United States
Environmental Protection
Agency

Office of Air Quality
Planning and Standards
Research Triangle Park NC 27711

EPA-450/4-90-017
August 1990

Air

EPA

EMISSION FACTOR DOCUMENTATION FOR AP-42 SECTION 2.5, SEWAGE SLUDGE INCINERATION

EPA-450/4-90-017

EMISSION FACTOR DOCUMENTATION FOR AP-42 SECTION 2.5, SEWAGE SLUDGE INCINERATION

By

Midwest Research Institute
Cary, NC 27511

EPA Contract No. 68-02-3891

EPA Project Officer: David C. Misenheimer

Office Of Air Quality Planning And Standards
Office Of Air And Radiation
U. S. Environmental Protection Agency
Research Triangle Park, NC 27711

August 1990

This report has been reviewed by the Office Of Air Quality Planning And Standards, U. S. Environmental Protection Agency, and has been approved for publication as received from the contractor. Approval does not signify that the contents necessarily reflect the views and policies of the Agency, neither does mention of trade names or commercial products constitute endorsement or recommendation for use.

EPA-450/4-90-017

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES

1. INTRODUCTION

The document "Compilation of Air Pollutant Emission Factors" (AP-42) has been published by the U. S. Environmental Protection Agency (EPA) since 1972. Supplements to AP-42 have been routinely published to add new emission source categories and to update existing emission factors. AP-42 is routinely updated by EPA to respond to new emission factor needs of EPA, State, and local air pollution control programs and industry.

An emission factor relates the quantity (weight) of pollutants emitted to a unit of activity of the source. The uses for the emission factors reported in AP-42 include:

1. Estimates of area-wide emissions;
2. Emission estimates for a specific facility; and
3. Evaluation of emissions relative to ambient air quality.

The purpose of this report is to provide background information from over 80 test reports to support revision of emission factors for sewage sludge incinerators.

Including the introduction (chapter 1) this report contains five chapters. Chapter 2 gives a description of the sewage sludge incineration industry. It includes a characterization of the industry, an overview of the different process types, a description of emissions, and a description of the technology used to control emissions resulting from sewage sludge incineration. Chapter 3 is a review of emissions data collection and analysis procedures. It describes the literature search, the screening of emission data reports, and the quality rating system for both emission data and emission factors. It also describes particle size determination and particle size data analysis methodology. Chapter 4 details pollutant emission factor development. It includes the review of specific data sets, the results of data analysis, and the data base protocol. Chapter 5 presents the AP-42 Section 2.5.

2. INDUSTRY DESCRIPTION

Incineration is a means of disposing sludge produced in sewage treatment plants. Incineration has the advantages of (1) destroying or reducing the organic matter present in the sludge, (2) lowering disposal and hauling costs by reducing solid mass approximately 95 percent, and (3) the potential for recovering energy through combustion of waste products. Disadvantages include the problems of disposal of the remaining, but reduced, waste and the potential for air pollution. Sludge incineration systems usually include a sludge pretreatment stage to thicken and dewater the incoming sludge, an incinerator, and some type of air pollution control equipment (commonly wet scrubbers).

2.1 CHARACTERIZATION OF THE INDUSTRY

There are about 250 sludge incinerators currently operating in 35 States.[1] The three major types of sewage sludge incinerators are multiple hearth, fluidized-bed, and electric infrared, which account for approximately 85, 10, and 5 percent of all sludge incinerators, respectively. The majority of these facilities are located on the East Coast and in the Midwest. New York has 21 sludge incineration facilities, the most of any State. Connecticut has the second highest total with 15, followed by Pennsylvania with 14 and Michigan, New Jersey, and Ohio with 12 facilities each. Table 2-1 shows the distribution of sludge incineration facility types by State.

Approximately 5.9 million dry megagrams (6.5 million dry tons) of sludge are generated in U.S. municipal wastewater plants each year.[2] It is estimated that 25 percent of this sludge is incinerated.[3] On this basis, the total amount of sludge incinerated annually is about 1.5 million dry megagrams (1.6 million dry tons).

2.2 PROCESS DESCRIPTION

Sewage sludge incineration refers to the oxidation of combustible materials generated by wastewater sewage treatment plants to reduce the volume of solid waste.

The first step in the process of sewage sludge incineration is the dewatering of the sludge. Sludge is generally dewatered until it is 15 to 30 percent solids. At this level, the sludge will usually burn without auxiliary fuel. After dewatering, the sludge is conveyed to the combustion device where the thermal oxidation occurs. The unburned residual ash is removed from the combustion device, usually on a continuous basis, and disposed. A portion of the noncombustibles, as well as unburned volatile organics, is carried out of the combustor through entrainment in the exhaust gas stream. Air pollution control devices, primarily wet scrubbers, are used to remove the entrained pollutants from the exhaust gas stream. The cleaned gas stream is then exhausted to the ambient air and the collected pollutants, now suspended in the scrubber water, are sent back to the head of the wastewater treatment plant.

Two main types of sludge incinerators account for approximately 95 percent of the units in use. These are multiple-hearth and fluidized-bed designs (see Figures 2-1 and 2-2). Multiple-hearth incinerators are vertically oriented cylindrical shells containing from 4 to 14 refractory hearths stacked one above the other. Sludge typically enters at the periphery of the top hearth and is raked inward by the teeth on a rotating rabble arm to a drop hole leading to the second hearth. The teeth on the rabble arm above the second hearth are positioned in the opposite direction to move the sludge outward. This outside-in, inside-out pattern is repeated on alternate hearths. Fluidized-bed incinerators also are vertically oriented cylindrical shells. Tuyeres are located at the base of the furnace within a refractory-lined grid. A bed of sand approximately 0.7-meters (2.5-feet) thick rests on the grid and is fluidized by air injected through the tuyeres. Sludge is introduced directly into the bed. Temperatures in a multiple-hearth furnace are 320°C (600°F) in the lower, ash-cooling hearth; 760° to 1100°C (1400° to 2000°F) in the central combustion hearths; and 540° to 650°C (1000° to 1200°F) in the upper, drying hearths. Temperatures in a fluidized-bed reactor are fairly uniform, from 680° to 820°C (1250° to 1500°F). In both types of furnaces, an auxiliary fuel may be required either during startup or when the moisture content of the sludge is too high to support combustion.

Another type of incinerator is the electric (infrared) furnace, the newest of the technologies currently in use for sludge incineration (see Figure 2-3). The furnace is horizontally oriented. The sludge is conveyed into one end of the incinerator where it is first dried and then burned as it travels beneath the infrared heating elements. Residual ash is discharged into a hopper at the opposite end of the furnace. Because electricity is used to provide the supplemental energy, excess-air requirements are lower for these facilities than for those that combust fossil fuels for supplemental energy; therefore, the supplemental energy requirements of the electric furnace are lower than those for multiple-hearth or fluidized-bed units.

Other technologies used for sludge incineration include cyclonic reactors, rotary kilns, and wet oxidation reactors. These are no longer in widespread use. Some sludge is coincinerated with refuse.

2.3 EMISSIONS

Sludge incinerators have the potential to emit significant quantities of pollutants to the atmosphere. One of these pollutants is particulate matter, which is emitted because of the turbulent movement of the combustion gases with respect to the burning sludge and resultant ash. The particle size distribution and concentration of the particulate emissions leaving the incinerator vary widely, depending on the composition of the sludge being burned and the type and operation of the incineration process.

Uncontrolled particulate matter emissions are usually highest for a fluidized-bed incinerator because the combustion gas velocities required to fluidize the bed result in entrainment of large quantities of ash in the flue gas. Particulate matter emissions from multiple-hearth incinerators are usually less than those from fluidized-bed incinerators because the agitation of ash and gas velocity through the bed are lower in the multiple-hearth incinerators. Electric furnaces have the lowest particulate matter emissions because the sludge is not stirred or mixed during incineration and air flows through the unit generally are quite low, resulting in minimal entrainment.

Incomplete combustion of sludge can result in emissions of intermediate products (e.g., volatile organic compounds and carbon monoxide). Other potential emissions include sulfur dioxide, nitrogen oxides, metals, acid gases, and toxic organic compounds. Tables 2-2 and 2-3 present the emission factor ranges for criteria pollutant and acid gas emissions from sludge incineration, respectively. Table 2-4 presents the emission factor ranges of metals and organic pollutants from sludge incineration. Table 2-5 presents a matrix of sewage sludge incineration sources for which emissions data have been obtained and emissions factors developed.

2.4 CONTROL TECHNOLOGY

Wet scrubbers are commonly used to control particulate matter emissions from sludge incinerators. There are two practical reasons for this: (1) a wastewater treatment plant is a source of relatively inexpensive scrubber water (plant effluent) and (2) a system for the treatment of the scrubber effluent is available (spent scrubber water is sent to the head of the treatment plant for solids removal). Gaseous emissions (e.g., SO_2, NO_x, CO, and VOC's) are also reduced in wet scrubbers.

In the past, a wide variety of wet scrubber types were used to control sludge incinerator emissions. Currently, the most widely used are venturi and impingement-tray scrubbers. Cyclone wet scrubbers are also commonly used, as are systems combining all three types of scrubbers.

Venturi scrubbers utilize high gas velocities and atomized liquid droplets to remove particulate matter from the gas stream. Atomized droplets of water or caustic solution are introduced to the gas stream, and the gases are accelerated to relatively high velocities in a venturi throat. Because the particles in the gas achieve velocities that are high relative to those of the droplets, the particles are collected by impaction on the surface of the droplets. The particulate-laden droplets subsequently are removed in a mist elimination system. The efficiency of a venturi scrubber depends on the energy used to accelerate the gas stream as indicated by the pressure drop across the system. Pressure drops in venturi scrubbers can range from less than 1 to 40 kPa. The efficiency of a typical venturi scrubber can range from 60 to 99 percent depending on the scrubber pressure drop and particle size distribution.

Impingement tray scrubbers consist of a vertical tower with one or more perforated plates mounted inside transversely to the shell. As the gas flows upward, it passes through the perforated plates and is forced to turn 180 degrees into a layer of liquid by an impingement baffle placed over the perforations. The particulate matter is collected in the liquid droplets as the gas passes through the liquid. The liquid flows downward through the tower, continuously removing the collected particles. A typical pressure drop through a baffle plate is 0.4 kPa per stage. Because these devices generally have relatively low pressure drops, they primarily collect large particles. The efficiency of a typical impingement tray scrubber can range from 60 to 90 percent depending on scrubber pressure drop and particle size distribution.

In cyclone scrubbers, a spiral motion is imparted to the gas as it passes upward through a vertical tower. Centrally located nozzles spray liquid droplet into the gas stream, creating a crosscurrent droplet motion. Particulate matter is captured by impaction on the droplets and by inertial impaction on the walls of the scrubber. The particulate-laden droplets are collected on the walls of the scrubber by the inertial force supplied by the gas stream, drain down the walls, and collect in the bottom of the scrubber for removal. Static pressure drops of 1 to 2 kPa are typical of cyclone scrubbers. Cyclone-design mist eliminators are commonly used to remove entrained droplets. The efficiency of a typical cyclone scrubber is approximately 95 percent.

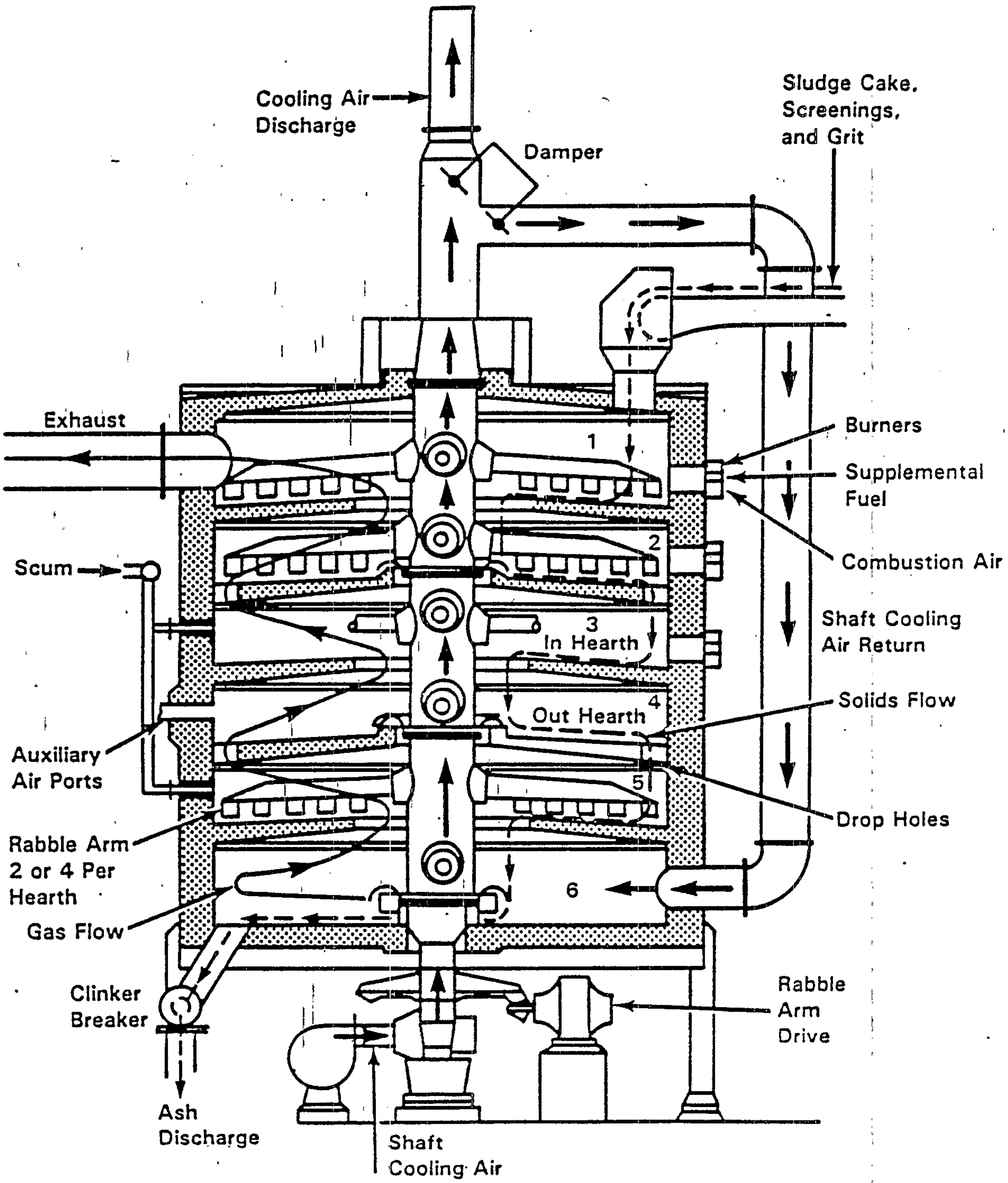

Figure 2-1 . Cross section of a multiple-hearth furnace.

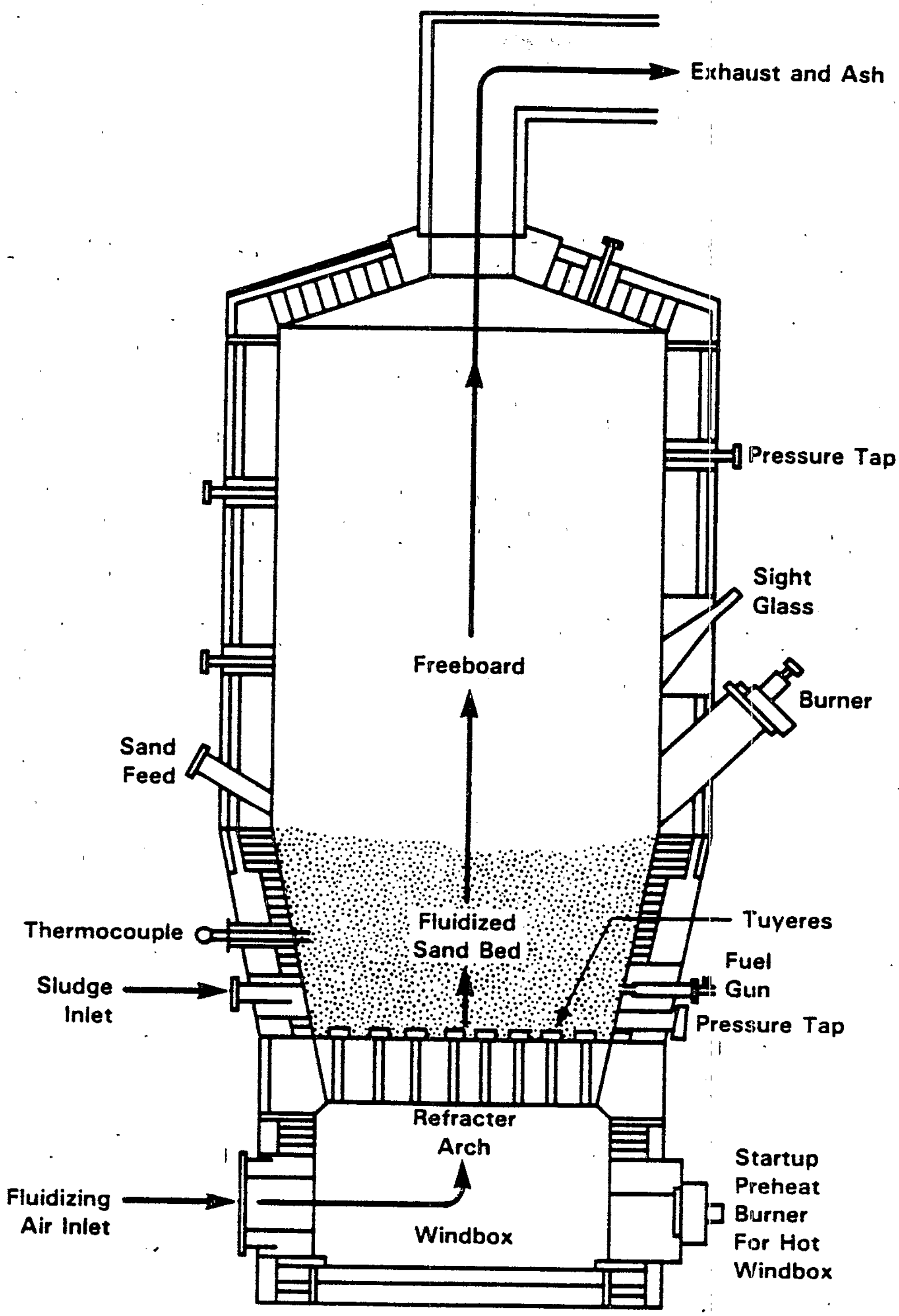

Figure 2-2. Cross section of a fluidized-bed furnace.

