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LOCATING AND ESTIMATING AIR TOXICS EMISSIONS FROM SEWAGE SLUDGE INCINERATORS

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LOCATING AND ESTIMATING AIR TOXICS EMISSIONS FROM SEWAGE SLUDGE INCINERATORS

By

Radian Corporation
Research Triangle Park, NC 27709

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

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REPORT USER FEEDBACK AND MAIL KEY REGISTRATION

The U.S. Environmental Protection Agency's (EPA) Office of Air Quality Planning and Standards (OAQPS) provides technical support to assist State and local air pollution control agencies in developing and implementing air toxics programs. One way that OAQPS provides assistance to agencies and other interested individuals is by compiling and publishing emission data for agencies and others who are interested in locating potential emitters of toxic air compounds and in making preliminary estimates of toxic air emissions. These reports published by EPA are introductory documents only, and they are not intended to provide exact estimates of air toxics releases from specific facilities. EPA will update and expand these reports and publish new documents as toxic air emissions data are obtained. Your comments on the usefulness of this report and availability of additional data which could be used to extend and improve it, are important input to this process. Please provide any information to us that will allow us to improve these reports. The format below is provided for your convenience.

Please check the appropriate blanks and mail to:

Pollutant Characterization Section
Noncriteria Pollutant Programs Branch (MD-15)
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

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1. PURPOSE OF DOCUMENT

This document is designed to assist Federal, State, and local air pollution agencies in inventorying air emissions of potentially toxic substances. It is one of a series the Environmental Protection Agency (EPA) is preparing to compile information on sources and emissions of these pollutants. Specifically, this document deals with emissions from sewage sludge incinerators (SSIs).

The emissions information in this document will be most useful in making preliminary estimates of air emissions and should not be used in exact assessments of emissions from any particular facility. The reason for this is that insufficient data are available to estimate the statistical accuracy of these emission factors. In addition, variability in sludge composition contributes to variations in emission factors. In fact, the difference between actual and calculated emissions could be as great as orders of magnitude in extreme cases. The size of error would depend on differences in source configurations, variability of sludge composition, control equipment design and operation, and overall operating practices. A source test is the best way to determine air emissions from a particular source. However, even when a source test is used for a specific facility, variability of sludge composition could change the composition of emissions.

To date, 22 reports in this series have been published, each with the generic title "Locating and Estimating (Toxic) Emissions from (or of) (Source Category or Substance)." Reports are available for the following substances or source categories: acrylonitrile, 1,3-butadiene, carbon tetrachloride, chloroform, ethylene dichloride, formaldehyde, nickel, chromium, manganese, phosgene, epichlorohydrin, vinylidene chloride, ethylene oxide, chlorobenzenes, polychlorinated biphenyls (PCBs), polycyclic organic matter (POM), benzene, organic liquid storage tanks, coal and oil combustion sources, municipal waste combustors, perchloroethylene and trichloroethylene. A reports is in production for styrene and others are planned.

2. OVERVIEW OF DOCUMENT

This section briefly outlines the contents of this report.

Section 3 is an overview of the sewage sludge incineration (SSI) industry, describing the major types of SSIs in the existing population: multiple hearth furnaces, fluidized bed furnaces, and electric furnaces. Several types of lesser importance are also presented. Included is a process description for each type of combustor, as well as a current facility list. In addition, this section describes the air emission control technologies currently in use at SSI facilities.

Section 4 focuses on the air emissions from SSIs. Emission factors are given in tabular format for organics and inorganics including metals.

Section 5 discusses the EPA reference methods and generally accepted methods of sampling and analysis for each pollutant. Appendix A contains a list of the existing SSI facilities. Included in the list are incinerator type, unit size, start-up date and type of air pollution control device.

This document does not discuss health or other environmental effects of emission from SSIs, nor does it discuss ambient air levels or ambient air monitoring techniques for emissions associated with SSIs.

Comments on this document are welcome, including information on process descriptions, operating practices, control measures, and emissions information that would enable EPA to improve the contents. All comments should be sent to:

Chief, Pollutant Characterization Section (MD-15)
Noncriteria Pollutant Programs Branch
U. S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

3. BACKGROUND INFORMATION

Incineration is a means of disposing of sewage sludge generated by the treatment of wastewater from residential, commercial, and industrial establishments. When compared to other forms of disposal, incineration has the advantages of reducing the solid mass and the potential for recovering energy through combustion. Disadvantages include the necessity of ash disposal and the potential for air emissions of pollutants.

This section provides background information on the current status of sewage sludge incineration. In Section 3.1, the sewage sludge incineration industry is briefly overviewed. Incinerator and emission control design are described in detail in Sections 3.2 and 3.3, respectively.

3.1 CHARACTERIZATION OF THE INDUSTRY

There are currently about 200 sewage sludge incineration (SSI) plants in operation in the United States. Three main types of incinerators are used: multiple hearth, fluidized bed, and electric infrared.[1] Some sludge is co-fired with municipal solid waste in combustors based on refuse combustion technology. Unprocessed refuse co-fired with sludge in combustors based on sludge incinerating technology is limited to multiple hearth incinerators only.

Over 80 percent of the identified operating sludge incinerators are of the multiple hearth design. About 15 percent are fluidized bed combustors and 3 percent are electric. The remaining combustors co-fire refuse with sludge.

Figure 3-1 shows the approximate geographic distribution of the existing SSI population. Most sludge incineration facilities are located in the Eastern United States, though there are a significant number on the West Coast. New York has the largest number of facilities with 33. Pennsylvania and Michigan have the next-largest numbers of facilities with 21 and 19 sites, respectively.

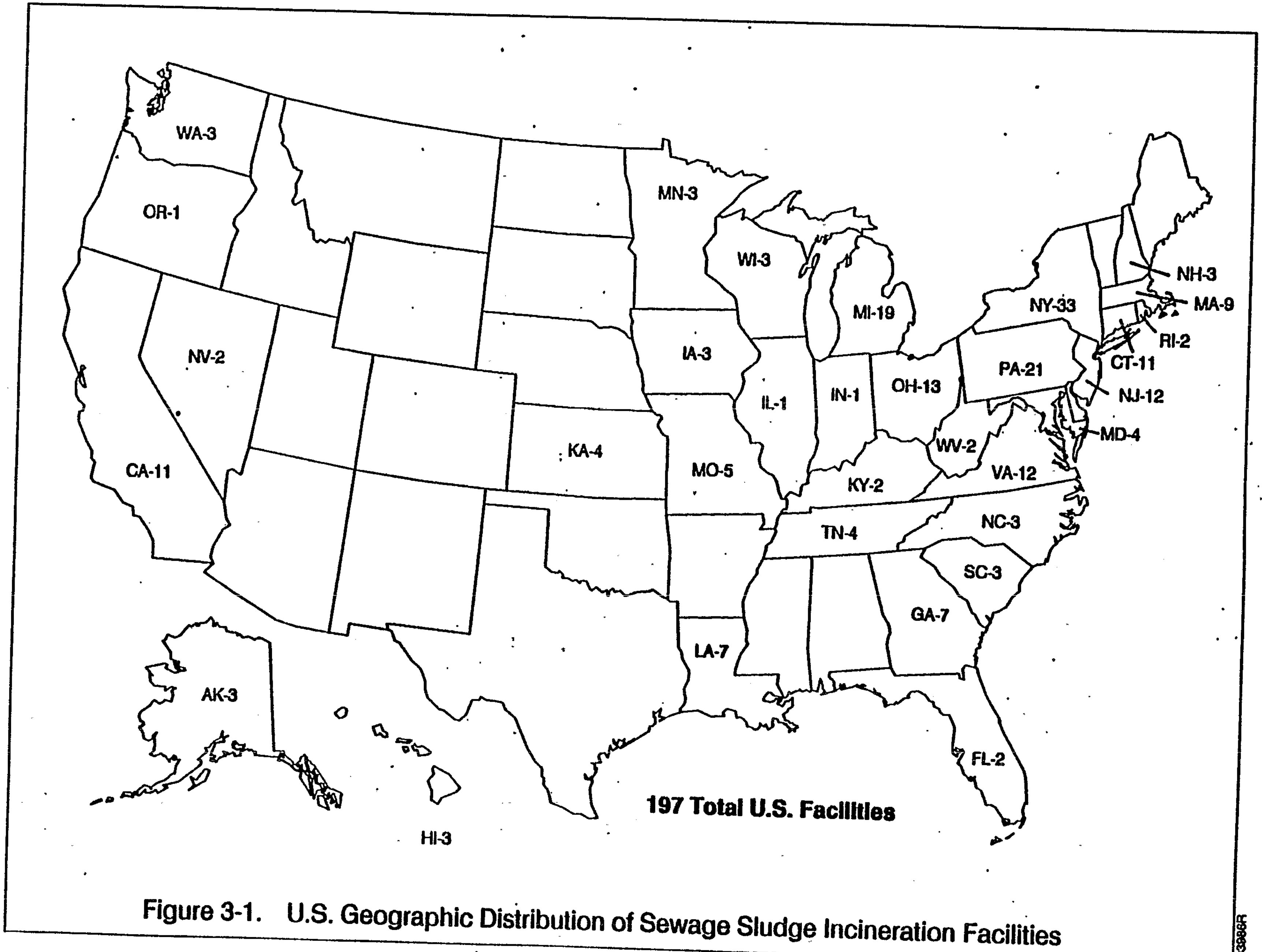

Figure 3-1. U.S. Geographic Distribution of Sewage Sludge Incineration Facilities

A list of the existing facilities is in Appendix A. Table A-1 is sorted by combustor technology, and shows incinerator type, unit capacity, year of facility start-up, and type of air pollution control device.

3.2 INCINERATOR PROCESS DESGRIPTIONS

Types of incineration described in this section include:

- Multiple hearth
- Fluidized bed
- Electric
- Single hearth cyclone
- Rotary kiln
- High pressure, wet air oxidation
- Co-incineration with refuse

3.2.1 Multiple Hearth Furnaces

The multiple hearth furnace was originally developed for mineral ore roasting nearly a century ago. The air-cooled variation has been used to incinerate sewage sludge since the 1930's. A cross section diagram of a typical multiple hearth furnace is shown in Figure 3-2. The basic multiple hearth furnace (MHF) is cylinder-shaped and oriented vertically. The outer shell is constructed of steel, lined with refractory, and surrounds a series of horizontal refractory hearths. A hollow cast iron rotating shaft runs through the center of the hearths. Cooling air for the center shaft and rabble arms is introduced into the shaft by a fan located at its base. Attached to the central shaft are the rabble arms, which extend above the hearths. Each rabble arm is equipped with a number of teeth, approximately 6 inches in length, and spaced about 10 inches apart. The teeth are shaped to rake the sludge in a spiral motion, alternating in direction from the outside in, to the inside out, between hearths. Typically, the upper and lower hearths are fitted with 4 rabble arms, and the middle hearths are fitted with two. Burners, providing auxiliary heat, are located in the sidewalls of the hearths.

Partially dewatered sludge is fed onto the perimeter of the top hearth by conveyors or pumps. The motion of the rabble arms rakes the sludge toward the center shaft where it drops through holes located at the center

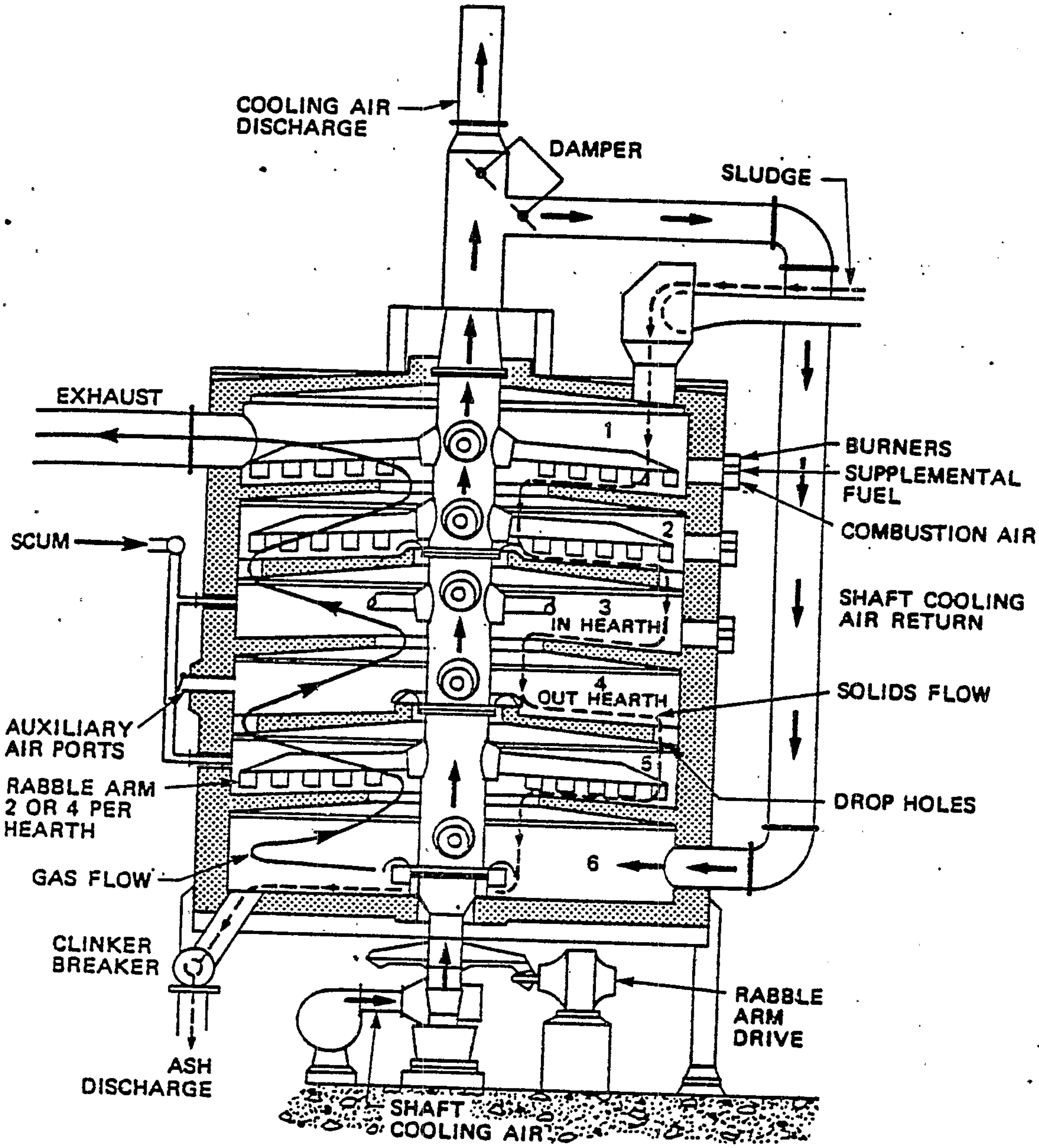

Figure 3-2. Cross section of a multiple hearth furnace.

of the hearth. In the next hearth the sludge is raked in the opposite direction. This process is repeated in all of the subsequent hearths. The effect of the rabble motion is to break up solid material to allow better surface contact with heat and oxygen, and is arranged so that sludge depth of about one inch is maintained in each hearth at the design sludge flow rate.

Scum may also be fed to one or more hearths of the incinerator. Scum is the material that floats on wastewater. It is generally composed of vegetable and mineral oils, grease, hair, waxes, fats, and other materials that will float and usually has a higher heating value and larger volatile fraction than sludge. Scum may be removed from many treatment units including preparation tanks, skimming tanks, and sedimentation tanks. Quantities of scum are generally small compared to those of other wastewater solids.

Ambient air is first ducted through the central shaft and its associated rabble arms. A portion, or all, of this air is then taken from the top of the shaft and recirculated into the lowermost hearth as preheated combustion air. Shaft cooling air which is not circulated back into the furnace is ducted into the stack downstream of the air pollution control devices. The combustion air flows upward through the drop holes in the hearths, countercurrent to the flow of the sludge, before being exhausted from the top hearth. Provisions are usually made to inject ambient air directly into on the middle hearths as well.

From the standpoint of the overall incineration process, multiple hearth furnaces can be divided into three zones. The upper hearths comprise the drying zone where most of the moisture in the sludge is evaporated. The temperature in the drying zone is typically between 425 and 760^{o}C (800 and 1,400^{o}F). Sludge combustion occurs in the middle hearths (second zone) as the temperature is increased between 815 and 925^{o}C (1,500 and 1,700^{o}F). The combustion zone can be further subdivided into the upper-middle hearths where the volatile gases and solids are burned, and the lower-middle hearths where most of the fixed carbon is combusted. The third zone, made up of the lowermost hearth(s), is the cooling zone. In this zone the ash is cooled as its heat is transferred to the incoming combustion air.

Multiple hearth furnaces are sometimes operated with afterburners to further reduce odors and concentrations of unburned hydrocarbons. In afterburning, furnace exhaust gases are ducted to a chamber where they are mixed with supplemental fuel and air and completely combusted. Some incinerators have the flexibility to allow sludge to be fed to a lower hearth, thus allowing the upper hearth(s) to function essentially as an afterburner.

Under normal operating conditions, 50 to 100 percent excess air must be added to an MHF in order to ensure complete combustion of the sludge. Besides enhancing contact between fuel and oxygen in the furnace, these relatively high rates of excess air are necessary in order to compensate for normal variations in both the organic characteristics of the sludge feed and the rate at which it enters the incinerator. When an inadequate amount of excess air is available, only partial oxidation of the carbon will occur with a resultant increase in emissions of carbon monoxide, soot, and hydrocarbons. Too much excess air, on the other hand, can cause increased entrainment of particulate and unnecessarily high auxiliary fuel consumption.

Some MHFs have been designed to operate in a starved air mode. Starved air combustion (SAC) is, in effect, incomplete combustion. The key to SAC is the usage of less than theoretical quantities of air in the furnace--30 to 90 percent of stoichiometric quantities. This makes SAC more fuel efficient than an excess air mode MHF. The SAC reaction products are combustible gases, tars and oils, and a solid char that can have appreciable heating value. The most effective utilization of these products is by burning of the total gas stream with subsequent heat recovery. When an SAC MHF is combined with an afterburner, an overall excess air rate of 25 to 50 percent can be maintained (as compared to 75 to 200 percent overall for an excess air MHF with an afterburner).

Multiple hearth furnace emissions are usually controlled by a venturi scrubber, an impingement tray scrubber, or a combination of both. Wet cyclones are also used.

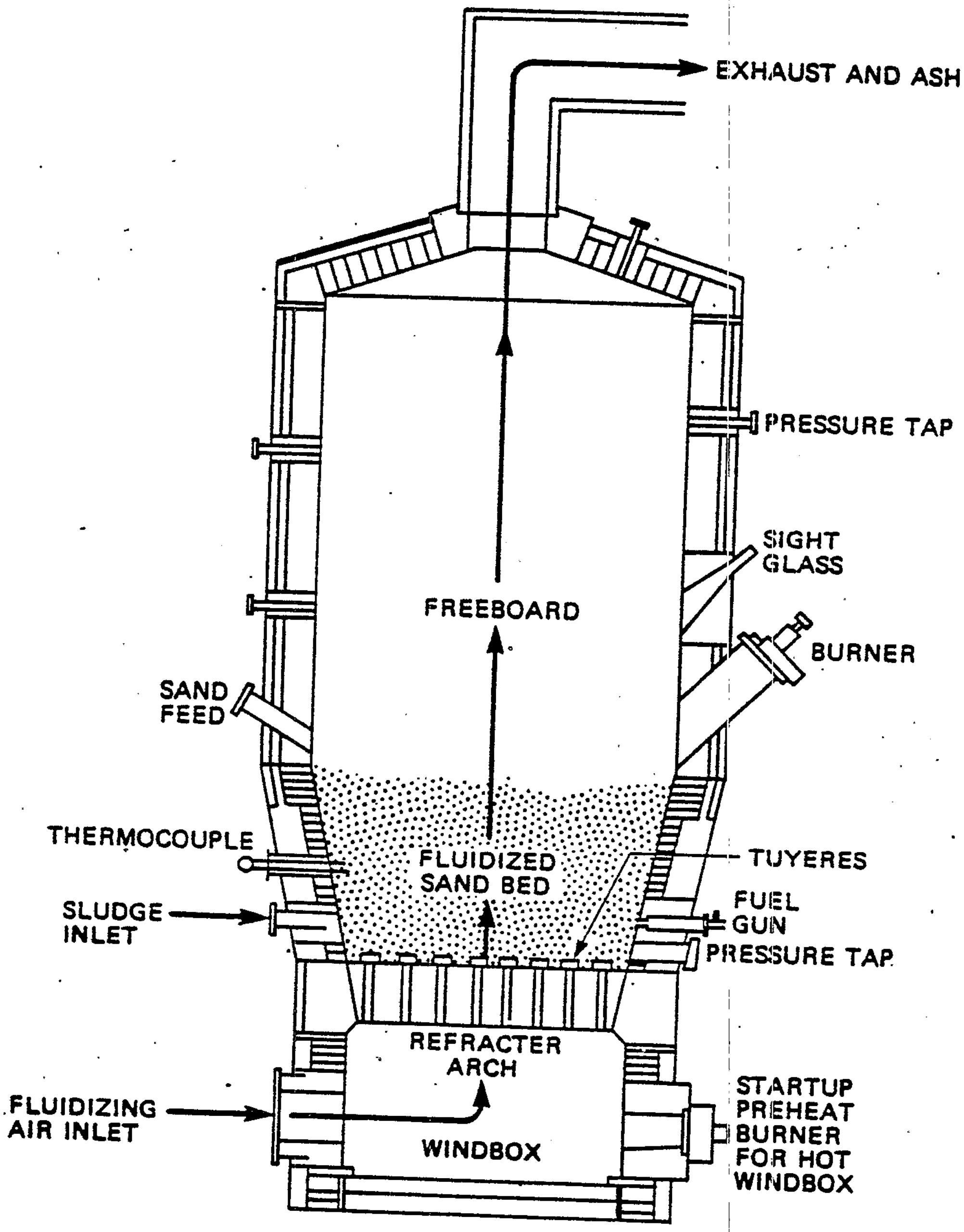

Figure 3-3. Cross section of a fluidized bed furnace.

3.2.2 Fluidized Bed Incinerators

Fluidized bed technology was first developed by the petroleum industry to be used for catalyst regeneration. Fluidized bed technology was first used for municipal sludge incineration in 1962. Figure 3-3 shows the cross section diagram of a fluidized bed furnace (FBF). Fluidized bed furnaces are cylindrically shaped and oriented vertically. The outer shell is constructed of steel, and is lined with refractory. Tuyeres (nozzles designed to deliver blasts of air) are located at the base of the furnace within a refractory-lined grid. A bed of sand, approximately 0.75 meters (2.5 feet) thick, rests upon the grid. Two general configurations can be distinguished on the basis of how the fluidizing air is injected into the furnace. In the "hot windbox" design the combustion air is first preheated by passing through a heat exchanger where heat is recovered from the hot flue gases. Alternatively, ambient air can be injected directly into the furnace from a cold windbox.

Partially dewatered sludge is fed into the bed of the furnace. Air injected through the tuyeres, at pressure of from 20 to 35 kPa (3 to 5 psig), simultaneously fluidizes the bed of hot sand and the incoming sludge. Temperatures of 725 to 825°C (1,350 to 1,500°F) are maintained in the bed. Residence times are on the order of 2 to 5 seconds. As the sludge burns, fine ash particles are carried out the top of the furnace. Some sand is also removed in the air stream; sand make-up requirements are on the order of 5 percent for every 300 hours of operation.

The overall process of combustion of the sludge occurs in two zones. Within the bed itself (zone 1) evaporation of the water and pyrolysis of the organic materials occur nearly simultaneously as the temperature of the sludge is rapidly raised. In the second zone, (freeboard area) the remaining free carbon and combustible gases are burned. The second zone functions essentially as an afterburner.

Fluidization achieves nearly ideal mixing between the sludge and the combustion air and the turbulence facilitates the transfer of heat from the hot sand to the sludge. The most noticeable impact of the better burning atmosphere provided by a fluidized bed incinerator is seen in the limited amount of excess air required for complete combustion of the sludge.

These incinerators can achieve complete combustion with 20 to 50 percent excess air, about half the amount of excess air typically required for incinerating sewage sludge in multiple hearth furnaces. As a consequence, FBF incinerators have generally lower fuel requirements compared to MHF incinerators.

