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Second Review of Standards of Performance for Sewage Sludge Incinerators

Emission Standards and Engineering Division

U.S. ENVIRONMENTAL PROTECTION AGENCY
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1.0 EXECUTIVE SUMMARY

The objective of this report is to review the New Source Performance Standard (NSPS) of 1.3 pounds of particulates/ton dry sludge input and the opacity standard of 20 percent for the incineration of sewage sludge (Subpart O 40 CFR 60). This standard is reviewed by gathering and summarizing information for sewage sludge incinerators built since the standard was last reviewed in 1978. The achievability, applicability, and need for revision of the standard is evaluated in light of these data. Selected data for incinerators built prior to 1978 are also presented and discussed in this report.

1.1 BACKGROUND

In 1982, the actual wastewater input into sewage treatment plants was just under 27,000 million gallons per day (MGD). Approximately 15 percent (4,525 MGD) of this wastewater flow entered plants capable of incinerating the sludge generated in the process of treating these wastewaters. It is estimated that between 1.1 and 1.5 million dry tons of sludge is incinerated annually in the U.S.

Since 1934 when incineration was first used as a sludge disposal technique, it is estimated that over 400 sludge incinerators have been built. Current estimates show that there are approximately 150 wastewater treatment plants capable of incinerating all, or part, of their sludge production. Since many facilities use more than one incinerator, a substantially greater number of individual incinerators are likely to exist.

Since the last NSPS review in 1978, it is estimated that at least 23 new sludge incineration facilities have been installed. Approximately 70 percent of these facilities use multiple-hearth incinerators, 15 percent use fluidized-bed incinerators, and 15 percent use electric incinerators. Between 1984 and 1989, it is estimated that 18 new installations will come on line and be subject to the provisions of the NSPS.

Twenty-two states treat sewage sludge incinerators as a distinct source category. In these states, the federal NSPS is applied. Most other states have general standards that encompass incineration of all types of municipal wastes and refuse. These standards are usually less stringent than the existing NSPS for sludge incinerators. Of 11 states surveyed, only Massachusetts and Connecticut have existing monitoring and reporting requirements for sewage sludge incinerators.

1.2 EMISSIONS CHARACTERISTICS OF SLUDGE INCINERATORS

Uncontrolled emissions from sewage sludge incinerators can vary from less than 10 lb/ton dry sludge to over 400 lb/ton dry sludge. In general, uncontrolled emission characteristics are a function of the incinerator type, sludge characteristics, and the operating practices used at individual incinerators. Uncontrolled emissions from multiple-hearth incinerators are typically about 50 lb/ton while uncontrolled emissions from fluidized-bed incinerators average about 88 lb/ton. For individual incinerators, actual uncontrolled emissions can vary substantially from these values depending on the sludge quality and operating practices used. However, no quantitative correlation has been identified between specific operating parameters and uncontrolled particulate emissions.

Sewage sludge incinerators also emit potentially toxic trace elements. Data for 12 incinerators indicate that emissions of trace elements are highly variable. Controlled emissions of cadmium range from 0.003 lb/dry ton sludge to 0.06 lb/dry ton. The highest controlled trace element emissions were for lead, which range from 0.002 to 0.16 lb/ton, and average 0.05 lb/dry ton sludge. Data on uncontrolled trace element emission rates from six incinerators average 0.03 lb/ton for cadmium, 0.18 lb/ton for chromium, 0.08 lb/ton for nickel, 0.45 lb/ton for lead, and 0.02 lb/ton for arsenic. The efficiency of control devices in reducing trace element emissions from sludge incinerators is generally less than that for total particulates.

For multiple-hearth and fluidized-bed incinerators built since 1978, the predominant control technology for particulate emissions are combination venturi/impingement-tray scrubbers. These devices were applied prior to 1978, but their use has become more widespread in recent years. For the 17 multiple-hearth incinerators built since 1978, scrubber pressure drops range from 10 to 45 inch W.G. Of the four new fluidized-bed incinerators installed since 1978, three are equipped with combination venturi/impingement-tray scrubbers. New electric incinerators are most often equipped with individual venturi scrubbers. Pressure drops for scrubbers used on the four electric incinerators built since 1978 are less than 10 inch W.G.