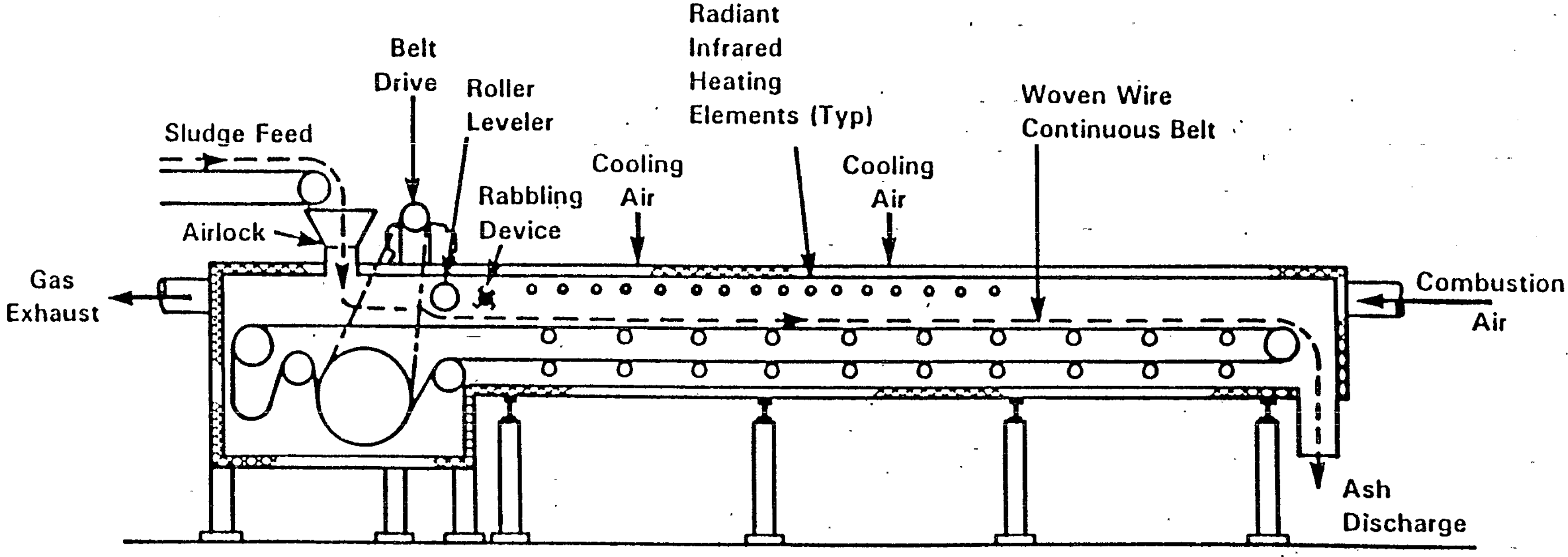

Figure 2-3. Cross section of an electric (infrared) furnace.

TABLE 2-1. DISTRIBUTION OF SLUDGE COMBUSTION FACILITIES BY STATE AND TYPE

Facility name/location	Incinerator type[a]	No. of incinerators	Total capacity, dry ton/d	Base controls[b]
Anchorage, Anchorage, Alaska	1	1	1.1	1
N. Little Rock, N. Little Rock, Ark.	5	1	c	5
Wrangell, Wrangell, Ark.	3	1	0.2	2
Barstow, Barstow, Calif.	2	1	2.5	6
C. Contra Costa, Walnut Creek, Calif.	1	2	44	1
Lake Arrowhead, Lake Arrowhead, Calif.	1	1	4.8	5
Palo Alto, Palo Alto, Calif.	1	2	6	1
Sacramento, Sacramento, Calif.	1	1	7.2	2
San Manteo, San Mateo, Calif.	1	1	4.9	3
S. Lake Tahoe, Lake Tahoe, Calif.	1	1	0.8	1
Yosemite, Yosemite National Park, Calif.	1	1	3.4	3
East Shore, New Haven, Conn.	1	1	29.2	2
Enfield, Enfield, Conn.	1	1	37.8	1
Glastonbury, Glastonbury, Conn.	1	1	11	1
Hartford, Hartford, Conn.	1	3	336	5
Mattabassett, Cromwell, Conn.	1	1	12.5	4
Middletown, Middletown, Conn.	1	1	7.2	2
Naugatuck, Naugatuck, Conn.	1	1	25	1
New Canaan, New Canaan, Conn.	4	1	38.9	2
New London, New London, Conn.	1	2	51.8	3
Norwalk, Norwalk, Conn.	2	1	36	2
Stamford, Stamford, Conn.	4	1	94.7	7
Stratford, Stratford, Conn.	1	1	20	1
Waterbury, Waterbury, Conn.	1	1	6.5	1
Willimantic, Willimantic, Conn.	1	1	19.2	1
Vernon, Vernon, Conn.	1	1	25	3
Jacksonville, Jacksonville, Fla.	1	1	28.4	3
Atlanta Bolton Rd., Atlanta, Ga.	1	2	129.6	3
Atlanta Utoy Creek, Atlanta, Ga.	1	1	8.1	2
Cobb County, Marietta, Ga.	1	1	19.8	3
Decatur, Decatur, Ga.	3	2	44.8	3
Gainesville, Gainesville, Ga.	3	2	5.5	2
R. M. Clayton, Atlanta, Ga.	5	2	60	5
Marietta, Marietta, Ga.	1	1	c	3
Savannah, Savannah, Ga.	1	2	12	3
Honouluili, Ewa, Hawaii	1	1	12	3
Sand Island, Honolulu, Hawaii	1	2	25.9	3
Granite City, Granite City, Ill.	1	1	c	5
Indianapolis, Indianapolis, Ind.	1	8	362.9	4
Cedar Rapids, Cedar Rapids, Iowa	1	1	24.3	3
Davenport, Davenport, Iowa	1	1	35.6	3
Dubuque, Dubuque, Iowa	2	2	7.5	10
Kansas City, Kansas City, Kans.	2	2	6.4	2
Turkey Creek, Shawnee Mission, Kans.	1	1	17.8	5
Covington, Covington, Ky.	1	1	c	5
Lake Charles, Lake Charles, La.	1	1	5	1
New Orleans, New Orleans, La.	1	1	16.2	4
New Orleans, New Orleans, La.	2	1	41	2

(continued)

TABLE 2-1. (continued)

Facility name/location	Incinerator type[a]	No. of incinerators	Total capacity, dry ton/d	Base controls[b]
Ocean City, Ocean City, Md.	2	1	7.2	1
Patapsco, Baltimore, Md.	1	3	98.4	3
Attleboro, Attleboro, Mass.	1	1	40.2	3
Chicopee, Chicopee, Mass.	1	1	9.6	3
Fitchburg, Fitchburg, Mass.	1	1	38.9	1
Lawrence, N. Andover, Mass.	1	2	90.8	9
Manchester, Manchester, Mass.	1	2	c	2
New Bedford, New Bedford, Mass.	1	1	16.2	1
Upper Blackstone, Millbury, Mass.	1	3	35.1	1
Ann Arbor, Ann Arbor, Mich.	1	1	54	5
Bay City, Bay City, Mich.	1	1	3.2	5
Detroit Complex 1, Detroit, Mich.	1	6	408	3
Detroit Complex 2, Detroit, Mich.	1	8	673.6	1
East Lansing, East Lansing, Mich.	1	2	32.4	5
Grand Rapids, Grand Rapids, Mich.	1	1	32.4	2
Kalamazoo, Kalamazoo, Mich.	1	1	48	3
Pontiac, Pontiac, Mich.	1	1	64.8	5
Port Huron, Port Huron, Mich.	2	1	7.6	1
Wayne Company, Wyandotte, Mich.	1	4	243.2	5
Warren, Warren, Mich.	1	1	25.4	8
Ypsilanti, Ypsilanti, Mich.	1	1	54	2
Duluth, Duluth, Minn.	4	2	34	2
Metropolitan, St. Paul, Minn.	1	6	777.6	3
Seneca, St. Paul, Minn.	1	2	19.4	3
Western Lake, Western Lake, Minn.	2	1	c	3
Independence, Independence, Mo.	2	1	9.7	3
Kansas City, Kansas City, Mo.	1	1	45.4	5
St. Louis Bissel Point, St. Louis, Mo.	1	5	324	4
St. Louis Lenay, St. Louis, Mo.	1	4	145.8	3
Papillion Creek, Omaha, Neb.	2	2	78	3
Round Hill, Lake Tahoe, Nev.	2	1	4.5	5
Lebanon, Lebanon, N.H.	1	1	7.2	3
Merrimack, Merrimack, N.H.	5	2	30	2
Atlantic City, Atlantic City, N.J.	1	1	25.9	3
Bergen County, Waldwick, N.J.	2	1	13.2	3
Jersey City, Jersey City, N.J.	1	1	13.8	2
Lincoln Park, Lincoln Park, N.J.	2	1	69	2
Parsippany, Parsippany, N.J.	1	2	77.8	0
Princeton, Princeton, N.J.	1	1	c	2
Recon, Three Bridges, N.J.	2	1	c	2
Somerset-Raritan, Raritan, N.J.	1	1	12	3
Stony Brook, Princeton, N.J.	1	2	39.5	3
Union Beach, Union Beach, N.J.	2	1	30	4
Waldwick, Waldwick, N.J.	1	1	18	3
Wayne, Wayne, N.J.	1	2	96	5
Albany North, Albany, N.Y.	1	2	129.4	1
Albany South, Albany, N.Y.	1	2	91.4	1
Amherst, Amherst, N.Y.	1	1	c	3
Arlington South, Arlington, N.Y.	2	1	8.4	5
Auburn, Auburn, N.Y.	1	1	40.5	5

(continued)

TABLE 2-1. (continued)

Facility name/location	Incinerator type[a]	No. of incinerators	Total capacity, dry ton/d	Base controls[b]
Beacon, Beacon, N.Y.	1	1	9.7	5
Birds Island, Buffalo, N.Y.	1	3	183.6	2
Glen Cove, New York, N.Y.	4	1	25	7
Hamburg, Erie County, N.Y.	2	2	288	3
Little Falls, Little Falls, N.Y.	2	1	3.9	2
N. Tonawanda, N. Tonawanda, N.Y.	1	1	c	3
Orangetown, Orangetown, N.Y.	1	1	16.8	3
Ossining, Ossining, N.Y.	1	1	c	2
Port Washington, Port Washington, N.Y.	2	1	c	3
Rochester Gates-Chill, Rochester, N.Y.	1	2	36	5
Rochester N.W. Quad, Rochester, N.Y.	1	2	48	5
Rochester Van Lare, Rochester, N.Y.	1	2	72	5
Saratoga, Saratoga, N.Y.	2	1	c	2
Schenectady, Schenectady, N.Y.	1	1	140	5
Utica, Onedia County, N.Y.	1	2	40	2
Watertown, Watertown, N.Y.	1	1	21	5
Greensboro, Greensboro, N.C.	1	1	45.4	1
Rocky Mount, Rocky Mount, N.C.	1	1	7.5	3
Rocky River, Concord, N.C.	1	1	50	3
Shelby, Shelby, N.C.	2	1	16.2	1
Akron, Akron, Ohio	1	2	19.4	2
Canton, Canton, Ohio	1	2	25	1
Cincinnati Mill Creek, Cincinnati, Ohio	1	4	168.4	1
Cleveland South, Cleveland, Ohio	1	4	259.2	5
Cleveland West, Cleveland, Ohio	1	2	194.4	5
Columbus Jackson Pike, Columbus, Ohio	1	1	38.9	2
Columbus South, Columbus, Ohio	1	2	45.4	2
Euclid, Euclid, Ohio	1	2	21.4	5
Jacksonville, Jacksonville, Ohio	1	3	c	2
Little Miami, Cincinnati, Ohio	1	4	333	3
Lorain, Lorain, Ohio	2	1	c	2
Youngstown, Youngstown, Ohio	1	1	40.5	6
Lawton, Lawton, Okla.	1	1	c	5
Tigard, Tigard, Oreg.	1	2	15	3
Delora-Chester, Chester, Pa.	1	2	19.4	5
Duryea, Duryea, Pa.	1	1	25.4	5
E. Norriton and Plymouth, Norristown, Pa.	1	1	100	5
Erie, Erie, Pa.	1	2	135	5
Harrisburg, Harrisburg, Pa.	4	2	135.4	7
Hatfield, Colmar, Pa.	1	1	5.7	5
Hazleton, Hazleton, Pa.	2	1	4.5	5
Hershey, Hershey, Pa.	1	1	40.5	1
Johnstown, Johnstown, Pa.	1	1	8.1	0
Kiski Valley, Appolo, Pa.	1	7	136.1	5
Tyrone, Tyrone, Pa.	2	1	5.1	2
Upper Gwynedd, N. Wales, Pa.	2	1	1.1	5
Wyoming Valley, Wilkes-Barre, Pa.	1	1	32.4	5
York, York, Pa.	1	2	38.4	5
Cranston, Cranston, R.I.	1	2	20.4	3
Fields Point, Providence, R.I.	1	1	60	3
Providence, Providence, R.I.	1	1	43	2

(continued)

TABLE 2-1. (continued)

Facility name/location	Incinerator type[a]	No. of incinerators	Total capacity, dry ton/d	Base controls[b]
Charleston, Charleston, S.C.	1	1	32.4	5
Columbia, Columbia, S.C.	1	2	8.2	5
Bristol, Bristol, Tenn.	1	1	16.2	5
Maryville, Maryville, Tenn.	1	1	13	3
Newport, Newport, Tenn.	1	1	7.8	5
Irving, Irving, Texas	2	1	c	2
Rowlett Creek, Plano, Texas	3	2	9.7	3
Arlington, Arlington, Va.	1	2	34.8	3
Chesapeake, Elizabeth, Va.	1	1	c	5
Fairfax, Fairfax, Va.	1	2	90.8	1
Fairfax, Fairfax, Va.	1	2	64.8	4
Hopewell, Hopewell, Va.	1	1	8.1	5
Newport News Boat Harbor, Newport News, Va.	1	2	9.8	5
Williamsburg, Williamsburg, Va.	1	2	5.3	5
Edmonds, Edmonds, Wash.	2	1	1.6	5
Lynnwood, Lynnwood, Wash.	2	1	0.7	5
Post Point, Bellingham, Wash.	5	1	c	5
Vancouver, Vancouver, Wash.	1	1	34	5
Brookfield, Brookfield, Wis.	1	1	3.9	1
Green Bay, Green Bay, Wis.	1	2	87.5	5
Milwaukee, Milwaukee, Wis.	1	1	7.1	5

[a]1 = Multiple hearth, 2 = fluidized bed; 3 = electric; 4 = sludge-refuse; 5 = unknown incinerator type.
[b]0 = Uncontrolled; 1 = impingement; 2 = venturi; 3 = venturi/impingement; 4 = wet cyclone; 5 = unknown scrubber type; 6 = spray chamber; 7 = electrostatic precipitator; 8 = wet cyclone/impingement; 9 = packed tower; 10 = venturi/packed tower.
[c]Capacity unknown.

TABLE 2-2. SUMMARY OF SSI CRITERIA POLLUTANT EMISSION FACTOR RANGES[a]

	Particle size, microns	Multiple hearth		Fluidized bed		Electric infrared	
		Uncon- trolled	After control device[b]	Uncon- trolled	After control device[b]	Uncon- trolled	After control device[b]
PM total		7.7-178 (15.4-357)	0.11-7.1 (0.22-14.2)	c	0.09-0.57 (0.18-1.14)	2.50-4.55 (5.0-9.10)	0.47-1.93 (0.94-3.86)
PM_{10}	0.625	0.30 (0.60)	0.07 (0.14)		0.08 (0.16)	0.34 (0.68)	0.30 (0.60)
	1.0	0.47 (0.94)	0.08 (0.16)		0.15 (0.30)	0.40 (0.80)	0.35 (0.70)
	2.5	1.1 (2.2)	0.09 (0.18)		0.18 (0.36)	0.60 (1.2)	0.50 (1.0)
	5.0	2.1 (4.2)	0.10 (0.20)		0.20 (0.40)	0.80 (1.6)	0.70 (1.4)
	10	4.1 (8.2)	0.11 (0.22)		0.22 (0.44)	1.3 (2.6)	1.0 (2.0)
	15	6.0 (12)	0.12 (0.24)		0.23 (0.46)	1.7 (3.4)	1.2 (2.4)
SO_2		4.7-25.1 (9.4-50.2)	0.001-3.84 (0.002-7.68)	c	0.1-9.3 (0.2-18.6)	9.2[d] (18.4)	2.3[d] (4.6)
NO_x		4.37-6.73 (8.74-13.4)	0.25-5.7 (0.50-11.4)	c	1.41-2.92 (2.82-5.84)	4.32[d] (8.64)	2.9[d] (5.8)
CO		19.5-53.0 (39.0-88.2)	1.7-1.8 (3.4-3.6)	c	2.1[d] (4.2)	c	c
Pb		0.047[d] (0.094)	0.005-0.039 (0.022-0.078)	c	0.002-0.005 (0.004-0.010)	c	c
VOC							
Methane		c	0.027-6.45 (0.054-12.9)	c	0.189-1.65 (0.378-3.30)	c	c
Nonmethane		0.106-2.62 (0.212-5.24)	0.22-1.53 (0.44-3.06)	c	c	c	c

[a]All emission factors reported in units of kg/Mg of dry sludge. Parentheses indicate units in lb/ton of dry sludge.
[b]Control devices include impingement, venturi, and cyclone scrubbers.
[c]No data are available.
[d]Data are available for only one test.

TABLE 2-3. SUMMARY OF SSI ACID GAS EMISSION FACTOR RANGES[a]

	Multiple hearth		Fluidized bed		Electric infrared	
	Uncontrolled	After control device	Uncontrolled	After control device	Uncontrolled	After control device
HCl	b	0.014-0.91 (0.028-1.82)	b	0.055[c] (0.110)	b	b
HF	b	b	b	b	b	b
H_2SO_4	0.047-0.579 (0.094-1.158)	0.042-1.15 (0.084-2.30)	b	0.027[c] (0.054)	b	b

[a]All emission factors reported in units of kg/Mg of dry sludge. Parentheses indicate units in lb/ton of dry sludge.
[b]No data are available.
[c]Data are available for only one test.