Fluidized bed incinerators most often have venturi scrubbers or venturi/impingement tray scrubber combinations for emissions control.

3.2.3 Electric Incinerators

Electric furnace technology is new compared to other sludge combustor designs; the first electric furnace was installed in 1975. Electric incinerators consist of a horizontally oriented, insulated furnace. A woven wire belt conveyor extends the length of the furnace and infrared heating elements are located in the roof above the conveyor belt. Combustion air is preheated by the flue gases and is injected into the discharge end of the furnace. Electric incinerators consist of a number of prefabricated modules, which can be linked together to provide the necessary furnace length. A cross section of an electric furnace is shown in Figure 3-4.

The dewatered sludge cake is conveyed into one end of the incinerator. An internal roller mechanism levels the sludge into a continuous layer approximately one inch thick across the width of the belt. The sludge is sequentially dried and then burned as it moves beneath the infrared heating elements. Ash is discharged into a hopper at the opposite end of the furnace. The preheated combustion air enters the furnace above the ash hopper and is further heated by the outgoing ash. The direction of air flow is countercurrent to the movement of the sludge along the conveyor. Exhaust gases leave the furnace at the feed end. Excess air rates vary from 20 to 70 percent.

When compared to MHF and FBF technologies, the electric furnace offers the advantage of lower capital cost, especially for smaller systems. However, electric costs in some areas may make an electric furnace infeasible. Another concern is replacement of various components such as the woven wire belt and infrared heaters, which have 3 to 5 year lifetimes.

Electric incinerators are usually controlled with a venturi scrubber or some other wet scrubber.

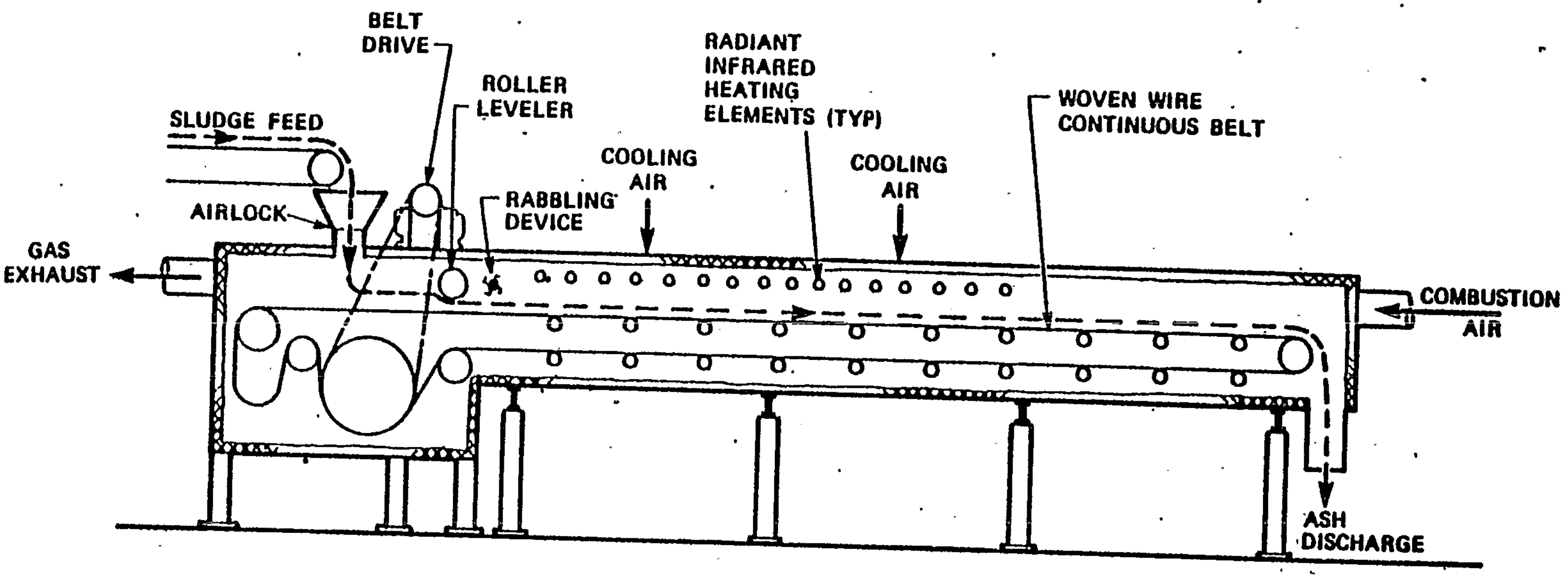

Figure 3-4. Cross section of an electric infrared furnace.

3.2.4 Other Technologies

A number of other technologies have been used for incineration of sewage sludge including cyclonic reactors, rotary kilns and wet oxidation reactors. These processes are not in widespread use in the United States and will be discussed only briefly.

The cyclonic reactor is designed for small capacity applications. It is constructed of a vertical cylindrical chamber that is lined with refractory. Preheated combustion air is introduced into the chamber tangentially at high velocities. The sludge is sprayed radially toward the hot refractory walls. Combustion is rapid: the residence time of the sludge in the chamber is on the order of 10 seconds. The ash is removed with the flue gases.

Rotary kilns are also generally used for small capacity applications. The kiln is inclined slightly from the horizontal plane, with the upper end receiving both the sludge feed and the combustion air. A burner is located at the lower end of the kiln. The circumference of the kiln rotates at a speed of about 6 inches per second. Ash is deposited into a hopper located below the burner.

The wet oxidation process is not strictly one of incineration; it instead utilizes oxidation with air at elevated temperature and pressure in the presence of water (flameless combustion). Thickened sludge, at about six percent solids, is first ground and mixed with a stoichiometric amount of compressed air. The sludge-air mixture is then preheated in a heat exchanger using the reactor effluent stream as the heat source before entering the pressurized reactor. The temperature of the reactor is held between 175 and 315°C (350 and 600°F). The pressure is normally 7,000 to 12,500 kPa (1,000 to 1,800 psig). Steam is usually used for auxiliary heat. The water and resulting ash are circulated out the reactor and are separated in a tank or lagoon. The liquid phase is recycled to the treatment plant. Off-gases must be treated to eliminate odors: wet scrubbing, afterburning or carbon absorption may be used.

3.2.5 Co-incineration with Refuse

Wastewater treatment plant sludge generally has a high water content and in some cases, fairly high levels of inert materials. As a result, its net fuel value is often low. If sludge is combined with other combustible materials in a co-combustion scheme, a furnace feed can be created that has both a low water concentration and a heat value high enough to sustain combustion with little or no supplemental fuel.

Virtually any material that can be burned can be combined with sludge in a co-combustion process. Common materials for co-combustion are coal, municipal solid waste, wood waste and agricultural waste. Thus, a municipal or industrial waste can be disposed of while providing an autogenous (self-sustaining) sludge feed, thereby solving two disposal problems.

There are two basic approaches to combusting sludge with municipal solid waste (MSW): 1) use of MSW combustion technology by adding dewatered or dried sludge to the MSW combustion unit, and 2) use of sludge combustion technology by adding raw or processed MSW as a supplemental fuel to the sludge furnace.

With the latter, MSW is processed by removing noncombustibles, shredding, air-classifying, and screening. Waste that is more finely processed is less likely to cause problems such as severe erosion of the hearths, poor temperature control, and refractory failures.[2]

3.3 EMISSIONS AND CONTROLS

Sewage sludge incinerators potentially emit significant quantities of pollutants. The major pollutants emitted are: 1) particulate matter, 2) metals, 3) carbon monoxide (CO), 4) nitrogen oxides (NO_x), 5) sulfur dioxide (SO_2) and 6) unburned hydrocarbons. Partial combustion of sludge can result in emissions of intermediate products of incomplete combustion (PICs) including toxic organic compounds.

Uncontrolled particulate emission rates vary widely depending on the type of incinerator, the volatiles and moisture content of the sludge, and the operating practices employed. Generally, uncontrolled particulate emissions are highest from fluidized bed incinerators because suspension burning results in much of the ash being carried out of the incinerator with the flue gas. Uncontrolled emissions from multiple hearth and fluidized bed incinerators are extremely variable, however. Electric incinerators appear to have the lowest rates of uncontrolled particulate release of the three major furnace types, possibly because the sludge is not disturbed during firing. In general, higher airflow rates increase the opportunity for particulate matter to be entrained in the exhaust gases. Sludge with low volatile content or high moisture content may compound this situation by requiring more supplemental fuel to burn. As more fuel is consumed, the amount of air flowing through the incinerator is also increased. However, no direct correlation has been established between air flow and particulate emissions.

Metals emissions are affected by fuel bed temperature and the level of particulate matter control, since metals which are volatilized in the combustion zone condense in the exhaust gas stream. Most metals (except mercury) are associated with fine particulate and are removed as the fine particulates are removed.

Carbon monoxide is formed when available oxygen is insufficient for complete combustion or when excess air levels are too high, resulting in lower combustion temperatures.

Nitrogen and sulfur oxide emissions are primarily the result of oxidation of nitrogen and sulfur in the sludge. Therefore, these emissions can vary greatly based on local and seasonal sewage characteristics.

Emissions of volatile organic compounds also vary greatly with incinerator type and operation. Incinerators with countercurrent air flow such as multiple hearth designs provide the greatest opportunity for unburned hydrocarbons to be emitted. In the MHF, hot air and wet sludge feed are contacted at the top of the furnace. Any compounds distilled from the solids are immediately vented from the furnace at temperatures too low to completely destruct them.

Particulate emissions from sewage sludge incinerators have historically been controlled by wet scrubbers, since the associated sewage treatment plant provides both a convenient source and a good disposal option for the scrubber water. The types of existing sewage sludge incinerator controls range from low pressure drop spray towers and wet cyclones to higher pressure drop venturi scrubbers and venturi/impingement tray scrubber combinations. A few electrostatic precipitators are employed, primarily where sludge is co-fired with municipal solid waste and baghouses have been used. The most widely used control device applied to a multiple hearth incinerator is the impingement tray scrubber. Older units use the tray scrubber alone while combination venturi/impingement tray scrubbers are widely applied to newer multiple hearth incinerators and to fluidized bed incinerators. Most electric incinerators and some fluidized bed incinerators use venturi scrubbers only.

In a typical combination venturi/impingement tray scrubber (shown in Figure 3-5), hot gas exits the incinerator and enters the precooling or quench section of the scrubber. Spray nozzles in the quench section cool the incoming gas and the quenched gas then enters the venturi section of the control device.

Venturi water is usually pumped into an inlet weir above the quencher. The venturi water enters the scrubber above the throat and floods the throat completely. This eliminates build-up of solids and reduces abrasion. Turbulence created by high gas velocity in the converging throat section deflects some of the water traveling down the throat into the gas stream. Particulate matter carried along with the gas stream impacts on these water particles and on the water wall. As the scrubber water and flue gas leave the venturi section, they pass into a flooded elbow where the stream velocity decreases, allowing the water and gas to separate. Most venturi sections come equipped with variable throats. By restricting the throat area within the venturi, the linear gas velocity is increased and the pressure drop is subsequently increased. Up to a certain point, increasing the venturi pressure drop increases the removal efficiency. Venturi scrubbers typically attain 60 to 99 percent removal efficiency for particulate matter, depending on pressure drop and particle size distribution.[3]

At the base of the flooded elbow, the gas stream passes through a connecting duct to the base of the impingement tray tower. Gas velocity is further reduced upon entry to the tower as the gas stream passes upward through the perforated impingement trays. Water usually enters the trays from inlet ports on opposite sides and flows across the tray. As gas passes through each perforation in the tray, it creates a jet which bubbles up the water and further entrains solid particles. At the top of the tower is a

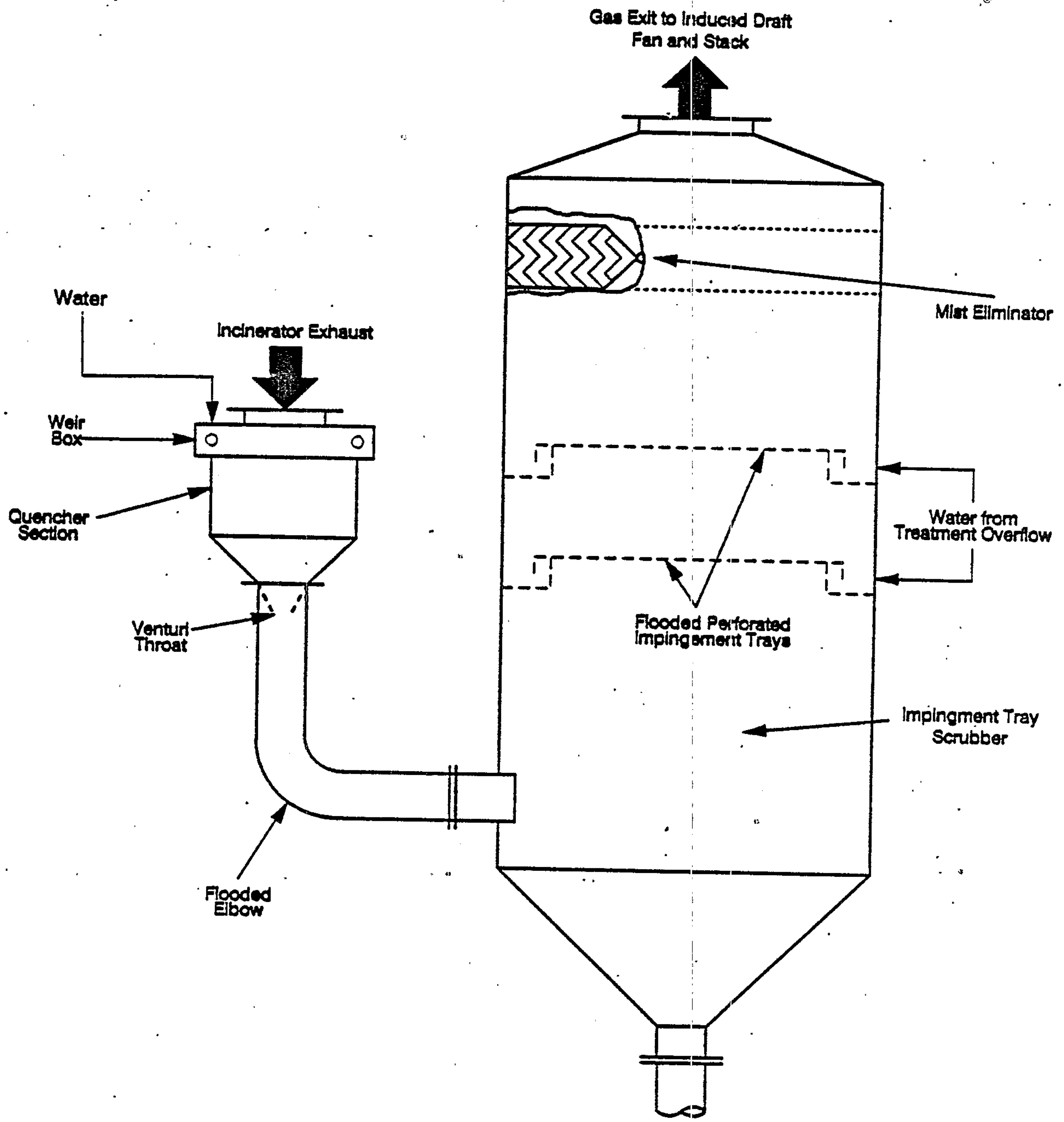

Figure 3-5. Venturi/impingement tray scrubber.

mist eliminator to reduce the carryover of water droplets in the stack effluent gas. The impingement section can contain from one to four trays, but most systems for which data are available have two or three trays.

3.4 REFERENCES

1. Second Review of Standards of Performance for Sewage Sludge Incinerators, EPA-450/3-84-010, U.S. Environmental Protection Agency, Research Triangle Park, NC. March 1984.

2. Process Design Manual for Sludge Treatment and Disposal, EPA-625/1-79-011, U.S. Environmental Protection Agency, Cincinnati, OH. September 1979.

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

4. EMISSION FACTORS

Emission factors have been developed for the various pollutants emitted from SSIs. These emission factors are derived from published emissions data; no new sampling of sources was done for this project. The factors relate the amount of pollutant emitted in the flue gas to the amount of sludge incinerated and may be used to estimate emissions from a facility. Flue gas emissions are the principal source of air toxics emissions from sewage sludge incinerators. The estimated emissions should be used with caution, however, because the emission factors are generally averages from several facilities and are not necessarily representative of the emissions from any particular facility. Additionally, because of limited data, a representative number of facilities could not be used in evaluating emission factors. In some cases, data from only one facility were available; these factors are noted individually, and should only be used with extreme caution.

If more accurate emission estimates are needed, source testing should be done. Data collected should include sludge feed rate and composition, ash composition, and stack emissions. The actual air toxics emissions from any given facility are a function of variables such as capacity, throughput, sludge composition, operating characteristics, and air pollution control device operations. The effects of these factors should be considered when testing. If such testing is done, the Pollutant Characterization Section requests copies of the tests be submitted so that better databases and emission factors may be developed in the future.

In this document, emission factors are presented for 32 inorganic compounds including metals, 25 volatile organic compounds, various isomers of chlorinated dibenzo-p-dioxins and dibenzofurans (CDD and CDF), and 7 other semivolatile organic compounds. Average emissions factors were evaluated per incinerator type and emission control type. The overall averages were derived by combining the average emission factors for each test of the same general incinerator and emission control type. For facilities where multiple operating conditions were evaluated or multiple tests were performed over a period of years, the average emission factor from each test condition or test was used in deriving the overall average.

Several individual emission factors were derived for each facility. For inorganic compounds, three factors were derived by dividing the mass emission rate of the pollutant by 1) the measured feed rate of that pollutant, by 2) the total particulate matter emission rate, and by 3) the total dry sludge feed rate. Which factor is selected to estimate emissions will depend on what information is available. The first factor should be used when the sludge feed composition is known in addition to the total dry sludge feed rate. The second factor can be used to predict emissions of specific compounds from the total particulate matter emission rate. The third factor can be used if only the total sludge feed rate is known. Organic compound emission factors were derived by dividing the mass emission rate of the pollutant by the total dry sludge feed rate.

The first two inorganic compound factors are presented on a fractional mass basis (ppm). All the emission factors on a total feed basis are presented in both SI and English units. When a pollutant was not detected, no value was reported; overall average emission factors include data from only those facilities where the compound was detected.

Emission factors for the different types of combustors and emission controls are presented in Sections 4.1 to 4.3.

4.1 EMISSION FACTORS FOR MULTIPLE HEARTH FURNACES

Emission factors for inorganic compound emissions from multiple hearth furnaces are presented in Tables 4-1 through 4-4. The emission factors are for uncontrolled flue gas emissions as well as controlled flue gas emissions. Emission factors for controlled emissions are separated by the different types of emission controls used with multiple hearth furnaces including cyclones, impingement tray scrubbers, venturi scrubbers and exhaust gas afterburners. Test data from facilities using a venturi scrubber (with or without other devices) are reported separately from those facilities using only low-energy scrubbers. In addition, pilot scale test data are presented for control by an electrostatic precipitator and by a

TABLE 4-1. INORGANIC COMPOUND EMISSION FACTORS ON A COMPOUND FEED BASIS FOR MULTIPLE HEARTH FURNACES BURNING SEWAGE SLUDGE

(Mass of Pollutant Emitted per Mass Fed) x 10^6

Pollutant	Uncontrolled Average	Uncontrolled Range	References	After Low-Energy Scrubber[a] Average	After Low-Energy Scrubber[a] Range	References	After High-Energy Scrubber[b] Average	After High-Energy Scrubber[b] Range	References
Aluminum	36,000	1700 - 70,000	6,7	917	9.04 - 2,260	19	23,000[c]	-	6
Antimony	42,000	690 - 84,000	6,7	4,660	2,570 - 5,960	19	6,800[c]	-	6
Arsenic	150,000	890 - 360,000	2,4,6,7	990	501 - 1,240	19	31,000[c]	3,800 - 75,000	1,2,4,6
Barium	33,000	1,500 - 64,000	6,7	1,420	65.9 - 3,670	19	8,700[c]	-	6
Beryllium	26,000	26,000 - 26,000	2,4	-	-	-	2,000[c]	-	1,2,4
Boron	-	-	-	-	-	-	-	-	-
Cadmium	1,100,000[d]	15,000 - 4,100,000[d]	2,4,6,7,14	129,000	4,410 - 366,000	19	140,000	55,000 - 220,000	1,2,4,6,14
Calcium	35,000	1,200 - 69,000	6,7	933	20.7 - 2,190	19	21,000[c]	-	6
Chromium	350,000	78,000 - 1,800,000[d]	2,4,6,7,14	3,430	769 - 5,660	19	11,000	350 - 43,000	1,2,6,14
Cobalt	29,000	780 - 57,000	6,7	1,440,000,000	762 - 4,320,000,000	19	3,500[c]	-	6
Copper	250,000	750 - 900,000	6,7,14	10,800	1,500 - 36,000	19	6,100	480 - 10,000	4,6,14
Gold	960	290 - 1,600	6,7	-	-	-	120[c]	-	6
Iron	240,000	59,000 - 1,200,000[d]	6,7,14	943	54.1 - 2,160	19	1,500	18 - 3,900	6,14
Lead	640,000	3,700 - 3,800,000[d]	2,4,6,7,14	41,200	11,800 - 128,000	19	87,000	30,000 - 210,000	1,2,4,6,14
Magnesium	30,000	980 - 59,000	6,7	984	29 - 2,280	19	810[c]	-	6
Manganese	340,000	810 - 1,300,000[d]	6,7,14	2,940	116 - 13,000	19	3,100	36 - 8,800	6,14
Molybdenum	-	-	-	-	-	-	-	-	-
Nickel	200,000	1,300 - 1,300,000[d]	2,4,6,7,14	7,250	466 - 23,700	19	14,000	130 - 51,000	1,2,4,6,14
Phosphous	31,000	540 - 62,000	6,7	1,140	196 - 2,040	19	580[c]	-	6
Potassium	-	-	-	1,460	139 - 2,170	19	-	-	-
Selenium	-	-	-	5,940	826 - 14,400	19	-	-	-
Silicon	-	-	-	829	65.6 - 1,670	19	-	-	-
Silver	360,000	8,500 - 1,800,000[d]	7,14	43,200	14,500 - 81,500	19	16,000	3,700 - 29,000	14
Sodium	28,000	870 - 56,000	6,7	2,720	1,520 - 4,490	19	7,200[c]	-	6
Strontium	-	-	-	-	-	-	-	-	-
Sulfur	1,300,000[e]	470 - 2,600,000[e]	6,7	6,630	3,710 - 9,110	-	32,000[c]	-	6
Thorium	-	-	-	-	-	-	-	-	-
Tin	70,000	2,800 - 140,000	6,7	12,800	5,280 - 25,500	19	66,000[c]	-	6
Titanium	30,000	670 - 59,000	6,7	1,170	17.2 - 3,070	19	2,100[c]	-	6
Vanadium	37,000	2,000 - 72,000	6,7	6,900	762 - 15,000	19	7,500	-	-
Zinc	330,000	800 - 1,200,000[d]	6,7,14	14,000	1,660 - 34,700	19	34,000	2,900 - 82,000	4,6,14
Zirconium	-	-	-	-	-	-	-	-	-

(continued)

TABLE 4-1. (Continued)

Pollutant	After ESP[a,b] Average[c,f]	Range	References	After Fabric Filter Average[c,f]	Range	References	After Scrubber and Afterburner[g] Average[c]	Range	References
Aluminum	12,000	- - -	6	2,000	- - -	7	-	- - -	-
Antimony	920	- - -	6	23	- - -	7	-	- - -	-
Arsenic	5,300	- - -	6	17	- - -	7	-	- - -	-
Barium	9,700	- - -	6	140	- - -	7	-	- - -	-
Beryllium	-	- - -	-	-	- - -	-	-	- - -	-
Boron	-	- - -	-	-	- - -	-	-	- - -	-
Cadmium	2,100	- - -	6	200	- - -	7	190,000	- - -	4
Calcium	18,000	- - -	6	8.9	- - -	7	-	- - -	-
Chromium	6,100	- - -	6	140	- - -	7	-	- - -	-
Cobalt	20,000	- - -	6	210	- - -	7	-	- - -	-
Copper	120	- - -	6	1.5	- - -	7	7,400	- - -	4
Gold	-	- - -	-	-	- - -	-	-	- - -	-
Iron	1,400	- - -	6	5.9	- - -	7	-	- - -	-
Lead	5,300	- - -	6	25	- - -	7	120,000	- - -	4
Magnesium	1,200	- - -	6	6.9	- - -	7	-	- - -	-
Manganese	2,600	- - -	6	2.5	- - -	7	-	- - -	-
Molybdenum	-	- - -	-	-	- - -	-	-	- - -	-
Nickel	21,000	- - -	6	130	- - -	7	1,100	- - -	4
Phosphous	410	- - -	6	2.1	- - -	7	-	- - -	-
Potassium	-	- - -	-	-	- - -	-	-	- - -	-
Selenium	-	- - -	-	1,000	- - -	7	-	- - -	-
Silicon	-	- - -	-	-	- - -	-	-	- - -	-
Silver	-	- - -	-	400	- - -	7	-	- - -	-
Sodium	220	- - -	6	9.5	- - -	7	-	- - -	-
Strontium	-	- - -	-	-	- - -	-	-	- - -	-
Sulfur	1,300,000[e]	- - -	6	13	- - -	7	-	- - -	-
Thorium	-	- - -	-	-	- - -	-	-	- - -	-
Tin	1,500	- - -	6	7.0	- - -	7	-	- - -	-
Titanium	390	- - -	6	3.0	- - -	7	-	- - -	-
Vanadium	3,100	- - -	6	15	- - -	7	-	- - -	-
Zinc	180	- - -	6	20	- - -	7	31,000	- - -	4
Zirconium	-	- - -	-	-	- - -	-	-	- - -	-

[a]Cyclone or impingement tray scrubber.