1.3 CURRENT EMISSION LEVELS ACHIEVABLE

New sewage sludge incinerators, when correctly operated and equipped with an appropriate control device, can achieve the existing New Source Performance Standards. Of the 17 multiple-hearth incinerators that have begun operating in the past five years, 11 are officially in compliance with the NSPS. Four new units have not yet been tested. The remaining multiple-hearth incinerator, located in Providence, Rhode Island, has demonstrated the capability to meet the NSPS, but has not yet officially complied with the standard. All of the four fluidized-bed sludge incinerators installed since 1978 are in compliance with the standard. Of the four electric incinerators installed since 1978, two were unable to achieve the NSPS. However, neither of these units is equipped with a scrubber capable of being operated at a pressure drop considered to represent Best Available Control Technology. One electric incinerator is officially in compliance, while another has not yet been tested.

For the 17 multiple-hearth incinerators that have been affected by the NSPS since 1978, the average emission rate is 0.76 lb/dry ton sludge input. If the Providence, Rhode Island incinerator is excluded, the average emission rate for multiple-hearth incinerators in compliance with the NSPS is 0.67 lb/dry ton. This is approximately one-half of the allowable emission rate. The data indicate that many multiple-hearth incinerators are capable of reducing emissions to well below the current NSPS level. The average emission rate achieved by fluidized-bed incinerators affected by the

NSPS since 1978 is 0.74 lb/dry ton sludge. Emission rates for new electric incinerators average 2.22 lb/dry ton sludge.

1.4 COSTS OF EMISSIONS CONTROL

The cost effectiveness of controlling particulate emissions from sewage sludge incinerators is estimated to range from $191 to $1743 per ton removed. These costs are based on conservative capital cost estimates for venturi/impingement-tray scrubbers operating at pressure drops of from 20 to 40 inches W.G. Cost effectiveness is most sensitive to incinerator size. Scrubber pressure drop has a small impact on overall cost effectiveness. For each 10 inch W.G. change in pressure drop, a change in cost effectiveness on the order of $10 is achieved. Figure 1-1 summarizes the estimated cost effectiveness of controlling particulate emissions from both fluidized-bed and multiple-hearth sewage sludge incinerators at a scrubber pressure drop of 40 inches W.G.

1.5 COINCINERATION WITH MUNICIPAL REFUSE

At the present time, there is no explicit statement in either Subpart O or Subpart E that defines which standard is to be applied in cases where sewage sludge is coincinerated with municipal refuse. Although about 23 facilities have coincinerated sewage sludge and municipal refuse at one time or another in the U.S., only 3 facilities have been identified as being operational over the next 5 years. In each case, sewage sludge will be coincinerated in a conventional refuse incinerator. Electrostatic precipitators will be employed to control particulate emissions at all three of these coincineration facilities. Insufficient data are available to indicate how coincineration will affect the particulate emissions from these incinerators.