TABLE 2-4. SUMMARY OF SSI METAL AND ORGANIC POLLUTANT EMISSION FACTOR RANGES[a]

	Multiple hearth		Fluidized bed		Electric infrared	
	Uncontrolled	After control device	Uncontrolled	After control device	Uncontrolled	After control device
Metal, g/Mg						
As	14.7[b]	0.004-0.849	c	0.003-0.019	c	c
Be	c	c	c	c	c	c
Cd	0.001-49.2	0.173-32.4	c	0.148-1.453	c	c
Cr	16.6[b]	0.062-16.1	c	0.091-0.575	c	c
Hg	c	0.97[b]	c	0.03[b]	c	c
Ni	5.41[b]	0.037-4.51	c	0.85[b]	c	c
Organic compounds, mg/Mg						
2,3,7,8-TCDD[h]	c	0.00026-0.00097	c	c	c	c
2,3,7,8-TCDF[h]	0.62[b]	0.0038-0.37	c	c	c	c
TCDD[h]	0.063[b]	0.0014-0.063	c	c	c	c
TCDF[h]	1.7[b]	0.026-1.4	c	c	c	c
PCDD[h]	0.85[b]	0.0056-0.36	c	c	c	c
PCDF[h]	3.8[b]	0.036-3.1	c	c	c	c
Phenol	14,000[b]	380[b]	c	c	c	c
Nitrobenzene	1,000[b]	300[b]	c	c	c	c
Pyrene	600[b]	210[b]	c	210[b]	c	c
Fluorene	900[b]	150-400	c	400[b]	c	c
Acenaphthylene	700[b]	140[b]	c	140[b]	c	c
Hexachloroethane	c	140[b]	c	c	c	c
Naphthalene	15,000[b]	6,000[b]	c	c	c	c
Chrysene	210[b]	c	c	c	c	c
Fluoroanthene	430[b]	150-800	c	c	c	c

(continued)

TABLE 2-4. (continued)

	Multiple hearth		Fluidized bed		Electric infrared	
	Uncon-trolled	After control device	Uncon-trolled	After control device	Uncon-trolled	After control device
<u>Organic compounds</u> (continued)						
Phenanthrene	2,200[b]	480[b]	c	c	c	c
Vinyl chloride	11,000[b]	5,500[b]	c	c	c	c
Acetone	7,000[b]	2,100[b]	c	c	c	c
Benzene	5,000[b]	5,000[b]	c	c	c	c
Toluene	4,200[b]	3,900[b]	c	c	c	c
Chlorobenzene	1,600[b]	1,100[b]	c	c	c	c
Styrene	2,000[b]	c	c	c	c	c
Methylene chloride	140[b]	c	c	c	c	c
Vinyl acetate	250[b]	250[b]	c	c	c	c
PCB	c	15[b]	c	15[b]	c	c
BaP	c	4.5[b]	c	4.5[b]	c	c
Carbazole	c	150[b]	c	150[b]	c	c

[a]Metals emission factors reported in g/Mg of dry sludge; organics emission factors reported in mg/Mg of dry sludge.
[b]Data are available for only one test.
[c]No data are available.
[d] TCDD = tetrachlorinated dibenzo-p-dioxin
TCDF = tetrachlorinated dibenzofuran
CDD = tetra- through octachlorinated dibenzo-p-dioxins
CDF = tetra- through octachlorinated dibenzofurans.
PCB = polychlorinated biphenyl.
BaP = benzo(a)pyrene

TABLE 2-5. MATRIX OF SEWAGE SLUDGE INCINERATION EMISSIONS DATA AND EMISSION FACTORS

Source	Criteria Pollutants and Acids								Metals						Toxic organics											
	PM	VOC	Pb	SO_2	NO_x	CO	H_2SO_4	HCl	As	Be	Cd	Cr	Hg	Ni	2,3,7,8-TCDD	4CDD	5CDD	6CDD	7CDD	8CDD	2,3,7,8-TCDF	4CDF	5CDF	6CDF	7CDF	8CDF
General								y																		
Multiple Hearth																										
Uncontrolled	x,y		x,y	x,y	x,y	x,y	x,y		x,y		x,y	x,y		x,y		x,y	x,y	x,y	x,y	x,y	x,y	x,y	x,y	x,y	x,y	x,y
Controlled																										
General			y			y	y			x,y					y	y	y	y	y	y	y	y	y	y	y	y
Impingement	x,y	x,y	x	x,y	x,y	x	x				x,y	x,y	x,y	x,y	x	x	x	x	x	x	x	x	x	x	x	x
Venturi	x,y	x,y		x,y	x,y		x	x	x,y		x,y	x,y		x,y												
Cyclone	x,y	x,y		x,y			x				x,y	x,y														
Venturi/ Impingement	x,y			x,y																						
Cyclone/ Impingement	x,y																									
Cyclone/Venturi	x,y	x,y														x			x	x	x	x	x	x		x
Cyclone/ Venturi/ Impingement	x,y	x,y	x						x,y		x,y	x,y		x,y	x	x	x	x	x	x		x	x	x	x	x
Fluidized bed																										
Controlled																										
General	y		y		x	y																				
Impingement	x			x,y			x,y				x,y	x,y														
Venturi	x	x,y		x,y																						
Venturi/ Impingement	x	x,y	x	x,y	x,y	x		x	x,y		x,y	x,y	x,y	x,y												
Cyclone/ Venturi/ Impingement	x																									
Electric infrared																										
Uncontrolled	x,y			x,y	x,y																					
Controlled																										
General	y			x,y	x,y																					
Impingement	x																									
Cyclone/Venturi	x																									
Venturi/ Impingement	x																									

x = sources for which emissions data have been obtained.
y = sources for which emission factors have been developed.

REFERENCES FOR CHAPTER 2

1. Memorandum and attachments from S. Schliesser, MRI, to Project File 7711-L. November 30, 1985. Telephone contact reports concerning capacity and annual production, type of incinerator, control technology, particulate and chromium emissions data, testing feasibility, stack dimensions, and plume disturbances from nationwide survey of operating sewage sludge incinerators.

2. Environmental Regulations and Technology: Use and Disposal of Municipal Wastewater Sludge, EPA 625/10-84-003, U. S. Environmental Protection Agency Technology Transfer, September 1984.

3. Seminar Publication: Municipal Wastewater Sludge Combustion Technology, EPA/626/4-85/015, U. S. Environmental Protection Agency, Cincinnati, Ohio, September 1985.

4. Control Techniques for Particulate Emissions From Stationary Sources - Volume 1, EPA-450/3-81-005a, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, September 1982.

3. GENERAL DATA REVIEW AND ANALYSIS PROCEDURES

3.1 LITERATURE SEARCH AND SCREENING

The first step of this investigation involved a search of available literature relating to criteria and noncriteria pollutant emissions associated with sewage sludge incineration. This search included: data collected under the auspices of State and Territorial Air Pollution Program Administrators and Association of Local Air Pollution Control Officials (STAPPA/ALAPCO); source test reports and background documents for Section 2.5 of AP-42 located in the files of EPA's Office of Air Quality Planning and Standards (OAQPS); references cited in the Second Review of Standards of Performance for Sewage Sludge Incinerators (EPA 450/3-84-010, March 1984); various EPA contractor reports; and Midwest Research Institute's (MRI) in-house files.

To reduce the large amount of literature collected to a final group of references pertinent to this report, the following general criteria were used:

1. Emissions data must be from a primary reference:

a. Source testing must be from a referenced study that does not reiterate information from previous studies.

b. The document must constitute the original source of test data. For example, a technical paper was not included if the original study was contained in the previous document. If the exact source of the data could not be determined, the document was eliminated.

2. The referenced study must contain test results based on more than one test run.

3. The report must contain sufficient data to evaluate the testing procedures and source operating conditions (e.g., one-page reports were generally rejected).

A final set of reference materials was compiled after a thorough review of the pertinent reports, documents, and information according to these criteria.

3.2 EMISSION DATA QUALITY RATING SYSTEM

As part of MRI's analysis of the emission data, the quantity and quality of the information contained in the final set of reference documents were evaluated. The following data were always excluded from consideration.

1. Test series averages reported in units that cannot be converted to the selected reporting units;

2. Test series representing incompatible test methods (i.e., comparison of EPA Method 5 front-half with EPA Method 5 front- and back-half);

3. Test series of controlled emissions for which the control device is not specified;

4. Test series in which the source process is not clearly identified and described; and

5. Test series in which it is not clear whether the emissions were measured before or after the control device.

Data sets that were not excluded were assigned a quality rating. The rating system used was that specified by the OAQPS for the preparation of AP-42 sections. The data were rated as follows:

A--Multiple tests performed on the same source using sound methodology and reported in enough detail for adequate validation. These tests do not necessarily conform to the methodology specified in either the inhalable particulate (IP) protocol documents or the EPA reference test methods, although these documents and methods were certainly used as a guide for the methodology actually used.

B--Tests that were performed by a generally sound methodology but lack enough detail for adequate validation.

C--Tests that were based on an untested or new methodology or that lacked a significant amount of background data.

D--Tests that were based on a generally unacceptable method but may provide an order-of-magnitude value for the source.

The following criteria were used to evaluate source test reports for sound methodology and adequate detail:

1. Source operation. The manner in which the source was operated is well documented in the report. The source was operating within typical parameters during the test.

2. Sampling procedures. The sampling procedures conformed to a generally acceptable methodology. If actual procedures deviated from accepted methods, the deviations are well documented. When this occurred, an evaluation was made of the extent such alternative procedures could influence the test results.

3. Sampling and process data. Adequate sampling and process data are documented in the report. Many variations can occur unnoticed and without warning during testing. Such variations can induce wide deviations in sampling results. If a large spread between test results cannot be explained by information contained in the test report, the data are suspect and were given a lower rating.

4. Analysis and calculations. The test reports contain original raw data sheets. The nomenclature and equations used were compared to those (if any) specified by EPA to establish equivalency. The depth of review of the calculations was dictated by the reviewer's confidence in the ability and conscientiousness of the tester, which in turn was based on factors such as consistency of results and completeness of other areas of the test report.

3.3 PARTICLE SIZE DETERMINATION

There is no one method which is universally accepted for the determination of particle size. A number of different techniques can be used which measure the size of particles according to their basic physical properties. Since there is no "standard" method for particle size analysis, a certain degree of subjective evaluation was used to determine if a test series was performed using a sound methodology for particle sizing.

For pollution studies, the most common types of particle sizing instruments are cyclones and cascade impactors. Traditionally, cyclones have been used as a preseparator ahead of a cascade impactor to remove the larger particles. These cyclones are of the standard reverse-flow design whereby the flue gas enters the cyclone through a tangential inlet and forms a vortex flow pattern. Particles move outward toward the cyclone wall with a velocity that is determined by the geometry and flow rate in the cyclone and by their size. Large particles reach the wall and are collected. A series of cyclones with progressively decreasing cut-points can be used to obtain particle size distributions.

Cascade impactors used for the determination of particle size in process streams consist of a series of plates or stages containing either small holes or slits with the size of the openings decreasing from one plate to the next. In each stage of an impactor, the gas stream passes through the orifice or slit to form a jet that is directed toward an impaction plate. For each stage, there is a characteristic particle diameter that has a 50 percent probability of impaction. This characteristic diameter is called the cut-point (D_{50}) of the stage. Typically, commercial instruments have six to eight impaction stages with a backup filter to collect those particles which are either too small to be collected by the last stage or which are reetrained off the various impaction surfaces by the moving gas stream.

3.4 PARTICULATE SIZE DATA ANALYSIS METHODOLOGY

The particulate emission information contained in the various reference documents was reduced to a common format using a family of computer programs developed especially for this purpose. These programs use the so-called "spline" fits. Spline fits result in cumulative mass size distributions very similar to those which would be drawn using a French curve and fully logarithmic graph paper. In effect, the logarithm of cumulative mass is plotted as a function of the logarithm of the particle size, and a smooth curve with a continuous, nonnegative derivative is drawn.

The process by which this smooth cumulative distribution is constructed involves passing an interpolation parabola through three measured data points at a time. The parabola is then used to interpolate additional points between measured values. When the set of interpolated points are added to the original set of data, a more satisfactory fit is obtained than would be the case using only the measured data. The size-specific emission factors are determined once the size distribution is obtained by a spline fit.

3.5 EMISSION FACTOR QUALITY RATING SYSTEM

The quality of the emission factors developed from analysis of the test data was rated utilizing the following general criteria:

A--Excellent: Developed only from A-rated test data taken from many randomly chosen facilities in the industry population. The source category is specific enough so that variability within the source category population may be minimized.

B--Above average: Developed only from A-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industries. As in the A-rating, the source category is specific enough so that variability within the source category population may be minimized.

C--Average: Developed only from A- and B-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. As in the A-rating, the source category is specific enough so that variability within the source category population may be minimized.

D--Below average: The emission factor was developed only from A- and B-rated test data from a small number of facilities, and there is reason to suspect that these facilities do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of the emission factor are noted in the emission factor table.

E--Poor: The emission factor was developed from C- and D-rated test data, and there is reason to suspect that the facilities tested do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of these factors are always noted.

The use of these criteria is somewhat subjective and depends to an extent on the individual reviewer. Details of the rating of each candidate emission factor are provided in Chapter 4 of this report.

REFERENCES FOR CHAPTER 3

1. Technical Procedures for Developing AP-42 Emission Factors and Preparing AP-42 Sections, Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. April 1980.

2. Interim Report to State/Local APC Agencies of Particle Size Distributions and Emission Factors (Including PM_{10}), Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. July 1986.

3. Lime and Cement Industry--Source Category Report. Volume II--Cement Industry, EPA Contract No. 68-02-3891, Midwest Research Institute, Kansas City, Missouri. August 1986.

4. POLLUTANT EMISSION FACTOR DEVELOPMENT

This chapter describes the test data and methodology used to develop pollutant emission factors for the sewage sludge incineration industry.

4.1 REVIEW OF SPECIFIC DATA SETS

A total of 84 references were documented and reviewed during the literature search. These references are listed at the end of this chapter.

The sources used for emission data for the previous AP-42 versions are customarily included in the source data for the revision. However, the few sources used for the 1974 and 1981 versions of the Sewage Sludge Incineration AP-42 are not of the quality found in most of the data collected for this revision. Further, the sources used in the previous versions are based on 1972 and 1973 reports. Therefore, none of these data were used in this revision.

The following efforts were made to ensure that the selection and rating of reference documents did not introduce a bias in the data. The majority of references used (82 percent) were compliance test reports. Given the impetus for compliance testing, these reports would be expected to characterize facilities with various levels of maintenance, operation, and control. Eighteen percent of the references used in this report were classified as research or special study tests. In some cases, it could be reasoned that such studies would involve testing of facilities with above average maintenance, operation, and control and would, therefore, not be representative of the industry. Rather than downgrade the ratings for these references, each reference was considered on its own merit.

The original group of 84 documents was reduced to a final set of primary references utilizing the criteria outlined in Chapter 3. For the 39 reference documents not used, the reason(s) for rejection are summarized below:

Ref.	Reason for rejection
8	Back-half collection included in results
23	Control device not specified
31	Insufficient lab, process, analytical data
35b	Duplicate of test in References 34 n and s
36	Not primary data
37a, b	Insufficient lab, process, analytical data
38	Duplicate of test in Reference 4
41a-j	Test results based on only one run
46	Duplicate of test in Reference 42
50	Not primary data
51	Test results based on only one run
52	Insufficient process, control data
55	Duplicate of test in Reference 30
56	Insufficient lab, process, analytical data
57	Insufficient lab, process, analytical data
58	Insufficient lab, process, analytical data
59	Test results on only one run
60	Test results on only one run
61	Test results on only one run
62	Insufficient lab, process, analytical data
63	Insufficient lab, process, analytical data
64	Insufficient lab, process, analytical data
65	Insufficient process data
66	Insufficient lab, process, analytical data
73	Control device not specified
74	Averages cannot be converted into selected reporting units
76	Scale reading problems during test
82	Insufficient lab, process, analytical data
83	Duplicate of tests in Reference 5

The following is a discussion of the data contained in each of the primary references used to develop candidate emission factors. Emission factor calculations were made in terms of weight of pollutant per weight of dry sludge incinerated. It should be noted that the terms "controlled" and "uncontrolled" in this discussion are indicative only of the location at which the measurements were made.

A summary of the particulate emission data discussed below is contained in Tables 4-1 and 4-2. Tables 4-3 through 4-7 present summaries of criteria pollutant (other than particulate matter) data, and Tables 4-8 through 4-16 contain summaries of noncriteria pollutant data. Table 4-17 summarizes the data presented in Tables 4-1 through 4-16.

4.1.1 References 1 Through 3

References 1 through 3 are tests performed on three different sludge incinerators by an EPA contractor. These tests were performed to gather emission data for a study conducted under Tier 4 of the National Dioxin Study. The primary objective of the tests was to determine the presence of dioxins and/or furan emissions from the incineration process. Controlled data for these emissions are provided in References 1 and 2. Reference 3 contains controlled and uncontrolled emissions data.

In References 1 and 3, testing results were also presented for uncontrolled emissions of oxides of nitrogen (NO_x), sulfur dioxide (SO_2), and carbon monoxide (CO). Uncontrolled nonmethane volatile organic compound (VOC) emissions results were provided in References 1 and 2. These values were obtained from continuous monitoring of the combustion gases during the dioxin/furan tests.

A rating of A was assigned to the data in each of the tests for criteria pollutants. A rating of B was assigned to the toxic organics (dioxins and furans) data because EPA Modified Method 5 was used for sampling. Modified Method 5 has not yet been validated for organics sampling by the Agency.

4.1.2 Reference 4

This report comprises emission tests performed on a fluidized-bed incinerator to demonstrate the relationship between the temperature of incineration and the emissions of certain trace metals. The tests were performed at three different operating temperatures. Results were obtained for controlled emissions of total particulate matter and metals (arsenic [As], cadmium [Cd], chromium [Cr], lead [Pb], and nickel [Ni]).

Modified Method 5 and source assessment sampling system (SASS) train results were presented for each test, but the report states that SASS train results were used in preference to the Modified Method 5 results because approximately 10 times as much flow was sampled by the SASS train method. Metal emissions did increase with increasing incineration temperature. Operating temperatures for a fluidized-bed incinerator usually range from 680° to 820°C (1250° to 1500°F). These tests were conducted at 704°, 816°, and 927°C (1300°F, 1500°F and 1700°F).

The data in this report were assigned a rating of B.

Particle size determinations for controlled emissions were made by sampling with an Andersen Cascade Impactor.