[b]Venturi scrubber alone or in series with low-energy devices.

[c]One data point.

[d]Reference 14 tests are biased; emissions reported are greater than quantity fed in some cases.

[e]Includes SO_2 gas from impinger catch, while sludge analysis reported only nonvolatile sulfur compounds.

[f]From pilot scale control device.

[g]Overall control by venturi scrubber, impingement tray scrubber, and afterburner in series.

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TABLE 4-2. INORGANIC COMPOUND EMISSION FACTORS ON A TOTAL PARTICULATE EMISSION BASIS FOR MULTIPLE HEARTH FURNACES BURNING SEWAGE SLUDGE

(Mass of Pollutant Emitted per Mass of Total Particulate Emitted) x 10^6

Pollutant	Uncontrolled Average	Uncontrolled Range	References	After Low-Energy Scrubber[a] Average	After Low-Energy Scrubber[a] Range	References	After High-Energy Scrubber[b] Average	After High-Energy Scrubber[b] Range	References
Aluminum	29,000	3,000 - 54,000	6,7	13,800	600 - 30,500	-	900,000[c]	- -	6
Antimony	210	180 - 240	6,7	533	500 - 600	-	400	140 - 660	6,10
Arsenic	230	7.0 - 910	2,4,6,7	5,310	122 - 15,600	14	580	12 - 2,900	1,2,4,6,10,14
Barium	1,600	210 - 3,000	6,7	2,200	200 - 5,600	-	10,000	110 - 21,000	6,10
Beryllium	1.1	0.10 - 0.12	2,4	-	- -	-	8.9[c]	2.1 - 16	2,10
Boron	-	- -	-	-	- -	-	130[c]	- -	10
Cadmium	1,500	130 - 5,100	2,4,6,7,14	20,800	700 - 77,700	14	6,400	87 - 29,000	1,2,4,6,10,14
Calcium	71,000	52,000 - 89,000	6,7	38,400	2,300 - 62,000	-	1,300,000[c,d]	- -	6
Chromium	1,800	130 - 5,100	2,4,6,7,14	5,600	2,190 - 9,400	14	6,400	85 - 41,000	1,2,6,10,14
Cobalt	53	44 - 62	6,7	500	500 - 500	-	170	90 - 260	6,10
Copper	4,200	760 - 8,900	6,7,14	12,200	7,700 - 18,100	14	13,000	3,400 - 42,000	4,6,10,14
Gold	5.0	0.55 - 9.4	6,7	-	- -	-	4.8[c]	- -	6
Iron	62,000	4,200 - 190,000	6,7,14	41,600	3,400 - 138,000	14	110,000	12,000 - 290,000	6,14
Lead	6,600	1,500 - 32,000	2,4,6,7,14	46,900	22,700 - 101,000	14	39,000	3,700 - 220,000	1,2,4,6,10,14
Magnesium	23,000	20,000 - 27,000	6,7	5,330	300 - 8,600	-	22,000[c]	- -	6
Manganese	12,000	330 - 88,000	6,7,14	1,370	100 - 2,740	14	1,500	340 - 5,000	6,10,14
Molybdenum	-	- -	-	-	- -	-	83[c]	- -	10
Nickel	990	130 - 4,800	2,4,6,7,14	2,800	1,580 - 4,330	14	3,300	47 - 16,000	1,2,4,6,10,14
Phosphous	59,000	53,000 - 64,000	6,7	29,600	8,400 - 46,900	-	34,000[c]	- -	6
Potassium	-	- -	-	9,270	1,800 - 17,100	-	-	- -	-
Selenium	0.76[c]	- -	6	400	400 - 400	-	11,000	560 - 21,000	6,10
Silicon	-	- -	-	45,800	9,100 - 81,300	-	-	- -	-
Silver	180	62 - 770	6,7,14	975	909 - 1,040	14	520[c]	150 - 970	6,10,14
Sodium	6,900	5,400 - 8,500	6,7	12,200	3,400 - 27,600	-	74,000[c]	- -	6
Strontium	-	- -	-	-	- -	-	29[c]	- -	10
Sulfur	470,000	190,000 - 910,000	6,7	36,300	18,000 - 52,500	-	810,000[c]	- -	6
Thorium	-	- -	-	-	- -	-	-	- -	-
Tin	1,200	1,100 - 1,300	6,7	16,600	11,600 - 23,900	-	20,000	3,400 - 37,000	6,10
Titanium	7,500	7,100 - 8,000	6,7	3,730	200 - 8,800	-	19,000[c]	- -	6
Vanadium	820	300 - 1,300	6,7	1,750	700 - 2,800	-	980	56 - 1,900	6,10
Zinc	10,000	2,400 - 21,000	6,7,14	47,300	22,700 - 97,700	14	53,000	9,400 - 1,000,000[d]	4,6,10,14
Zirconium	-	- -	-	-	- -	-	-	- -	-

(continued)

TABLE 4-2. (Continued)

Pollutant	After ESP Average[c,e]	After ESP Range	References	After Fabric Filter Average[c,e]	After Fabric Filter Range	References	After Scrubber and Afterburner[f] Average[c]	After Scrubber and Afterburner[f] Range	References
Aluminum	220,000	- - -	6	530,000	- - -	7	-	- - -	-
Antimony	46	- - -	6	1,200	- - -	7	-	- - -	-
Arsenic	1,400	- - -	6	2,400	- - -	7	69	- - -	4
Barium	11,000	- - -	6	2,400	- - -	7	-	- - -	-
Beryllium	-	- - -	-	-	- - -	-	-	- - -	-
Boron	-	- - -	-	-	- - -	-	-	- - -	-
Cadmium	170	- - -	6	10,000	- - -	7	3,700	- - -	4
Calcium	530,000	- - -	6	60,00	- - -	7	-	- - -	-
Chromium	1,700	- - -	6	14,000	- - -	7	-	- - -	-
Cobalt	420	- - -	6	2,000	- - -	7	-	- - -	-
Copper	430	- - -	6	1,900	- - -	7	9,600	- - -	4
Gold	6.3	- - -	6	-	- - -	-	-	- - -	-
Iron	27,000	- - -	6	83,000	- - -	7	-	- - -	-
Lead	2,400	- - -	6	4,500	- - -	7	59,000	- - -	4
Magnesium	1,400	- - -	6	24,000	- - -	7	-	- - -	-
Manganese	290	- - -	6	180	- - -	7	-	- - -	-
Molybdenum	-	- - -	-	-	- - -	-	-	- - -	-
Nickel	2,000	- - -	6	5,100	- - -	7	540	- - -	4
Phosphous	11,000	- - -	6	37,000	- - -	7	-	- - -	-
Potassium	-	- - -	-	-	- - -	-	-	- - -	-
Selenium	800	- - -	6	5,700	- - -	7	-	- - -	-
Silicon	-	- - -	-	-	- - -	-	-	- - -	-
Silver	16	- - -	6	440	- - -	7	-	- - -	-
Sodium	1,400	- - -	6	8,600	- - -	7	-	- - -	-
Strontium	-	- - -	-	-	- - -	-	-	- - -	-
Sulfur	19,000,000[d]	- - -	6	77,000	- - -	7	-	- - -	-
Thorium	-	- - -	-	-	- - -	-	-	- - -	-
Tin	580	- - -	6	590	- - -	7	-	- - -	-
Titanium	1,600	- - -	6	4,700	- - -	7	-	- - -	-
Vanadium	190	- - -	6	1,700	- - -	7	-	- - -	-
Zinc	530	- - -	6	31,000	- - -	7	33,000	- - -	4
Zirconium	-	- - -	-	-	- - -	-	-	- - -	-

[a]Cyclone or impingement tray scrubber.

[b]Venturi scurbber alone or in series with low-energy devices.

[c]One data point.

[d]Includes impinger catch.

[e]From pilot scale control device.

[f]Overall control by venturi scrubber, impingement tray scrubber, and afterburner in series.

TABLE 4-3. INORGANIC COMPOUND EMISSION FACTORS IN SI UNITS ON A TOTAL FEED BASIS FOR MULTIPLE HEARTH FURNACES BURNING SEWAGE SLUDGE

(grams of Pollutant Emitted per megagram of Dry Sludge Feed) x 10^3

Pollutant	Uncontrolled			After Low-Energy Scrubber[a]			After High-Energy Scrubber[b]		
	Average	Range	References	Average	Range	References	Average	Range	References
Aluminum	440,000	770 - 880,000	6,7	10,000	305 - 25,000	19	290,000[c]	- -	6
Antimony	1,600	47 - 3,200	6,7	305	195 - 370	19	260[c]	- -	6
Arsenic	5,500	160 - 28,000	2,4,6,7,14	2,050	115 - 10,050	19	320	20 - 850	2,6,14
Barium	25,000	42 - 49,000	6,7	1,700	115 - 4,650	19	6,700[c]	- -	6
Beryllium	9.5	9.0 - 10	2	-	- -	-	0.8[c]	- -	2
Boron	-	- -	-	-	- -	-	-	- -	-
Cadmium	19,000	1,000 - 54,000	2,4,6,7,14	13,500	550 - 50,000	19	2,000	240 - 8,000	1,2,4,6,14
Calcium	730,000	12,000 - 1,400,000	6,7	23,000	1,350 - 42,000	19	430,000[c]	- -	6
Chromium	160,000	95 - 1,000,000	2,4,6,7,14	3,950	1,900 - 7,500	19	2,000	150 - 11,000	1,2,6,14
Cobalt	520	9 - 1,000	6,7	215	49 - 400	19	63[c]	- -	6
Copper	230,000	1,100 - 900,000	6,7,14	9,000	2,800 - 15,000	19	5,500	700 - 11,000	4,6,14
Gold	2.1	1.0 - 3.0	6,7	-	- -	-	1.2[c]	- -	6
Iron	3,200,000	13,000 - 11,000,000	6,7,14	32,500	1,900 - 115,000	19	32,000	1,600 - 75,000	6,14
Lead	340,000	800 - 2,400,000	2,4,6,7,14	37,500	16,500 - 70,000	19	20,000	3,000 - 55,000	1,2,4,6,14
Magnesium	220,000	4,200 - 440,000	6,7	3,400	175 - 7,000	19	6,000[c]	- -	6
Manganese	180,000	75 - 750,000	6,7,14	1,300	85 - 4,300	19	500	45 - 1,300	6,14
Molybdenum	-	- -	-	-	- -	-	-	- -	-
Nickel	45,000	65 - 190,000	2,4,6,7,14	1,750	180 - 3,100	19	2,200	100 - 14,000	1,2,4,6,14
Phosphous	530,000	11,000 - 1,100,000	6,7	17,000	4,700 - 27,500	19	9,800[c]	- -	6
Potassium	-	- -	-	5,000	1,000 - 7,500	19	-	- -	-
Selenium	-	- -	-	650	215 - 1,500	19	-	- -	-
Silicon	-	- -	-	30,500	5,000 - 65,000	19	-	- -	-
Silver	8,500	20 - 23,000	7,14	950	600 - 1,500	-	310	85 - 550	14
Sodium	70,000	1,000 - 140,000	6,7	6,000	2,000 - 11,500	19	18,000[c]	- -	6
Strontium	-	- -	-	-	- -	-	-	- -	-
Sulfur	7,900,000	3,800 - 16,000,000	6,7	19,500	15,000 - 21,500	-	200,000[c]	- -	6
Thorium	-	- -	-	-	- -	-	-	- -	-
Tin	9,800	250 - 19,300	6,7	10,500	6,000 - 19,500	19	9,200[c]	- -	6
Titanium	66,000	1,400 - 131,000	6,7	2,750	135 - 7,000	19	4,700[c]	- -	6
Vanadium	2,600	260 - 4,900	6,7	600	49 - 1,150	19	500[c]	- -	6
Zinc	850,000	1,500 - 5,500,000	6,7,14	2,400	650 - 60,000	19	26,000	5,500 - 50,000	4,6,14
Zirconium	-	- -	-	-	- -	-	-	- -	-

(continued)

TABLE 4-3. (Continued)

Pollutant	After ESP Average[c,e]	After ESP Range	References	After Fabric Filter Average[c,e]	After Fabric Filter Range	References	After Scrubber and Afterburner[d] Average[c]	After Scrubber and Afterburner[d] Range	References
Aluminum	150,000	- - -	6	880	- - -	7	-	- - -	-
Antimony	35	- - -	6	1.5	- - -	7	-	- - -	-
Arsenic	1,200	- - -	6	3.1	- - -	7	-	- - -	-
Barium	7,500	- - -	6	3.9	- - -	7	-	- - -	-
Beryllium	-	- - -	-	-	- - -	-	-	- - -	-
Boron	-	- - -	-	-	- - -	-	-	- - -	-
Cadmium	150	- - -	6	13	- - -	7	2,000	- - -	4
Calcium	370,000	- - -	6	94	- - -	7	-	- - -	-
Chromium	1,500	- - -	6	17	- - -	7	-	- - -	-
Cobalt	370	- - -	6	2.3	- - -	7	-	- - -	-
Copper	200	- - -	6	2.2	- - -	7	5,300	- - -	4
Gold	-	- - -	-	-	- - -	-	-	- - -	-
Iron	27,000	- - -	6	100	- - -	7	-	- - -	-
Lead	1,700	- - -	6	6	- - -	7	33,000	- - -	4
Magnesium	9,000	- - -	6	30	- - -	7	-	- - -	-
Manganese	360	- - -	6	0.2	- - -	7	-	- - -	-
Molybdenum	-	- - -	-	-	- - -	-	-	- - -	-
Nickel	5,600	- - -	6	6.1	- - -	7	200	- - -	4
Phosphous	6,900	- - -	6	42	- - -	7	-	- - -	-
Potassium	-	- - -	-	-	- - -	-	-	- - -	-
Selenium	-	- - -	-	1.9	- - -	7	-	- - -	-
Silicon	-	- - -	-	-	- - -	-	-	- - -	-
Silver	-	- - -	-	1.0	- - -	7	-	- - -	-
Sodium	540	- - -	6	12	- - -	7	-	- - -	-
Strontium	-	- - -	-	-	- - -	-	-	- - -	-
Sulfur	7,800,000	- - -	6	100	- - -	7	-	- - -	-
Thorium	-	- - -	-	-	- - -	-	-	- - -	-
Tin	200	- - -	6	0.6	- - -	7	-	- - -	-
Titanium	870	- - -	6	6.2	- - -	7	-	- - -	-
Vanadium	200	- - -	6	2.0	- - -	7	-	- - -	-
Zinc	410	- - -	6	39	- - -	7	19,000	- - -	4
Zirconium	-	- - -	-	-	- - -	-	-	- - -	-

[a] Cyclone or impingement tray scrubber.

[b] Venturi scrubber alone or in series with low-energy devices.

[c] One data point.

[d] Overall control by venturi scrubber, impingement tray scrubber and afterburner in series.

[e] From pilot scale control device.

TABLE 4-4. INORGANIC COMPOUND EMISSION FACTORS IN ENGLISH UNITS ON A TOTAL FEED BASIS FOR MULTIPLE HEARTH FURNACES BURNING SEWAGE SLUDGE

(lbs of Pollutant Emitted per ton of Dry Sludge Feed) $\times 10^6$

Pollutant	Uncontrolled		References	After Low-Energy Scrubber[a]		References	After High-Energy Scrubber[b]		References
	Average	Range		Average	Range		Average	Range	
Aluminum	880,000	1,500 - 1,800,000	6,7	2,000	610 - 50,000	19	590,000[c]	- - -	6
Antimony	3,200	94 - 6,400	6,7	610	390 - 740	19	510[c]	- - -	6
Arsenic	11,000	320 - 57,000	2,4,6,7,14	4,100	230 - 21,000	19	630	41 - 1,700	2,6,14
Barium	49,000	83 - 99,000	6,7	3,400	230 - 9,300	19	13,000[c]	- - -	6
Beryllium	19	17 - 20	2	-	- - -	-	2[c]	- - -	2
Boron	-	- - -	-	-	- - -	-	-	- - -	-
Cadmium	38,000	2,000 - 110,000	2,4,6,7,14	27,000	1,100 - 100,000	19	4,100	470 - 16,000	1,2,4,6,14
Calcium	1,500,000	24,000 - 2,900,000	6,7	46,000	2,700 - 84,000	19	860,000[c]	- - -	6
Chromium	310,000	190 - 2,000,000	2,4,6,7,14	7,900	3,800 - 15,000	19	4,100	300 - 21,000	1,2,6,14
Cobalt	1,000	17 - 2,100	6,7	430	99 - 800	19	130[c]	- - -	6
Copper	460,000	2,100 - 1,800,000	6,7,14	18,000	5,600 - 30,000	19	11,000	1,400 - 22,000	4,6,14
Gold	4	2 - 6	6,7	-	- - -	-	2[c]	- - -	6
Iron	6,400,000	25,000 - 22,000,000	6,7,14	65,000	3,800 - 230,000	19	65,500	3,200 - 150,000	6,14
Lead	690,000	1,600 - 4,700,000	2,4,6,7,14	75,000	33,000 - 140,000	19	40,000	6,100 - 110,000	1,2,4,6,14
Magnesium	440,000	8,500 - 880,000	6,7	6,800	350 - 14,000	19	12,000[c]	- - -	6
Manganese	360,000	150 - 1,500,000	6,7,14	2,600	170 - 8,700	19	990	90 - 2,500	6,14
Molybdenum	-	- - -	-	-	- - -	-	-	- - -	-
Nickel	91,000	130 - 370,000	2,4,6,7,14	3,500	360 - 6,200	19	4,400	210 - 27,000	1,2,4,6,14
Phosphous	1,100,000	21,000 - 2,100,000	6,7	34,000	9,400 - 55,000	19	20,000[c]	- - -	6
Potassium	-	- - -	-	10,000	2,000 - 15,000	19	-	- - -	-
Selenium	-	- - -	-	1,300	430 - 3,000	19	-	- - -	-
Silicon	-	- - -	-	61,000	10,000 - 130,000	19	-	- - -	-
Silver	17,000	41 - 46,000	6,7,14	1,900	1,200 - 3,100	19	630	170 - 1,100	14
Sodium	140,000	2,100 - 280,000	6,7	12,000	4,000 - 23,000	19	36,000[c]	- - -	6
Strontium	-	- - -	-	-	- - -	-	-	- - -	-
Sulfur	16,000,000	7,600 - 32,000,000	6,7	39,000	30,000 - 43,000	19	400,000[c]	- - -	6
Thorium	-	- - -	-	-	- - -	-	-	- - -	-
Tin	20,000	510 - 39,000	6,7	21,000	12,000 - 39,000	19	18,000[c]	- - -	6
Titanium	130,000	2,800 - 240,000	6,7	5,500	270 - 14,000	19	9,400[c]	- - -	6
Vanadium	5,100	540 - 9,700	6,7	1,200	99 - 2,300	19	1,000[c]	- - -	6
Zinc	1,700,000	3,100 - 11,000,000	6,7,14	48,000	1,300 - 120,000	19	53,000	11,000 - 100,000	4,6,14
Zirconium	-	- - -	-	-	- - -	-	-	- - -	-

(continued)

TABLE 4-4. (Continued)

Pollutant	After ESP Average[c,e]	After ESP Range	References	After Fabric Filter Average[c,e]	After Fabric Filter Range	References	After Scrubber and Afterburner[d] Average[c]	After Scrubber and Afterburner[d] Range	References
Aluminum	300,000	- - -	6	1,800	- - -	7	-	- - -	-
Antimony	70	- - -	6	3.1	- - -	7	-	- - -	-
Arsenic	2,500	- - -	6	6.2	- - -	7	-	- - -	-
Barium	15,000	- - -	6	7.7	- - -	7	-	- - -	-
Beryllium	-	- - -	-	-	- - -	-	-	- - -	-
Boron	-	- - -	-	-	- - -	-	-	- - -	-
Cadmium	310	- - -	6	27	- - -	7	4,100	- - -	4
Calcium	740,000	- - -	6	190	- - -	7	-	- - -	-
Chromium	3,000	- - -	6	34	- - -	7	-	- - -	-
Cobalt	750	- - -	6	4.7	- - -	7	-	- - -	-
Copper	390	- - -	6	4.4	- - -	7	10,000	- - -	4
Gold	-	- - -	-	-	- - -	-	-	- - -	-
Iron	54,000	- - -	6	200	- - -	7	-	- - -	-
Lead	3,300	- - -	6	11	- - -	7	65,000	- - -	4
Magnesium	18,000	- - -	6	60	- - -	7	-	- - -	-
Manganese	730	- - -	6	0.5	- - -	7	-	- - -	-
Molybdenum	-	- - -	-	-	- - -	-	-	- - -	-
Nickel	11,000	- - -	6	12	- - -	7	410	- - -	4
Phosphous	14,000	- - -	6	83	- - -	7	-	- - -	-
Potassium	-	- - -	-	-	- - -	-	-	- - -	-
Selenium	-	- - -	-	3.7	- - -	7	-	- - -	-
Silicon	-	- - -	-	-	- - -	-	-	- - -	-
Silver	-	- - -	-	1.9	- - -	7	-	- - -	-
Sodium	1,100	- - -	6	23	- - -	7	-	- - -	-
Strontium	-	- - -	-	-	- - -	-	-	- - -	-
Sulfur	16,000,000	- - -	6	200	- - -	7	-	- - -	-
Thorium	-	- - -	-	-	- - -	-	-	- - -	-
Tin	400	- - -	6	1.3	- - -	7	-	- - -	-
Titanium	1,700	- - -	6	13	- - -	7	-	- - -	-
Vanadium	420	- - -	6	4	- - -	7	-	- - -	-
Zinc	820	- - -	6	80	- - -	7	38,000	- - -	4
Zirconium	-	- - -	-	-	- - -	-	-	- - -	-

[a]Cyclone or impingement tray scrubber.

[b]Venturi scrubber alone or in series with low-energy devices.

[c]One data point.

[d]Overall control by venturi scrubber, impingement tray scrubber and afterburner in series.

[e]From pilot scale control device.

fabric filter. It should be noted that data from reference 14 are apparently biased high. The test report authors noted, but did not explain their "consistent error", and reported an average of 20 percent more mass emitted than fed, on a compound-specific basis. No attempt has been made here to adjust or modify the values reported by the original reference. Unreasonable (physically impossible) results have been individually noted in the tables.

4.2 EMISSION FACTORS FOR FLUIDIZED BED COMBUSTORS

Emission factors for inorganic compound emissions from fluidized bed combustors are presented in Table 4-5 through 4-8. Fluidized bed combustors are generally controlled by high-energy scrubbers, and no data are available for any other control devices. Emission factors are presented for both uncontrolled and controlled emissions.

4.3 EMISSION FACTORS FOR ORGANIC COMPOUNDS

Emission factors for volatile organic compounds are presented in Tables 4-9 and 4-10 in SI and English units, respectively. All data are from multiple hearth furnaces and are separated by control device type. All tested facilities are controlled by a venturi scrubber; emissions controlled by a scrubber and an afterburner are reported separately. Uncontrolled emissions are also reported.

