-01	1.00E-01	1.50E-01	4.60E-01	7.20E+00	3.54E+01
	6	3.10E-02	5.20E-02	1.50E-01	1.00E-01	1.50E-01	4.70E-01	7.30E+00	2.54E+01
	Average:	3.17E+00	5.40E-02	1.57E-01	1.07E-01	1.57E-01	4.77E-01	4.68E+01	2.68E+01
Site 3	1	3.00E-01 *	5.80E+00	2.70E-01 *	1.10E+00	3.00E-01	8.80E-01 *	6.20E+00	1.11E+00 *
	2	3.10E-01 *	5.00E+00	2.80E-01 *	2.00E+00	3.00E-01 *	8.90E-01 *	3.06E+01	1.07E+00 *
	3	3.20E-01 *	1.40E+00	8.60E+00	8.40E+00	9.00E-01	9.30E-01 *	1.01E+01	1.07E+00 *
	Average:	3.10E-01 *	4.07E+00	3.06E+00 *	3.83E+00	5.00E-01 *	9.00E-01 *	1.53E+01	1.08E+00 *
Site 4	1	0.00E+00	1.49E+02	1.02E+02	5.51E+02	1.76E+02	6.76E+01		
(Values from the control	2	0.00E+00	1.85E+02	6.50E+01	1.97E+02	1.54E+02	1.02E+01		
device outlet)	3	0.00E+00	1.10E+02	1.00E+02	4.78E+02	1.23E+02	2.26E+02		
	4	3.19E+00	4.51E+01	5.08E+01	4.96E+01	1.03E+02	0.00E+00		
	5	1.12E+00	1.29E+01	4.14E+01	1.89E+01	7.42E+01	0.00E+00		
	6	1.87E+00	2.69E+01	9.02E+01	6.25E+01	1.29E+02	0.00E+00		
	Average:	1.03E+00	8.82E+01	7.49E+01	2.26E+02	1.27E+02	5.07E+01		
Site 5	1	1.30E+00	2.30E+01						
	2	1.20E+00	2.50E+01						
	3	1.50E+00	2.70E+01						
	Average:	1.33E+00	2.50E+01						
Site 6	1		1.44E+02	5.20E+00	4.14E+00	1.67E+00		7.63E+00	
(Values from the control	2		4.45E+01	1.66E+01	1.48E+01	6.71E+00		1.03E+01	6.15E+00
device outlet)	3		1.35E+02	6.40E+00	3.96E+00	7.34E+00		3.21E+00	
	Average		1.08E+02	9.40E+00	7.86E+00	5.24E+00		7.05E+00	2.05E+00
Site 9	1		8.42E+01	2.10E+01	5.94E+03	2.24E+01	0.00E+00	2.92E+01	2.56E+01
(Values from the control	2		1.61E+01	3.38E+01	3.72E+03	2.75E+01	1.43E+02		
device outlet)	3		1.47E+01	3.21E+01	2.58E+03	2.38E+01	5.67E+01		
	Average		3.83E+01	2.90E+01	4.08E+03	2.46E+01	6.62E+01	1.46E+01	1.28E+01
Site 10	1	5.80E+02	2.46E+04	1.46E+03	9.30E+02			3.72E+03	0.00E+00
	2	0.00E+00	7.29E+03	4.67E+03	7.27E+04			5.40E+04	5.34E+03
	3	0.00E+00	5.90E+03	0.00E+00	8.00E+03			1.04E+03	8.40E+02
	4	0.00E+00	2.02E+04	3.50E+02	2.96E+03			9.70E+02	1.40E+02
	5	0.00E+00	5.36E+03	2.30E+04	7.46E+04			1.24E+04	1.14E+04
	6	0.00E+00	2.04E+04	0.00E+00	6.25E+04			2.15E+04	0.00E+00
	7	0.00E+00	0.00E+00	2.36E+04	3.11E+06			1.97E+04	1.63E+04
	8	0.00E+00	2.29E+04	2.63E+04	5.40E+06			3.72E+04	1.14E+04
	9	0.00E+00	2.24E+03	5.75E+04	6.09E+06			1.11E+06	9.76E+03
	Average	6.44E+01	1.21E+04	1.52E+04	1.87E+06			2.90E+04	6.14E+03
SITE AVERAGE - MIN		3.20E-02	6.40E-02	1.57E-01	1.07E-01	1.57E-01	9.00E-01	7.05E+00	1.08E+00
SITE AVERAGE - MAX		6.44E+01	1.21E+04	1.52E+04	1.87E+06	1.27E+02	1.03E+02	2.90E+04	6.14E+03
SITE AVERAGE - 95TH		6.12E+01	1.15E+04	1.44E+04	1.77E+06	1.20E+02	9.80E+01	2.76E+04	5.83E+03