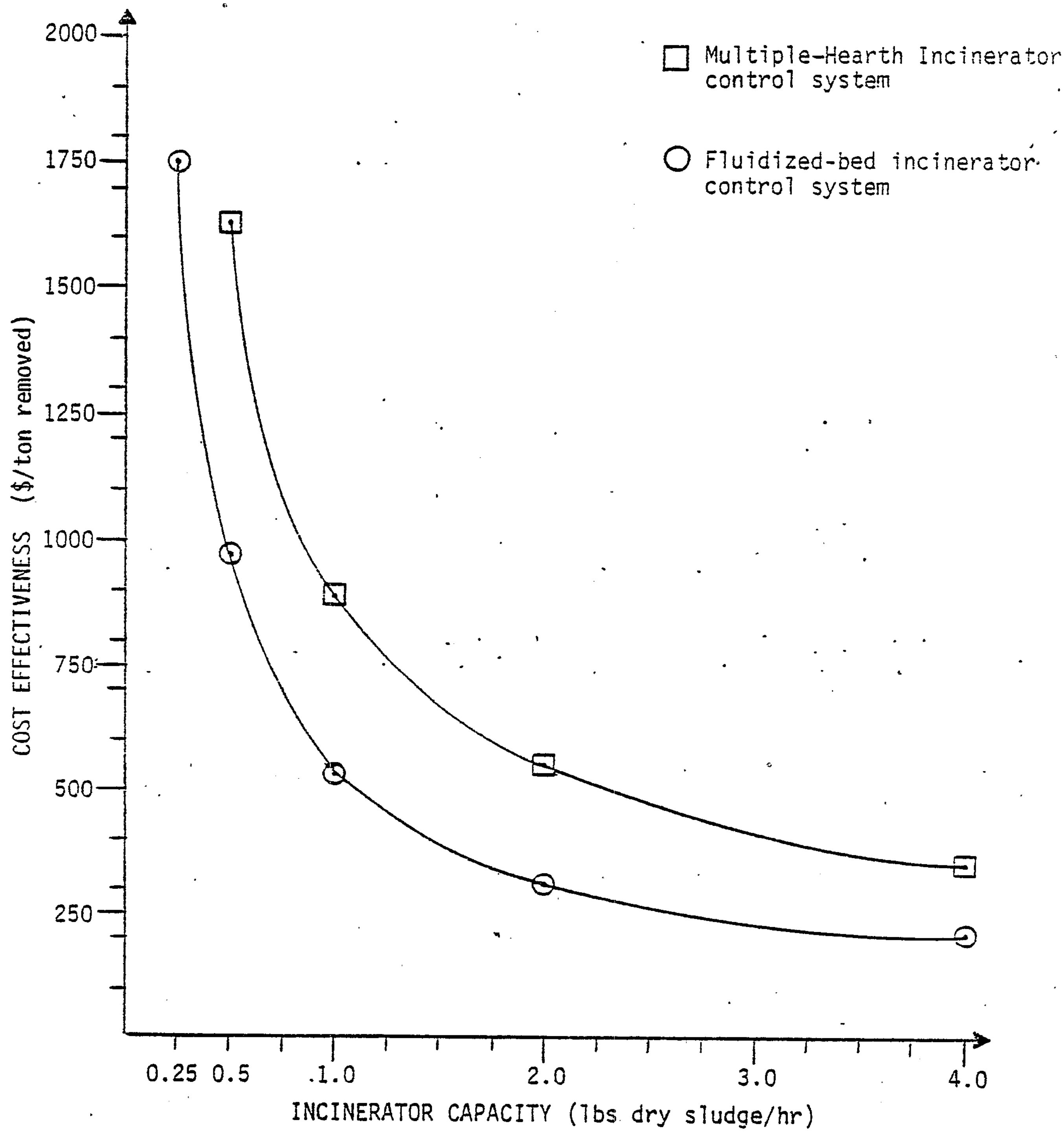

Figure 1-1. Cost Effectiveness of Sludge Incinerator Particulate Control at a Pressure Drop of 40 inches W.G.

2.0 DESCRIPTION OF THE INDUSTRY

2.1 INTRODUCTION

Sewage sludge incinerators are subject to particulate emission limits of 1.3 pounds per ton of dry sludge input and limited to a maximum stack opacity of 20 percent, as promulgated under subpart O of the New Source Performance Standards (NSPS). As part of the review of the NSPS, this chapter provides background information on the number and location of sewage sludge incinerators in the U.S., the types of incineration technologies employed, as well as on the initial development of the standard. State regulations applicable to sludge incinerators are also reviewed.

In Section 2.2, the industry is broadly characterized. Information on the number and location of sludge incinerators, as well as an estimate of the amount of sludge incinerated, is presented. The prevalence of alternative incineration techniques, and the growth in the use of incineration, are also discussed in the first section.

Section 2.3 provides detailed descriptions of the major technologies employed to incinerate sewage sludge. Both design and operating characteristics of these incinerators are discussed.

In Section 2.4 of this chapter, background information on the development of the NSPS for sewage sludge incinerators is presented. The technical basis of the original standard is reviewed, as are the subsequent revisions made to the standard. State regulations, particularly those relating to monitoring and reporting requirements, are also reviewed in this section.

2.2 CHARACTERIZATION OF THE INDUSTRY

Over 33,000 publicly owned sewage treatment works are currently operating in the U.S. These plants have a combined capacity to treat over 35,000 million gallons of municipal wastewaters each day. In 1982, the actual wastewater input into sewage treatment plants was just under

27,000 million gallons per day (MGD), representing a capacity utilization of 76 percent. Approximately 15 percent of the total 1982 wastewater flow entered plants that are capable of incinerating all, or a portion of the sludge generated in the process of treating these wastewaters. However, nearly all plants employ more than one sludge disposal technique, and some incinerators are not currently operating.

2.2.1 Number and Location of Sewage Sludge Incinerators

There are two main sources of information on the number and locations of sewage sludge incinerators in the U.S. The first is the NEEDS survey conducted biennially by EPA in compliance with Sections 205(a) and 516(b)(2) of the Clean Water Act.[1] The survey encompasses more than 32,000 existing and planned publicly owned treatment works (POTW) in the U.S. Second, a survey of incineration facilities has recently been completed as part of work conducted by EPA's Sludge Task Force.

The EPA Sludge Task Force utilized the NEEDS survey as a starting point.[2] However, the Sludge Task Force validated the NEEDS data through contacts with all of the regional offices of EPA, with state and local agencies, vendors of sludge incinerators, as well as individual plants. The EPA Sludge Task Force continues to update their data on a regular basis, and is considered to be the most reliable source of information on the number and location of sludge incinerators currently operating in the U.S.