Emission factors for semivolatile compounds are reported in Tables 4-11 and 4-12 in SI and English units, respectively. Emission factors are for uncontrolled and controlled emissions. All data are for emissions from multiple hearth furnaces except one FBC data set controlled by a high energy scrubber. The emission factors from the FBC facility were within the range of the MHF data and were therefore not reported separately.

4.4 OTHER COMBUSTOR TYPES

Emission factors for the other sludge incinerator types described in Section 3 have not been separately prepared because of insufficient data. The expected emissions from electric furnaces, single hearth cyclones, rotary kilns, and high pressure wet air oxidation systems cannot be quantified with the available data. Data for emissions from co-incineration of sewage sludge with refuse are also not available.

TABLE 4-5. INORGANIC COMPOUND EMISSION FACTORS ON A COMPOUND FEED BASIS FOR FLUIDIZED BED COMBUSTORS BURNING SEWAGE SLUDGE

(Mass of Pollutant Emitted per Mass in Sludge Feed) x 10^6

Pollutant	Uncontrolled		References	After Low-Energy Scrubber[a]		References	After High-Energy Scrubber[b]		References
	Average	Range		Average[c]	Range		Average	Range	
Aluminum	-	- -	-	150	- - -	19	-	- - -	-
Antimony	-	- -	-	760	- - -	19	-	- - -	-
Arsenic	-	- -	-	3,700	- - -	19	4,300[b]	1,100 - 7,500	3,20
Barium	-	- -	-	170	- - -	19	-	- - -	-
Beryllium	-	- -	-	-	- - -	-	-	- - -	-
Boron	-	- -	-	-	- - -	-	-	- - -	-
Cadmium	210,000	55,000 - 360,000	14	340	- - -	19	60,000	460 - 138,000	3,14,18,20
Calcium	-	- -	-	220	- - -	19	-	- - -	-
Chromium	64,000	46,000 - 82,000	14	240	- - -	19	2,600	34 - 7,000	3,14,,18,20
Cobalt	-	- -	-	2,300	- - -	19	-	- - -	-
Copper	69,000	45,000 - 93,000	14	200	- - -	19	1,300	14 - 6,000	14,18,20
Gold	-	- -	-	-	- - -	-	-	- - -	-
Iron	85,000	79,000 - 91,000	14	110	- - -	19	520	1.9 - 1,300	14
Lead	300,000	72,000 - 520,000	14	740	- - -	19	110,000	160 - 510,000	3,14,18,20
Magnesium	-	- -	-	220	- - -	19	-	- - -	-
Manganese	61,000	41,000 - 82,000	14	260	- - -	19	2,400	0.55 - 4,700	3,14
Molybdenum	-	- -	-	-	- - -	-	-	- - -	-
Nickel	1,800,000[c]	53,000 - 3,500,000[c]	14	1,400	- - -	19	210,000	7.4 - 850,000	3,14,18,20
Phosphous	-	- -	-	200	- - -	19	-	- - -	-
Potassium	-	- -	-	170	- - -	19	-	- - -	-
Selenium	-	- -	-	1,700	- - -	19	-	- - -	-
Silicon	-	- -	-	61	- - -	19	-	- - -	-
Silver	2,500,000[c]	46,000 - 5,000,000[c]	14	-	- - -	-	1,700,000[d]	40 - 3,300,000[d]	3,14
Sodium	-	- -	-	640	- - -	19	-	- - -	-
Strontium	-	- -	-	-	- - -	-	-	- - -	-
Sulfur	-	- -	-	3,400	- - -	19	-	- - -	-
Thorium	-	- -	-	-	- - -	-	-	- - -	-
Tin	-	- -	-	460	- - -	19	-	- - -	-
Titanium	-	- -	-	160	- - -	19	-	- - -	-
Vanadium	-	- -	-	1,100	- - -	19	-	- - -	-
Zinc	74,000	52,000 - 95,000	14	330	- - -	19	620	290 - 1,400	3,14,18,20
Zirconium	-	- -	-	-	- - -	-	-	- - -	-

[a] Impingement tray scrubber or cyclone.

[b] Venturi followed by impingement tray scrubber.

[c] One data point.

[d] Reference 14 tests are biased; emissions reported are greater than quantity fed in some cases.

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TABLE 4-6. INORGANIC COMPOUND EMISSION FACTORS ON A TOTAL PARTICULATE EMISSION BASIS FOR FLUIDIZED BED COMBUSTORS BURNING SEWAGE SLUDGE

(Mass of Pollutant Emitted per Mass of Total Particulate Emitted) x 10^6

Pollutant	Uncontrolled		References	After Low-Energy Scrubber[a]		References	After High-Energy Scrubber[b]		References
	Average	Range		Average[c]	Range		Average	Range	
Aluminum	-	- - -	-	31,000	- - -	19	90,000[c]	- - -	11
Antimony	-	- - -	-	-	- - -	-	-	- - -	-
Arsenic	19	1.3 - 36	14	-	- - -	-	18,000	8.7 - 70,000	3,11,14,20
Barium	-	- - -	-	4,000	- - -	19	2,200[c]	- - -	11
Beryllium	-	- - -	-	-	- - -	-	-	- - -	-
Boron	-	- - -	-	-	- - -	-	670[c]	- - -	11
Cadmium	47	7.9 - 87	14	1,300	- - -	19	150,000	110 - 740,000	3,11,14,20
Calcium	-	- - -	-	88,000	- - -	19	140,000[c]	- - -	11
Chromium	370	64 - 670	14	2,800	- - -	19	360,000	78 - 1,800,000[d]	3,11,14,20
Cobalt	-	- - -	-	-	- - -	-	17[c]	- - -	11
Copper	3,200	170 - 6,300	14	2,800	- - -	19	12,000	280 - 42,000	11,14,20
Gold	-	- - -	-	-	- - -	-	-	- - -	-
Iron	39,000	770 - 76,000	14	45,000	- - -	19	12,000	520 - 24,000	11,14
Lead	1,500	280 - 2,700	14	23,000	- - -	19	320,000	990 - 1,200,000[d]	3,11,14,20
Magnesium	-	- - -	-	10,000	- - -	19	17,000[c]	- - -	11
Manganese	4,400	26 - 8,900	14	4,600	- - -	19	1,800	16 - 4,600	11,14
Molybdenum	-	- - -	-	-	- - -	-	61[c]	- - -	11
Nickel	630	600 - 660	14	-	- - -	-	3,800,000[d]	22 - 15,000,000[d]	3,11,14
Phosphous	-	- - -	-	41,000	- - -	19	63,000[c]	- - -	11
Potassium	-	- - -	-	11,000	- - -	19	9,100[c]	- - -	11
Selenium	-	- - -	-	3,600	- - -	19	-	- - -	-
Silicon	-	- - -	-	53,000	- - -	19	170,000[c]	- - -	11
Silver	250	150 - 360	14	-	- - -	-	41,000	36 - 120,000	11,14
Sodium	-	- - -	-	20,000	- - -	19	31,000[c]	- - -	11
Strontium	-	- - -	-	-	- - -	-	590[c]	- - -	11
Sulfur	-	- - -	-	140,000	- - -	19	-	- - -	-
Thorium	-	- - -	-	-	- - -	-	-	- - -	-
Tin	-	- - -	-	5,900	- - -	19	-	- - -	-
Titanium	-	- - -	-	6,600	- - -	19	1,100[c]	- - -	11
Vanadium	-	- - -	-	1,800	- - -	19	28[c]	- - -	11
Zinc	4,000	170 - 7,800	14	17,000	- - -	19	6,200	4,200 - 9,400	11,14,20
Zirconium	-	- - -	-	-	- - -	-	17[c]	- - -	11

[a]Cyclone or impingement tray scrubber.

[b]Venturi followed by impingement tray scrubber.

[c]One data point.

[d]Reference 14 tests are biased; emissions reported are greater than quantity fed in some cases.

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TABLE 4-7. INORGANIC COMPOUND EMISSION FACTORS IN SI UNITS ON A TOTAL FEED BASIS FOR FLUIDIZED BED COMBUSTORS BURNING SEWAGE SLUDGE

(grams of Pollutant Emitted per megagram of Dry Sludge Feed) x 10^3

Pollutant	Uncontrolled		References	After Low-Energy Scruber[a]		References	After High-Energy Scrubber[a]		References
	Average	Range		Average[c]	Range		Average	Range	
Aluminum	-	- - -	-	1,900	- - -	19	-	- - -	-
Antimony	-	- - -	-	24	- - -	19	-	- - -	-
Arsenic	700	350 - 1,000	14	340	- - -	19	50	2.8 - 120	3,14,20
Barium	-	- - -	-	240	- - -	19	-	- - -	-
Beryllium	-	- - -	-	-	- - -	-	-	- - -	-
Boron	-	- - -	-	-	- - -	-	-	- - -	-
Cadmium	3,500	1,000 - 6,000	14	85	- - -	19	800	3.5 - 3,100	3,14,18,20
Calcium	-	- - -	-	5,000	- - -	19	-	- - -	-
Chromium	285,000	6,500 - 500,000	14	170	- - -	19	280	2.4 - 700	3,14,18,20
Cobalt	-	- - -	-	70	- - -	19	-	- - -	-
Copper	97,000	60,000 - 135,000	14	170	- - -	19	1,300	10 - 3,600	14,18,20
Gold	-	- - -	-	-	- - -	-	-	- - -	-
Iron	670,000	600,000 - 730,000	14	2,700	- - -	19	3,200	20 - 6,500	14
Lead	125,000	26,000 - 220,000	14	1,400	- - -	19	40,000	60 - 190,000	3,14,18,20
Magnesium	-	- - -	-	600	- - -	19	-	- - -	-
Manganese	52,000	20,000 - 85,000	14	270	- - -	19	1,200	0.60 - 2,400	14
Molybdenum	-	- - -	-	-	- - -	-	-	- - -	-
Nickel	260,000	5,500 - 520,000	14	260	- - -	19	35,000	0.80 - 135,000	3,14,18
Phosphous	-	- - -	-	2,500	- - -	19	-	- - -	-
Potassium	-	- - -	-	650	- - -	19	-	- - -	-
Selenium	-	- - -	-	220	- - -	19	-	- - -	-
Silicon	-	- - -	-	3,200	- - -	19	-	- - -	-
Silver	59,000	3,500 - 115,000	14	-	- - -	-	33,000	3.0 - 67,000	14
Sodium	-	- - -	-	1,200	- - -	19	-	- - -	-
Strontium	-	- - -	-	-	- - -	-	-	- - -	-
Sulfur	-	- - -	-	8,500	- - -	19	-	- - -	-
Thorium	-	- - -	-	-	- - -	-	-	- - -	-
Tin	-	- - -	-	360	- - -	19	-	- - -	-
Titanium	-	- - -	-	390	- - -	19	-	- - -	-
Vanadium	-	- - -	-	110	- - -	19	-	- - -	-
Zinc	100,000	75,000 - 140,000	14	1,000	- - -	19	1,200	240 - 2,500	14,20
Zirconium	-	- - -	-	-	- - -	-	-	- - -	-

[a]Cyclone or impingement tray scrubber.

[b]Venturi followed by impingement tray scrubber.

[c]One data point.

TABLE 4-8. INORGANIC COMPOUND EMISSION FACTORS IN ENGLISH UNITS ON A TOTAL FEED BASIS FOR FLUIDIZED BED COMBUSTORS BURNING SEWAGE SLUDGE

(lbs of Pollutant Emitted per ton of Dry Sludge Feed) x 10^3

Pollutant	Uncontrolled		References	After Low-Energy Scrubber[a]		References	After High-Energy Scrubber[b]		References
	Average	Range		Average[c]	Range		Average	Range	
Aluminum	-	- - -	-	3.8	- - -	19	-	- - -	-
Antimony	-	- - -	-	0.047	- - -	19	-	- - -	-
Arsenic	1.4	0.7 - 2.0	14	0.68	- - -	19	0.10	0.0056 - 0.25	3,14,20
Barium	-	- - -	-	0.47	- - -	19	-	- - -	-
Beryllium	-	- - -	-	-	- - -	-	-	- - -	-
Boron	-	- - -	-	-	- - -	-	-	- - -	-
Cadmium	7.0	2.0 - 12	14	0.17	- - -	19	1.6	0.007 - 6.3	3,14,18,20
Calcium	-	- - -	-	10	- - -	19	-	- - -	-
Chromium	57	13 - 100	14	0.33	- - -	19	0.56	0.0047 - 1.4	3,14,18,20
Cobalt	-	- - -	-	0.14	- - -	19	-	- - -	-
Copper	190	120 - 270	14	0.33	- - -	19	2.6	0.02 - 7.6	14,18,20
Gold	-	- - -	-	-	- - -	-	-	- - -	-
Iron	1,300	1,200 - 1,500	14	5.3	- - -	19	6.4	0.04 - 13	14
Lead	250	52 - 440	14	2.7	- - -	19	79	0.12 - 380	3,14,18,20
Magnesium	-	- - -	-	1.2	- - -	19	-	- - -	-
Manganese	100	41 - 170	14	0.54	- - -	19	2.5	0.0012 - 4.9	14
Molybdenum	-	- - -	-	-	- - -	-	-	- - -	-
Nickel	520	11 - 1,000	14	0.52	- - -	19	70	0.0016 - 270	3,14,18
Phosphous	-	- - -	-	5.0	- - -	19	-	- - -	-
Potassium	-	- - -	-	1.3	- - -	19	-	- - -	-
Selenium	-	- - -	-	0.43	- - -	19	-	- - -	-
Silicon	-	- - -	-	6.4	- - -	19	-	- - -	-
Silver	120	7.0 - 230	14	-	- - -	-	67	0.006 - 130	14
Sodium	-	- - -	-	2.4	- - -	19	-	- - -	-
Strontium	-	- - -	-	-	- - -	-	-	- - -	-
Sulfur	-	- - -	-	17	- - -	19	-	- - -	-
Thorium	-	- - -	-	-	- - -	-	-	- - -	-
Tin	-	- - -	-	0.71	- - -	19	-	- - -	-
Titanium	-	- - -	-	0.78	- - -	19	-	- - -	-
Vanadium	-	- - -	-	0.21	- - -	19	-	- - -	-
Zinc	210	150 - 270	14	2.0	- - -	19	2.4	0.48 - 5.1	14,20
Zirconium	-	- - -	-	-	- - -	-	-	- - -	-

[a] Cyclone or impingement tray scrubber.

[b] Venturi followed by impingement tray scrubber.

[c] One data point.

TABLE 4-9. VOLATILE ORGANIC COMPOUND EMISSION FACTORS IN SI UNITS FOR MULTIPLE HEARTH AND FLUIDIZED BED INCINERATORS BURNING SEWAGE SLUDGE (grams of Pollutant Emitted per megagram of Dry Sludge Feed) x 10^3

Pollutant	Uncontrolled		References	After High Energy Scrubber[a]		References	After Scrubber and Afterburner[b]		References
	Average	Range		Average	Range		Average[c]	Range	
Acetone	-	- - -	-	3,400[c]	- - -	5	-	- - -	-
Acetonitrile	69,000	54,000 - ∞	4	9,700[c]	- - -	4	740	- - -	4
Acrylonitrile	34,000	22,000 - 47,000	2,4	22,000	8,200 - 33,000	1,2,4	490	- - -	4
Benzene	7,500	5,800 - 9,800	2,4,5	8,300	400 - 14,000	1,2,3,4,5	170	- - -	4
Bromodichloromethane	9,800	7,600 - 12,000	4	1,500[c]	- - -	5	-	- - -	-
Bromomethane	760[c]	- - -	5	-	- - -	-	-	- - -	-
Carbon Tetrachloride	22	3.1 - 37	2,4	24	3.1 - 68	1,2,3,4	8.8	- - -	4
Chlorobenzene	910	310 - 1,600	2,4,5	980	5.0 - 3,100	1,2,3,4,5	260	- - -	4
Chloroethane	430[c]	- - -	5	800[c]	- - -	5	-	- - -	-
Chloroform	71	5.1 - 140	2,4,5	3,300	5.1 - 8,500	1,2,3,4,5	490	- - -	4
1,1-Dichloroethane	-	- - -	-	350[c]	- - -	5	-	- - -	-
1,2-Dichloroethane	-	- - -	-	14[c]	- - -	1	31	- - -	4
Trans-1,2-Dichloroethene	49	6.0 - 92	2,5	1,300	6.0 - 5,200	1,2,4,5	-	- - -	-
1,1-Dichloroethene	20[c]	- - -	5	370[c]	- - -	5	-	- - -	-
Ethylbenzene	1,200	300 - 2,500	2,4,5	1,000	22 - 2,300	1,2,3,4,5	19	- - -	4
Methylene Chloride	85	29 - 140	4	1,500	76 - 2,200	1,3,4,5	420	- - -	4
Methyl Ethyl Ketone	6,900	1,200 - 12,000	2,4	5,700	1,200 - 8,900	2,4,5	50	- - -	4
Pyridine	-	- - -	-	-	- - -	-	-	- - -	-
Tetrachloroethene	800	290 - 1,400	2,4,5	5,700	130 - 21,000	1,2,3,4,5	910	- - -	4
Toluene	6,800	3,600 - 16,000	2,4,5	9,900	62 - 19,000	1,2,3,4,5	660	- - -	4
1,1,1-Trichloroethane	70	4.6 - 130	2,4,5	970	4.6 - 3,200	1,2,3,4,5	1,400	- - -	4
Trichloroethene	250	55 - 440	2,4,5	1,500	11 - 4,400	1,2,3,4,5	1,500	- - -	4
Vinyl Chloride	5,100	1,100 - 9,600	2,4,5	3,800	800 - 9,600	1,2,4,5	-	- - -	-
Xylene, m/p-	670[c]	- - -	5	2,000[c]	- - -	5	-	- - -	-
Xylene, o-	950[c]	- - -	5	1,500	960 - 2,000	5	-	- - -	-

[a] Venturi scrubber alone or in series with other low-energy devices.

[b] Overall control by venturi scrubber, impingement tray scrubber, and afterburner in series.

[c] One data point.

TABLE 4-10. VOLATILE ORGANIC COMPOUND EMISSION FACTORS IN ENGLISH UNITS FOR MULTIPLE HEARTH AND FLUIDIZED BED INCINERATORS BURNING SEWAGE SLUDGE (lbs of Pollutant Emitted per ton of Dry Sludge Feed) x 10^6

Pollutant	Uncontrolled		References	After High Energy Scrubber[a]		References	After Scrubber and Afterburner[b]		References
	Average	Range		Average	Range		Average[c]	Range	
Acetone	-	- - -	-	6,800[c]	- - -	5	-	- - -	-
Acetonitrile	140,000	110,000 - ∞	4	19,000[c]	- - -	4	15	- - -	4
Acrylonitrile	68,000	44,000 - 94,000	2,4	45,000	16,000 - 67,000	1,2,4	970	- - -	4
Benzene	15,000	12,000 - 20,000	2,4,5	17,000	800 - 28,000	1,2,3,4,5	340	- - -	4
Bromodichloromethane	20,000	15,000 - 24,000	4	3,000[c]	- - -	5	-	- - -	-
Bromomethane	1,500[c]	- - -	5	-	- - -	-	-	- - -	-
Carbon Tetrachloride	45	62 - 75	2,4	48	6.3 - 140	1,2,3,4	18	- - -	4
Chlorobenzene	1,800	620 - 3,300	2,4,5	1,900	10 - 6,100	1,2,3,4,5	530	- - -	4
Chloroethane	860[c]	- - -	5	1,600[c]	- - -	5	-	- - -	-
Chloroform	140	10 - 280	2,4,5	6,600	10 - 17,000	1,2,3,4,5	980	- - -	4
1,1-Dichloroethane	-	- - -	-	700[c]	- - -	5	-	- - -	-
1,2-Dichloroethane	-	- - -	-	28[c]	- - -	1	62	- - -	4
Trans-1,2-Dichloroethene	98	12 - 180	2,5	2,700	12 - 10,000	1,2,4,5	-	- - -	-
1,1-Dichloroethene	40[c]	- - -	5	740[c]	- - -	5	-	- - -	-
Ethylbenzene	2,400	600 - 5,100	2,4,5	2,100	43 - 4,600	1,2,3,4,5	39	- - -	4
Methylene Chloride	170	58 - 280	4	2,900	150 - 4,400	1,3,4,5	850	- - -	4
Methyl Ethyl Ketone	14,000	2,300 - 24,000	2,4	11,000	2,300 - 18,000	2,4,5	10	- - -	4
Pyridine	-	- - -	-	-	- - -	-	-	- - -	-
Tetrachloroethene	1,600	580 - 2,900	2,4,5	11,000	270 - 43,000	1,2,3,4,5	1,800	- - -	4
Toluene	14,000	7,100 - 33,000	2,4,5	20,000	120 - 37,000	1,2,3,4,5	1,300	- - -	4
1,1,1-Trichloroethane	140	9.1 - 260	2,4,5	1,900	9.1 - 6,400	1,2,3,4,5	2,700	- - -	4
Trichloroethene	500	110 - 880	2,4,5	3,000	21 - 8,800	1,2,3,4,5	3,100	- - -	4
Vinyl Chloride	10,000	2,100 - 19,000	2,4,5	7,600	1,600 - 19,000	1,2,4,5	-	- - -	-
Xylene, m/p-	1,300[c]	- - -	5	4,000[c]	- - -	5	-	- - -	-
Xylene, o-	1,900[c]	- - -	5	3,000	1,900 - 4,000	5	-	- - -	-

[a] Venturi scrubber alone or in series with other low-energy devices.

[b] Overall control by venturi scrubber, impingement tray scrubber, and afterburner in series.

[c] One data point.

TABLE 4-11. SEMI-VOLATILE ORGANIC COMPOUND EMISSION FACTORS IN SI UNITS FOR MULTIPLE HEARTH AND FLUIDIZED BED INCINERATORS BURNING SEWAGE SLUDGE

(grams of Pollutant Emitted per megagram of Dry Sludge Feed)

Pollutant	Uncontrolled Average[a]	Uncontrolled Range	References	After Low-Energy Scrubber[b] Average[a]	After Low-Energy Scrubber[b] Range	References	After High-Energy Scrubber[c] Average[d]	After High-Energy Scrubber[c] Range	References
Dioxins (CDD), g/Mg x 10^6									
Mono-CDD	-	- - -	-	-	- - -	-	-	- - -	-
Di-CDD	-	- - -	-	-	- - -	-	60	29 - 100	4,10
Tri-CDD	-	- - -	-	-	- - -	-	120	1.7 - 230	4,10
2378-TCDD	-	- - -	-	0.94	- - -	17	1.3	0.22 - 2.6	4,15
Other-TCDD	35	- - -	17	54	- - -	17	90	1.1 - 150	4,15,16
Penta-CDD	1.4	- - -	17	7.2	- - -	17	47	0.76 - 84	4,15
Hexa-CDD	42	- - -	17	47	- - -	17	38	2.6 - 67	4,15
Hepta-CDD	220	- - -	17	150	- - -	17	15	0.59 - 24	4,15,16
Octa-CDD	250	- - -	17	110	- - -	17	16	3.1 - 29	4,15,16
Furans (CDF), g/Mg x 10^6									
Mono-CDF	-	- - -	-	-	- - -	-	31	2.8 - 47	4,10
Di-CDF	-	- - -	-	-	- - -	-	310	310 - 310	4
Tri-CDF	-	- - -	-	-	- - -	-	550	7.9 - 970	4,10
2378-TCDF	360	- - -	17	350	- - -	17	39	3.3 - 88	4,10,16
Other TCDF	980	- - -	17	1,000	- - -	17	230	19 - 580	4,10,15,16
Penta-CDF	880	- - -	17	690	- - -	17	84	4.8 - 200	4,10,15,16
Hexa-CDF	91	- - -	17	220	- - -	17	35	0.80 - 87	4,10,15,16
Hepta-CDF	510	- - -	17	430	- - -	17	21	1.0 - 53	4,10,15
Octa-CDF	520	- - -	17	320	- - -	17	3.6	0.20 - 8.6	4,10,15,16
Other Organics, g/Mg x 10^3									
Bis (2-ethyl hexyl) phthalate	1,100	- - -	2	-	- - -	-	650	250 - 960	1,2,3
1,2-Dichlorobenzene	410	- - -	2	190[a]	- - -	21	440[a]	- - -	2
1,3-Dichlorobenzene	-	- - -	-	-	- - -	-	40[a]	- - -	2
1,4-Dichlorobenzene	450	- - -	2	550[e]	- - -	21	1,300	510 - 2,200	1,2
Napthalene	22,000[e]	20,000 - 24,000	2,4	8,500[a]	- - -	21	1,900[a]	- - -	2
2-Nitrophenol	6,000	- - -	2	-	- - -	-	1,300[a]	- - -	2
Phenol	53,000[e]	49,000 - 57,000	2,4	490[a]	- - -	21	2,000[a]	- - -	2

[a]One data point.