* Detection Limits

** Reported as ug/dscm,
Dioxins/furan were reported in ng/dscm
and converted to ng/L

Emission Rate (ng/l)**

Municipal Sludge Incinerators	Test No.	1,4 Dichloro benzene	Phenol	2,4-Dichloro phenol	2,4-Dinitro phenol	Pentachloro phenol	Benzo(a) pyrene	1,2,4-Tri chlorobenzene	Aldrin
Site 1	1	6.77E+01	1.69E+01 *	2.66E+01 *	1.72E+02 *	5.11E+01 *	1.16E+01 *	1.98E+01 *	1.15E+02 *
	2								
	3	2.18E+01 *	1.98E+01 *	3.07E+01 *	2.00E+02 *	5.92E+01 *	1.34E+01 *	2.29E+01 *	1.33E+02 *
	4	7.22E+01	4.22E+01 *	6.63E+01 *	4.31E+02 *	1.28E+02 *	2.89E+01 *	4.94E+01 *	2.87E+02 *
	5	1.25E+02	2.85E+01 *	4.47E+01 *	2.90E+02 *	8.62E+01 *	1.96E+01 *	3.33E+01 *	1.94E+02 *
	Average:	7.17E+01 *	2.68E+01 *	4.21E+01 *	2.73E+02 *	8.11E+01 *	1.84E+01 *	3.14E+01 *	1.82E+02 *
Site 2 (Values from the control device outlet)	1	5.07E+01	1.73E+02	2.40E+00 *	4.34E+01 *	9.60E+00 *	1.80E+00 *	2.40E+00 *	2.40E+00 *
	2	2.47E+01	1.07E+02	1.70E+00 *	3.11E+01 *	6.80E+00 *	9.00E-01 *	1.30E+00 *	1.70E+00 *
	3	4.17E+01	2.08E+02	1.50E+00 *	2.77E+01 *	6.00E+00 *	1.10E+00 *	1.10E+00 *	1.50E+00 *
	4	1.66E+01	6.17E+01	1.50E+00 *	2.82E+01 *	6.20E+00 *	1.10E+00 *	1.10E+00 *	1.50E+00 *
	5	2.97E+01	1.53E+02	1.50E+00 *	2.79E+01 *	6.10E+00 *	1.10E+00 *	1.10E+00 *	1.50E+00 *
	6	3.62E+01	5.01E+01	1.60E+00 *	2.81E+01 *	6.20E+00 *	1.20E+00 *	1.20E+00 *	1.50E+00 *
	Average:	3.33E+01	1.25E+02	1.70E+00 *	3.11E+01 *	6.80E+00 *	1.20E+00 *	1.37E+00 *	1.68E+00 *
Site 3	1	1.11E+00 *	1.11E+00 *	2.22E+00 *	4.08E+01 *	8.88E+00 *	1.67E+00 *	1.67E+00 *	2.22E+00 *
	2	1.07E+00 *	1.07E+00 *	2.14E+00 *	3.90E+01 *	8.56E+00 *	1.60E+00 *	1.60E+00 *	2.14E+00 *
	3	1.07E+00 *	1.07E+00 *	2.13E+00 *	3.89E+01 *	8.52E+00 *	1.60E+00 *	1.60E+00 *	2.13E+00 *
	Average:	1.08E+00 *	1.08E+00 *	2.16E+00 *	3.96E+01 *	8.66E+00 *	1.62E+00 *	1.62E+00 *	2.16E+00 *
Site 4 (Values from the control device outlet)	1		2.30E+00						
	2		4.50E+00						
	3		5.70E+00						
	4								
	5								
	6								
	Average:		4.17E+00						
Site 5	1		5.40E+00		3.60E+01				
	2		3.80E+00		5.50E+01				
	3		6.50E+00		5.20E+01				
	Average:		5.23E+00		4.77E+01				
Site 8 (Values from the control device outlet)	1	1.99E+01							
	2	3.01E+01							
	3	1.18E+01							
	Average	2.06E+01							
Site 9 (Values from the control device outlet)	1	3.08E+01	0.00E+00					6.99E+02	
	2		1.76E+02						
	3								
	Average	1.54E+01	8.80E+01					3.50E+02	
Site 10	1	3.80E+02	0.00E+00						
	2	1.26E+04	9.47E+03						
	3	4.41E+03	1.20E+03						
	4	2.68E+03	7.87E+03						
	5	1.16E+04	2.70E+03						
	6	0.00E+00	1.06E+04						
	7	1.71E+04	1.27E+04						
	8	1.64E+04	1.51E+04						
	9	1.46E+04	1.98E+04						
	Average	8.86E+03	8.83E+03						
SITE AVERAGE - MIN		1.08E+00	1.08E+00	1.70E+00	3.11E+01	6.80E+00	1.20E+00	1.37E+00	1.68E+00
SITE AVERAGE - MAX		8.86E+03	8.83E+03	4.21E+01	2.73E+02	8.11E+01	1.84E+01	3.50E+02	1.82E+02
SITE AVERAGE - 95TH		8.41E+03	8.38E+03	4.00E+01	2.61E+02	7.74E+01	1.78E+01	3.33E+02	1.73E+02