The latest update (July, 1983) of the Task Force survey lists 153 treatment plants that are incinerating all, or part, of their sludge production. Neither the NEEDS data, nor the update prepared by the EPA Sludge Task Force, list the number of individual incinerators. Since many treatment plants in the U.S. utilize more than one incinerator (for example, the wastewater treatment plant in Indianapolis, Indiana, operates 8 incinerators), a substantially greater number of individual incinerators is implied.

The locations of the plants employing incineration are shown in Figure 2-1. The largest concentrations of sludge incineration facilities are found in the Northeast and along the Great Lakes.

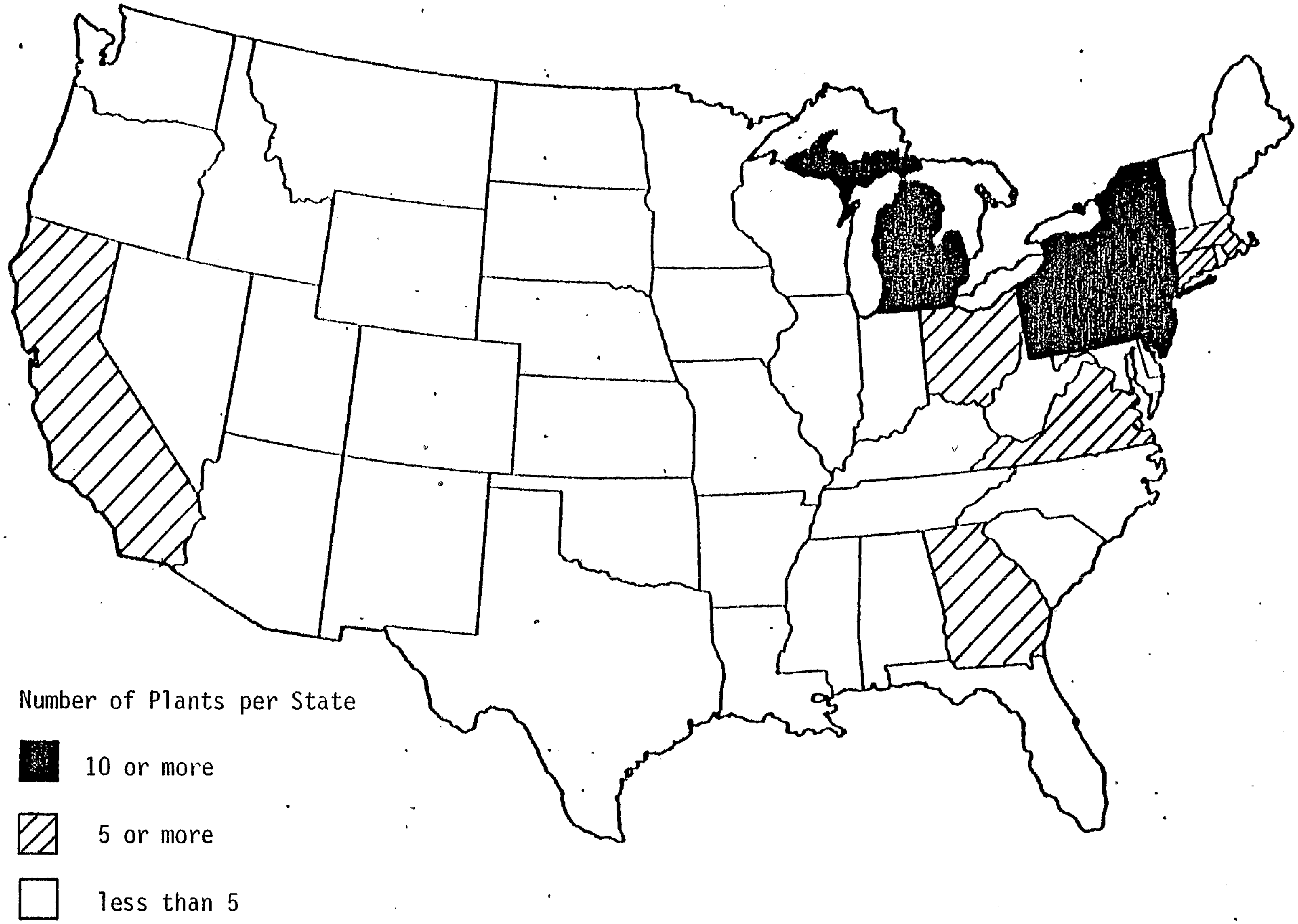

Figure 2-1. Location of Currently Operating Sewage Sludge Incineration Facilities in the U.S.