[b]Impingement tray scrubber.

[c]Venturi alone or with other low-energy devices in series.

[d]Includes data from a fluidized bed combustor.

[e]More than one data point.

TABLE 4-12. SEMI-VOLATILE ORGANIC COMPOUND EMISSION FACTORS IN ENGLISH UNITS FOR MULTIPLE HEARTH AND FLUIDIZED BED INCINERATORS BURNING SEWAGE SLUDGE

(lbs of Pollutant Emitted per ton of Dry Sludge Feed)

Pollutant	Uncontrolled		References	After Low-Energy Scrubber[b]		References	After High-Energy Scrubber[c]		References
	Average[a]	Range		Average[a]	Range		Average[d]	Range	
Dioxins (CDD), lb/ton x 10^9									
Mono-CDD	-	- - -	-	-	- - -	-	-	- - -	-
Di-CDD	-	- - -	-	-	- - -	-	120	58 - 210	4,10
Tri-CDD	-	- - -	-	-	- - -	-	240	3.5 - 460	4,10
2378-TCDD	-	- - -	-	1.9	- - -	17	2.6	0.44 - 5.3	4,15
Other-TCDD	71	- - -	17	110	- - -	17	180	2.3 - 310	4,15,16
Penta-CDD	2.8	- - -	17	15	- - -	17	94	1.5 - 170	4,15
Hexa-CDD	83	- - -	17	94	- - -	17	75	5.2 - 130	4,15
Hepta-CDD	450	- - -	17	300	- - -	17	29	1.2 - 49	4,15,16
Octa-CDD	500	- - -	17	210	- - -	17	33	6.2 - 59	4,15,16
Furans (CDF), lb/ton x 10^9									
Mono-CDF	-	- - -	-	-	- - -	-	61	5.5 - 94	4,10
Di-CDF	-	- - -	-	-	- - -	-	620	620 - 620	4
Tri-CDF	-	- - -	-	-	- - -	-	1,100	16 - 1,900	4,10
2378-TCDF	71	- - -	17	700	- - -	17	79	6.6 - 180	4,10,16
Other TCDF	2,000	- - -	17	2,000	- - -	17	460	38 - 1,200	4,10,15,16
Penta-CDF	1,800	- - -	17	1,400	- - -	17	170	9.6 - 400	4,10,15,16
Hexa-CDF	180	- - -	17	440	- - -	17	70	1.6 - 170	4,10,15,16
Hepta-CDF	1,000	- - -	17	860	- - -	17	42	2.0 - 110	4,10,15
Octa-CDF	1,000	- - -	17	650	- - -	17	7.1	0.39 - 17	4,10,15,16
Other Organics, lb/ton x 10^6									
Bis (2-ethyl hexyl) phthalate	2,100	- - -	2	-	- - -	-	1,300[a]	500 - 1,900	1,2,3
1,2-Dichlorobenzene	820	- - -	2	370[a]	- - -	21	870[a]	- - -	2
1,3-Dichlorobenzene	-	- - -	-	-	- - -	-	80[a]	- - -	2
1,4-Dichlorobenzene	910	- - -	2	1,100[a]	- - -	21	2,700	1,000 - 4,300	1,2
Napthalene	44,000[e]	40,000 - 49,000	2,4	17,000	- - -	21	3,900[a]	- - -	2
2-Nitrophenol	12,000	- - -	2	-	- - -	-	2,700[a]	- - -	2
Phenol	110,000[e]	99,000 - 120,000	2,4	990[a]	- - -	21	4,000[a]	- - -	2

[a] One data point.

[b] Impingement tray scrubber.

[c] Venturi alone or with other low-energy devices in series.

[d] Includes one data set from a fluidized bed combustor; all other data from multiple hearth furnaces.

[e] More than one data point.

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5. SAMPLING AND ANALYSIS PROCEDURES

The purpose of this section is to provide a brief discussion of the EPA reference methods and/or generally accepted methods of sampling and analysis used to gather emissions data on air toxics emitted from sewage sludge incinerators. Different sampling and analytical methods than the ones described may have been used previously. Slight modifications of the methods may be specified by some State agencies to make results consistent with their regulatory compliance results. However, these sampling methods are widely used and accepted and should yield results comparable with data from other facilities.

This section presents a general description of the sampling and analytical methods for the determination of particulate, metals, CDD/CDF and other semivolatile organics, volatile organics and particle size air emissions from sewage sludge incinerators. EPA reference methods are described when available. Otherwise, the state-of-the-art draft methods are described.

5.1 PARTICULATE DETERMINATION BY EPA METHOD 5

The particulate mass is defined as any material which condenses at or above the filtration temperature of 248 ± 25°F after removal of uncombined water. The Method 5 sampling train is shown in Figure 5-1. The particulate matter is withdrawn isokinetically and collected on the glass fiber filter.

The particulate sample is recovered by rinsing the glass probe liner and front half of the glass filter holder with acetone. The acetone rinses are evaporated and desiccated along with the filter. Both fractions are weighed to a constant weight. The final weight is adjusted for an acetone blank.[1]

5.2 METALS DETERMINATION BY EPA/EMSL DRAFT PROTOCOL

Sampling for particulate matter and toxic metals is currently performed according to the EPA draft protocol entitled "Methodology for the Determination of Trace Metal Emissions in Exhaust Gases from Stationary

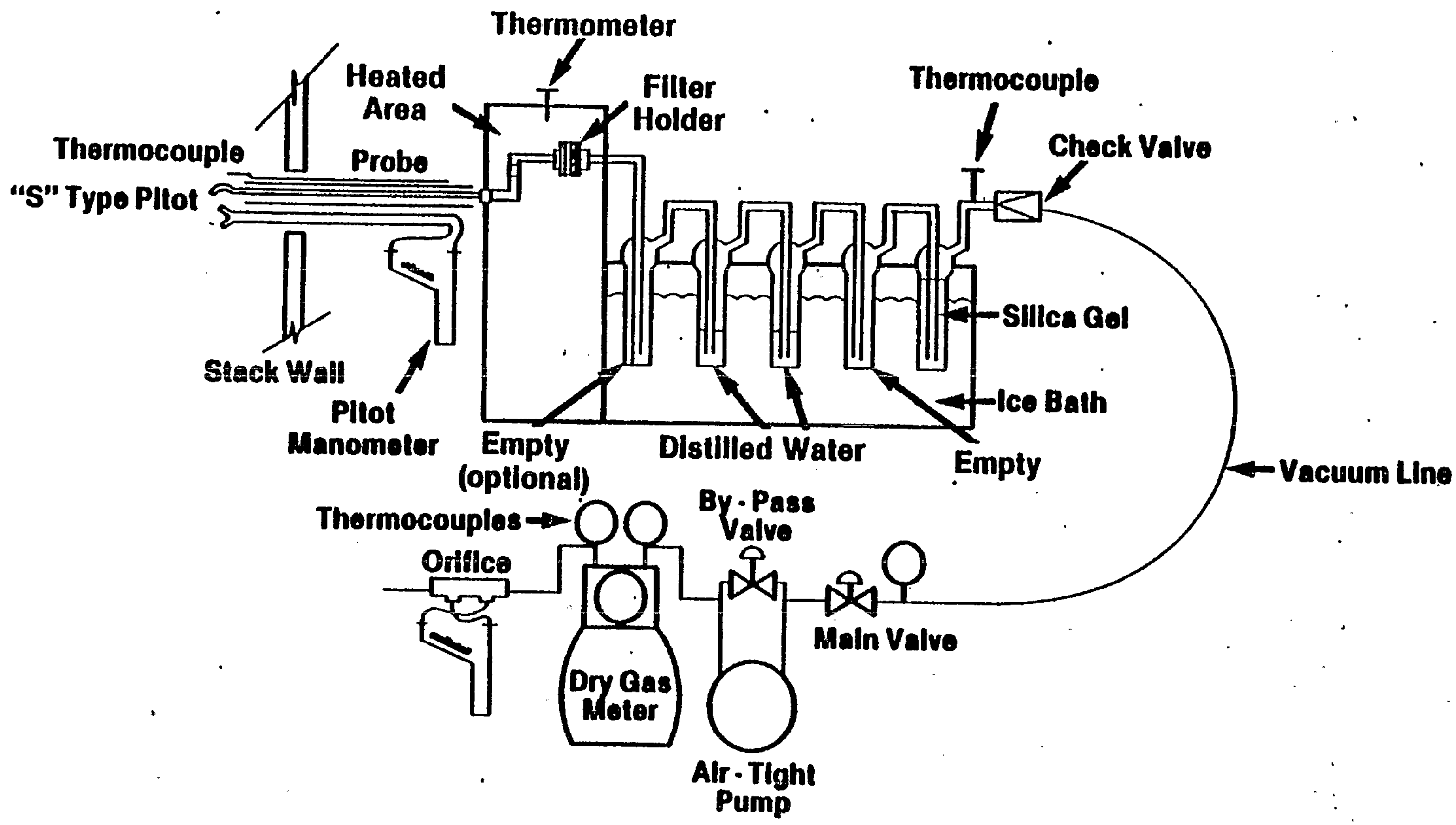

Figure 5-1. Particulate sampling train.

Source Combustion Processes."[2] This method is applicable for the determination of particulates and Pb, Zn P, Cr, Cu, Ni, Mn, Cd, Se, As, Hg, Be, Th, Ag, Sb, and Ba emissions from municipal waste incinerators, sewage sludge incinerators, and hazardous waste incinerators. The metals sampling train is shown in Figure 5-2.

Earlier sampling efforts may have employed EPA Method 12 which is specifically designed for lead. With Method 12, the flue gas passed through nitric acid only impingers which were than analyzed for the desired metals in additional to lead. However, some metals such as nickel and mercury, where found to be insufficiently collected in some cases.

The EPA draft method is based on Method 5 except for the following:

- The glassware is cleaned prior to sampling with an 8 hour soak in 10 percent (v/v) nitric acid solution.
- The impingers contain:
  - first impinger - empty
  - second impinger - HNO_3/H_2O_2
  - third impinger - HNO_3/H_2O_2
  - fourth impinger - acidic $KMnO_4$

The sampling train is recovered and the samples are analyzed according to the scheme shown in Figure 5-3. The first, second and third impingers are analyzed for all metals. The fourth impinger is analyzed only for mercury which is typically not collected efficiently in the HNO_3/H_2O_2 impingers.

The digested samples are analyzed by inductively coupled argon plasma (ICAP) spectroscopy for all metals except mercury. If arsenic or lead levels are less than 2 ppm, graphite furnace atomic absorption spectroscopy (AAS) is used. For mercury analysis, cold vapor AAS is used.

5.3 CDD/CDF AND PCB/PAH/CB/CP DETERMINATION BY THE DRAFT ASME/EPA METHOD

The state-of-the-art development for organics sampling is to collect CDD/CDF, polychlorinated biphenyls (PCB), polynuclear aromatic hydrocarbons (PAH), chlorobenzenes (CB), and chlorophenols (CP) in a single sampling train and to separate the fractions during analysis.[3,4] Previous sampling methods collected the CDD/CDF and PCB, PAH, CB and CP in separate trains

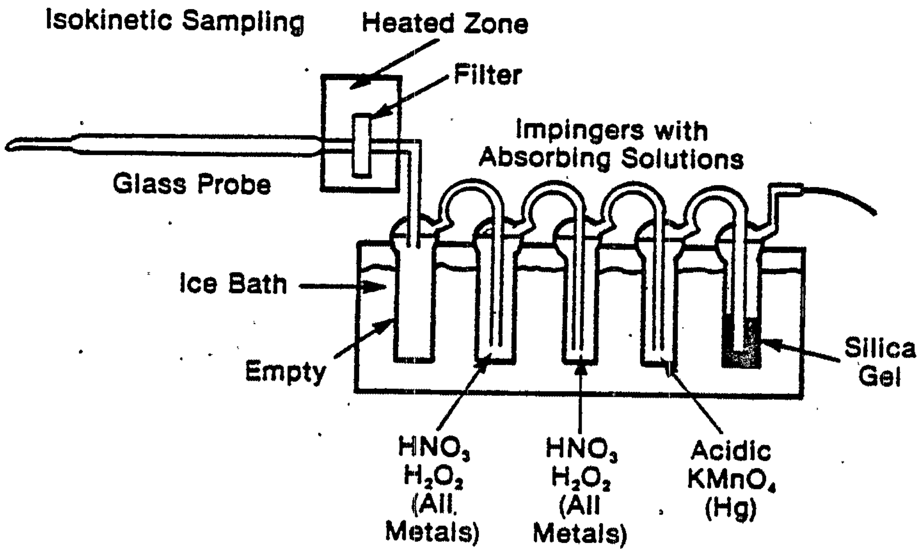

Figure 5-2. EMSL metals sampling train configuration.

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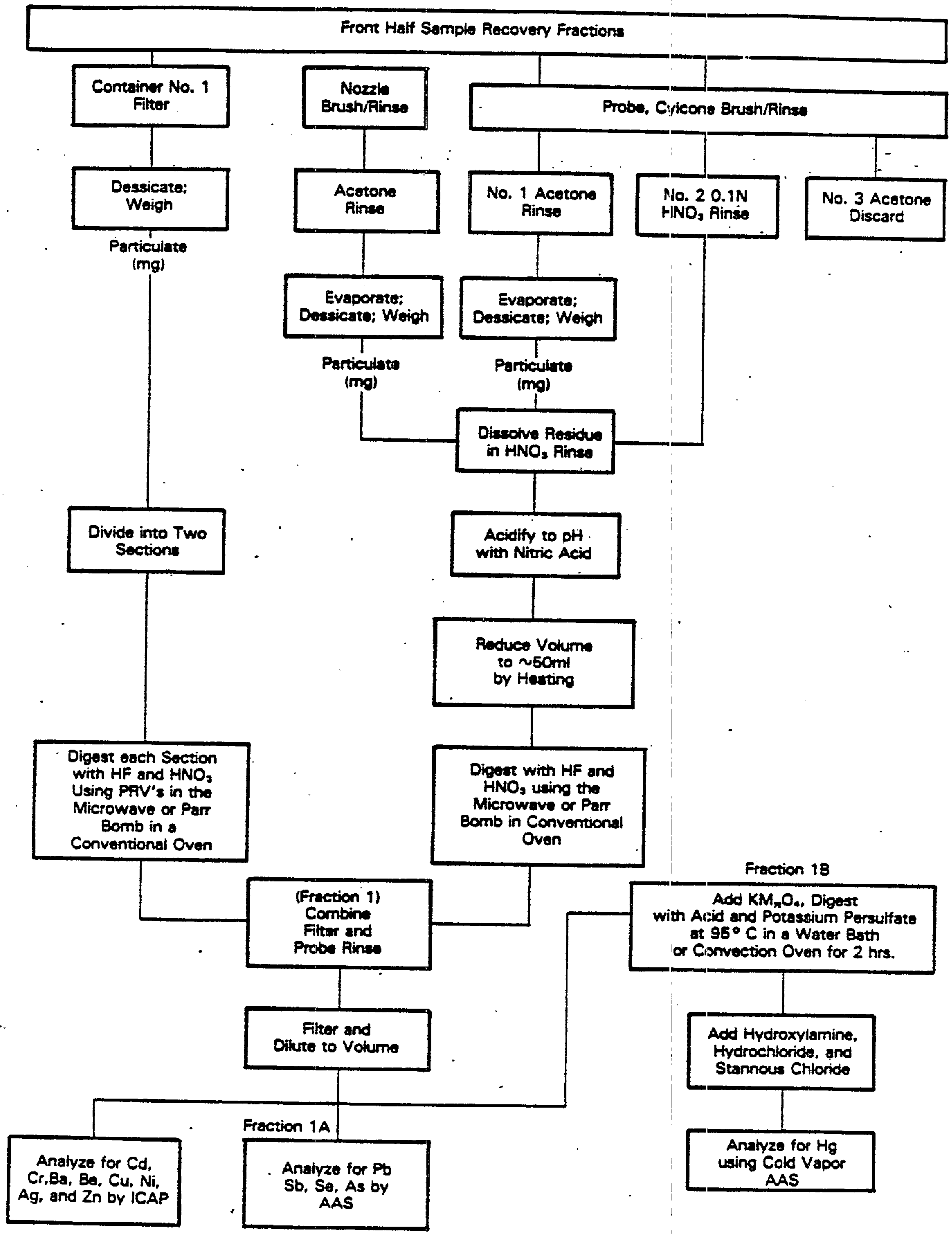

Figure 5-3. Digestion and analysis scheme for EMSL trace metal train components - front half.

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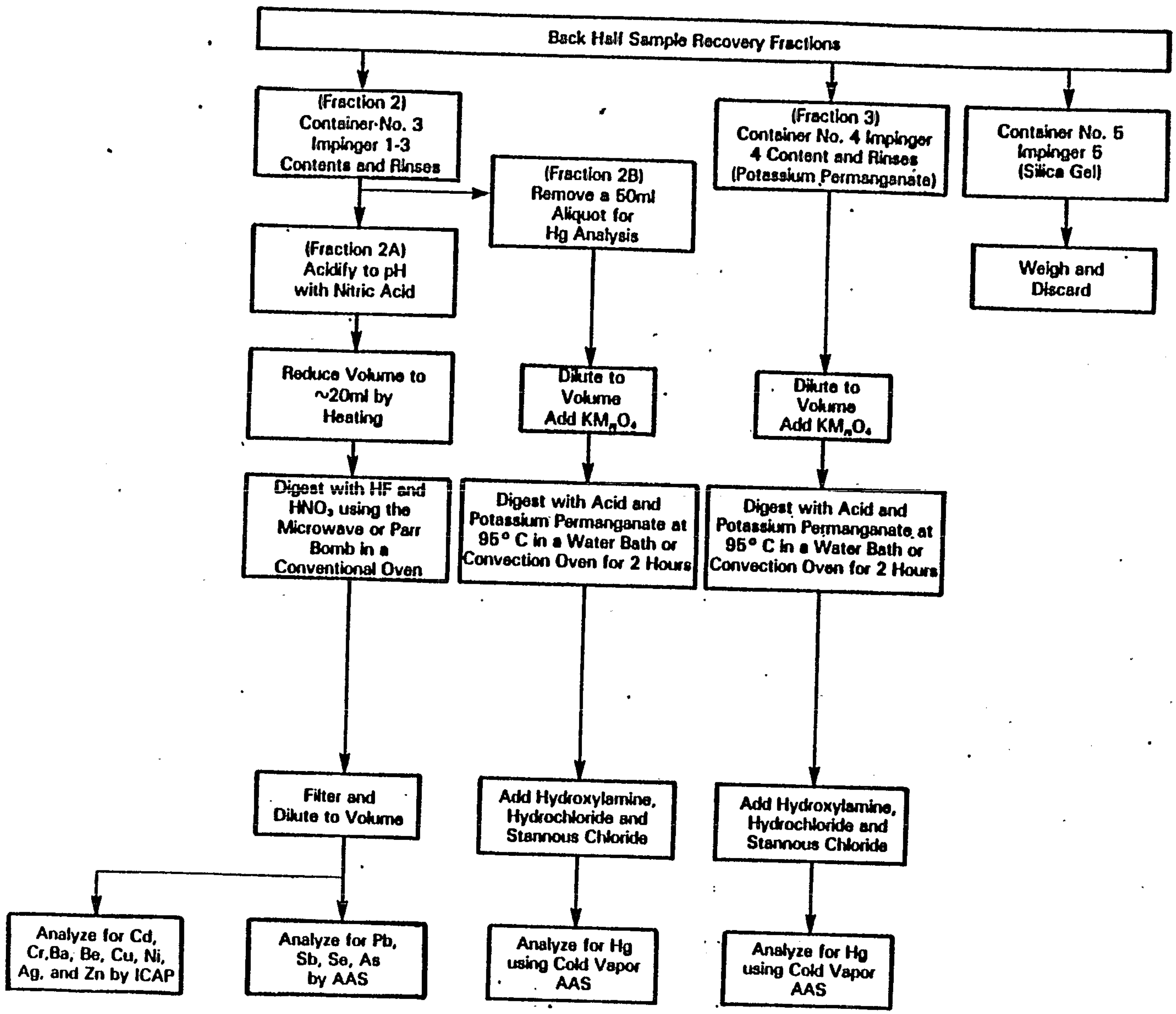


Figure 5-3. (Continued)

Digestion and analysis scheme for EMSL trace metal train components - back half.

that were essentially identical. Since December 1984 when the draft ASME/EPA method was prepared, many modifications have been incorporated, not all of which can be discussed in this brief section.

The sampling train is based on Method 5, but as shown in Figure 5-4, includes a condenser and XAD resin trap after the filter and before the impingers. The sampling train glassware, XAD resin, and filters are cleaned by baking, and rinsing with acetone and toluene prior to sampling. After sampling, the sampling train is recovered with acetone followed by methylene chloride and toluene rinses. The solvents should be of the highest grade available to prevent the introduction of chemical impurities which can interfere with the quantitative analytical determinations.

The state-of-the-art extraction scheme is shown in Figure 5-5. The extracted samples are analyzed by gas chromatography and mass spectroscopy (GC/MS). The typical organics available are summarized in Tables 5-1 and 5-2.

5.4 VOLATILE ORGANIC SAMPLING TRAIN (VOST) METHOD

Sampling for volatile organic compounds (VOC) is conducted according to SW-846, Method 0030. The sorbent cartridges are analyzed according to SW-846, Method 5040. Specific compounds of interest, which typically vary depending on the test program, are listed in Table 5-3. A brief flow diagram of the VOST analysis is shown in Figure 5-6.[5]

The VOST is designed to collect volatile organic compounds with boiling points between 30^{o}C and 100^{o}C and has a flue gas detection limit of about 0.1 ug/m^3 for most compounds. A schematic diagram of the VOST is shown in Figure 5-7. The flue gas is sampled from the stack through a glass probe with a glass wool plug. The probe temperature is maintained above 300^{o}F. The gas sample is then cooled to 68^{o}F by a water-cooled condenser and passes through a pair of resin traps in series, a silica gel drying tube, a rotameter, a sampling pump, and a dry gas meter. The first resin trap contains Tenax and the second trap contains Tenax followed by petroleum-based charcoal.