* Detection Limits

** Reported as ug/dscm,
Dioxins/furan were reported in ng/dscm
and converted to ng/L

Emission Rate (ng/l)**

Municipal Sludge Incinerators	Test No.	Chlordane	Dieldrin	PCBs	2378 TCDD	Other TCDD	2378 PCDD	Other PCDD	2378 HxCDD
Site 1	1		1.04E+02 *						
	2		0.00E+00						
	3		1.20E+02 *						
	4		2.59E+02 *						
	5		1.75E+02 *						
	Average:		1.32E+02 *						
Site 2	1	3.57E+01 *	3.60E+00 *	2.72E+02 *					
(Values from the control	2	2.56E+01 *	2.60E+00 *	1.94E+02 *					
device outlet)	3	2.26E+01 *	2.30E+00 *	1.72E+02 *					
	4	2.32E+01 *	2.30E+00 *	1.76E+02 *					
	5	2.29E+01 *	2.30E+00 *	1.74E+02 *					
	6	2.29E+01 *	2.30E+00 *	1.74E+02 *					
	Average:	2.58E+01 *	2.57E+00 *	1.94E+02 *					
Site 3	1	3.33E+00 *	3.33E+00 *	2.53E+02 *					
	2	3.21E+01 *	3.21E+00 *	2.44E+02 *					
	3	3.19E+01 *	3.19E+00 *	2.43E+02 *					
	Average:	2.24E+01 *	3.24E+00 *	2.47E+02 *					
Site 4	1				1.20E-04	8.49E-03	1.20E-04	2.86E-03	3.30E-04
(Values from the control	2				1.40E-04	8.00E-03	2.00E-04	3.17E-03	5.20E-04
device outlet)	3				1.20E-04	5.40E-03	1.20E-04	1.81E-03	3.70E-04
	4				2.00E-05	1.73E-03	3.00E-05	8.40E-04	1.50E-04
	5				1.00E-06	1.08E-02	2.00E-04	5.71E-03	8.50E-04
	6				8.00E-05	1.08E-02	1.90E-04	5.79E-03	8.10E-04
	Average:				8.02E-05	7.54E-03	1.43E-04	3.36E-03	5.05E-04
Site 5	1								
	2								
	3								
	Average:								
Site 8	1				2.23E-06	3.60E-06			
(Values from the control	2				0.00E+00	0.00E+00			
device outlet)	3				0.00E+00	0.00E+00			
	Average				7.43E-07	1.20E-06			
Site 9	1					1.14E+00			
(Values from the control	2					1.50E-01			
device outlet)	3					0.00E+00			
	Average					6.46E-04			
Site 10	1								
	2								
	3								
	4								
	5								
	6								
	7								
	8								
	9								
	Average								
SITE AVERAGE - MIN		2.24E+01	2.57E+00	1.94E+02	7.43E-07	1.20E-06	0.00E+00	0.00E+00	0.00E+00
SITE AVERAGE - MAX		2.58E+01	1.32E+02	2.47E+02	8.02E-05	7.54E-03	1.43E-04	3.36E-03	5.05E-04
SITE AVERAGE - 95TH		2.42E+01	1.25E+02	2.35E+02	7.62E-05	7.16E-03	1.43E-04	3.36E-03	5.05E-04