4.1.3 References 5o through 5r

These references contain data from particulate and gaseous emissions tests conducted at four sludge incinerators. Each test provides controlled particulate matter emission data, and, except for incinerator "q," uncontrolled data are also presented. Controlled emission factors for Cd, Cr, Pb, SO_2, and H_2SO_4 are presented for each incinerator. Data from incinerator "p" include controlled results for Ni. Uncontrolled emission factors for SO_2 and H_2SO_4 are presented for incinerators "o," "p," and "r."

A rating of A was assigned to the data for incinerators "o" and "p." These reports provided adequate detail for validation, and the methodology appeared to be sound. The report for incinerator "q" did not contain sufficient process information to determine whether the incinerator was operating within design specifications. The report for incinerator "r" showed a wide, unexplained deviation in test results. For these reasons, References 5q and 5r were given a B rating.

4.1.4 References 6 and 7

These are chromium and organics screening study test reports. The tests were conducted by an EPA contractor on two incinerators located at the same site. Tests were conducted at the inlet and outlet of the scrubber to determine the concentration and mass emission rates of total particulate matter, semivolatile organic compounds and VOC's. Results were also obtained for controlled methane VOC emissions.

Total particulate matter emissions were determined using EPA Method 5. Volatile organic compounds were measured with a Volatile Organic Sampling Train (VOST) and semivolatile organic compound emissions were determined using Modified Method 5 with an XAD-2 resin trap.

The data for metals and total particulate matter presented in Reference 7 were assigned a rating of A. The data for semivolatile organic compound emissions, presented in Reference 6, were rated B because Modified Method 5 has not been approved for sampling of these compounds. The report states that the VOC results must be considered as "estimates" because the samples saturated the analytical systems during analysis.

Further, the inlet results were obtained from one incinerator and the outlet results from another. Therefore, the volatile organic emission results were assigned a rating of D and will be used for "order-of-magnitude" values only.

Particle size distribution measurements were made at the scrubber inlet and outlet. Four samples were collected at the scrubber inlet and five at the scrubber outlet. Particle size fractions were analyzed gravimetrically. Because the Method 5 particulate matter tests were conducted at the same time the particle size determinations were made, the results can be used in the development of particle size-specific emission factors.

4.1.5 References 9 through 13

These are the results of five particulate matter emissions compliance tests performed on five different sludge incinerators located at one treatment plant. Each test was conducted in accordance with EPA Methods 1 through 5 and provided controlled emissions data.

It was determined that the tests were generally of good quality. However, original raw field data sheets, laboratory data sheets, and sampling train calibration data were not included with the reports. For this reason, a rating of B was assigned to the test data in these references.

4.1.6 References 14 and 15

These are reports of compliance tests conducted to determine particulate matter emissions from two different sludge incinerators. Each test was performed in accordance with EPA Methods 1 through 5 and provided controlled emissions data. The quality of each test was generally good. However, in each case, information pertaining to design operating parameters (e.g., sludge feed rate) was not provided; thus, it could not be determined if the sources were operating within typical ranges of these parameters. Therefore, the test data from these references were assigned a rating of B.

4.1.7 Reference 16

Reference 16 is a particulate matter emissions compliance test report that provides controlled emissions data. The tests were performed in accordance with EPA Methods 1 through 5. The quality of the tests and process description provided were good, and the information required was complete. A rating of A was assigned to the test data.

4.1.8 References 17 through 20

References 17 and 18 contain the results of two compliance tests for one incinerator. References 19 and 20 contain information from compliance tests for two incinerators at another site. For each test, EPA Methods 1, 2, 3, and 5 were used to provide controlled particulate matter emissions data.

The quality of each test was good, and enough detail was provided for adequate validation. The test data from each reference were assigned a rating of A.

4.1.9 Reference 21

Reference 21 is a source sampling report of testing performed concurrently at the sludge incinerator scrubber inlet and scrubber stack to determine particulate matter emissions and particle size distributions. The results of the EPA Method 5 tests provided controlled and uncontrolled particulate matter emissions data.

The tests were of good quality and all necessary data pertaining to process descriptions and sampling and analytical data were provided. However, because design parameters for the incinerator were missing, it is not known if the source was operating within typical ranges for these parameters during the test. Because of this, the data were rated B.

Particle sizing was performed using a cascade impactor attached to a probe on the Method 5 sampling train. The report presents the scrubber collection efficiencies by particle size range.

4.1.10 References 22a through 22d

These compliance test reports present controlled particulate emissions data for incinerators within the same metropolitan sewer district. The tests were performed using EPA Methods 1 through 5. While the testing methodology appears to be sound, all four reports lacked enough detail for adequate validation. Field, laboratory, and calibration data were not provided in the reports. In addition, the conditions under which the source was operated were not well documented. For these reasons, each of the four tests was assigned a C rating.

4.1.11 References 24 and 25

These are reports of two particulate matter emissions compliance tests performed on the same incinerator at different times. The testing methodology was sound, and the level of detail of the documentation was adequate (except for missing design parameters). However, the results of the tests, taken only 1 month apart, show a wide deviation. Particulate matter emissions averaged 1.62 kilograms per dry megagram of sludge (3.25 pounds per dry ton of sludge) in the first test and 0.36 kilograms per dry megagram of sludge (0.73 pounds per dry ton of sludge) in the second test. While there may be a reasonable technical explanation for the deviation, none was provided. Therefore, each test was assigned a C rating.

4.1.12 References 26 through 29

These are reports of compliance tests conducted on four different sludge incinerators. Results are presented for controlled emissions of total particulate matter, NO_X (for References 26 through 28), SO_2, acid gases (HCl for References 26 through 28, and H_2SO_4 for Reference 27), and methane VOC. Reference 29 also contains controlled CO emission data. Reference 28 containing controlled Pb and Hg emissions data. Controlled metal emissions data are included in References 26 and 28 for As, Cd, Cr, and Ni. Metal emissions data from Reference 27 were not used because, according to information obtained from the State agency, the results were based on sludge analysis.

The testing methodology for each test appeared to be generally sound. Each of the reports lacked sufficient detail for adequate validation of the results. Also, this State requires front- and back-half collections to be included in particulate matter emission results, and the reports did not include a breakdown of the collections. The State agency was contacted for additional information including dry feed rates for each of the test runs and weights for the front-half collections of particulate matter.

Because raw data sheets, design feed rates, and other process data were missing from the reports, each data set was rated B.

4.1.13 Reference 30

Reference 30 is a particulate matter emissions compliance test report. Sufficient documentation was provided for validation and the testing methodology was generally sound. However, the first run of the test was made with the percentage of isokinetic nozzle velocity less than the desired minimum of 90. The report discussion mentions this deviation and states that corrections were made for this in the report. Nevertheless, it was decided that only the second and third runs would be used in determining the average emission value for this test. A rating of B was assigned to the data.

4.1.14 Reference 32

This compliance report presented the results for particulate matter emissions testing of one sludge incinerator. The testing methodology was sound and the level of documentation was sufficient for validation purposes. However, background data pertaining to the source operation and design parameters were not provided. For this reason, the data were assigned a B rating.

4.1.15 Reference 33

Reference 33 is a particulate matter emissions compliance report for one sludge incinerator. The tests were performed in accordance with EPA Method 5 and provided controlled emissions data. Complete background information and testing details were provided. The data were given an A rating.

4.1.16 Reference 34n and s

This report presents the results of a source emissions survey conducted for an incineration systems manufacturer. Testing was performed on two incinerators at one site to determine particulate matter concentrations at both the scrubber inlet and outlet. Tests at the scrubber inlet consisted of one run for each incinerator and both back- and front-half collections were used. Three runs were used for each outlet test, and the results were based on the front-half collections only.

The testing methodology was sound and the source process was described adequately. Original field data, calibration information, and laboratory analysis sheets were not included in the report. For this reason, the controlled (outlet) data for each test were given a B rating. Uncontrolled (inlet) data were assigned a D rating because the results were based on a single run. These data (using the front-half collection results only) may provide an order-of-magnitude value for the source.

Particle size distribution for uncontrolled emissions was determined using a Coulter Counter. Results of particle sizing are presented in Reference 35b (a duplicate of the particulate emissions test described in Reference 34).

4.1.17 References 35a, 35c, 35d, and 35e

These are reports presenting emission data for four infrared sludge incinerators. Each of the reports provides controlled particulate matter emission data, and Reference 35e provides uncontrolled data as well. Reference 35e also presents emissions data for NO_x and SO_2 before and after the control device.

The data are part of summary reports compiled for an incinerator manufacturer, and background information was not included. Raw data, analytical reports, sampling procedures, calibration information, and process descriptions were missing. Because of these deficiencies, each of the tests was assigned a C rating.

References 35a and 35e provided controlled and uncontrolled particle size data. In the case of Reference 35a, the uncontrolled particulate size distribution data were established 5 months after the particulate loading tests. Therefore, these data cannot be used.

4.1.18 References 39 and 40

These reports are part of research projects designed to investigate the performance of air pollutant abatement systems for controlling metals and organics emitted from sewage sludge incinerators. The tests were conducted by an EPA contractor. The reports pertain to tests conducted to determine the efficiency of an ESP and a baghouse, respectively. In each case, testing was done on incinerators with existing scrubber systems, and slipstreams were used for experimental testing of the control devices. Because comparative data were needed, the reports contain scrubber inlet and outlet data representing emissions not controlled by the ESP or the baghouse.

Controlled and uncontrolled emissions data are provided in Reference 39 for particulate matter, As, Cd, Cr, Pb, and Ni. Uncontrolled emissions data are presented for nonmethane VOC's in both reports and for NO_x, CO, and SO_2 in Reference 39.

The methodologies were sound, and background information and documentation provided were complete in both reports. Therefore, both reports were assigned A ratings.

Each report provides controlled and uncontrolled particulate matter mass concentrations by SASS size fractions.

4.1.19 References 42 through 44

These are particulate matter emission compliance reports for sludge incinerators at three different sites. In each case, the methodologies were sound, and appropriate background information and documentation were provided. Each data set was given an A rating.

4.1.20 Reference 45

This is a particulate matter and sulfur dioxide emissions test report for a sludge incinerator. The report provides controlled emissions data for each of these pollutants. While the methodology used was sound, the report did not include sufficient background information to establish the design feed rate value. Therefore, a B rating was assigned to the data.

4.1.21 Reference 47

Reference 47 is a particulate matter emission compliance report for one sludge incinerator. Method 5 procedure was used for the test. The report did not include complete documentation for validation purposes, nor did it provide design parameters for the source. Therefore, the data were given a rating of B.

4.1.22 References 48 and 49

These references are reports of two particulate matter emission compliance tests for the same incinerator. The tests were done in 1982 and 1984. Each report contained documentation adequate for validation, and the test methodologies were deemed to be sound. An A rating was assigned to each.

4.1.23 References 53 and 54

These are reports of compliance tests performed on two different sludge incinerators. The reports contain controlled emissions data for particulate matter. Reference 53 also contains data for Hg emissions after the control device.

In each case, sound testing methodologies were used. However, each report lacked enough detail for adequate validation, e.g., source manner of operation was not well documented. The State agency was contacted to determine dry feed rates for use in emission factor calculations. Both reports were assigned a B rating.

4.1.24 References 67 through 72

References 67 through 72 comprise seven compliance tests on seven different sludge incinerators. Each of the reports presents controlled particulate matter emissions data. Other controlled emissions data reported include: Reference 68--NO_x, CO, and nonmethane VOC's; Reference 69--NO_x, SO_2, and methane VOC's; References 71 and 72--NO_x, and SO_2.

Each of the tests was considered to have used sound testing methodologies, and the reports included enough detail for adequate validation. The data were assigned an A rating in each case.

4.1.25 Reference 75

This is a report of a compliance test performed on one incinerator and provides controlled particulate matter emissions data. Sufficient process information and field data were provided for validation of the results. However, no information regarding the sampling procedures and test methodology was included with the report. The State agency was contacted for this information and confirmed that EPA Method 5 was used. The data were assigned a rating of A.

4.1.26 References 77 through 79

References 77 through 79 are reports of compliance tests performed on three different sludge incinerators. Each test report provides controlled particulate matter emissions data, and Reference 79 also provides controlled emissions data for nonmethane VOC's. For each test report, the methodology was judged to be sound. Each report included appropriate and complete background information with details sufficient for validation. The reports were assigned A ratings.

4.1.27 Reference 80

This is a report of a compliance test performed on one sludge incinerator. Controlled particulate matter emissions results are presented. Laboratory, calibration, and field data sheets were provided, but information pertaining to the source process was not included. The State agency was contacted to obtain this information. The data were assigned an A rating.

4.1.28 Reference 81

This compliance test report provides controlled emissions data for total particulate matter. The testing methodology was judged to be sound, and adequate detail was provided for validation. A rating of A was assigned to the data.

4.1.29 Reference 84

This test report provides controlled emissions data for noncriteria pollutants. The report included original raw field data sheets, laboratory data sheets, sampling train calibration data, and process data. The quality of each test was good. The data from the reference were assigned a rating of A.

4.2 RESULTS OF DATA ANALYSIS

4.2.1 Total Particulate Matter Emissions Data

Both uncontrolled and controlled particulate matter emission factors were determined from the data contained in the reference documents described above. In the case of uncontrolled emissions, References 5o, p, r; 7; 21; 34n and s; 35e; and 39 contained useful data. For all of these except Reference 39, the emission factors were determined from the test data by manual and computer calculations from emission factors expressed in units other than mass of pollutant per megagram of dry sewage sludge incinerated. For Reference 39, the appropriate uncontrolled emission factor was extracted directly from the test report. References 34n and s each contained a single-run value for uncontrolled particulate matter emissions. As discussed in Section 4.1.16, these emission results were used as order-of-magnitude values only.

For controlled processes, a procedure similar to that described above for determining uncontrolled emission factors was used. References 4; 5o through 5r; 7; 9 through 21; 22a through 22d; 24 through 30; 32; 33; 34n and 34s; 35a, 35c, 35d, 35e; 39; 49; 53; 54; 67 through 72; 75; 77 through 81; and 84 contained useful data. Except for References 4, 10, 11, 13, 15, 17 through 22a-22d, 23, 24, 25, 32, 33, 34n and 34s, 35c and 35d, 39, 42, 47, 48, 49, and 70, the controlled emission factors were calculated (manually and with the computer program) from data presented in other terms. A summary of all available particulate matter emission factors is shown in Table 4-1.

4.2.2 Particle Size Data

Both uncontrolled and controlled particulate matter emission factors were determined from the data contained in the reference documents described above. In the case of uncontrolled emissions, References 7, 21, 35a, 34n and s, and 35e contained useful data. For controlled emissions, References 4, 7, 21, 35a, and 35e contained useful data. A summary of all available PM_{10} emission factors is shown in Table 4-2.

4.2.3 Other Criteria Pollutant Emissions Data

4.2.3.1 Volatile Organic Compounds. Controlled VOC emission factors were determined for both methane and nonmethane VOC's. References 68, 79, and 84 were used to determine controlled nonmethane VOC emission factors. References 6, 26 through 29, and 69 were used to determine controlled methane VOC emission factors. Uncontrolled nonmethane VOC emission factors were determined from data contained in References 1, 2, 39, and 40. No data were available to develop emission factors for uncontrolled methane VOC's. In all cases, the emission factors were determined from the test data by calculations from emission factors expressed in terms other than mass of pollutant per megagram of dry sludge incinerated. A summary of VOC emission factors is shown in Table 4-3.

4.2.3.2 Lead. Controlled Pb emission factors were determined from the data contained in References 4, 5o through 5r, 28, 39, and 84. Only Reference 39 contained uncontrolled emissions data. None of the data reports indicated that Pb emission values were based on data from lead compounds. Therefore, elemental Pb was assumed in each case. Because the lead emission factor is the sum of both front- and back-half catches, the lead emission weight cannot be compared to the particulate matter emission weight.

In each case, calculations were performed to convert from the units used in the reports to conventional emission factor units. A summary of Pb emission factors is shown in Table 4-4.

4.2.3.3 Sulfur Dioxide, Oxides of Nitrogen and Carbon Monoxide. Data for determining uncontrolled emission factors for SO_2 were taken from References 1, 3, 5o, 5p, 5r, 35e, and 39. Uncontrolled emissions data for NO_X were taken from References 1, 3, 35e, and 39; and for CO from References 1, 3, 39, and 84.

Controlled emissions data used to determine emission factors were provided in the following reports:

SO_2: References 5o through 5r, 26 through 29, 35e, 45, 69, 71, and 72

NO_X: References 26 through 28, 35e, 68, 69, 71, and 72

CO: References 29, 68, and 72.

The emission factors were determined from the test data by calculations. Tables 4-5 through 4-7 present a summary of emission factors for those pollutants.

4.2.4 Noncriteria Pollutant Emissions Data

4.2.4.1 Acid Gases. Reference 5o, 5p, and 5r contained data for uncontrolled acid gas (H_2SO_4) emissions. References 5o through 5r and 27 provided data for the determination of controlled emission factors for H_2SO_4. References 26 through 28 were used for emission factors for HCl. Calculations were required to convert into conventional emission factor units. A summary of acid gas emission factors is shown in Table 4-8.

4.2.4.2 Toxic Organics. References 1, 2, 3, and 84 were used for the development of controlled emission factors for several dioxin and furan compounds. Tables 4-9 through 4-14 present summaries of organic emission factors.

4.2.4.3 Noncriteria Metals. Reference 39 provided uncontrolled emission data for As, Cd, Cr, and Ni. Reference 7 provided uncontrolled emission data for Cd. References 4, 26, 28, and 39 provided data for the determination of controlled emission factors for As, Cd, Cr, and Ni. Reference 5p was used for Cd, Cr, and Ni. References 5o, 5q, and 5r were used for controlled emissions of Cd and Cr. No emission data were presented for Be. Controlled emissions data were presented for Hg in

References 28 and 53. All results were converted to conventional emission factor reporting units. A summary of emission factors for metals is presented in Tables 4-15 and 4-16.

4.3 PROTOCOL FOR DATA BASE

4.3.1 Engineering Methodology

Using the criteria discussed in Section 3.2, 29 reports representing 39 source tests were rejected. The remaining 55 reports representing 65 source tests were thoroughly reviewed to establish a data base for the following classes of pollutants: particulate matter and other criteria pollutants, acid gases, metals, and organic compounds.

Data log forms (see Appendix A) were created to document and facilitate transfer of reported emission and process information to pollutant-specific data base files created using dBase III™. A program was written to perform most of the calculations and to present the results in a consistent and comparable format. Pollutant-specific tables were generated by computer to (1) list results for uncontrolled and controlled emission levels and collection efficiency, (2) present emission results as an emission factor in pollutant mass per mass of sludge feed, and (3) identify the facility by reference number and type. The sections below briefly describe the methodology and rationale used to develop the data base files and programs.