A VOST run consists of collecting four pairs of traps, with each pair used for 20 minutes at a sample flow rate of 1 liter per minute. The

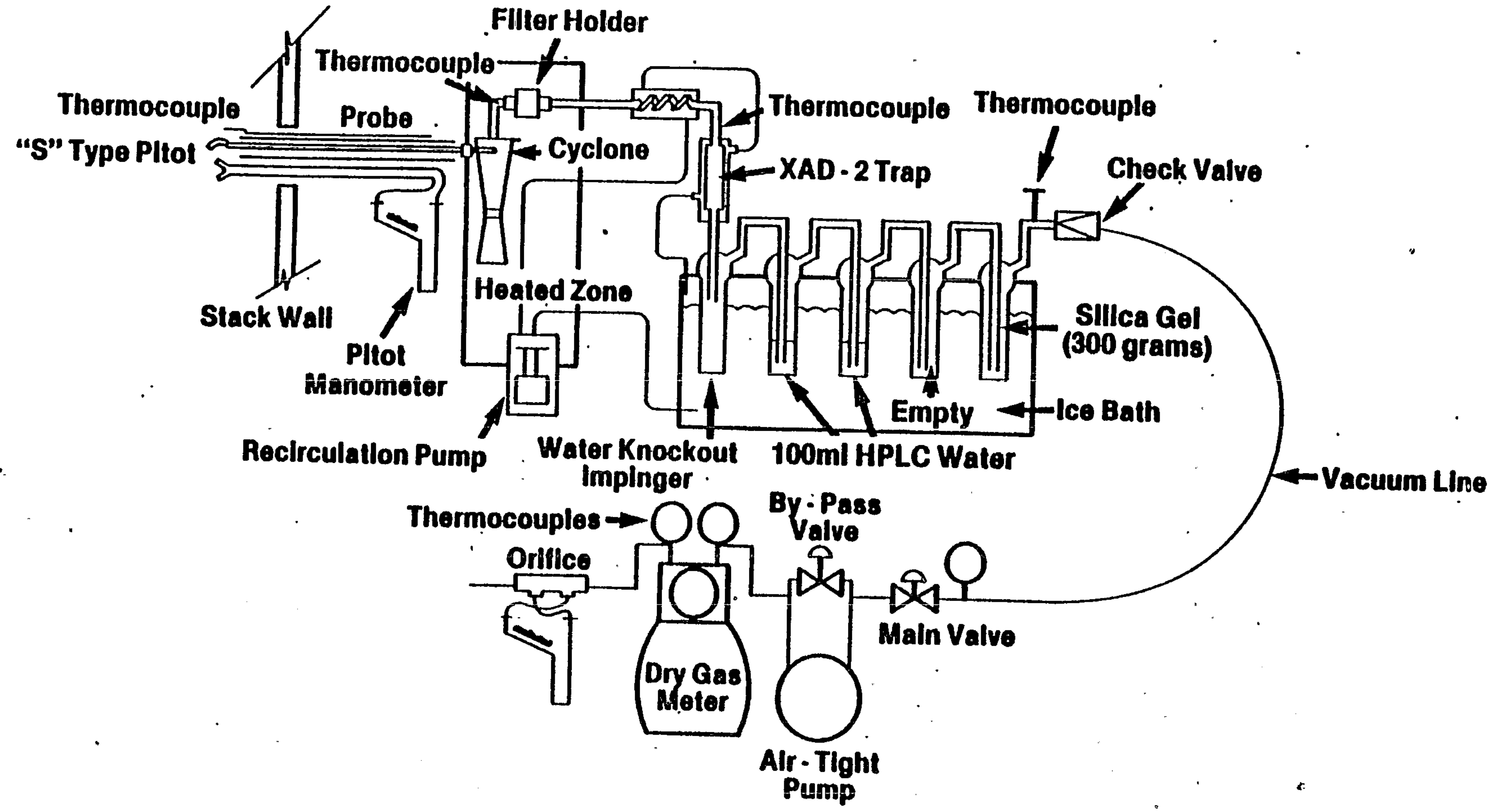


Figure 5-4. CDD/CDF/CB/CP/PCB/PAH sampling train configuration.

Fortification Standard I

nitrobenzene-d5 (50 ug)
2-fluorophenol (100 ug)

Fortification Standard II

phenol-d5 (100 ug)
2-fluorobiphenyl (50 ug)
terphenyl-d14 (50 ug)
3,4,3',3' tetra PCB-C13 (1 ug)
2,2',3,3',5,5',6,6'octaPCB-C13 (1 ug)

PCB Recovery Standard

Chrysene-d12 (0.1 ug)

CB,CP,PAH Internal Standards

1,4-dichlorbenzene-d4 (40 ug)
naphthalene-d8 (40 ug)
acenaphthalene-d10 (40 ug)
phenanthrene-d10 (40 ug)
chrysene-d12 (40 ug)
perylene-d12 (40 ug)

CDD/CDF Internal Standards

$^{13}C_{12}$-2,3,7,8-TCDD
$^{13}C_{12}$-1,2,3,7,8-PeCDD
$^{13}C_{12}$-1,2,3,6,7,8-HxCDD
$^{13}C_{12}$-1,2,3,4,6,7,8-HpCDD
$^{13}C_{12}$-OCDD
$^{13}C_{12}$-2,3,7,8-TCDF
$^{13}C_{12}$-1,2,3,7,8-PeCDF
$^{13}C_{12}$-1,2,3,6,7,8-HxCDF
$^{13}C_{12}$-1,2,3,4,6,7,8-HpCDF

CDD/CDF Surrogate Standards

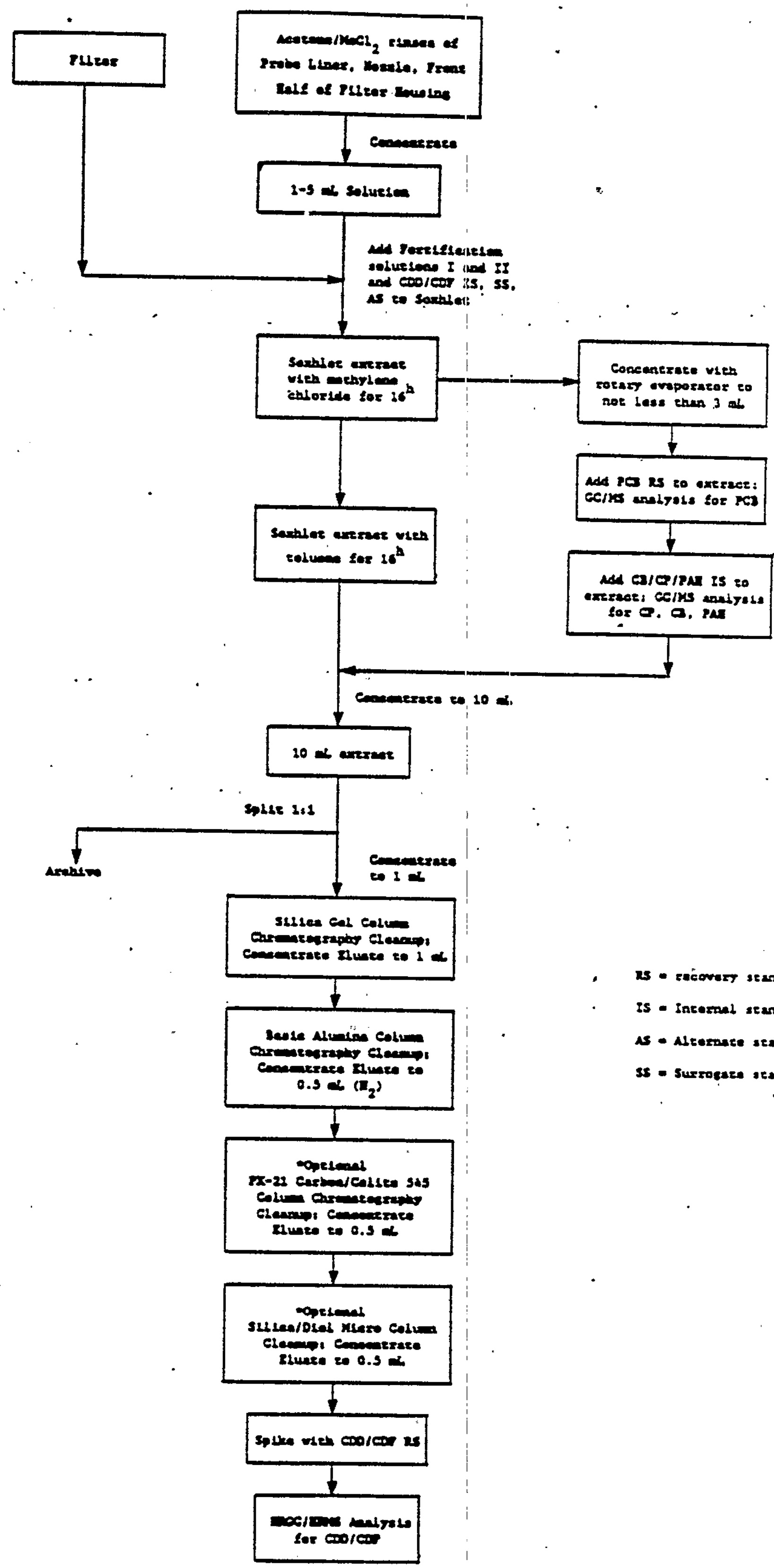
$^{37}Cl_4$-2,3,7,8-TCDD
$^{13}C_{12}$-1,2,3,4,7,8-HxCDD
$^{13}C_{12}$-2,3,4,7,8-PeCDF
$^{13}C_{12}$-1,2,3,4,7,8-HxCDF
$^{13}C_{12}$-1,2,3,4,7,8,9-HpCDF

CDD/CDF Alternate Standards

$^{13}C_{12}$-1,2,3,7,8,9-HxCDF

CDD/CDF Recovery Standards

$^{13}C_{12}$-1,2,3,4-TCDD
$^{13}C_{12}$-1,2,3,7,8,9-HxCDD



RS = recovery standard
IS = Internal standard
AS = Alternate standard
SS = Surrogate standard

Figure 5-5. Extraction and analysis schematic for CDD/CDF/CB/CP/PCB/PAH flue gas samples.

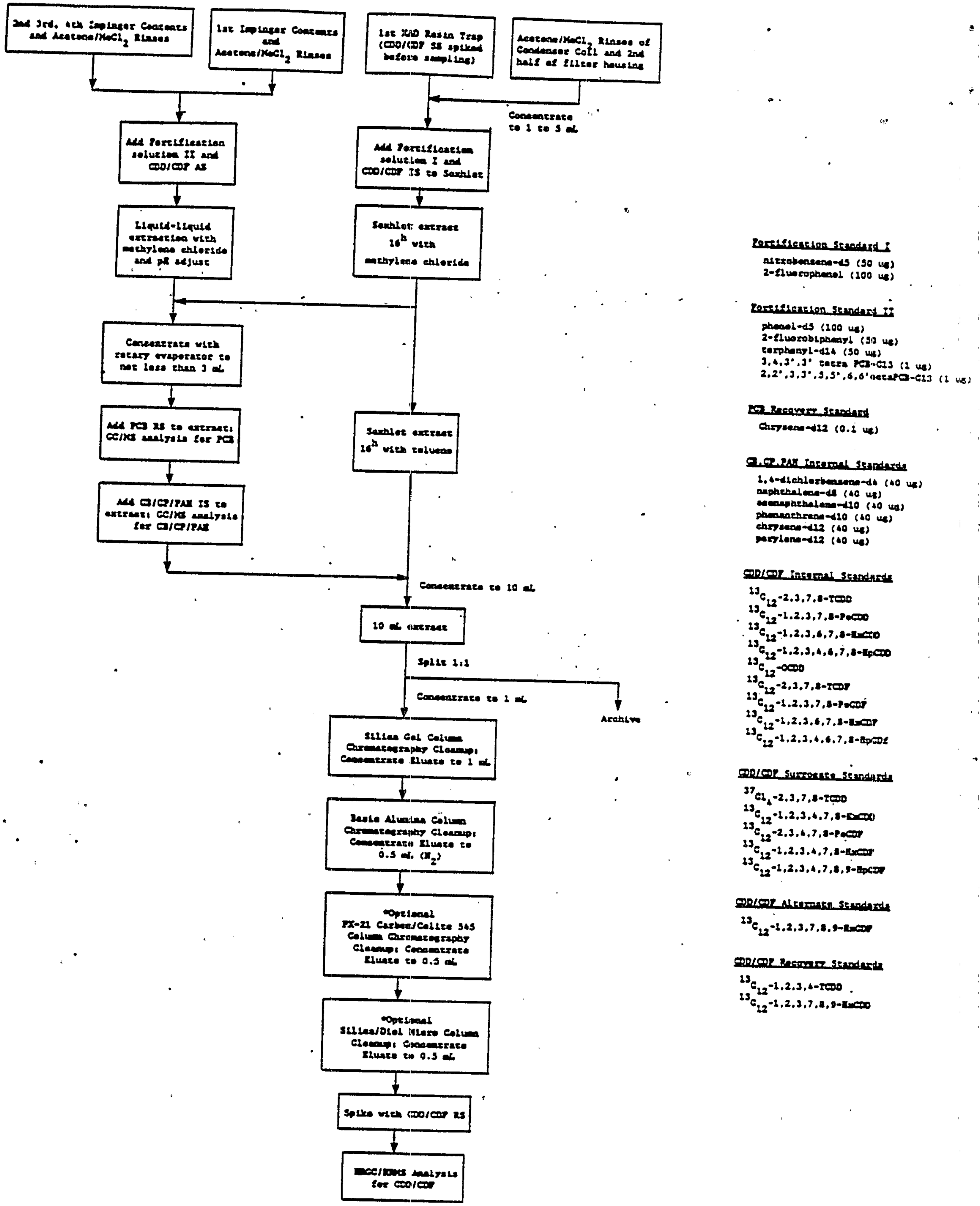


Figure 5-5. (Continued)

TABLE 5-1. TYPICAL CDD/CDF TARGET CONGENERS

DIOXINS	
	Total trichlorinated dibenzo-p-dioxins (TrCDD)
	2,3,7,8 tetrachlorodibenzo-p-dioxin (2,3,7,8 TCDD)
	Total tetrachlorinated dibenzo-p-dioxins (TCDD)
	1,2,3,7,8 pentachlorodibenzo-p-dioxin (1,2,3,7,8 PeCDD)
	Total pentachlorinated dibenzo-p-dioxins (PeCDD)
	1,2,3,4,7,8 hexachlorodibenzo-p-dioxin (1,2,3,4,7,8 HxCDD)
	1,2,3,6,7,8 hexachlorodibenzo-p-dioxin (1,2,3,6,7,8 HxCDD)
	1,2,3,7,8,9 hexachlorodibenzo-p-dioxin (1,2,3,7,8,9 HxCDD)
	Total hexachlorinated dibenzo-p-dioxins (HxCDD)
	1,2,3,4,6,7,8 heptachlorodibenzo-p-dioxin (1,2,3,4,6,7,8 HpCDD)
	Total heptachlorinated dibenzo-p-dioxins (HpCDD)
	Total octachlorinated dibenzo-p-dioxins (OCDD)
FURANS	
	Total trichlorinated dibenzofurans (TrCDF)
	2,3,7,8 tetrachlorodibenzofurans (2,3,7,8 TCDF)
	Total tetrachlorinated dibenzofurans (TCDF)
	1,2,3,7,8 pentachlorodibenzofuran (1,2,3,7,8 PeCDF)
	2,3,4,7,8 pentachlorodibenzofuran (2,3,4,7,8 PeCDF)
	Total pentachlorinated dibenzofurans (PeCDF)
	1,2,3,4,7,8 hexachlorodibenzofuran (1,2,3,4,7,8 HxCDF)
	1,2,3,6,7,8 hexachlorodibenzofuran (1,2,3,6,7,8 HxCDF)
	2,3,4,6,7,8 hexachlorodibenzofuran (2,3,4,6,7,8 HxCDF)
	1,2,3,7,8,9 hexachlorodibenzofuran (1,2,3,7,8,9 HxCDF)
	Total hexachlorinated dibenzofurans (HxCDF)
	1,2,3,4,6,7,8 heptachlorodibenzofuran (1,2,3,4,6,7,8 HpCDF)
	1,2,3,4,7,8,9 heptachlorodibenzofuran (1,2,3,4,7,8,9 HpCDF)
	Total heptachlorinated dibenzofurans (HpCDF)
	Total octachlorinated dibenzofurans (OCDF)

TABLE 5-2. TYPICAL CB, PCB, CP, AND PAH TARGET COMPOUNDS

Chlorobenzenes

Total Dichlorobenzenes
- 1,2-dichlorobenzene
- 1,3-dichlorobenzene
- 1,4-dichlorobenzene

Total Trichlorobenzenes
- 1,2,4-trichlorobenzene
- 1,3,5-trichlorobenzene
- 1,2,3-trichlorobenzene

Total Tetrachlorobenzenes
- 1,2,3,4-tetrachlorobenzene
- 1,2,3,5-tetrachlorobenzene
- 1,2,4,5-tetrachlorobenzene

Pentachlorobenzene

Hexachlorobenzene

Polychlorinated Biphenyls

Total Monochlorobiphenyls
- 2-chlorobiphenyl

Total Dichlorobiphenyls
- 2,3-dichlorobiphenyl

Total Trichlorobiphenyls
- 2,4,5-trichlorobiphenyl

Total Tetrachlorobiphenyls
- 2,2′4,6-tetrachlorobiphenyl

Total Pentachlorobiphenyls
- 2,2′,3′,4,5-pentachlorobiphenyl

Total Hexachlorobiphenyls
- 2,2′4,4,5,6′-hexachlorobiphenyl

Total Heptachlorobiphenyls
- 2,2′3,4,5′,6,6-heptachlorobiphenyl

Total Octachlorobiphenyls
- 2,2′,3,3,′,4,5′,6,6′-octachloro-biphenyl

Total nonachlorobiphenyls
- 2,2′,3,3′,4,4′,5,6,6′-nonachloro-biphenyl

Decachlorobiphenyl

Chlorophenols

- 2-chlorophenol
- 3-chlorophenol
- 4-chlorophenol

Total Dichlorophenols
- 2,3-dichlorophenol
- 2,4-dichlorophenol
- 2,5-dichlorophenol
- 2,6-dichlorophenol
- 3,4-dichlorophenol
- 3,5-dichlorophenol

Total Trichlorophenols
- 2,3,4-trichlorophenols
- 2,3,5-trichlorophenol
- 2,3,6-trichlorophenol
- 2,4,5-trichlorophenol
- 2,4,6-trichlorophenol

Total Tetrachlorophenols
- 2,3,4,6-tetrachlorophenol
- 2,3,5,6-tetrachlorophenol

(continued)

TABLE 5-2. (Continued)

Chlorophenols, (continued)	
	Pentachlorophenol
	4-chloro-3-methylphenol
Polynuclear Aromatic Hydrocarbons	
1,4-Dichlorobenzene-d4	
Naphthalene-d8	
Acenaphthene-d10	
Acenaphthylene	
Acenaphthene	
Fluorene	
Phenanthrene-d10	
Phenanthrene	
Anthracene	
Fluoranthene	
Chrysene-d12	
Pyrene	
Benzo(a)anthracene	
Chrysene	
Perylene-d12	
Benzo(b)fluoranthene	
Benzo(k)fluoranthene	
Benzo(a)pyrene	
Indeno(1,2,3-cd)pyrene	
Dibenz(a;h)anthracene	
Benzo(g,h,i)perylene	
Benzo(e)pyrene	
Perylene	

TABLE 5-3. TYPICAL TARGET VOC

Acetaldehyde	trans-1,2-Dichloroethene
Acrolein	1,1-Dichloroethylene
Acrylonitrile	Dichlorofluoromethane
Benzene	1,2-Dichloropropane
Bromodichloromethane	cis-1,3-Dichloropropene
Carbon Tetrachloride	trans-1,3-Dichloropropene
Chlorobenzene	Epoxyethane (ethylene oxide)
Chloroethane	1,2-Epoxypropane (propylene oxide)
2-Chloroethylvinyl ether	Ethylbenzene
Chloroform	Methylene Chloride
Chloromethane	2-Nitropropane
2-Chlorophenol[a]	PAN (Peroxyacetylnitrate)
3-Chlorophenol[a]	Tetrachloroethene
4-Chlorophenol[a]	Toluene
Chloropropane	1,1,1-Trichloroethane
2-Chloropropane	1,1,2-Trichloroethane
Dibromochloromethane	Trichloroethene
1,1-Dichloroethane	Trichlorofluoromethane
1,2-Dichloroethane	1,1,2-Trichloropropane
4,2-Dichloroethane	Vinyl Chloride
1,1-Dichloroethene	

[a]Measured in chlorophenol analysis.

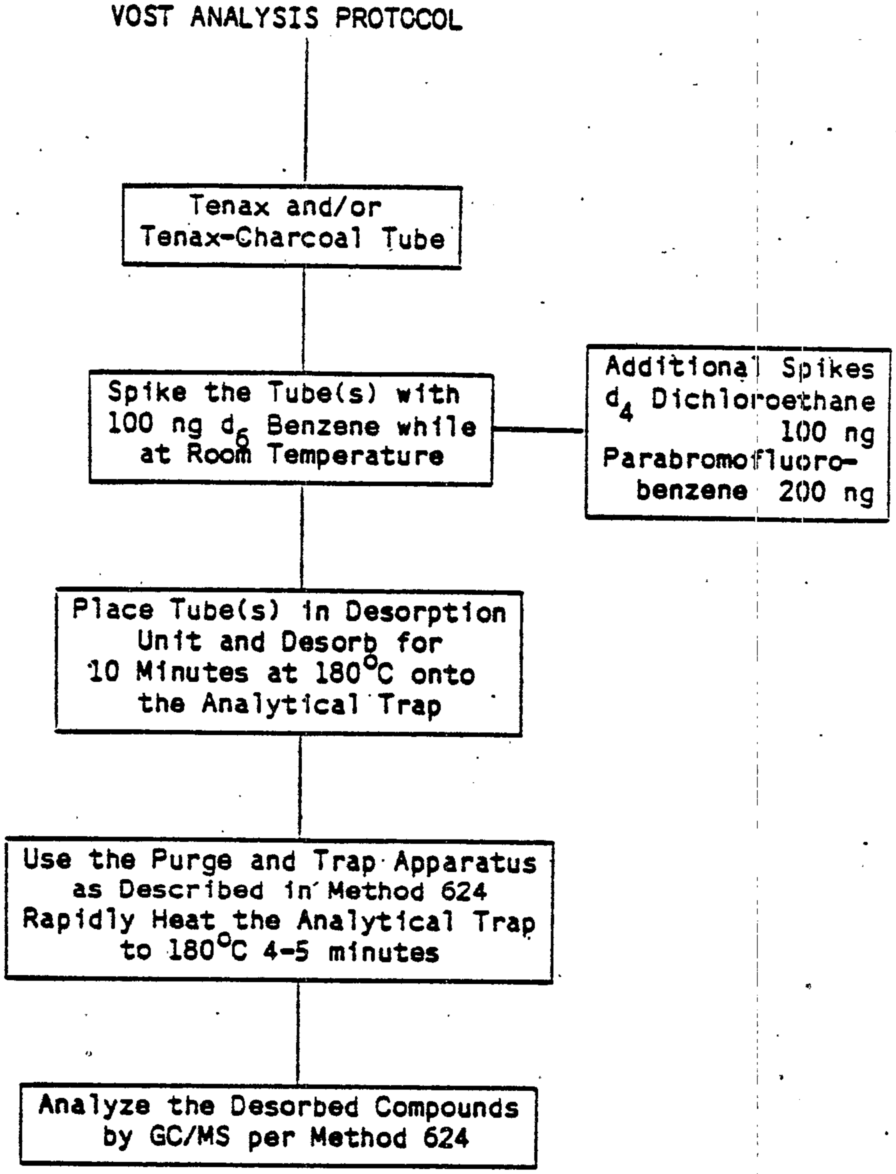


Figure 5-6. VOST analysis protocol.

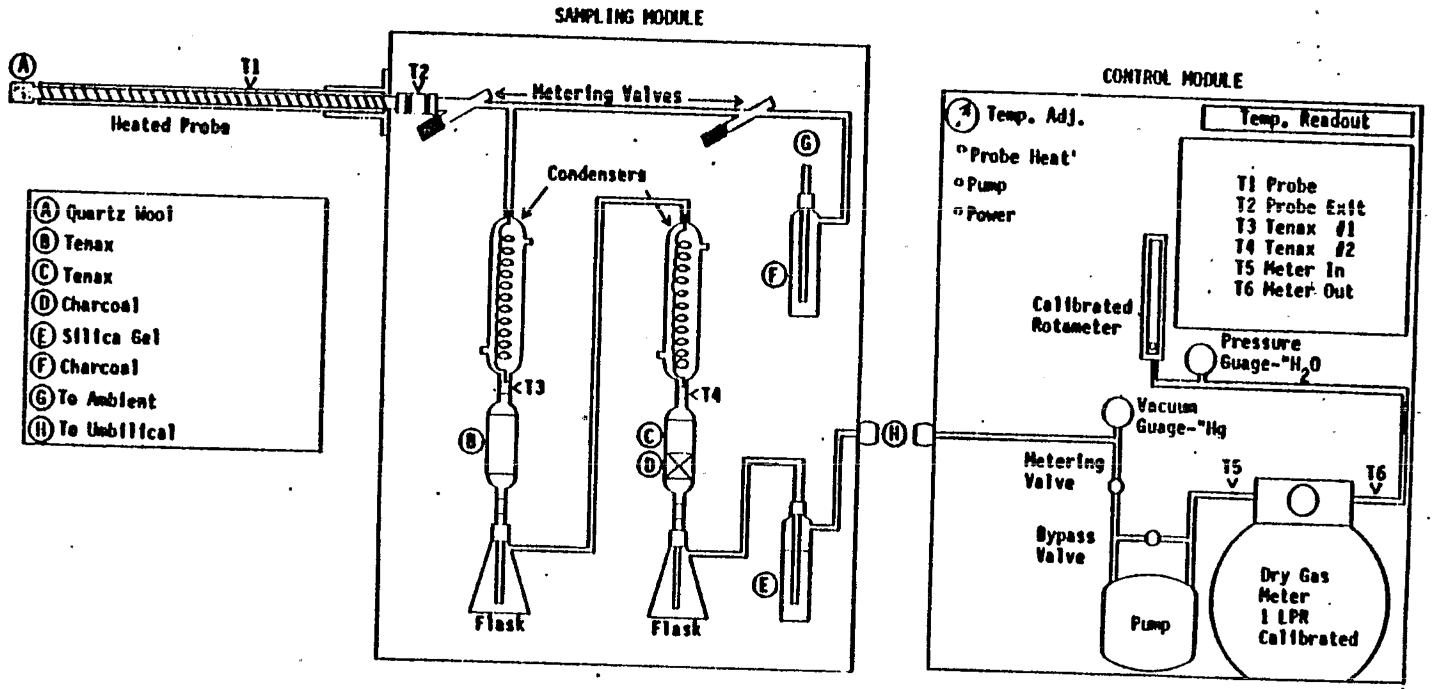


Figure 5-7. VOST sampling train configuration.

samples are collected at a fixed point representing average gas velocity. Since the target species are gaseous components of the flue gas, isokinetic sampling is not a consideration for this method.