* Detection Limits

** Reported as ug/dscm,
Dioxins/furan were reported in ng/dscm
and converted to ng/L

Municipal Sludge Incinerators	Test No.	Other HxCDD	2378 HpCDD	Other HpCDD	2378 TCDF	Ethylbenzene	1,1,1 Tri-chloroethane	Hexachloro ethane	Nitro-benzene
Site 1	1					1.11E+01	3.30E+00		
	2					1.34E+01	6.20E+00		
	3					9.98E+01	6.30E+00		
	4					1.33E+01	9.10E+00		
	5					2.43E+01	2.80E+00		
	Average:					3.24E+01	5.54E+00		
Site 2	1					1.60E-01	3.70E-02		
(Values from the control	2					1.60E-01	3.70E-02		
device outlet)	3					1.60E-01	3.80E-02		
	4					1.60E-01	3.70E-02		
	5					1.50E-01	3.60E-02		
	6					1.50E-01	3.60E-02		
	Average:					1.57E-01	3.68E-02		
Site 3	1					3.00E-01	2.60E+00		
	2					2.90E-01 *	2.10E+00		
	3					2.50E+00	2.80E+00		
	Average:					1.03E+00	2.50E+00		
Site 4	1	1.85E-03	4.30E-04	4.80E-04	4.14E-03	2.55E+02	6.37E+01		
(Values from the control	2	1.83E-03	5.30E-04	5.80E-04	4.42E-03	2.21E+01	1.62E+02		
device outlet)	3	1.44E-03	4.60E-04	4.80E-04	4.47E-03	2.53E+01	1.13E+02		
	4	7.20E-04	1.80E-04	2.10E-04	1.23E-03	1.85E+00	7.80E+01		
	5	3.93E-03	7.90E-04	1.04E-03	4.20E-03	4.33E-01	7.30E+01		
	6	3.67E-03	7.10E-04	8.00E-04	3.67E-03	1.60E+00	1.25E+02		
	Average:	2.24E-03	5.17E-04	5.98E-04	3.69E-03	5.10E+01	1.02E+02		
Site 5	1					6.50E+00	6.50E+00	6.00E-01	2.90E+00
	2					8.70E+00	5.70E+00	9.00E-01	3.00E+00
	3					7.60E+00	5.80E+00	8.00E-01	3.60E+00
	Average:					7.60E+00	6.00E+00	7.70E-01	3.17E+00
Site 6	1	9.90E-06		6.97E-06	4.92E-06	1.29E+00	6.76E+00		
(Values from the control	2	8.43E-07		0.00E+00	5.56E-07	4.40E+00	6.98E+00		
device outlet)	3	0.00E+00		0.00E+00	1.49E-07	2.22E+00	6.56E+00		
	Average	3.58E-06		2.32E-06	1.88E-06	2.64E+00	6.77E+00		
Site 9	1	1.30E-01		2.50E-01	1.39E+00	1.37E+02	2.34E+01	0.00E+00	
(Values from the control	2	0.00E+00		5.00E-02	2.80E-01	1.07E+02	2.22E+01	1.43E+05	
device outlet)	3	0.00E+00		0.00E+00	0.00E+00	5.71E+01	6.90E+00	5.57E+04	
	Average	6.50E-02		1.50E-01	8.35E-01	1.00E+02	1.75E+01	6.62E+04	
Site 10	1						1.19E+03		
	2						8.00E+02		
	3						1.98E+03		
	4						6.73E+03		
	5						3.57E+04		
	6						1.06E+04		
	7						0.00E+00		
	8						2.60E+04		
	9						2.24E+04		
	Average						1.17E+04		
SITE AVERAGE - MIN		3.58E-06	0.00E+00	2.32E-06	1.88E-06	1.57E-01	3.68E-02	0.00E+00	0.00E+00
SITE AVERAGE - MAX		6.50E-02	5.17E-04	1.50E-01	8.35E-01	1.00E+02	1.17E+04	6.62E+04	3.20E+00
SITE AVERAGE - 95TH		6.20E-02	5.17E-04	1.40E-01	7.90E-01	9.50E+01	1.11E+04	6.29E+04	3.20E+00