The emission data, documented on the data log forms, were averaged as the arithmetic mean of different sampling runs prior to inclusion in the data base. Test programs at most facilities consisted of three sampling runs conducted during distinct and controlled normal operating conditions.

Due to the variety of formats used to report units of measure at different sludge incineration facilities, the emission data required some preprocessing to standardize the units of measure prior to computer calculation of emission factors. Emission factors were then calculated in terms of kg/Mg of dry sludge and lb/ton of dry sludge for all pollutants. Computerized preprocessing was possible with the data bases for acid gases, criteria pollutants, and organic compounds because the variety of measurement units was limited. The list of conversion factors used in the data base preprocessing is included as Table 4-18.

In the acid gases and criteria pollutants data bases, some preprocessing required simple calculations in addition to unit conversions. If the pollutant-specific data, D1, were reported in ng/dscm corrected to 12 percent CO_2 in the test report, the following calculation

$$DI=D1x(\text{percent concentration of } CO_2)/12$$

was performed to present the "uncorrected" value in the resulting table. When the data, D1, were reported in ng/dscf in the test report, the conversion

$$D1=D1x35.31$$

was required to present D1 as ng/dscm. Acid gas and criteria pollutant data were presented in ppmdv corrected to 12 percent CO_2. In order to convert data, D1, from mg/dscm corrected to 12 percent CO_2 to ppmdv at 12 percent CO_2, the relation

$$D1=D1x(1000x0.02404)/(\text{molecular weight of pollutant})$$

was employed.

Calculation of emission factors was performed using conversion factors (CF's) to relate process conditions to emission concentration levels. The CF's were calculated manually for each facility that provided percent concentration of CO_2, process feed rate, and stack gas flow measurements. The emission factors in 10^{-10} lb/ton were calculated using the "corrected" concentration data in English units, E1 in 10^{-10} gr/dscf, and the following equation

$$EF=CFxE1$$

where

$$CF = \frac{(\text{Percent concentration of } CO_2)(\text{stack gas flow in dscfm})(7.14x10^{-4})}{\text{Process rate in ton/h}}$$

The emission factor in μg/Mg were then calculated using

$$EF \text{ in } \mu g/Mg=(EF \text{ in } 10^{-10} \text{ lb/ton})x0.05$$

In order to calculate emission factors from data presented in ppmdv at 12 percent CO_2, a second conversion factor, CCF, was needed. CCF was defined as

$$CCF = \frac{(\text{molecular weight of pollutant})(1.3x10^{-8})(CF)}{7.14x10^{-4}}$$

An emission factor value may be calculated from

EF in lb/ton feed=(D1 in ppmdv @ 12 percent CO_2)(CCF).

Because test periods were nonsimultaneous, CF values for some facilities were different for the various pollutants. Determinations of emission factors were made only when process feed rates were documented or derivable from plant records of sludge process rates.

Quality control and quality assurance procedures were used to assure that the data base accurately reflected the reported test data. Each data log form was checked by other MRI staff to assure documentation of reported emission and process data prior to development of the computer data base. The data log forms provided the structure for the computer data base files and quality check. After emission tables were generated, a final comparison was made between randomly selected test reports, their associated data log form, and the produced emission table to assure the quality of the data acquisition and the associated calculations.

4.3.2 Computer Programming Methodology

The dBase III™ programs initially were modified and titled in a pollutant-specific fashion; these gradually were developed into a more generalized format to allow for improved quality control and consistent data manipulation. The programs were written in a modular fashion with a main procedure, MAINRPT, calling several subroutines. The subroutines were designed to (1) conduct the preprocessing and emission factor calculations; (2) print the table heading and column identifications; (3) print the facility reference number, type, control device type, and facility rating; and (4) print the emission factors in SI and English units.

The data base files remained pollutant specific so that the files could be checked against the test reports. These files are presented in Table 4-19. These data base files were used to generate the pollutant-specific tables shown in Table 4-20. These programs required simple modifications prior to producing the desired tables. These modifications included selecting desired table number and data type and altering the field name used in the program to reflect this data type.

TABLE 4-1. SUMMARY OF EMISSION FACTORS FOR PARTICULATE MATTER FROM SEWAGE SLUDGE INCINERATORS

Source category/reference/rating	Uncontrolled, kg/Mg (lb/ton)	Controlled, kg/Mg (lb/ton)	Efficiency, percent
Multiple hearth			
Cyclone			
5r,b	23.1 (46.2)	1.17 (2.34)	94.9
79,a		2.930 (5.86)	
Cyclone/impingement			
78,a		0.404 (0.808)	
Cyclone/venturi			
10,b		0.240 (0.480)	
11,b		0.280 (0.560)	
13,b		0.150 (0.300)	
84,a		0.368 (0.736)	
Cyclone/venturi/impingement			
39,a	15.9 (31.8)	0.309 (0.618)	98.1
Impingement			
50,a	178 (356)	0.458 (0.916)	99.7
5p,a	13.4 (26.8)	1.72 (3.44)	87.2
7,a	7.7 (15.4)	0.108 (0.216)	98.6
9,b		0.916 (1.832)	
12,b		0.937 (1.874)	
22d,c		0.375 (0.750)	
30,b		0.233 (0.466)	
53,b		0.574 (1.148)	
54,b		0.521 (1.042)	
67,a		1.116 (2.232)	
68,a		1.16 (2.32)	
71,a		0.179 (0.358)	
72,a		0.726 (1.452)	
75,a		0.233 (0.466)	
Venturi			
21,b	12.4 (24.8)	1.73 (3.46)	86.1
24,c		0.365 (0.730)	
25,c		1.625 (3.250)	
26,b		0.274 (0.548)	
27,b		7.065 (14.13)	
32,b		1.60 (3.20)	
47,b		0.540 (1.08)	
70,a		0.429 (0.859)	
77,a		0.880 (1.76)	
Venturi/impingement			
15,b		0.235 (0.470)	
16,a		0.411 (0.822)	
17,a		0.105 (0.210)	
18,a		0.270 (0.540)	
19,a		0.370 (0.740)	
20,a		0.290 (0.580)	
22a,c		0.925 (1.850)	
22b,c		0.460 (0.920)	
22c,c		0.865 (1.730)	
33,a		0.255 (0.510)	
42,a		0.165 (0.330)	
45,b		0.509 (1.018)	
48,a		0.910 (1.820)	
49,a		5.60 (11.2)	

(continued)

TABLE 4-1. (continued)

Source category/ reference/rating	Uncontrolled, kg/Mg (lb/ton)	Controlled, kg/Mg (lb/ton)	Efficiency, percent
80,a		0.636 (1.272)	
81,a		0.170 (0.340)	
Fluidized bed			
Cyclone/venturi/impingement			
43,a		0.431 (0.862)	
44,a		0.55 (1.10)	
Impingement			
5q,b		0.114 (0.228)	
14,b		0.149 (0.298)	
Venturi			
69,a		0.570 (1.140)	
Venturi/impingement			
4,b		0.090 (0.180)	
28,b		0.292 (0.584)	
29,b		0.427 (0.854)	
Electric infrared			
Cyclone/venturi			
35c,c		1.93 (3.86)	
Impingement			
35a,c		0.821 (1.642)	
Venturi/impingement			
34n,d,b	2.50 (5.00)	0.472 (0.944)	81.1
34s,d,b[a]	4.05 (8.10)	0.640 (1.28)	
35d,c		0.875 (1.750)	
35e,c	4.55 (9.10)	1.818 (3.636)	60.0

[a]Efficiency cannot be calculated due to different inlet and outlet test run times.

TABLE 4-2. SUMMARY OF EMISSION FACTORS FOR PARTICLE SIZE (PM_{10}) DATA FROM SEWAGE SLUDGE INCINERATORS

Source category/ reference/rating	Cut diameter, microns	Uncontrolled		Controlled		Control efficiency, %
		Cum. % < cut	Emission factor, lb/ton feed	Cum. % < cut	Emission factor, lb/ton feed	
Multiple hearth						
Impingement						
7,a	0.625	4.11	0.61	59.3	0.15	75
	1.00	6.37	0.94	62.4	0.16	83
	2.50	15.0	2.22	68.9	0.17	92
	5.00	28.7	4.24	74.3	0.19	96
	10.0	54.8	8.11	80.1	0.20	98
	15.0	80.0	11.8	83.7	0.21	98
Venturi						
21,b	0.625	12.7	3.17	73.9	2.59	18
	1.00	13.6	3.38	77.2	2.71	20
	2.50	15.4	3.82	84.3	2.96	23
	5.00	16.9	4.19	90.1	3.16	25
	10.0	18.5	4.61	96.2	3.38	27
	15.0	19.6	4.87	99.3	3.49	28
Fluidized bed						
Venturi						
4,b	0.625			32	0.16	
	1.0			60	0.30	
	2.50			71	0.35	
	5.00			78	0.39	
	10.0			86	0.43	
	15.0			92	0.46	
Electric infrared						
Impingement						
35a,c	0.625			3.41	0.059	
	1.0			5.32	0.092	
	2.50			12.6	0.22	
	5.00			24.3	0.42	
	10.0			46.8	0.81	
	15.0			68.9	1.19	
Venturi/impingement						
34n,d	0.625	59.4	0.17			
	1.0	65.3	0.19			
	2.50	78.5	0.23			
	5.00	90.3	0.26			
	10.0	99.0	0.29			
	15.0	100.0	0.29			
34s,d	0.625	59.8	0.88			
	1.0	65.7	0.97			
	2.50	78.9	1.16			
	5.00	90.6	1.33			
	10.0	99.0	1.46			
	15.0	100.00	1.47			
35e,c	0.625	11.1	1.01	31.1	1.13	--
	1.0	13.9	1.26	36.2	1.32	--
	2.50	23.2	2.11	49.4	1.80	15
	5.00	36.9	3.36	63.9	2.33	31
	10.0	64.4	5.86	85.5	3.11	47
	15.0	93.7	8.53	100.0	3.64	57

TABLE 4-3. SUMMARY OF EMISSION FACTORS FOR VOLATILE ORGANIC COMPOUNDS FROM SEWAGE SLUDGE INCINERATORS

Source category/ reference/rating	Uncontrolled, kg/Mg (lb/ton)		After control device, kg/Mg (lb/ton)		Efficiency, percent
	Methane	Nonmethane	Methane	Nonmethane	
Multiple hearth					
Cyclone					
79,a				1.53 (3.06)	
Cyclone/venturi					
2,a		0.510 (1.02)			
84,a				0.220 (0.440)	
Cyclone/venturi/impingement					
1,a		2.620 (5.24)			
39,a		0.146 (0.292)			
40,a		0.108 (0.216)			
Impingement					
6,d			0.39 (0.78)		
68,a				0.785 (1.57)	
Venturi					
26,a			0.027 (0.054)		
27,b			6.45 (12.9)		
Fluidized bed					
Venturi					
69,a			1.65 (3.30)		
Venturi/impingement					
28,b			0.189 (0.378)		
29,b			0.610 (1.220)		

TABLE 4-4. SUMMARY OF EMISSION FACTORS FOR LEAD FROM SEWAGE SLUDGE INCINERATORS

Source category/ reference/rating	Uncontrolled, kg/Mg (lb/ton)	Controlled, kg/Mg (lb/ton)	Efficiency, percent
Multiple hearth			
Cyclone			
5r,b		0.037 (0.074)	
Cyclone/venturi			
84,a		0.0052 (0.0104)	
Cyclone/venturi/impingement			
39,a	0.047 (0.094)	0.011 (0.022)	77.2
Impingement			
50,a		0.019 (0.038)	
5p,a		0.039 (0.078)	
Fluidized bed			
Impingement			
5q,b		0.003 (0.006)	
Venturi/impingement			
4,b		0.005 (0.010)	
28,b		0.002 (0.004)	

TABLE 4-5. SUMMARY OF EMISSION FACTORS FOR SULFUR DIOXIDE FROM SEWAGE SLUDGE INCINERATORS

Source category/ reference/rating	Uncontrolled, kg/Mg (lb/ton)	Controlled, kg/Mg (lb/ton)	Efficiency, percent
Multiple hearth			
Cyclone			
5r,b	8.34 (16.68)	1.77 (3.54)	78.7
Cyclone/venturi/impingement			
1,a	19.7 (39.4)		
39,a	25.1 (50.2)		
Impingement			
3,a	9.98 (19.96)		
5o,a	14.4 (28.8)	0.031 (0.062)	99.7
5p,a	4.686 (9.372)	0.107 (0.214)	97.7
71,a		0.360 (0.720)	
72,a		0.807 (1.614)	
Venturi			
26,b		0.78 (1.56)	
27,b		3.84 (7.68)	
Venturi/impingement			
45,b		0.001 (0.002)	
Fluidized bed			
Impingement			
5q,b		0.347 (0.694)	
Venturi			
69,a		9.25 (18.5)	
Venturi/impingement			
28,b		0.10 (0.20)	
29,b		0.78 (1.56)	
Electric infrared			
Venturi/impingement			
35e,c	9.2 (18.4)	2.32 (4.64)	74.7

TABLE 4-6. SUMMARY OF EMISSION FACTORS FOR OXIDES OF NITROGEN FROM SEWAGE SLUDGE INCINERATORS

Source category/ reference/rating	Uncontrolled, kg/Mg (lb/ton)	After control device, kg/Mg (lb/ton)	Efficiency, percent
<u>Multiple hearth</u>			
Cyclone/venturi/impingement			
1,a	4.37 (8.74)		
39,a	6.73 (13.46)		
Impingement			
3,a	5.965 (11.930)		
68,a		5.65 (11.30)	
71,a		0.888 (1.776)	
72,a		3.77 (7.54)	
Venturi			
26,b		0.248 (0.496)	
27,b		1.705 (3.410)	
<u>Fluidized bed</u>			
Venturi			
69,a		2.92 (5.84)	
Venturi/impingement			
28,b		1.41 (2.82)	
<u>Electric infrared</u>			
Venturi/impingement			
35e,c	4.32 (8.64)	2.90 (5.80)	32.9

TABLE 4-7. SUMMARY OF EMISSION FACTORS FOR CARBON MONOXIDE FROM SEWAGE SLUDGE INCINERATORS

Source category/ reference/rating	Uncontrolled, kg/Mg (lb/ton)	After control device, kg/Mg (lb/ton)	Efficiency, percent
Multiple hearth			
Cyclone			
84,a	53 (106)		
Cyclone/venturi/impingement			
1,a	19.5 (39.0)		
39,a	44.1 (88.2)		
Impingement			
3,a	27.0 (54.0)		
68,a		1.65 (3.30)	
72,a		1.78 (3.56)	
Fluidized bed			
Venturi/impingement			
29,b		2.13 (4.26)	

TABLE 4-8. SUMMARY OF SULFURIC ACID, HYDROGEN CHLORIDE, AND HYDROGEN FLUORIDE EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

Source category/ reference/rating	H_2SO_4 Uncontrolled, kg/Mg (lb/ton)	H_2SO_4 After control device, kg/Mg (lb/ton)	H_2SO_4 Efficiency, percent	HCl Uncontrolled, kg/Mg (lb/ton)	HCl After control device, kg/Mg (lb/ton)	HCl Efficiency, percent	HF Uncontrolled, kg/Mg (lb/ton)	HF After control device, kg/Mg (lb/ton)	HF Efficiency, percent
Multiple hearth									
Cyclone									
5r,b	0.580 (1.16)	0.207 (0.414)	64.3						
Impingement									
5o,a	0.491 (0.982)	0.042 (0.084)	91.4						
5p,a	0.047 (0.094)	0.072 (0.144)	-54.5						
Venturi									
26,b					0.014 (0.028)				
27,d		1.15 (2.30)			0.910 (1.820)				
Fluidized bed									
Impingement									
5q,b		0.027 (0.054)							
Venturi/impingement									
28,b					0.055 (0.110)				

TABLE 4-9. SUMMARY OF 2,3,7,8 TETRA-, TOTAL TETRA- AND TOTAL PENTACHLORINATED DIBENZO-P-DIOXIN EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS[a]

Source category/ reference/rating	2,3,7,8 tetra			Tetra			Penta		
	Uncontrolled	After control device	Efficiency, percent	Uncontrolled	After control device	Efficiency, percent	Uncontrolled	After control device	Efficiency, percent
Multiple hearth									
Cyclone/venturi 2,b					1.40 (2.80)				
Cyclone/venturi/ impingement 1,b		0.263 (0.526)			63.8 (127.6)			1.51 (3.02)	
Impingement 3,b		0.971 (1.942)		62.7 (125.4)	56.5 (113)	9.9	2.74 (5.48)	7.32 (14.64)	-167

[a]Units in μg/Mg of dry sludge, parentheses indicate units in lb/ton E-9 of dry sludge.

TABLE 4-10. SUMMARY OF TOTAL HEXA-, TOTAL HEPTA- AND TOTAL OCTACHLORINATED DIBENZO-p-DIOXIN EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS[a]

Source category/ reference/rating	Hexa			Hepta			Octa		
	Uncontrolled	After control device	Efficiency, percent	Uncontrolled	After control device	Efficiency, percent	Uncontrolled	After control device	Efficiency, percent
Multiple hearth									
Cyclone/venturi 2,b					0.774 (1.548)			3.439 (6.878)	
Cyclone/venturi/ impingement 1,b		4.38 (8.76)			14.1 (28.2)			30.7 (61.4)	
Impingement 3,b	67.7 (135.4)	47.8 (95.6)	29.4	340 (680)	144 (288)	57.6	375 (750)	105 (210)	72.2

[a]Units in μg/Mg of dry sludge, parentheses indicate units in lb/ton E-9 of dry sludge.

TABLE 4-11. SUMMARY OF TOTAL TETRA- THROUGH OCTACHLORINATED DIBENZO-P-DIOXIN EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

Source category/reference/rating	Uncontrolled, µg/Mg (lb/ton, E-9)	After control device, µg/Mg (lb/ton, E-9)	Efficiency, percent
Multiple hearth			
Cyclone/venturi 2,b		5.63 (11.26)	
Cyclone/venturi/impingement 1,b		113 (226)	
Impingement 3,b	847 (1,694)	360 (720)	57.4

TABLE 4-12. SUMMARY OF 2,3,7,8 TETRA-, TOTAL TETRA- AND TOTAL PENTACHLORINATED DIBENZOFURAN EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS[a]

Source category/ reference/rating	2,3,7,8 tetra			Tetra			Penta		
	Uncontrolled	After control device	Efficiency, percent	Uncontrolled	After control device	Efficiency, percent	Uncontrolled	After control device	Efficiency, percent
Multiple hearth									
Cyclone/venturi									
2,b		7.50 (15.0)			74 (148)			16.8 (33.6)	
84,a		3.8 (7.6)			26.1 (52.2)			6.0 (12.0)	
Cyclone/venturi/ impingement									
1,b					188 (376)			57.5 (115)	
Impingement									
3,b	620 (1,240)	371 (742)	40.2	1,708 (3,416)	1,395 (2,790)	18.3	980 (1,960)	718 (1,436)	26.7

[a]Units in µg/Mg of dry sludge, parentheses indicate units in lb/ton E-9 of dry sludge.