5.5 PARTICLE SIZE SEMIVOLATILE ORGANIC SOURCE ASSESSMENT SAMPLING SYSTEM (SASS)

Particulate matter and semivolatile organics are withdrawn at a constant rate near isokinetic conditions. Three heated stainless steel cyclones (10 um, 3 um and 1 um) and a final filter collect and separate the particulate matter. Since isokinetic sampling conditions are not guaranteed, this method is not used for compliance determinations.

A schematic of the sampling train is shown in Figure 5-8. After the cyclones and filter, the flue gas is cooled and organics are removed by a sorbent cartridge. Following the sorbent cartridge is a set of impingers which contain a nitric acid and peroxide mixture to condense moisture and remove metals. The analytical scheme for the train is presented in Figures 5-9, 5-10 and 5-11.[6]

5.6 SLUDGE ANALYSES

Sludge samples are often analyzed for metals, moisture and volatile organics. The metals analyses are done according to SW-846, Method 3050 for digestion and Methods 6010, 7421 and 7060 for analysis. The analysis protocol is shown in Figure 5-12.

The volatile organic analysis follows SW-846, Method 8240. The analysis protocol is shown in Figure 5-13.

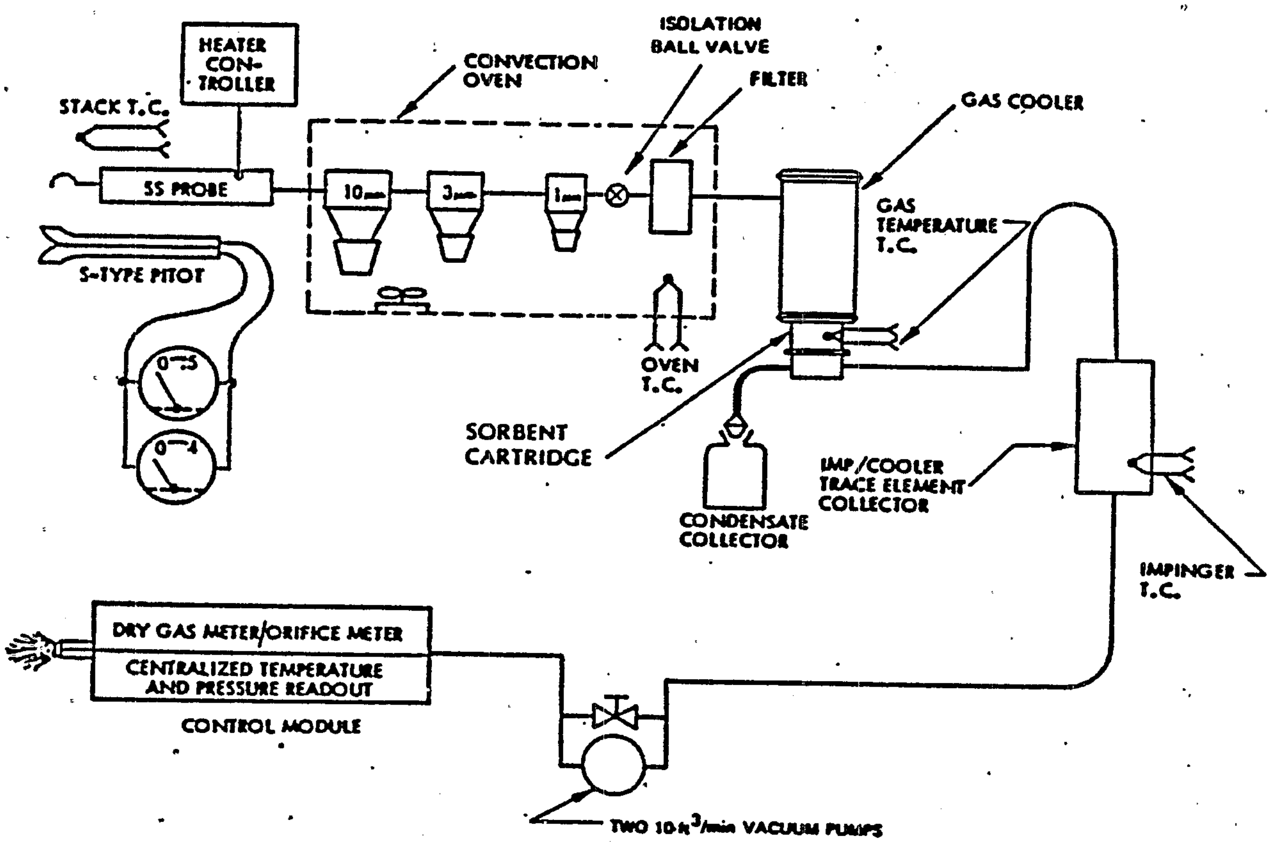
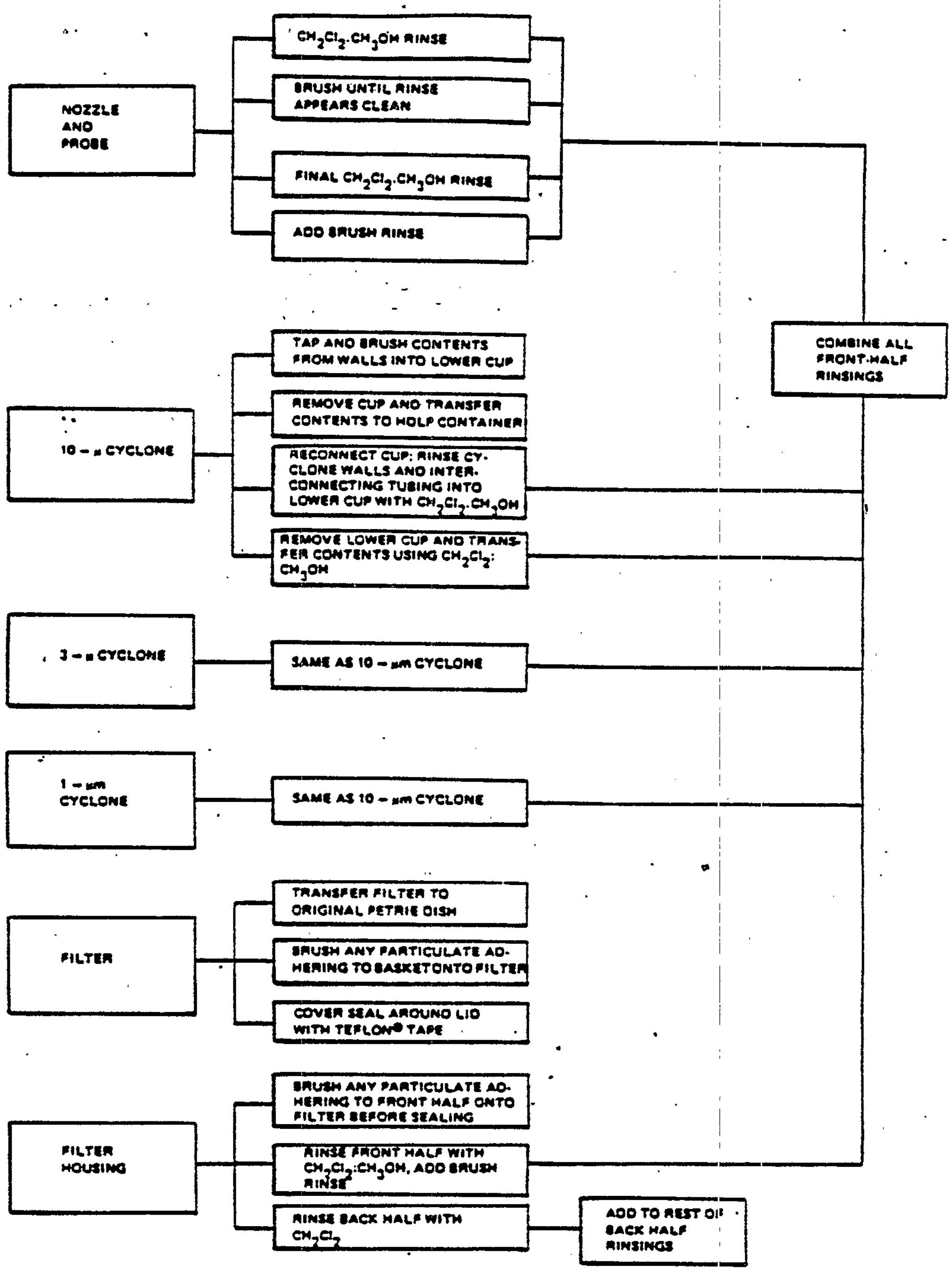


Figure 5-8. SASS sample diagram.

Source: IERL Procedures Manual: Level 1 Environmental Assessment Second Edition, EPA-600/7-78-201



NOTES: ALL CH_2Cl_2:CH_3OH MIXTURES ARE 50:50 V/V.
ALL CONTAINERS FOR SAMPLES FOR ORGANIC ANALYSIS MUST BE GLASS.
USE TEFLON® OR GLASS WASH BOTTLES; TEFLON® IS PREFERRED.

Figure 5-9. SASS sample handling and transfer: nozzle, probe, cyclones and filter.

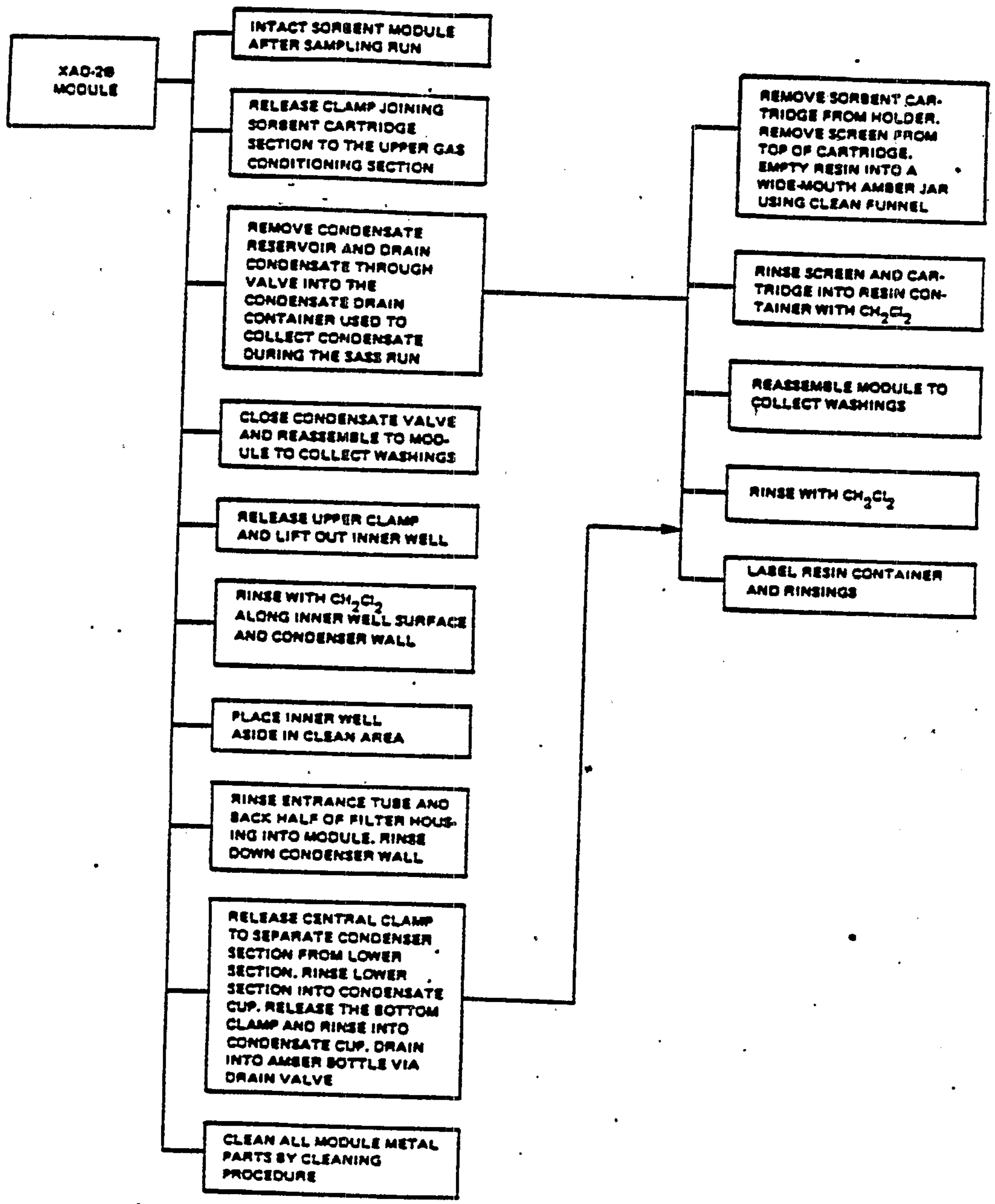


Figure 5-10. SASS sample handling and transfer: organic module section.

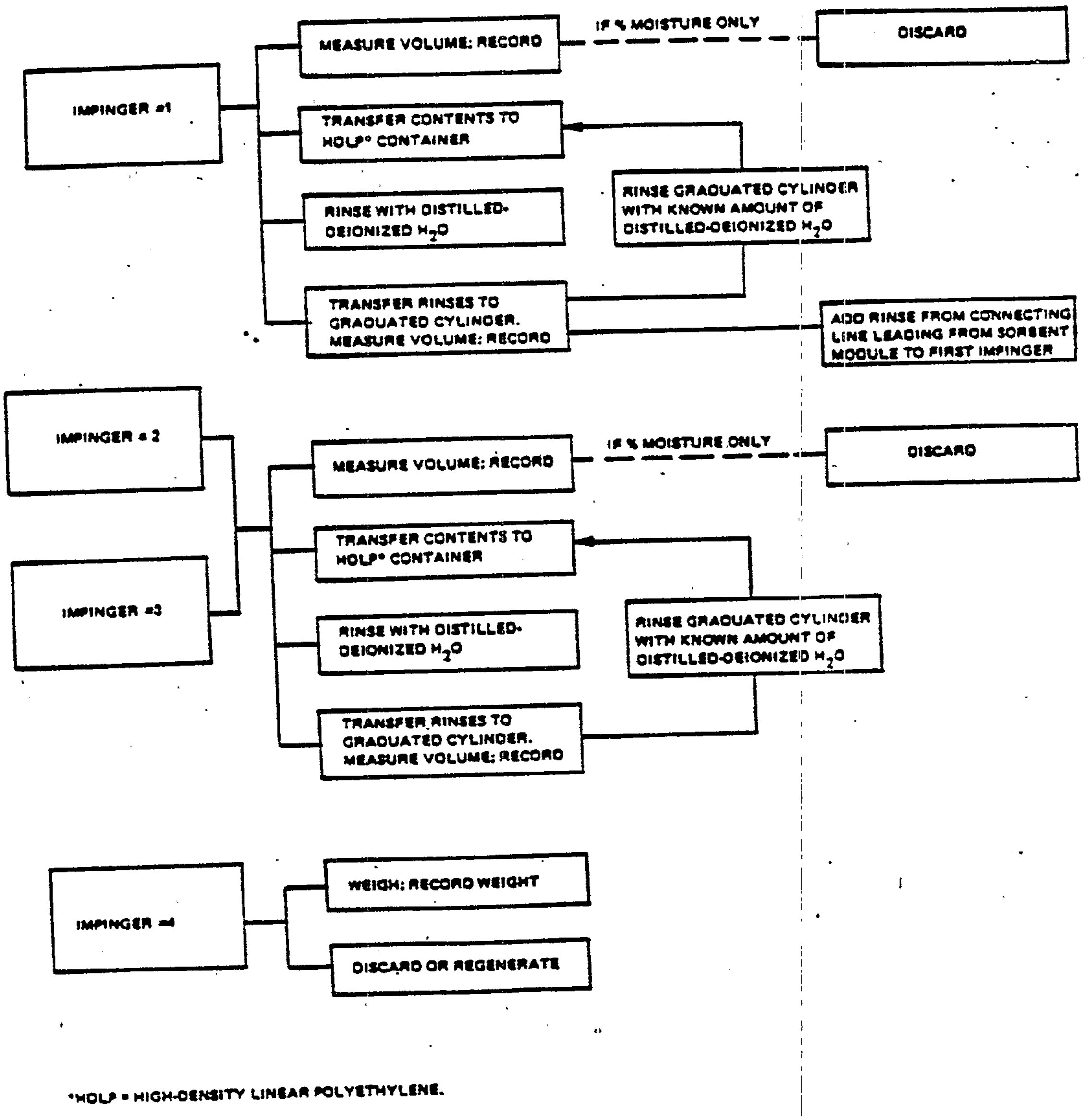


Figure 5-11. SASS sample handling and transfer: impinger train.

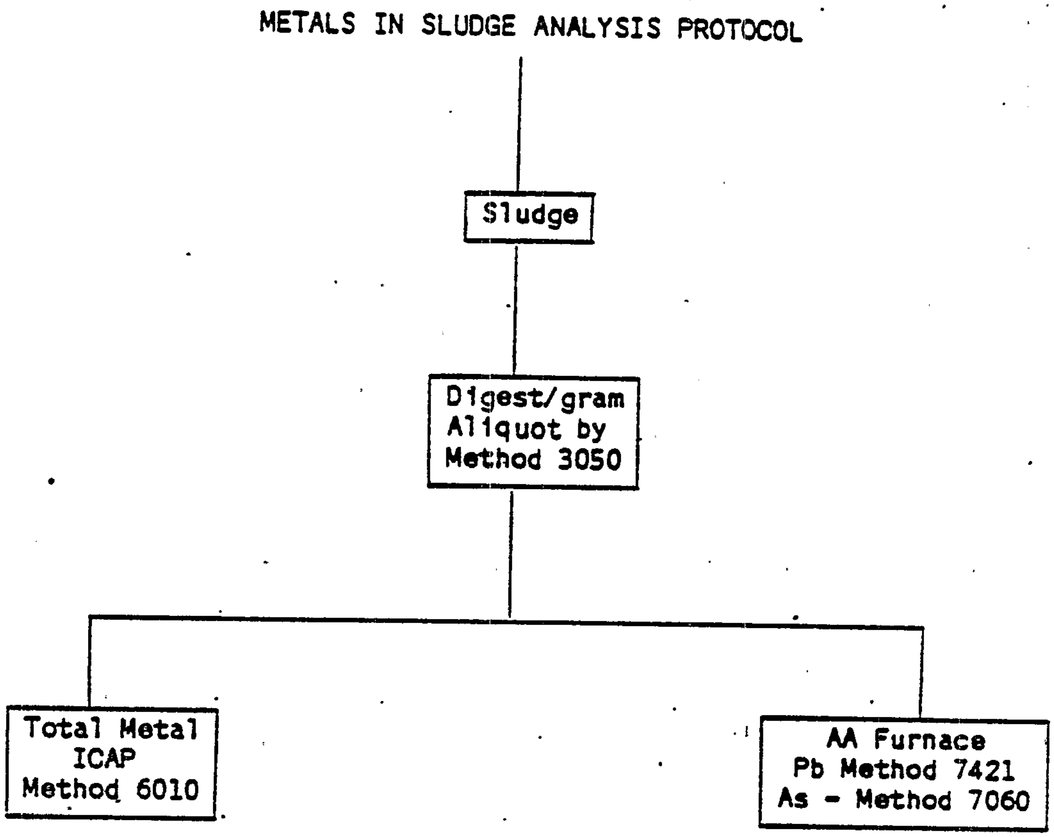


Figure 5-12. Analysis protocol for metals in sludge.

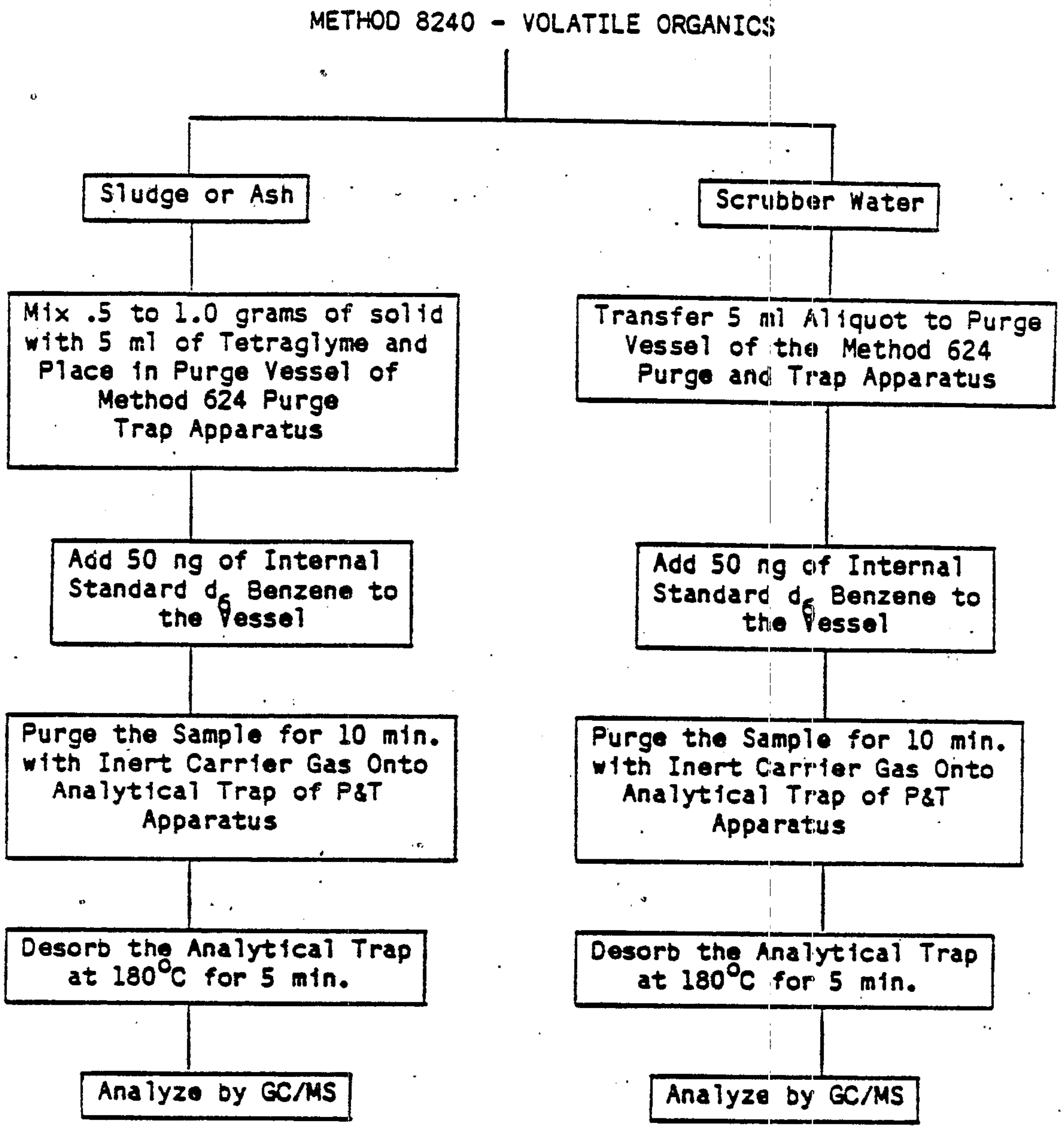


Figure 5-13. Analysis protocol for volatile organics in solids wastes.