* Detection Limits

** Reported as ug/dscm,
Dioxins/furan were reported in ng/dscm
and converted to ng/L

Emission Rate (ng/l)**

Municipal Sludge Incinerators	Test No.	1,1-Dichloro-ethene	1,3-Dichloro-propene
Site 1	1		
	2		
	3		
	4		
	5		
	Average:		
Site 2	1		
(Values from the control	2		
device outlet)	3		
	4		
	5		
	6		
	Average:		
Site 3	1		
	2		
	3		
	Average:		
Site 4	1		
(Values from the control	2		
device outlet)	3		
	4		
	5		
	6		
	Average:		
Site 5	1	1.20E+00	
	2	7.00E-01	
	3	1.20E+00	1.00E-01
	Average:	1.03E+00	9.00E-02
Site 8	1		
(Values from the control	2		
device outlet)	3		
	Average		
Site 9	1		
(Values from the control	2		
device outlet)	3		
	Average		
Site 10	1		
	2		
	3		
	4		
	5		
	6		
	7		
	8		
	9		
	Average		
SITE AVERAGE - MIN		0.00E+00	0.00E+00
SITE AVERAGE - MAX		1.03E+00	9.00E-02
SITE AVERAGE - 95TH		9.78E+00	8.55E-02

* Detection Limits

** Reported as ug/dscm,
Dioxins/furan were reported in ng/dscm
and converted to ng/L

APPENDIX M

PERFORMANCE INDICATOR PARAMETERS FOR AIR POLLUTION CONTROL DEVICES

Appendix M

PERFORMANCE INDICATOR PARAMETERS FOR AIR POLLUTION CONTROL DEVICES

APC Device	Parameter	Example Measuring Devices
Venturi scrubber	Pressure drop	Differential pressure (ΔP) gauge/transmitter
	Liquid flow rate	Orifice plate with ΔP gauge/transmitter
	Gas temperature (inlet and/or outlet)	Thermocouple/transmitter
	Gas flow rate	Annubar or induced fan (ID) parameters
Impingement scrubber	Pressure drop	ΔP gauge/transmitter
	Liquid flow rate	Orifice plate with ΔP gauge/transmitter
	Gas temperature (inlet and/or outlet)	Thermocouple/transmitter
	Gas flow rate	Annubar or ID fan parameters
Mist eliminator (types include a wet cyclone, vane demister, chevron demister, mesh pad, etc.)	Pressure drop	Differential pressure gauge/transmitter
	Liquid flow	Orifice plate with ΔP gauge/transmitter
Dry scrubber (spray dryer absorber)	Liquid/reagent flow rate to atomizer	Magnetic flowmeter
	pH of liquid/reagent to atomizer	pH meter/transmitter
	For rotary atomizer: Atomizer motor power	Wattmeter

(continued)

Source: MRI, 1990.

Appendix M (CONCLUDED)

	For dual fluid flow:	
	Compressed air pressure	Pressure gauge
	Compressed airflow rate	Orifice plate with ΔP gauge/transmitter
	Gas temperature (inlet and/or outlet)	Thermocouple/transmitter
Fabric filter	Pressure drop (for each compartment)	ΔP gauges/transmitters
	Broken bags	Proprietary monitors
	Opacity	Transmissometer
	Gas temperature (inlet and/or outlet)	Thermocouple(s)
	Gas flow rate	Annubar or ID fan parameters
Wet electrostatic precipitator (ESP)	Secondary voltage (for each transformer/rectifier)	Kilovolt meters/transmitter
	Secondary currents (for each transformer/rectifier)	Milliammeters/transmitter
	Liquid flow(s) (for separate liquid feeds)	Orifice plate(s) with ΔP gauge/transmitter
	Gas temperature (inlet and/or outlet)	Thermocouple(s)
	Gas flow rate	Annubar or ID fan parameters

APPENDIX N

CALCULATION OF THE AMOUNT OF SEWAGE SLUDGE USED OR DISPOSED

CALCULATION OF THE AMOUNT OF SEWAGE SLUDGE USED OR DISPOSED FOR THE PART 503 FREQUENCY OF MONITORING REQUIREMENTS

Office of Science and Technology
U.S. Environmental Protection Agency
401 M Street, S.W.
Washington, D.C. 20460

November 23, 1992

CALCULATION OF THE AMOUNT OF SEWAGE SLUDGE USED OR DISPOSED FOR THE PART 503 FREQUENCY OF MONITORING REQUIREMENTS

INTRODUCTION

The Standards for the Use or Disposal of Sewage Sludge in 40 CFR Part 503 contain frequency of monitoring requirements for land application of sewage sludge, placement of sewage sludge on a surface disposal site, and firing of sewage sludge in a sewage sludge incinerator. These requirements indicate how often sewage sludge has to be monitored for pollutant concentrations, pathogen densities, and vector attraction reduction. They are based on the amount of sewage sludge used or disposed during a 365 day period.