TABLE 4-13. SUMMARY OF TOTAL HEXA-, TOTAL HEPTA- AND TOTAL OCTACHLORINATED DIBENZOFURAN EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS[a]

Source category/ reference/rating	Hexa			Hepta			Octa		
	Uncontrolled	After control device	Effi- ciency, percent	Uncontrolled	After control device	Effi- ciency, percent	Uncontrolled	After control device	Effi- ciency, percent
Multiple hearth									
Cyclone/venturi									
2,b		5.67 (11.34)						0.257 (0.514)	
84,a		1.2 (2.4)			0.9 (1.8)			1.2 (2.4)	
Cyclone/venturi/ impingement									
1,b		1.777 (3.554)			2.89 (5.78)			1.79 (3.58)	
Impingement									
3,b	99.5 (199)	219 (438)	-119	481 (962)	410 (820)	14.9	491 (982)	310 (620)	36.9

[a]Units in μg/Mg of dry sludge, parentheses indicate units in lb/ton E-9 of dry sludge.

TABLE 4-14. SUMMARY OF TOTAL TETRA- THROUGH OCTACHLORINATED DIBENZOFURAN EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

Source category/reference/rating	Uncontrolled, µg/Mg (lb/ton, E-9)	After control device, µg/Mg (lb/ton, E-9)	Efficiency, percent
Multiple hearth			
Cyclone/venturi			
2,b		97 (194)	
84,a		35.5 (71.0)	
Cyclone/venturi/impingement			
1,b		250 (500)	
Impingement			
3,b	3,766 (7,532)	3,050 (6,100)	18.9

TABLE 4-15. SUMMARY OF ARSENIC, BERYLLIUM, AND CADMIUM EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

Source category/ reference/rating	Arsenic			Beryllium			Cadmium		
	Uncon- trolled, g/Mg (lb/ton, E-3)	After control device, g/Mg (lb/ton, E-3)	Effi- ciency, percent	Uncon- trolled, g/Mg (lb/ton, E-3)	After control device, g/Mg (lb/ton, E-3)	Effi- ciiency, percent	Uncon- trolled, g/Mg (lb/ton, E-3)	After control device, g/Mg (lb/ton, E-3)	Effi- ciency, percent
Multiple hearth									
Cyclone									
5r,b								32.4 (64.8)	
Cyclone/venturi									
84,a								25.0 (50.0)	
Cyclone/venturi/impingement									
39,a	14.7 (29.4)	0.849 (1.698)	94.2				49.2 (98.4)	8.1 (16.28)	83.4
Impingement									
5o,a								1.51 (3.02)	
5p,a								1.20 (2.40)	
7,a							0.001 (0.002)		
Venturi									
26,b		0.004 (0.008)						0.173 (0.346)	
Fluidized bed									
Impingement									
5q,b								0.148 (0.296)	
Venturi/impingement									
4,b		0.003 (0.006)						0.55 (1.10)	
28,b		0.019 (0.038)						1.45 (2.90)	

TABLE 4-16. SUMMARY OF CHROMIUM, MERCURY, AND NICKEL EMISSION FACTORS FROM SEWAGE SLUDGE INCINERATORS

Source category/ reference/rating	Chromium			Mercury			Nickel		
	Uncontrolled, g/Mg (lb/ton, E-3)	After control device, g/Mg (lb/ton, E-3)	Efficiency, percent	Uncontrolled, g/Mg (lb/ton, E-3)	After control device, g/Mg (lb/ton, E-3)	Efficiency, percent	Uncontrolled, g/Mg (lb/ton, E-3)	After control device, g/Mg (lb/ton, E-3)	Efficiency, percent
Multiple hearth									
Cyclone									
5r,b		3.86 (7.72)							
Cyclone/venturi									
84,a		0.8 (1.6)						0.65 (1.3)	
Cyclone/venturi/ impingement									
39,a	16.5 (33)	11.2 (22.4)	32.0				5.4 (10.8)	4.51 (9.02)	16.5
Impingement									
5o,a		3.52 (7.04)							
5p,a		16.1 (32.2)							
53,b					0.968 (1.936)			4.12 (8.24)	
Venturi									
26,b		0.062 (0.124)						0.037 (0.074)	
Fluidized bed									
Impingement									
5q,b		0.319 (0.638)							
Venturi/impingement									
4,b		0.091 (0.182)							
28,b		0.575 (1.15)			0.03 (0.06)			0.848 (1.696)	

TABLE 4-17. SUMMARY OF SEWAGE SLUDGE INCINERATOR EMISSION DATA

Pollutant/source	No. of data points	Data ratings	Emission factor range, kg/Mg	Average emission factor, kg/Mg	Effi-ciency	Emission factor rating	Ref. No.
Particulate matter							
Multiple hearth							
Uncontrolled	6	a,b	7.7-178	42		C	5o,5p,5r,7,21,39
Controlled							
Impingement	13	a,b	0.108-1.72	0.7	95	C	5o,5p,7,9,12,30,53,54 67,68,71,72,75
Venturi	7	a,b	0.27-7.1	2	86	C	21,26,27,32,47,70,77
Venturi/impingment	13	a,b	0.11-5.6	0.8		C	15-20,33,42,45,48,49,80,81
Cyclone	2	a,b	1.2-2.9	2	95	D	5r,79
Cyclone/impingment	1	a	--	0.4		D	78
Cyclone/venturi (and impingment)	5	a,b	0.15-0.37	0.27	98	C	10,11,13,39,84
Fluidized bed							
Uncontrolled	--	--	--	--		--	
Controlled	8	a,b	0.09-0.57	0.33		C	4,5q,14,28,29,43,44,69
Electric infrared							
Uncontrolled	3	c,d	2.5-4.5	3.7		D	35e,34n,34s
Controlled	6	c,d	0.47-1.9	1.1	71	D	35a,35c,34d,34e,35n,35s
Methane VOC							
Multiple hearth							
After control device							
Impingement	1	d	--	0.39		D	6
Venturi	2	a,b	0.027-6.45	3.24		D	26,27
Fluidized bed							
After control device							
Venturi	1	a	--	1.65		D	69
Venturi/impingment	2	b	0.189-0.61	0.40		D	28,29
Nonmethane VOC							
Multiple hearth							
Uncontrolled	4	a	0.106-2.62	0.846		C	1,2,39,40
After control device							
Cyclone	1	a	--	1.530		D	79
Cyclone/venturi	1	a	--	0.220		D	84
Impingement	1	a	--	0.785		D	68
Fluidized bed							

(continued)

TABLE 4-17. (continued)

Pollutant/source	No. of data points	Data ratings	Emission factor range, kg/Mg	Average emission factor, kg/Mg	Effi-ciency	Emission factor rating	Ref. No.
Lead (Pb)							
Multiple hearth							
Uncontrolled	1	a	--	0.05		D	39
Controlled	5	a,b	0.005-0.039	0.02	77	C	5o,5p,5r,39
Fluidized bed							
Controlled	3	b	0.002-0.005	0.003		C	4.5q,28
Sulfur dioxide (SO_2)							
Multiple hearth							
Uncontrolled	6	a,b	4.7-25	10		C	1,3,5o,5p,39,54
Controlled							
Cyclone	1	b	--	1.8	79	D	5r
Venturi and/or impingment	7	a,b	0.001-3.8	0.9	98	C	5o,5p,26,27,45,71,72
Fluidized bed							
Uncontrolled	--	--	--	--		--	
Controlled							
Venturi and/or impingment	4	a,b	0.1-9.3	3		C	5q,28,29,69
Electric infrared							
Uncontrolled	1	c	--	9.2		D	35e
Controlled	1	c	--	2.3		D	35e
Nitrogen oxides (NO_x)							
Multiple hearth							
Uncontrolled	3	a	4.4-6.7	5.7		B	1,3,39
After control device							
Impingement	3	a	0.9-5.7	3		B	68,71,72
Venturi	2	b	0.2-1.7	1		D	26,27
Fluidized bed							
After control device							
Venturi/impingment	2	a,b	1.41-2.92	2.2		D	28,69
Electric infrared							
Uncontrolled	1	c	--	4.3		D	35e
After control device	1	c	--	2.9		D	35e

(continued)

TABLE 4-17. (continued)

Pollutant/source	No. of data points	Data ratings	Emission factor range, kg/Mg	Average emission factor, kg/Mg	Effi-ciency	Emission factor rating	Ref. No.
Carbon monoxide, CO							
Multiple hearth							
Uncontrolled	4	a	20-53	36		B	1,3,39,84
After control device	2	a	1.7-1.8	2		D	68,72
Fluidized							
After control device							
Venturi/impingement	1	b	--	2.1		D	29
Sulfuric acid (H_2SO_4)							
Multiple hearth							
Uncontrolled	3	a,b	0.05-0.58	0.4		C	5r,5o,5p
After control device	3	a,b	0.04-0.21	0.1		C	5r,5o,5p
Fluidized bed							
Impingement	1	b	--	0.03		D	5q
Hydrogen chloride (HCl)							
After control device	2	b	0.014-0.055	0.04		D	26,28
Arsenic (As)							
Multiple hearth							
Uncontrolled	1	a	--	15		D	39
After control device							
Cyclone/venturi/ impingement	1	a	--	0.8	94	D	39
Venturi	1	b	--	0.004		D	26
Fluidized bed							
After control device							
Venturi/impingement	2	b	0.003-0.019	0.01		D	4,28
Cadmium (Cd)							
Multiple hearth							
Uncontrolled	2	a	0.001-49	25		D	7,39
After control device							
Cyclone (and venturi/ impingement)	3	a,b	8.1-32	22	83	D	5r,39,84
Impingement	2	a	1.2-1.5	1.35		D	5o,5p
Venturi	1	b	--	0.2		D	26

(continued)

TABLE 4-17. (continued)

Pollutant/source	No. of data points	Data ratings	Emission factor range, kg/Mg	Average emission factor, kg/Mg	Effi-ciency	Emission factor rating	Ref. No.
Cadmium (continued)							
Fluidized bed							
After control device							
Impingement (and venturi)	3	b	0.15-1.5	0.7		C	4,5q,28
Chromium (Cr)							
Multiple hearth							
Uncontrolled	1	a	--	17		D	39
After control device							
Impingement	2	a	3.5-16	9		D	5o,5p
Cyclone (and venturi/ impingement)	3	a,b	0.8-11	5		D	54,39,84
Venturi	1	b	--	0.06		D	26
Fluidized bed							
After control device							
Impingement (and venturi)	3	b	0.09-0.58	0.3		C	4,5q,28
Mercury (Hg)							
Multiple hearth							
After control device							
Impingement	1	b	--	1		D	53
Fluidized bed							
After control device							
Venturi/impingement	1	b	--	0.03		D	28
Nickel (Ni)							
Multiple hearth							
Uncontrolled	1	a	--	5.4		D	39
After control device							
Impingement (and cyclone/ venturi)	3	a	0.65-4.5	3.1		D	5p,39,84
Venturi	1	b	--	0.04		D	26
Fluidized bed							
After control device							
Venturi/impingement	1	b	--	0.8		D	28

(continued)

TABLE 4-17. (continued)

Pollutant/source	No. of data points	Data ratings	Emission factor range, kg/Mg	Average emission factor, kg/Mg	Effi-ciency	Emission factor rating	Ref. No.
2,3,7,8 Tetrachlorodibenzo-p-dioxin							
Multiple hearth							
After control device	2	b	0.26-0.97	0.6		D	1,3
Total tetrachlordibenzo-p-dioxin							
Multiple hearth							
Uncontrolled	1	b	--	63		D	3
After control device	3	b	1.4-64	40		D	1-3
Total pentachlorodibenzo-p-dioxin							
Multiple hearth							
Uncontrolled	1	b	--	2.7		D	3
After control device	2	b	1.5-7.3	4.4		D	1,3
Total hexachlorodibenzo-p-dioxin							
Multiple hearth							
Uncontrolled	1	b	--	68		D	3
After control device	2	b	4.4-48	26		D	1,3
Total heptachlorodibenzo-p-dioxin							
Multiple hearth							
Uncontrolled	1	b	--	340		D	3
After control device	3	b	0.77-144	53		C	1-3
Total octachlorodibenzo-p-dioxin							
Multiple hearth							
Uncontrolled	1	b	--	375		D	3
After control device	3	b	3.4-105	46		C	1-3
Total tetra- through octachlorodibenzo-p-dioxin							
Multiple hearth							
Uncontrolled	1	b	--	847		D	3
After control device	3	b	5.6-360	159		C	1-3

(continued)

TABLE 4-17. (continued)

Pollutant/source	No. of data points	Data ratings	Emission factor range, kg/Mg	Average emission factor, kg/Mg	Effi-ciency	Emission factor rating	Ref. No.
2,3,7,8 tetrachlorodibenzofuran							
Multiple hearth							
Uncontrolled	1	b	--	620		D	3
After control device	3	a,b	3.8-371	127		D	2,3,84
Total tetrachlorodibenzofuran							
Multiple hearth							
Uncontrolled	1	b	--	1,710		D	3
After control device	4	a,b	26.1-1,400	420		C	1-3,84
Total pentachlorodibenzofuran							
Multiple hearth							
Uncontrolled	1	b	--	980		D	3
After control device	4	a,b	6-718	200		C	1-3,84
Total hexachlorodibenzofuran							
Multiple hearth							
Uncontrolled	1	b	--	100		D	3
After control device	4	a,b	1.2-219	57		C	1-3,84
Total heptachlorodibenzofuran							
Multiple hearth							
Uncontrolled	1	b	--	481		D	3
After control device	3	a,b	0.9-410	138		D	1,3,84
Total octachlorodibenzofuran							
Multiple hearth							
Uncontrolled	1	b	--	491		D	3
After control device	4	a,b	0.26-310	78		C	1-3,84
Total tetra- through octachlorodibenzofuran							
Multiple hearth							
Uncontrolled	1	b	--	3,770		D	3
After control device	4	a,b	36-3,050	858		C	1-3,84

TABLE 4-18. LIST OF CONVERSION FACTORS

Multiply	By	To obtain
mg/dscm	4.37 E-4	gr/dscf
m^2	10.764	ft^2
acm/min	35.31	acfm
m/s	3.281	ft/s
kg/h	2.205	lb/h
kPa	4.0	in. of H_2O
lpm	0.264	gal/min
kg/Mg	2.0	lb/ton

Temperature conversion equations

F=(9/5)*C+32

C=(5/9)*(F-32)

TABLE 4-19. LIST OF DATA FILES

Name	Contents
SSLACID	Acid gas data
SSLCRIT	Criteria pollutant data
SSLORG	Organic data: 2,3,7,8-tetra's, total measured tetra's, penta's, hexa's, hepta's, octa's, tetra through octa's, benzene, benzo-a-pyrene, chlorinated phenols, and chlorinated benzenes
SSLSITE	Facility type, name, control device, test condition, rating, and reference number
SSLPROC	Stack gas flow, process rate, percent CO_2 concentration, percent O_2 concentration
SSLMET	Metals data: As, Be, Cd, Cr, Hg, Ni, Pb

TABLE 4-20. SUMMARY OF COMPUTER PROGRAMS

Name	Input data file	Tables produced
SPART	SSLCRITS	Criteria pollutant tables
NONCRIT	SSLMET	Metals
ACID	SSLCID	Acid gases
ORG	SSLORG	2,3,7,8-tetra's, total tetra's, penta's, hexa's, hepta's, octa's, and tetra through octa's
TORG	SSLORG	Total measured dioxins and furans

REFERENCES FOR CHAPTER 4

1. Final Draft Test Report--Site 01 Sewage Sludge Incinerator SSI-A. National Dioxin Study. Tier 4: Combustion Sources, EPA Contract No. 68-03-3148, Radian Corporation, Research Triangle Park, North Carolina, July 1986.

2. Final Draft Test Report--Site 03 Sewage Sludge Incinerator SSI-B. National Dioxin Study. Tier 4: Combustion Sources, EPA Contract No. 68-03-3148, Radian Corporation, Research Triangle Park, North Carolina, July 1986.

3. Draft Test Report--Site 12 Sewage Sludge Incinerator SSI-C, EPA Contract No. 68-03-3138, Radian Corporation, Research Triangle Park, North Carolina, April 1986.

4. Trichon, M. and R. T. Dewling, The Fate of Trace Metals in a Fluidized-Bed Sewage Sludge Incinerator. (Port Washington). (GCA).

5. Particulate and Gaseous Emission Tests at Municipal Sludge Incinerator Plants "O", "P", "Q", and "R" (4 tests), EPA Contract No. 68-02-2815, Engineering-Science, McLean, Virginia, February 1980.

6. Organics Screening Study Test Report. Sewage Sludge Incinerator No. 13. Detroit Water and Sewer Department. Detroit, Michigan, EPA Contract No. 68-02-3849. PEI Associates, Inc., Cincinnati, Ohio, August 1986.

7. Chromium Screening Study Test Report. Sewage Sludge Incinerator No. 13. Detroit Water and Sewer Department. Detroit Michigan, EPA Contract No. 68-02-3849, PEI Associates, Inc., Cincinnati, Ohio, August 1986.

8. Results of the July 11, 1983, Emission Compliance Test on the No. 6 Incineration System at the MWCC Metro Plant in St. Paul, Minnesota, [STAPPA/ALAPCO/05/27/86-No. 02], Interpoll Inc., Circle Pines, Minnesota, July 1983.

9. Results of the October 24, 1980, Particulate Compliance Test on the No. 1 Sludge Incinerator Wet Scrubber Stack at the MWCC St. Paul Wastewater Treatment Plant in St. Paul, Minnesota, [STAPPA/ALAPCO/05/27/86-No. 02], Interpoll Inc., Circle Pines, Minnesota, November 1980.

10. Results of the June 6, 1983, Emission Compliance Test on the No. 10 Incinerator System in the F&I 2 Building at the MWCC Metro Plant in St. Paul, Minnesota, [STAPPA/ALAPCO/05/27/86-No. 02], Interpoll Inc., Circle Pines, Minnesota, June 1983.