5.6 REFERENCES

1. Method 5 - Determination of Particulate Emissions from Stationary Sources. 40 CFR Ch. 1, Part 60, Appendix A, Method 5. July 1, 1988.

2. Draft - Methodology for the Determination of Trace Metal Emissions in Exhaust Gases from Stationary Source Combustion Processes. U.S. Environmental Protection Agency. Research Triangle Park, N.C.

3. Sampling for the Determination of Chlorinated Organic Compounds in Stack Emissions - Draft. American Society of Mechanical Engineers and the U.S. Environmental Protection Agency. December 31, 1984.

4. Analytical Procedures to Assay Stack Effluent Samples and Residual Combustion Products for Polychlorinated PCDD and PCDF - Draft. American Society of Mechanical Engineers and the U.S. Environmental Protection Agency. December 31, 1984. Revised by Triangle Laboratories - February 1989.

5. Volatile Organic Sampling Train. SW-846, Method 0030. Revision 0. September 1986.

6. Modified Method 5 Train and Source Assessment Sampling System Operator's Manual. Schlickenrieder, Lynn M., et al. (Arthur D. Little, Inc.). U.S. Environmental Protection Agency. Research Triangle Park, North Carolina. February 1985.

APPENDIX A

U.S. SEWAGE SLUDGE INCINERATORS

TABLE A-1. U.S. SEWAGE SLUDGE INCINERATORS SORTED BY STATE AND TYPE[1]

Facility	City	State	Type[2]	Number of units	Total capacity (dry tpd)	Unit capacity (dry tpd)	Start-up date	Control device(s)
Anchorage	Anchorage	AK	MH	1	1.1	1.1	NA	Impingement
Wrangell	Wrangell	AK	EL	1	0.2	0.2	NA	Venturi
Petersburg	Petersburg	AK	EL	NA	NA	NA	NA	NA
Martinez	Martinez	CA	MH	NA	NA	NA	NA	NA
Redwood City	Redwood City	CA	MH	NA	NA	NA	NA	NA
Yosemite	Yosemite National Park	CA	MH	1	3.4	3.4	NA	Venturi/Impingement
San Mateo	San Mateo	CA	MH	1	4.9	4.9	NA	Venturi/Impingement
South Lake Tahoe	Lake Tahoe	CA	MH	1	0.8	0.8	NA	Impingement
Lake Arrowhead	Lake Arrowhead	CA	MH	1	4.8	4.8	NA	Scrubber (type unknown)
Palo Alto	Palo Alto	CA	MH	2	6	3.0	NA	Impingement
Tahoe Truckee	Truckee	CA	MH	NA	NA	NA	NA	NA
Central Contra Costa	Walnut Creek	CA	MH	2	44	22.0	NA	NA
Sacramento	Sacramento	CA	MH	1	7.2	7.2	NA	NA
Barstow	Barstow	CA	FB	1	2.5	2.5	NA	Spray Chamber
Mattabassett	Cromwell	CT	MH	1	12.5	12.5	NA	Wet Cyclone
East Shore WPCF	New Haven	CT	MH	1	29.2	29.2	NA	Venturi
Willimantic WPCF	Willimantic	CT	MH	NA	NA	NA	NA	Impingement
Hartford WPCF	Hartford	CT	MH	3	336	112.0	NA	Scrubber (type unknown)
New London WPCF	New London	CT	MH	2	51.8	25.9	NA	Venturi/Impingement
Waterbury WPCF	Waterbury	CT	MH	1	6.5	6.5	NA	Impingement
Norwalk	Norwalk	CT	FB	2	36	36.0	NA	Venturi
Mattabassett	Cromwell	CT	FB	1	NA	NA	1989	NA
West Haven	West Haven	CT	FB	2	NA	NA	1967/86	NA
Stamford	Stamford	CT	R/S	1	94.7	94.7	NA	Electrostatic Precipitator
New Canaan	New Canaan	CT	R/S	1	38.9	38.9	NA	Venturi
Jacksonville	Jacksonville	FL	MH	1	28.4	28.4	NA	Venturi/Impingement
Pensacola WWTP	Pensacola	FL	MH	1	NA	NA	NA	NA
Cobb County	Marietta	GA	MH	2	19.8	19.8	NA	Venturi/Impingement
Atlanta (Bolton Rd)	Atlanta	GA	MH	2	129.6	64.8	NA	Venturi/Impingement
Savannah	Savannah	GA	MH	2	12	6.0	NA	Venturi Impingement
Atlanta (Utoy)	Atlanta	GA	MH	1	8.1	8.1	NA	Venturi
R.M. Clayton WWTP	Atlanta	GA	MH	NA	NA	NA	NA	Scrubber (type unknown)

(Continued)

TABLE A-1. (Continued)

Facility	City	State	Type[a]	Number of units	Total capacity (dry tpd)	Unit capacity (dry tpd)	Start-up date	Control device(s)
Gainesville	Gainesville	GA	EL	2	5.5	2.8	NA	Venturi
Decatur	Decatur	GA	EL	2	44.8	22.4	NA	Venturi/Impingement
Honouliuli WWTP	Honouliuli	HI	MH	NA	NA	NA	NA	Venturi/Impingement
San Island WWTF	Honolulu	HI	MH	2	25.9	13.0	NA	Venturi/Impingement
Oahu	Oahu	HI	MH	NA	NA	NA	NA	NA
Cedar Rapids WPCF	Cedar Rapids	IA	MH	1	24.3	24.3	NA	Venturi/Impingement
Davenport	Davenport	IA	MH	1	35.6	35.6	NA	Venturi/Impingement
Dubuque	Dubuque	IA	FB	2	56	28.0	1970	Venturi
Decatur STP	Decatur	IL	MH	NA	NA	NA	NA	NA
Indianapolis-Belmont	Indianapolis	IN	MH	8	362.9	45.4	NA	Wet Cyclone
Mission Township STP	Johnson County	KA	MH	NA	NA	NA	NA	NA
Turkey Creek MSD #1	Shawnee Mission	KA	MH	1	17.8	17.8	NA	Scrubber (type unknown)
Kaw Point	Kansas City	KA	FB	2	40	20	1967	Venturi
Kansas City	Kansas City	KA	FB	1	18	18.0	1980	Venturi
Kenton County	Kenton County	KY	MH	NA	NA	NA	NA	NA
Cynthiana	Cynthiana	KY	EL	NA	NA	NA	NA	NA
East Bank STP #1	New Orleans	LA	MH	1	30	30.0	1966	Wet Cyclone
Lake Charles-Plant B	Lake Charles	LA	MH	NA	NA	NA	NA	NA
New Orleans West Bank STP	Algiers	LA	MH	NA	NA	NA	NA	NA
Lake Charles-Plant C	Lake Charles	LA	MH	NA	NA	NA	NA	NA
Lake Charles	Lake Charles	LA	MH	NA	NA	NA	NA	NA
East Bank STP #2	New Orleans	LA	MH	1	6	6.0	NA	NA
Natchitoches	Natchitoches	LA	FB	1	41	41.0	1980	Venturi
Lynn	Lynn	LA	FB	1	NA	NA	NA	NA
Fitchburg East WWTP	Fitchburg	MA	MH	NA	NA	NA	NA	NA
Chicopee	Chicopee	MA	MH	1	38.9	38.9	NA	Impingement
Upper Blackstone WWTP	Millbury	MA	MH	1	7.2	7.2	NA	Venturi/Impingement
New Bedford WWTP	New Bedford	MA	MH	3	35.1	11.7	NA	Impingement
Fall River	Fall River	MA	MH	1	16.2	16.2	NA	Impingement
Chicopee	Chicopee	MA	MH	NA	NA	NA	NA	NA
Attleboro Advanced WTF	Attleboro	MA	MH	1	7.2	7.2	NA	Venturi/Impingement
Greater Lawrence SD WWTP	North Andover	MA	MH	NA	NA	NA	NA	Venturi/Impingement
Annapolis City STP	Annapolis	MD	MH	2	90.8	45.4	NA	Packed Tower
			MH	NA	NA	NA	NA	NA

gep.03a

(Continued)

TABLE A-1. (Continued)

Facility	City	State	Type[a]	Number of units	Total capacity (dry tpd)	Unit capacity (dry tpd)	Start-up date	Control device(s)
Cox Creek WWTP	Riviera Beach	MD	MH	NA	NA	NA	NA	NA
Patapsco	Baltimore	MD	MH	3	98.4	32.8	NA	NA
Ocean City	Ocean City	MD	FB	2	8	4.0	1969/86	Venturi/Impingement
Wyandotte STP	Wayne County	MI	MH	4	243.2	60.8	NA	NA
Trenton WWTP	Trenton	MI	MH	NA	NA	NA	NA	NA
Ann Arbor	Ann Arbor	MI	MH	1	54	54.0	NA	Scrubber (type unknown)
Lansing WWTP	Lansing	MI	MH	NA	NA	NA	NA	NA
Warren	Warren	MI	MH	1	25.9	25.9	NA	Wet Cyclone/Impingement
Owosso WWTP	Owosso	MI	MH	NA	NA	NA	NA	NA
Detroit (1)	Detroit	MI	MH	6	408	68.0	NA	Venturi/Impingement
Pontiac STP	Pontiac	MI	MH	1	64.8	64.8	NA	Scrubber (type unknown)
Detroit (2)	Detroit	MI	MH	8	673.8	84.2	NA	Impingement
Grand Rapids	Grand Rapids	MI	MH	1	32.4	32.4	NA	Venturi
Kalamazoo WWTP	Kalamazoo	MI	MH	1	48	48.0	NA	Venturi/Impingement
Niles WWTP	Niles	MI	MH	NA	NA	NA	NA	NA
East Lansing	East Lansing	MI	MH	2	32.4	16.2	NA	Scrubber (type unknown)
Ypsilanti Community WWTP	Ypsilanti	MI	MH	1	54	54.0	NA	Venturi
Battle Creek	Battle Creek	MI	MH	NA	NA	NA	NA	NA
Bay City STP	Bay City	MI	MH	1	3.2	3.2	NA	Scrubber (type unknown)
Port Huron	Port Huron	MI	FB	1	7.6	7.6	1974	Venturi/Impingement
Bay County STP	Bay County	MI	EL	NA	NA	NA	NA	NA
Metropolitan TP	St. Paul	MN	MH	6	777.6	129.6	NA	Venturi/Impingement
Seneca TP	St. Paul	MN	MH	2	19.4	9.7	NA	Venturi/Impingement
Duluth	Duluth	MN	R/S	2	34	17.0	NA	Venturi
Kansas City	Kansas City	MO	MH	1	45.4	45.4	NA	Scrubber (type unknown)
St. Louis (Lenay STP)	St. Louis	MO	MH	4	145.8	36.5	NA	Venturi/Impingement
St. Louis (Bissel Point STP)	St. Louis	MO	MH	5	324	64.8	NA	Wet Cyclone
Independence	Independence	MO	FB	1	9.7	9.7	1979	Venturi/Impingement
Little Blue Valley	Little Blue Valley	MO	FB	1	NA	NA	1989	NA
Greensboro	Greensboro	NC	MH	1	45.4	45.4	NA	Impingement
Rocky Mount	Rocky Mount	NC	MH	1	7.5	7.5	NA	Venturi/ Impingement
Shelby	Shelby	NC	FB	1	16.2	16.2	1966	Impingement
Manchester WWTP	Manchester	NH	MH	NA	NA	NA	NA	Venturi

(Continued)

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TABLE A-1. (Continued)

Facility	City	State	Type[a]	Number of units	Total capacity (dry tpd)	Unit capacity (dry tpd)	Start-up date	Control device(s)
Lebanon WWTP	Lebanon	NH	MH	1	7.2	7.2	NA	Venturi/Impingement
Merrimack WWTP	Merrimack	NH	MH	NA	NA	NA	NA	Venturi
Stony Brook RSA STP #1	Princeton	NJ	MH	2	39.5	19.8	NA	Venturi/Impingement
Rockaway Valley	Parsippany-Troy Hills	NJ	MH	NA	NA	NA	NA	NA
Atlantic City	Atlantic City	NJ	MH	1	25.9	25.9	NA	Venturi/Impingement
Parsippany	Parsippany	NJ	MH	2	77.8	38.9	NA	Uncontrolled
Wayne	Wayne	NJ	MH	2	96	48.0	NA	Scrubber (type unknown)
Mountain View Sewer Authority	Wayne Township	NJ	MH	NA	NA	NA	NA	NA
West Side STP	Jersey City	NJ	MH	1	13.8	13.8	NA	Venturi
Two Bridges	Lincoln Park	NJ	FB	1	66	66	1979	Venturi/Impingement
NW Bergen County Utilities	Waldwick	NJ	FB	1	18	18.0	1970	Venturi
Somerset Raritan Valley Authority	Bridgewater	NJ	FB	1	14	14.0	1972	Venturi/Impingement
Gloucester Township	Blackwood	NJ	FB	1	9.6	9.6	1985	Venturi/Impingement
Bayshore Regional Sewer Authority	Union Beach	NJ	FB	1	30	30.0	1974	Venturi/Impingement
Douglas County SID #1 WWTF	Zephyr Cove	NV	FB	1	5	5.0	1985	Venturi/Impingement
Round Hill	Douglas County	NV	FB	2	9.0	4.5	1966/84	Scrubber (type unknown)
West STP	Oswego	NY	MH	NA	NA	NA	NA	NA
Frank E. Van Lare WWTP	Rochester	NY	MH	2	72	36.0	NA	Scrubber (type unknown)
Amherst	Amherst	NY	MH	NA	NA	NA	NA	Venturi/Impingement
Gates Chile Ogden STP	Rochester	NY	MH	2	36	18.0	NA	Scrubber (type unknown)
Auburn	Auburn	NY	MH	1	40.5	40.5	NA	Scrubber (type unknown)
New Rochelle SD STP	New Rochelle	NY	MH	NA	NA	NA	NA	NA
Orangetown DPW	Orangetown	NY	MH	1	16.8	16.8	NA	Venturi/Impingement
Mamaroneck	Mamaroneck	NY	MH	NA	NA	NA	NA	NA
Disposal District No. 15	Southampton	NY	MH	NA	NA	NA	NA	NA
Niagra County	Niagra County	NY	MH	NA	NA	NA	NA	NA
Two Mile Creek STP	Tonawanda	NY	MH	NA	NA	NA	NA	NA
Rochester (NW Quad)	Rochester	NY	MH	2	48	24.0	NA	Scrubber (type unknown)
Watertown	Watertown	NY	MH	1	21	21.0	NA	Scrubber (type unknown)
Albany (North)	Albany	NY	MH	2	129.6	64.8	NA	Impingement
Port Chester SDSTP	Port Chester	NY	MH	NA	NA	NA	NA	NA
Birds Island STP	Buffalo	NY	MH	3	183.6	61.2	NA	Venturi
Dunkirk STP	Dunkirk	NY	MH	NA	NA	NA	NA	NA

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TABLE A-1. (Continued)

Facility	City	State	Type[a]	Number of units	Total capacity (dry tpd)	Unit capacity (dry tpd)	Start-up date	Control device(s)
East STP	Oswego	NY	MH	NA	NA	NA	NA	NA
Albany (South)	Albany	NY	MH	2	91.8	45.9	NA	Impingement
NW Quadrant TP	Greece	NY	MH	NA	NA	NA	NA	NA
Schenectady STP	Schenectady	NY	MH	1	140	140.0	NA	Scrubber (type unknown)
Beacon WPCP	Beacon	NY	MH	1	9.7	9.7	NA	Scrubber (type unknown)
Saratoga	Saratoga	NY	FB	1	NA	NA	NA	NA
Watertown	Watertown	NY	FB	1	NA	NA	NA	NA
Arlington	Arlington	NY	FB	1	8.4	8.4	NA	Scrubber (type unknown)
Port Washington	Port Washington	NY	FB	1	NA	NA	1968	NA
Utica	Oneida County	NY	FB	3	60	20.0	1972/87	Venturi
Hamburg	Erie County	NY	FB	2	288	144.0	NA	Venturi/Impingement
Little Falls	Little Falls	NY	FB	1	3.9	3.9	NA	Venturi
Glens Falls	Glens Falls	NY	FB	1	NA	NA	NA	NA
Southtowns Advanced WWTF	Buffalo	NY	FB	1	43.2	21.6	1981	Venturi/Packed Tower
Bath	Bath	NY	FB	1	NA	NA	NA	NA
Glen Cove	New York	NY	R/S	1	25	25.0	NA	Electrostatic Precipitator
Akron WWTP	Akron	OH	MH	4	38.8	9.7	NA	Venturi/Impingement
Cleveland (Southerly WWTP)	Cleveland	OH	MH	4	259.2	64.8	1979	Venturi/Impingement
Columbus (Jackson Pike WWTP)	Columbus	OH	MH	1	38.9	38.9	NA	Venturi
Canton WWTP	Canton	OH	MH	2	50	25	NA	Impingement
Columbus (South)	Columbus	OH	MH	2	45.4	22.7	NA	Venturi
Cincinnati (Millcreek)	Cincinnati	OH	MH	4	168.4	42.1	NA	Impingement
Cleveland (Westerly STP)	Cleveland	OH	MH	2	194.4	97.2	1982	Impingement
Euclid WWTP	Euclid	OH	MH	2	21.6	10.8	NA	Scrubber (type unknown)
Little Miami WWTP	Cincinnati	OH	MH	3	NA	NA	NA	Venturi/Impingement
Willoughby-Eastlake WWTP	Willoughby	OH	MH	1	21	21	1974	Scrubber/Tray
Youngstown WWTP	Youngstown	OH	MH	1	40.5	40.5	NA	Spray Chamber
Lorain	Lorain	OH	FB	1	NA	NA	NA	NA
Tigard	Tigard	OR	MH	3	15	15	NA	Venturi/Impingement
Warren County	Franklin	OH	R/S	NA	NA	NA	NA	NA
Ambridge STP	Ambridge	PA	MH	NA	NA	NA	NA	NA
York	York	PA	MH	2	38.8	19.4	NA	Scrubber (type unknown)
Bridgeport STP	Bridgeport	PA	MH	NA	NA	NA	NA	NA

(Continued)

TABLE A-1. (Continued)

Facility	City	State	Type[a]	Number of units	Total capacity (dry tpd)	Unit capacity (dry tpd)	Start-up date	Control device(s)
Erie	Erie	PA	MH	2	135	67.5	NA	Electrostatic Precipitator
Upper Moreland-Hatboro TP	Willow Grove	PA	MH	NA	NA	NA	NA	NA
City of Johnstown	Johnstown	PA	MH	1	8.1	8.1	NA	Uncontrolled
Alcosan WWTP	Pittsburgh	PA	MH	NA	NA	NA	NA	NA
Delcora-Chester STP	Chester	PA	MH	2	19.4	9.7	NA	Scrubber (type unknown)
Kiski Valley WPCA	Appolo	PA	MH	7	136.1	19.4	NA	Scrubber (type unknown)
E. Norristown Plymouth TP	Norristown	PA	MH	NA	NA	NA	NA	Scrubber (type unknown)
Cumberland City	Lemoine Boro	PA	MH	NA	NA	NA	NA	NA
Wyoming Valley Sanitation Authority	Wilkes-Barre	PA	MH	1	32.4	32.4	NA	NA
Duryea	Duryea	PA	MH	1	25.9	25.9	NA	Scrubber (type unknown)
Lower Lackawanna STP	Old Forge	PA	MH	NA	NA	NA	NA	NA
Hatfield Township STP	Colmar	PA	MH	1	5.7	5.7	NA	Scrubber (type unknown)
Hershey	Hershey	PA	MH	1	40.5	40.5	NA	Impingement
Tyrone	Tyrone	PA	FB	1	5.1	5.1	NA	NA
Upper Gwynedd	North Wales	PA	FB	1	1.1	1.1	1973	Scrubber (type unknown)
Hazelton	West Hazelton	PA	FB	1	4.5	4.5	1967	Venturi
Trout Run WPCC	Upper Marion Township	PA	FB	1	NA	NA	1981	NA
Harrisburg	Harrisburg	RI	R/S	2	135.4	67.7	NA	Electrostatic Precipitator
Cranston	Cranston	RI	MH	2	20.4	10.2	NA	Venturi/Impingement
Providence	Providence	RI	MH	2	NA	NA	NA	Venturi
Columbia	Columbia	SC	MH	2	8.2	4.1	NA	Scrubber (type unknown)
Charleston	Charleston	SC	MH	1	32.4	32.4	NA	Scrubber (type unknown)
North Charleston	North Charleston	SC	FB	1	NA	NA	NA	NA
Central WWTP	Nashville	TN	MH	2	92	46.0	NA	NA
Bristol	Bristol	TN	MH	1	16.2	16.2	NA	Scrubber (type unknown)
Maryville Regional STP	Maryville	TN	MH	1	13	13.0	NA	Venturi/Impingement
Newport	Newport	TN	MH	1	7.8	7.8	NA	Scrubber (type unknown)
Fairfax	Fairfax	VA	MH	2	64.8	32.4	NA	Wet Cyclone
Alexandria STP	Alexandria	VA	MH	NA	NA	NA	NA	NA
Williamsburg WPCF	Williamsburg	VA	MH	2	55.7	27.8	NA	Venturi/Impingement
Fairfax (Lower Potomac STP)	Fairfax	VA	MH	2	90.8	45.4	NA	Impingement
Potomac River STP	Woodbridge	VA	MH	NA	NA	NA	NA	NA
Boat Harbor WPCF	Newport News	VA	MH	2	33.7	16.9	NA	Venturi/Impingement

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TABLE A-1. (Continued)

Facility	City	State	Type[2]	Number of units	Total capacity (dry tpd)	Unit capacity (dry tpd)	Start-up date	Control device(s)
Arlington COWPCP	Arlington	VA	MH	2	34.8	17.4	NA	Venturi/Impingement
Hopewell	Hopewell	VA	MH	2	8.1	8.1	NA	Scrubber (type unknown)
Army Base WWTP (Hampton Rds.)	Norfolk	VA	MH	2	25.5	12.8	NA	Venturi/Impingement
Lamberts Point WPCF	Norfolk	VA	MH	2	57.9	29.0	NA	Venturi/Impingement
Chesapeake-Elizabeth WPCF	Virginia Beach	VA	MH	2	22.8	11.4	NA	Venturi/Impingement
Vancouver	Vancouver	WA	MH	1	34	34.0	NA	Scrubber (type unknown)
Edmonds	Edmonds	WA	FB	1	1.6	1.6	NA	Scrubber (type unknown)
Lynnwood	Lynnwood	WA	FB	1	0.7	0.7	NA	Scrubber (type unknown)
Brookfield STP	Brookfield	WI	MH	1	3.9	3.9	NA	Impingement
Green Bay WWTP	Green Bay	WI	MH	2	87.5	87.5	NA	Scrubber (type unknown)
Milwaukee	Milwaukee	WI	MH	1	7.1	7.1	NA	Scrubber (type unknown)
Clarksburg STP	Clarksburg	WV	MH	NA	NA	NA	NA	NA
Huntington	Huntington	WV	FB	1	NA	NA	1989	NA

Note: NA Means Information Not Available.

[1]As of May 31, 1989.

[2]Type Key: MH=Multiple Hearth; FB=Fluidized Bed; EL=Electric; R/S=Refuse/Sludge.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-405/2-90-009		

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	6.
7. AUTHOR(S)	8. PERFORMING ORGANIZATION CODE 90-203-080-83-02
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15. SUPPLEMENTARY NOTES

EPA Project Officer: William B. Kuykendal

16. ABSTRACT This document is intended to assist groups interested in inventorying air emissions of various potentially toxic substances from sewage sludge incinerators. Its intended audience includes Federal, State and local air pollution personnel. The document presents information on the process description of the various types of sewage sludge incinerators and their air pollution control equipment. Emission factors are presented for each major type of sewage sludge incinerators for the following: metals including arsenics, beryllium, cadmium, chromium, and nickel; and organics including chlorinated dibenzo-p-dioxins, dibenzofurans, benzene, chlorinated benzene, and phenol.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. Identifiers/Open ended terms	c. COSATI Field/Group
Sewage Sludge Incineration Air Toxics Emissions Emission Factors		

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