For land application, the frequency of monitoring requirements are based either on the amount of bulk sewage sludge applied to the land or the amount of sewage sludge received by a person who prepares the sewage sludge for sale or give away in a bag or similar enclosure for application to the land. As those amounts increase, the frequency of monitoring increases.

For surface disposal and firing of sewage sludge in a sewage sludge incinerator, the frequency of monitoring requirements are based on the amount of sewage sludge placed on a surface disposal site and the amount of sewage sludge fired in a sewage sludge incinerator, respectively. For these two practices, the frequency of monitoring also increases as the amount of sewage sludge used or disposed increases.

This document discusses calculation of the amounts of sewage sludge used or disposed for the Part 503 frequency of monitoring requirements. The assumptions on which those requirements are based and the calculations for the amounts used or disposed are presented below. Also presented below are the Part 503 frequency of monitoring requirements.

ASSUMPTIONS

- Wastewater is treated in "typical" secondary wastewater treatment plant (i.e., primary settling followed by biological treatment followed by secondary settling).
- Sewage sludge is stabilized in an anaerobic digester prior to use or disposal.
- Influent wastewater BOD5 concentration = 200 mg/l.
- Effluent wastewater BOD5 concentration = 30 mg/l.
- Influent wastewater TSS concentration = 200 mg/l.
- Effluent wastewater TSS concentration = 30 mg/l.

- TSS percent removal in primary treatment process = 60.
- Percent volatile solids in the influent to digester = 60.
- Percent volatile solids reduction in digester = 38.
- Percent fixed solids in the influent to digester = 40
- Solids concentration factor during secondary settling = 0.9

CALCULATIONS FOR TREATMENT WORKS WITH A FLOW RATE OF ONE MGD

- TSS removal in primary treatment process:

Influent TSS x Flow rate x Conversion factor x Percent removal

200 mg/l x 1 MGD x 8.34 x 0.6 = 1,000 pounds per day.

- BOD5 removal through secondary settling process:

Influent BOD5 - Effluent BOD5 = 200 - 30 = 170 mg/l

Concentration removed x Flow rate x Conv. fact. x Conc. fact.

170 mg/l x 1 MGD x 8.34 x 0.9 = 1,276 pounds per day.

- Sewage sludge to the digester:

Primary settling sludge + secondary settling sludge = total

1,000 + 1,276 = 2,276 pounds per day.

- Amount of sewage sludge used or disposed:

Fixed solids = total amount x percent of total solids.

Fixed solids = 2,276 x 0.4 = 910 pounds per day.

Volatile solids = total amount x percent of total solids x percent remaining after digestion.

Volatile solids = 2,276 x 0.6 x (1.0 - 0.38) = 847 pounds/day

Total amount used or disposed = Fixed solids + volatile solids

910 + 847 = 1,757 pounds per day

$$\text{Total amount} = 1{,}757\ \frac{\text{pounds}}{\text{days}} \times 365\ \frac{\text{days}}{\text{year}} \times 1\ \frac{\text{metric ton}}{2{,}200\ \text{pounds}}$$

Total amount for 1 MGD = 292 metric tons per year.

Report amount in two significant figures:

Use 290 metric tons per year for 1 MGD treatment works (dry weight basis)

CALCULATION FOR A TREATMENT WORKS WITH A FLOW RATE OF FIVE MGD

Total amount = Amount for 1 MGD treatment works times 5

Total amount = 290 x 5 = 1,450 metric tons per year

Report amount in two significant figures:

Use 1,500 metric tons per year for five MGD treatment works (dry weight basis)

CALCULATION FOR A TREATMENT WORKS WITH A FLOW RATE OF 50 MGD

Total amount = Amount for 1 MGD treatment works x 50

Total amount = 290 x 50 = 14,500 metric tons per year

Report amount in two significant figures:

Use 15,000 metric tons per year for 50 MGD treatment works (dry weight basis)

PART 503 FREQUENCY OF MONITORING REQUIREMENTS

Results of the above calculations were used as the basis for the frequency of monitoring requirements in Part 503. Those frequencies are presented below.

FREQUENCY OF MONITORING

Amount of sewage sludge used or disposed (metric tons per 365 day period-dry weight)	Frequency
Greater than zero but less than 290	once per year
Equal to or greater than 290 but less than 1,500	once per quarter (four times per year)
Equal to or greater than 1,500 but less than 15,000	once per 60 days (six time per year)
Equal to or greater than 15,000	once per month (12 times per year)