11. Results of the May 23, 1983, Emission Compliance Test on the No. 9 Incinerator System in the F&I 2 Building at the MWCC Metro Plant in St. Paul, Minnesota, [STAPPA/ALAPCO/05/27/86-No. 02], Interpoll Inc., Circle Pines, Minnesota, May 1983.

12. Results of the November 25, 1980, Particulate Emission Compliance Test on the No. 4 Sludge Incinerator Wet Scrubber Stack at the MWCC St. Paul Wastewater Treatment Plant in St. Paul, Minnesota, [STAPPA/ALAPCO/05/27/86-No. 02], Interpoll Inc., Circle Pines, Minnesota, December, 1980.

13. Results of the March 28, 1983, Particulate Emission Compliance Test on the No. 8 Incinerator at the MWCC Metro Plant in St. Paul, Minnesota, [STAPPA/ALAPCO/05/28/86-No. 06], Interpoll Inc., Circle Pines, Minnesota, April 1983.

14. Particulate Emission Test Report for a Sewage Sludge Incinerator at the City of Shelby Wastewater Treatment Plant, [STAPPA/ALAPCO/07/28/86-No. 06]. North Carolina DNR, February 1979.

15. Source Sampling Evaluation for Rocky River Wastewater Treatment Plant, Concord, North Carolina, [STAPPA/ALAPCO/05/28/86-No. 06], Mogul Corp., Charlotte, North Carolina, July 1982.

16. Performance Test Report: Rocky Mount Wastewater Treatment Facility, [STAPPA/ALAPCO/07/28/86-No. 06], Envirotech, Belmont, California, July 1983.

17. Performance Test Report for the Incineration System at the Honouliulu Wastewater Treatment Plant at Honouliulu, Oahu, Hawaii. [STAPPA/ALAPCO/05/22/86-No. 11], Zimpro, Rothschild, Wisconsin, January 1984.

18. (Test Results) Honolulu Wastewater Treatment Plant, Ewa, Hawaii, [STAPPA/ALAPCO/05/22/86-No. 11], Zimpro, Rothschild, Wisconsin, November 1983.

19. Air Pollution Source Test. Sampling and Analysis of Air Pollutant Effluent from Wastewater Treatment Facility--Sand Island Wastewater Treatment Plant, Honolulu, Hawaii, [STAPPA/ALAPCO/05/22/86-No. 11], Ultrachem, Walnut Creek, California, December 1978.

20. Air Pollution Source Test. Sampling and Analysis of Air Pollutant Effluent From Wastewater Treatment Facility--Sand Island Wastewater Treatment Plant, Honolulu, Hawaii--Phase II, [STAPPA/ALAPCO/05/22/86-No. 11], Ultrachem, Walnut Creek, California, December 1979.

21. Stationary Source Sampling Report. EEI Reference No. 2988. Osborne Wastewater Treatment Plant. Greensboro, North Carolina. Particulate Emissions and Particle Size Distribution Testing. Sludge Incinerator Scrubber Inlet and Scrubber Stack, [STAPPA/ALAPCO/07/28/86-No. 06], Entropy, Research Triangle Park, North Carolina, October 1985.

22. (Four tests). Southwestern Ohio Air Pollution Control Agency. Metropolitan Sewer District--Little Miami Treatment Plant (three tests: August 9, 1985, September 16, 1980, and September 30, 1980) and Mill Creek Treatment Plant (one test: January 9, 1986), [STAPPA/ALAPCO/05/28/86-No. 14].

23. Emissions Testing of Incinerator No. 2. Green Bay Metropolitan Sewer District, Green Bay, Wisconsin, [STAPPA/ALAPCO/06/12/86-No. 19], Engineering Science, McLean, Virginia, October 1981.

24. City of Milwaukee South Shore Treatment Plant, Milwaukee, Wisconsin. Particulate Emissions Compliance Testing, [STAPPA/ALAPCO/06/12/86-No. 19], Entropy, Research Triangle Park, North Carolina, December 1980.

25. City of Milwaukee South Shore Treatment Plant, Milwaukee, Wisconsin. Particulate Emissions Compliance Testing, [STAPPA/ALAPCO/06/12/86-No. 19], Entropy, Research Triangle Park, North Carolina, November 1980.

26. Stack Test Report--Bayshore Regional Sewage Authority. Union Beach, New Jersey, [STAPPA/ALAPCO/05/22/86-No. 12], New Jersey State Department of Environmental Protection, Trenton, New Jersey, March 1982.

27. Stack Test Report--Jersey City Sewage Authority. Jersey City, New Jersey, [STAPPA/ALAPCO/05/22/86-No. 12], New Jersey State Department of Environmental Protection, Trenton, New Jersey, December 1980.

28. Stack Test Report--Northwest Bergen County Sewer Authority. Waldwick, New Jersey, [STAPPA/ALAPCO/05/22/86-No. 12], New Jersey State Department of Environmental Protection, Trenton, New Jersey, March 1982.

29. Stack Test Report--Pequannock, Lincoln Park, and Fairfield Sewerage Authority, Lincoln Park, New Jersey, [STAPPA/ALAPCO/05/22/86-No. 12],New Jersey State Department of Environmental Protection, Trenton, New Jersey, December 1975.

30. Atmospheric Emission Evaluation. Anchorage Water and Wastewater Utility Sewage Sludge Incinerator, ASA, Bellevue, Washington, April 1984.

31. Stack Sampling Report for City of New London (CT) No. 1 Sludge Incinerator, Recon Systems, Inc., Three Bridges, New Jersey, April 1984.

32. Stack Sampling Report for Municipal Sewage Sludge Incinerator No. 1, Scrubber Outlet (Stack), Providence, Rhode Island, Recon Systems, Inc., Three Bridges, New Jersey, November 1980.

33. Stack Sampling Report, Compliance Test No. 3, at Attleboro Advanced Wastewater Treatment Facility, Attleboro, Massachusetts, David Gordon Associates, Inc., Newton Upper Falls, Massachusetts, May 1983.

34. (Two tests). Source Emission Survey. North Texas Municipal Water District. Rowlett Creek Plant. Plano, Texas, Shirco, Inc., Dallas, Texas, November 1978.

35. (Five tests). Emissions Data for Infrared Municipal Sewage Sludge Incinerators, Shirco, Inc., Dallas, Texas, January 1980.

36. Liao, P. B. and M. J. Pilat. Air Pollutant Emissions from Fluidized Bed Sewage Sludge Incinerators. Water and Sewage Works. February 1972.

37. (Two tests) Emission Evaluation for: Merrimack Wastewater Treatment Plant, Merrimack, New Hampshire, Mogul Corp., Chagrin Falls, Ohio, November 1977.

38. Performance of Emission Tests and Material Balance for a Fluidized-Bed Sludge Incinerator, GCA Corp, Bedford, Massachusetts, November 1980.

39. Electrostatic Precipitator Efficiency on a Multiple Hearth Incinerator Burning Sewage Sludge, EPA Contract No. 68-03-3148, Radian Corp., Research Triangle Park, North Carolina, August 1986.

40. Baghouse Efficiency on a Multiple Hearth Incinerator Burning Sewage Sludge, EPA Contract No. 68-03-3148, Radian Corp., Research Triangle Park, North Carolina, August 1986.

41. Farrell, J. B. and H. Wall. Air Pollution Discharges from Ten Sewage Sludge Incinerators, U. S. Environmental Protection Agency, Cincinnati, Ohio, August 1985.

42. Emission Test Report. Sewage Sludge Incinerator. Davenport Wastewater Treatment Plant. Davenport, Iowa, [STAPPA/ALAPCO/11/04/86-No. 119], PEDCo Environmental, Cincinnati, Ohio, October 1977.

43. Sludge Incinerator Emission Testing. Unit No. 1 for City of Omaha, Papillion Creek Water Pollution Control Plant, [STAPPA/ALAPCO/10/28/86-No. 100], Particle Data Labs, Ltd., Elmhurst, Illinois, September 1978.

44. Sludge Incinerator Emission Testing. Unit No. 2 for City of Omaha, Papillion Creek Water Pollution Control Plant, [STAPPA/ALAPCO/10/28/86-No. 100], Particle Data Labs, Ltd., Elmhurst, Illinois, May 1980.

45. Particulate and Sulfur Dioxide Emissions Test Report for Zimpro on the Sewage Sludge Incinerator Stack at the Cedar Rapids Water Pollution Control Facility, [STAPPA/ALAPCO/11/04/86-No. 119], Serco, Cedar Falls, Iowa, September 1980.

46. City of Davenport (IA) Particulate Emission Test, [STAPPA/ALAPCO/11/04/86-No. 119], Zimpro, Rothschild, Wisconsin, September 1977.

47. Newport Wastewater Treatment Plant, Newport, Tennessee. (Nichols; December 1979). [STAPPA/ALAPCO/10/27/86-No. 21].

48. Maryville Wastewater Treatment Plant Sewage Sludge Incinerator Emission Test Report, [STAPPA/ALAPCO/10/27/86-No. 21], Enviro-measure, Inc., Knoxville, Tennessee, August 1984.

49. Maryville Wastewater Treatment Plant Sewage Sludge Incinerator Emission Test Report, [STAPPA/ALAPCO/10/27/86-No. 21], Enviro-measure, Inc., Knoxville, Tennessee, October 1982.

50. Newport (Tennessee) Utilities Board, [STAPPA/ALAPCO/10/27/86-No. 21], Entropy, Research Triangle Park, North Carolina, December 1974.

51. Kiski Valley (Pennsylvania) Water Pollution Control Authority. Source Test Report, [STAPPA/ALAPCO/11/04/86-No. 122], Pennsylvania, Department of Environmental Resources, May 1986.

52. Anchorage Water and Sewer Utilities. Point Woronzof Wastewater Treatment Facility, [STAPPA/ALAPCO/10/28/80-No. 108], Chemical and Geological Laboratories of Alaska, Inc., September 1982.

53. Southerly Wastewater Treatment Plant, Cleveland, Ohio, Incinerator No. 3, [STAPPA/ALAPCO/11/12/86-No. 124], Envisage Environmental, Inc., Richfield, Ohio, May 1985.

54. Southerly Wastewater Treatment Plant, Cleveland, Ohio. Incinerator No. 1, [STAPPA/ALAPCO/11/12/86-No. 124], Envisage Environmental, Inc., Richfield, Ohio, August 1985.

55. Atmospheric Emission Evaluation. Anchorage Water and Wastewater Utility Sewage Sludge Incinerator, [STAPPA/ALAPCO/10/28/86-No. 108], American Services Associates, Bellevue, Washington, April 1984.

56. Source Test Report Review. R. M. Clayton WPC Plant; Atlanta, Georgia. Nos. 1 and 2 Incinerators, (May 11 thru 12, 1983). [STAPPA/ALAPCO/06/23/86-No. 16].

57. Source Test Report Review. Flat Creek Wastewater Treatment Plant; Gainesville, Georgia. Nos. 51 and 1 Incinerators, [STAPPA/ALAPCO/06/23/86-No. 16], Department of Natural Resources, Atlanta, Georgia, January 1985.

58. City of Bellingham Post Point Wastewater Treatment Plant Mercury Source Test, (January 29-30, 1979). [STAPPA/ALAPCO/10/28/86-No. 106].

59. Source Test Report. East Norriton and Plymouth Township Joint Sewer Authority, [STAPPA/ALAPCO/11/04/86-No. 122], Pennsylvania Department of Environmental Resources, July 1986.

60. Source Test Report. Erie Sewer Authority, Erie, Pennsylvania. Sludge Incinerator No. 1, [STAPPA/ALAPCO/11/04/86-No. 122], Pennsylvania Department of Environmental Resources, July 1981.

61. Source Test Report. Erie Sewer Authority, Erie, Pennsylvania. Sludge Incinerator No. 2, [STAPPA/ALAPCO/11/04-86-No. 122], Pennsylvania Department of Environmental Resources, July 1981.

62. Cities of Columbia and Charleston (three tests). [STAPPA/ALAPCO/05/29/86-No. 15], South Carolina Bureau of Air Quality Control, May 1976 and August 1977.

63. Letter from American Interplex to J. D. Helms, August 16, 1984. North Little Rock (Arkansas) Stack Emission Summary.

64. Report from U. S. Environmental Protection Agency, Region II to Barry Mitsch, Radian Corp. Information on Sewage Sludge Incinerators in Region II and Emissions Data Report for Atlantic City, New Jersey.

65. Hobbs, B. Testing and Evaluation of Sewage Sludge Incinerator at Fields Point Wastewater Treatment Facility, Providence, Rhode Island, GCA Corp., Bedford, Massachusetts, August 1982.

66. Report: South Essex Sewerage District: A Case History, MA Department of Environmental Quality Engineering. November 1982.

67. Final Report for an Emission Compliance Test Program (July 1, 1982) at City of Waterbury Wastewater Treatment Plant Sludge Incinerator, Waterbury, Connecticut, [STAPPA/ALAPCO/12/17/86-No. 136], York Services Corp, July 1982.

68. Incinerator Compliance Test at the City of Stratford Sewage Treatment Plant in Stratford, Connecticut, [STAPPA/ALAPCO/12/17/86-No. 136], Emission Testing Labs. September 1974.

69. Emission Compliance Tests Conducted at Norwalk Wastewater Treatment Plant, South Smith Street, Norwalk, Connecticut, [STAPPA/ALAPCO/12/17/86-No. 136], York Research Corp, Stamford, Connecticut. February 1975.

70. Final Report--Emission Compliance Test Program at East Shore Wastewater Treatment Plant, New Haven, Connecticut, [STAPPA/ALAPCO/12/17/86-No. 136], York Services Corp., Stamford, Connecticut, September 1982.

71. Incinerator Compliance Test at Enfield Sewage Treatment Plant in Enfield, Connecticut, [STAPPA/ALAPCO/12/17/86-No. 136], York Research Corp., Stamford, Connecticut, July 1973.

72. Incinerator Compliance Test at The Glastonbury Sewage Treatment Plant in Glastonbury, Connecticut, [STAPPA/ALAPCO/12/17/86-No. 136], York Research Corp., Stamford, Connecticut, August 1973.

73. Report on Measurement of Particulate Emissions from the (Hartford, Connecticut) Sewage Sludge Incinerator of the Metropolitan District Commission, [STAPPA/ALAPCO/12/17/86-No. 136], The Research Corp., Wethersfield, Connecticut, August 1977.

74. Emissions Tests at the Hartford Sewage Sludge Incinerator Brainard Road, Hartford, Connecticut, [STAPPA/ALAPCO/12/17/86-No. 136], The Research Corp., Wetherfield, Connecticut, May 1973.

75. Results of the May 5, 1981, Particulate Emission Measurements of the Sludge Incinerator Located at the Metropolitan District Commission Incinerator Plant, Hartford, Connecticut, [STAPPA/ALAPCO/12/17/86-No. 136], Henry Souther Laboratories.

76. Incinerator Compliance Test at The Willimantic Sewage Treatment Plant in Willimantic, Connecticut, [STAPPA/ALAPCO/12/17/86-No. 136], York Research Corp., Stamford, Connecticut, February 1974.

77. Official Air Pollution Tests Conducted on the Nichols Engineering and Research Corporation Sludge Incinerator Located on the Wastewater Treatment Plant, Middletown, Connecticut, [STAPPA/ALAPCO/12/17/86-No. 136]. Rossnagel and Associates, Cherry Hill, New Jersey, November 1976.

78. Measured Emissions From the West Nichols-Neptune Multiple Hearth Sludge Incinerator at the Naugatuck Treatment Company, Naugatuck, Connecticut, April 24, 1985, [STAPPA/ALAPCO/12/17/86-No. 136], The Research Corp., East Hartford, Connecticut, April 1985.

79. Compliance Test Report--(August 27, 1986) Mattabasset District Pollution Control Plant Main Incinerator, Cromwell, Connecticut, [STAPPA/ALAPCO/12/17/86-No. 136], ROJAC Environmental Services, Inc., West Hartford, Connecticut, September 1986.

80. Stack Sampling Report (May 21, 1986) City of New London No. 2 Sludge Incinerator Outlet Stack Compliance Test, [STAPPA/ALAPCO/12/17/86-No. 136], Recon Systems, Inc., Three Bridges, New Jersey, June 1986.

81. Particulate Emission Tests, Town of Vernon Municipal Sludge Incinerator, February 10, 11, 1981, Vernon, Connecticut, [STAPPA/ALAPCO/12/17/86-No. 136], The Research Corp., Wethersfield, Connecticut, March 1981.

82. Six Tests on Buckman Incinerator No. 1, Jacksonville, Florida. 1982 through 1986. Provided by the Department of Health, Welfare, and Bio-Environmental Services, City of Jacksonville, Florida, [STAPPA/ALAPCO/01/05/87-No. 137].

83. (Four tests). Bennett, R. L. and K. T. Knapp. Characterization of Particulate Emissions from Municipal Wastewater Sludge Incinerators, ES and T Volume 16, No. 12, 1982.

84. Non-Criteria Emissions Monitoring Program for the Envirotech Nine-Hearth Sewage Sludge Incinerator at the Metropolitan Wastewater Treatment Facility, St., Paul, Minnesota, ERT Document No. P-E081-500; October 1986.

5. AP-42 SECTION 2.5: SEWAGE SLUDGE INCINERATION

The revision to Section 2.5 of AP-42 is presented in the following pages as it would appear in the document.

2.5 SEWAGE SLUDGE INCINERATION

2.5.1 Process Description[1-3]

In sewage sludge incineration, materials generated by wastewater treatment plants are oxidized to reduce the volume of solid waste.

In the first step in the process, the sludge is dewatered until it is 15 to 30 percent solids so that it will burn without auxiliary fuel. Dewatered sludge is conveyed to a combustion device where thermal oxidation occurs. The unburned residual ash is removed from the combustion device, usually on a continuous basis, and disposed. The exhaust gas stream is directed to an air pollution control device, typically a wet scrubber.

Approximately 95 percent of sludge incinerators are multiple-hearth and fluidized-bed designs. Multiple-hearth incinerators are vertically oriented cylindrical shells containing from 4 to 14 refractory hearths stacked one above the other. Sludge typically enters at the periphery of the top hearth and is raked inward by the teeth on a rotating rabble arm to a drop hole leading to the second hearth. The teeth on the rabble arm above the second hearth are positioned in the opposite direction to move the sludge outward. This outside-in, inside-out pattern is repeated on alternate hearths. Fluidized-bed incinerators also are vertically oriented cylindrical shells. A bed of sand approximately 0.7-meters (2.5-feet) thick rests on the grid and is fluidized by air injected through the tuyeres located at the base of the furnace within a refractory-lined grid. Sludge is introduced directly into the bed. Temperatures in a multiple-hearth furnace are 320°C (600°F) in the lower, ash-cooling hearth; 760° to 1100°C (1400° to 2000°F) in the central combustion hearths; and 540° to 650°C (1000° to 1200°F) in the upper, drying hearths. Temperatures in a fluidized-bed reactor are fairly uniform, from 680° to 820°C (1250° to 1500°F). In both types of furnaces, an auxiliary fuel may be required either during startup or when the moisture content of the sludge is too high to support combustion.

Electric (infrared) furnaces are the newest of the technologies currently in use for sludge incineration. The sludge is conveyed into one end of the horizontally oriented incinerator where it is first dried and then burned as it travels beneath the infrared heating elements.

Other sludge incineration technologies that are no longer in widespread use include cyclonic reactors, rotary kilns, and wet oxidation reactors. Some sludge is coincinerated with refuse.

2.5.2 Emissions and Controls[1,2,4]

Sludge incinerators have the potential to emit significant quantities of pollutants to the atmosphere. One of these pollutants is particulate matter, which is emitted because of the turbulent movement of the combustion gases with respect to the burning sludge and resultant ash. The particle size distribution and concentration of the particulate emissions leaving the incinerator vary widely, depending on the composition of the sludge being burned and the type and operation of the incineration process.

Total particulate emissions are usually highest for a fluidized-bed incinerator because the combustion gas velocities required to fluidize the bed result in entrainment of large quantities of ash in the flue gas. Particulate emissions from multiple-hearth incinerators are usually less than those from fluidized-bed incinerators because the agitation of ash and gas velocity through the bed are lower in the multiple-hearth incinerators. Electric furnaces have the lowest particulate matter emissions because the sludge is not stirred or mixed during incineration and air flows through the unit generally are quite low, resulting in minimal entrainment.

Incomplete combustion of sludge can result in emissions of intermediate products (e.g., volatile organic compounds and carbon monoxide). Other potential emissions include sulfur dioxide, nitrogen oxides, metals, acid gases, and toxic organic compounds.

Wet scrubbers are commonly used to control particulate and gaseous (e.g., SO_2, NOx, CO, and VOC's) emissions from sludge incinerators. There are two practical reasons for this: (1) a wastewater treatment plant is a source of relatively inexpensive scrubber water (plant effluent) and (2) a system for the treatment of the scrubber effluent is available (spent scrubber water is sent to the head of the treatment plant for solids removal and pH adjustment). The most widely used scrubber types are venturi and impingement-tray. Cyclone wet scrubbers and systems combining all three types of scrubbers are also used.

Pressure drops for venturi, impingement tray, and cyclone scrubbers are 1 to 40 kPa, 0.4 kPa per stage, and 1 to 2 kPa, respectively. Collection efficiency can range from 60 to 99 percent depending on the scrubber pressure drop, particle size distribution, and particulate concentration.

Emission factors and emission factor ratings for sludge incinerators are shown in Table 2.5-1. Table 2.5-2 shows the cumulative particle size distribution and size specific emission factors for sewage sludge incinerators. Figures 2.5-1, 2.5-2, and 2.5-3 show the cumulative particle size distribution and size-specific emission factors for multiple-hearth, fluidized-bed, and electric infrared incinerators, respectively.

TABLE 2.5-1. EMISSION FACTORS FOR SEWAGE SLUDGE INCINERATORS[a]

Pollutant	Cut diameter, microns	Multiple hearth: Uncontrolled emissions, kg/Mg (lb/ton)[b]	Multiple hearth: After scrubber emissions, kg/Mg (lb/ton)[b]	Multiple hearth: Emission factor rating	Fluidized bed: Uncontrolled emissions, kg/Mg (lb/ton)[b]	Fluidized bed: After scrubber emissions, kg/Mg (lb/ton)[b]	Fluidized bed: Emission factor rating	Electric infrared: Uncontrolled emissions, kg/Mg (lb/ton)[b]	Electric infrared: After scrubber emissions, kg/Mg (lb/ton)[b]	Electric infrared: Emission factor rating
PM_{10}	0.625	0.30 (0.60)	0.07 (0.14)[b]	D	NA	0.08 (0.16)[d]	D	0.50 (1.0)	0.30 (0.60)[e]	E
	1.0	0.47 (0.94)	0.08 (0.16)			0.15 (0.30)		0.60 (1.2)	0.35 (0.70)	
	2.5	1.1 (2.2)	0.09 (0.18)			0.18 (0.36)		1.0 (2.0)	0.50 (1.0)	
	5.0	2.1 (4.2)	0.10 (0.20)			0.20 (0.40)		1.7 (3.4)	0.70 (1.4)	
	10.0	4.1 (8.2)	0.11 (0.22)			0.22 (0.44)		3.0 (6.0)	1.0 (2.0)	
	15.0	6.0 (12)	0.12 (0.24)			0.23 (0.46)		4.3 (8.6)	1.2 (2.4)	
Total particulate		40 (80)	0.40 (0.80)[e]	C	NA	3.0 (6.0)[e]	C	10 (20)	2.0 (4.0)[e]	E
Lead		0.05 (0.10)	0.03 (0.06)[e]	C	NA	0.003 (0.006)[e]	D	NA	NA	
Sulfur dioxide[f]		10 (20)	2.0 (4.0)[e]	D	10 (20)	2.0 (4.0)[e]	D	10 (20)	2.0 (4.0)[e]	D
Nitrogen oxides		5.5 (11)	2.5 (5.0)[e]	C	NA	1.0 (2.0)[e]	D	4.3 (8.6)	3.0 (6.0)[e]	E
Carbon monoxide		30 (60)	2.0 (4.0)[e]	C	NA	2.1 (4.2)[e]	E	NA	NA	
Volatile organic compounds										
Methane		2.3 (4.6)	2.3 (4.6)[e]	D	0.80 (1.6)	0.80 (1.6)[e]	E	NA	NA	
Nonmethane		0.85 (1.7)	0.85 (1.7)[e]	D	NA	NA		NA	NA	

NA = not available.
[a]Reference 5.
[b]Unit expressed in terms of dried sludge.
[c]Impingement scrubber.
[d]Venturi scrubber.
[e]Impingement and venturi scrubbers.
[f]Because data were limited, an average for all three types of incinerators is presented.

TABLE 2.5-2. CUMULATIVE PARTICLE SIZE DISTRIBUTION AND SIZE SPECIFIC EMISSION FACTORS FOR SEWAGE SLUDGE INCINERATORS[a]

Particle size, microns	Cumulative mass % ≤ stated size						Cumulative emission factor, kg/Mg (lb/ton)					
	Uncontrolled			Controlled			Uncontrolled			Controlled		
	MH[b]	Fb[c]	EI[d]	MH[b]	Pb[c]	EI[d]	MH[b]	Fb[c]	EI[d]	MH[b]	Fb[c]	EI[d]
15	15	NA	43	30	7.7	60	6.0 (12)	NA	4.3 (8.6)	0.12 (0.24)	0.23 (0.46)	1.2 (2.4)
10	10	NA	30	27	7.3	50	4.1 (8.2)	NA	3.0 (6.0)	0.11 (0.22)	0.22 (0.44)	1.0 (2.0)
5.0	5.3	NA	17	25	6.7	35	2.1 (4.2)	NA	1.7 (3.4)	0.10 (0.20)	0.20 (0.40)	0.70 (1.4)
2.5	2.8	NA	10	22	6.0	25	1.1 (2.2)	NA	1.0 (2.0)	0.09 (0.18)	0.18 (0.36)	0.50 (1.0)
1.0	1.2	NA	6.0	20	5.0	18	0.47 (0.94)	NA	0.60 (1.2)	0.08 (0.16)	0.15 (0.30)	0.35 (0.70)
0.625	0.75	NA	5.0	17	2.7	15	0.30 (0.60)	NA	0.50 (1.0)	0.07 (0.14)	0.08 (0.16)	0.30 (0.60)
TOTAL	100	100	100	100	100	100	40 (80)	NA	10 (20)	0.40 (0.80)	3.0 (6.0)	2.0 (4.0)

[a]Reference 5.
[b]MH = multiple hearth.
[c]FB = fluidized bed.
[d]EI = electric infrared.
NA = not available.

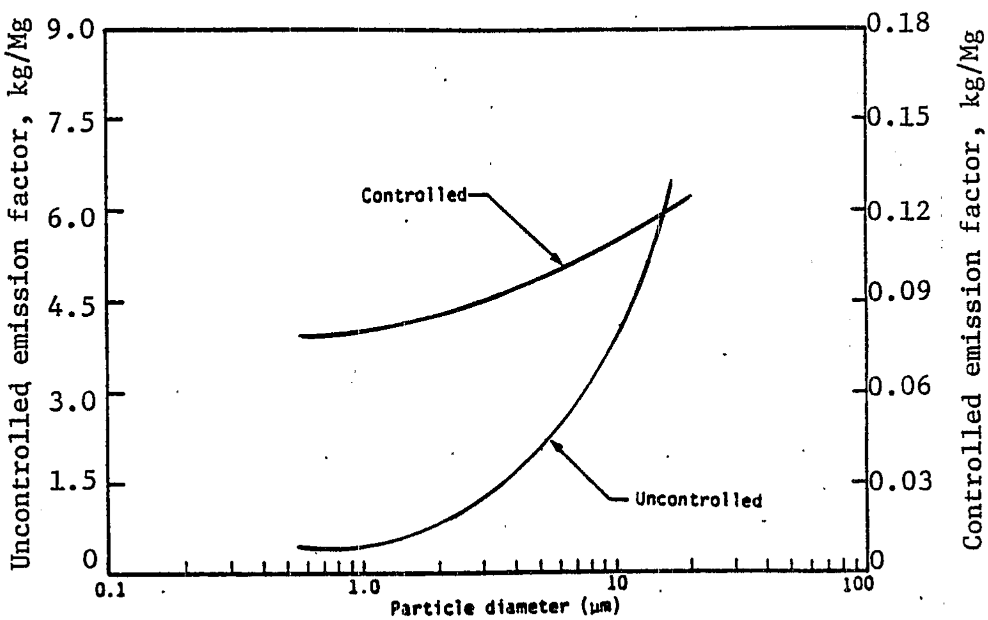

Figure 2.5-1. Cumulative particle size distribution and size-specific emission factors for multiple-hearth incinerators.

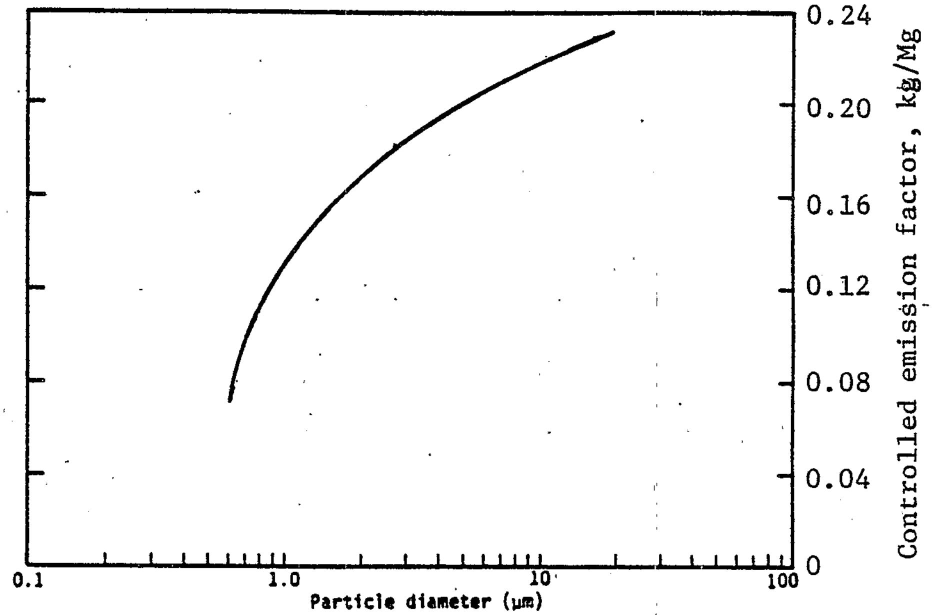

Figure 2.5-2. Cumulative particle size distribution and size-specific emission factors for fluidized-bed incinerators.

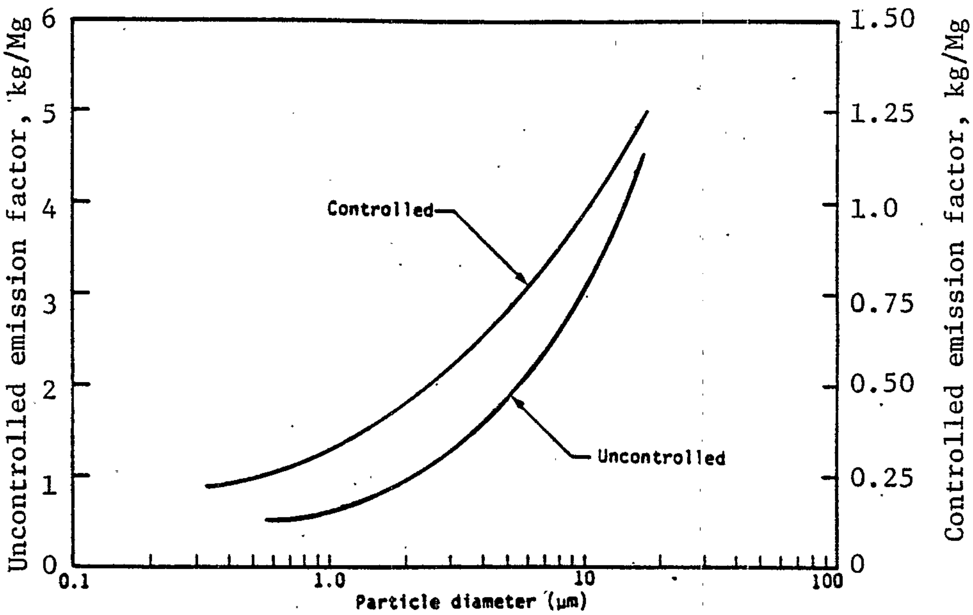

Figure 2.5-3. Cumulative particle size distribution and size-specific emission factors for electric (infrared) incinerators.

REFERENCES FOR SECTION 2.5

1. Environmental Regulations and Technology: Use and Disposal of Municipal Wastewater Sludge, EPA-625/10-84-003, U. S. Environmental Protection Agency, Cincinnati, OH, September 1984.

2. Seminar Publication: Municipal Wastewater Sludge Combustion Technology, EPA-625/4-85/015, U. S. Environmental Protection Agency, Cincinnati, OH, September 1985.

3. Written communication from C. Hester, Midwest Research Institute, Cary, NC, to J. Crowder, Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1985.

4. Control Techniques for Particulate Emissions From Stationary Sources Volume 1, EPA-45/3-81-005a, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1982.

5. Draft report. Emission Factor Documentation for AP-42 Section 2.5-- Sewage Sludge Incineration, Monitoring and Data Analysis Division, Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1987.

APPENDIX A.

DATA TRANSFER LOG FORM

SSI/RI Crit/Part/Acid/Met/Part Size Date:__________ By:__________

Source:__________ Control Device: __________

Test: Stack/Material Balance/Other: __________ OVERALL RATING: A B C D

****

Check for Rejection:

	accept	reject
1. Test series averages can be converted to selected reporting units	___	___
2. Test series represent compatible test methods	___	___
3. Test series of controlled emissions specify the control device	___	___
4. Test series clearly identify and describe the source process	___	___
5. Test series clearly specify emissions as controlled/uncontrolled	___	___

If not Rejected, Evaluate:

	yes	no	rating*
1. SOURCE OPERATION			A B C D
a. Source manner of operation well documented	___	___	
b. Source operating within typical parameters during test	___	___	
2. SAMPLING PROCEDURES			A B C D
a. Deviation from Standard Methods	___	___	
b. Deviations well documented	___	___	
c. Deviations result in questionable test results	___	___	
3. SAMPLING AND PROCESS DATA			A B C D
a. Wide deviation in test results	___	___	
b. Deviation explained in report	___	___	
4. ANALYSIS AND CALCULATIONS			A B C D
a. Original raw data sheets included	___	___	
b. Nomenclature and equations equivalent to EPA-specified	___	___	
c. Calculations warrant review	___	___	

COMMENTS: __________

*Rating: A = Sound methodology; enough detail for adequate validation.
B = Generally sound methodology but lack enough detail for adequate validat
C = Based on untested or new methodology or lack a significant amount of background data.
D = Based on generally unacceptable method but may provide an order-of-magnitude value for the source.

ID ______________________________ Ref# __________ By __________
****

Incinerator Type/Mfg ______________________________

Control Device Type/Mfg ______________________________

Comments: ______________________________

____

Particulate Sizing on Pages ______________________________

TOXIC METALS EMISSIONS DATA

<u>Process Measurements</u>

	Page	Table	Location	Units	Runs 1	2	3	4	5	6
Feed Rate										
Flow Rate										
O_2										
CO_2										
<u>Emissions</u>										
Inlet			As							
			Be							
			Cd							
			Cr							
			Pb							
			Hg							
			Ni							
Outlet			As							
			Be							
			Cd							
			Cr							
			Pb							
			Hg							
			Ni							

ACID GAS EMISSIONS DATA

Process Measurements	Page	Table	Location	Units	Runs 1	2	3	4	5	6
Feed Rate										
Flow Rate										
O_2										
CO_2										
Emissions										
Inlet			H_2SO_4							
			HCl							
			HF							
Outlet			H_2SO_4							
			HCl							
			HF							

CRITERIA POLLUTANTS EMISSIONS DATA

Process Measurements	Page	Table	Location	Units	Runs 1	2	3	4	5	6
Feed Rate										
Flow Rate										
O_2										
CO_2										
Emissions										
Inlet			PM							
			NO_x							
			SO_2							
			CO							
Outlet			PM							
			NO_x							
			SO_2							
			CO							

TOXIC ORGANICS EMISSIONS DATA

Process Measurements

	Page	Table	Location	Units	1	2	3	4	5	6
Feed Rate										
Flow Rate										
O_2										
CO_2										

Emissions (Units:______)

	Inlet						Outlet				
	Page	Table	1	2	3	ave	Page	Table	1	2	3
2378 TCDD											
2378 TCDF											
Tot TCDD											
Tot TCDF											
Tot PCDD											
Tot PCDF											
Tot HxCDD											
Tot HxCDF											
Tot HpCDD											
Tot HpCDF											
Tot OcCDD											
Tot OcCDF											
Tet-OctCDD											
Tet-OctCDF											
Tot PCB											
Formaldehyd											
Tot ClB											
Tot ClP											
BaP											
Benzene											