2.2.2 Amount of Sludge Incinerated

No precise data are available on the amount of sludge incinerated annually in the U.S. As part of their project, the EPA Sludge Task Force has estimated that seven million dry tons of sludge are produced annually by wastewater treatment plants in the U.S.[3] Of this total, the Task Force estimates that between 15 and 22 percent is disposed of through incineration. On this basis, the total amount of sludge incinerated annually is between 1.1 and 1.5 million dry tons.

This estimate can be confirmed on the basis of the amount of wastewater entering plants that employ incineration as a disposal technique. The corresponding flow of wastewaters into the incineration facilities listed in the EPA Sludge Task Force survey is 4,525 MGD. Although the amount of sludge generated per gallon of wastewater treated can vary greatly as a function of the specific treatment processes employed, an average value of 0.65 dry tons of sludge per million gallons of wastewater was derived from 35 POTW's that employ incineration.[4] Applying this value to the wastewater in-flow given by the Sludge Task Force, yields about 1.1 million dry tons of sludge incinerated annually.

Since it is not known precisely how much of the sludge generated at treatment plants that are equipped with incinerators is actually disposed of in this manner, the lower end of the range estimated above (1.1 million tons/year) is considered the most reliable.

2.2.3 Prevalence of Alternative Incineration Techniques

A variety of different technologies are available for incineration of municipal sewage sludge. By far the most common is the multiple-hearth furnace (MHF). Of the 153 incineration plants listed by the Sludge Task Force, 120 (78 percent) employ multiple-hearth incinerators. Fluidized-bed furnaces (FBF) account for most of the additional incinerators currently operating in the U.S. The Sludge Task Force lists 24 treatment plants that employ fluidized-bed incinerators (about 16 percent of the total). Electric (infrared) incinerators are also sometimes used for disposing of sewage sludge, particularly in smaller rural communities. EPA's Sludge Task Force identified six treatment plants that utilize electric furnaces. The Sludge

Task Force data also list one plant that employs a rotary kiln incinerator. The individual technologies available for incinerating sewage sludge are discussed in more detail in Section 2.3.

2.2.4 Number and Type of Incinerators Installed Since 1978

Since this report focuses on the compliance status of incinerators installed after the last review of the standard in 1978, a survey was conducted to identify all sludge incinerators that have either commenced operation over the past five years, or that are under construction. Incineration facilities affected by the NSPS that were installed prior to 1978 were discussed in the previous review. The survey was conducted in three stages.

First, a questionaire was sent to all ten regional offices of EPA. Information was requested for incinerators built since 1978 on the location, capacity, and design of each incinerator as well its associated emissions control equipment. In addition, the regional EPA offices were requested to provide emissions data for these units. Responses were obtained from eight of the ten regional EPA offices, identifying a total of 16 incinerators built since 1978 and 7 under construction. Complete information was available for only a few of these units, however.

Therefore, follow-up telephone contacts were made to regional, state, and local air pollution control agencies. In all, over 40 individuals were contacted during the second stage of the survey. Further information was collected on the incinerators identified in the written survey and an additional nine new (i.e. operating since 1978) incinerators were identified. All 23 new plants identified in the third and final stage of the survey were contacted in order to obtain more detailed information on actual operating parameters at these facilities.

The results of the survey are presented in Tables 2-1 and 2-2. Of the 25 new incinerators listed in Table 2-1, nearly 70 percent utilize multiple-hearth furnaces. This is consistent with data for the total U.S. population of sludge incinerators. Also, the incinerators installed since 1978 are concentrated geographically in the Northeast and Great Lakes regions of the U.S. Of the 7 incinerators listed in Table 2-2 as currently under construction in the U.S., 4 utilize the multiple-hearth design.

TABLE 2-1. SEWAGE SLUDGE INCINERATORS INSTALLED IN THE U.S. SINCE 1978

Location	Design Type
Petersburg, Alaska	Electric
Wrangell, Alaska	Electric
Marietta, Georgia	Multiple-Hearth
Oahu, Hawaii	Multiple-Hearth
Cedar Rapids, Iowa	Multiple-Hearth
Kansas City, Kansas	Fluid-Bed
Cynthiana, Kentucky	Electric
Kenton County, Kentucky	Multiple-Hearth
Attleboro, Massachusetts	Multiple-Hearth
Battle Creek, Michigan	Multiple-Hearth
Bay County, Michigan	Electric
St. Paul, Minnesota	Multiple-Hearth (2)
Independence, Missouri	Fluid-Bed
Atlantic City, New Jersey	Multiple-Hearth
Amherst, New York	Multiple-Hearth
Hamburg, New York	Fluid-Bed (2)
N. Tonawanda, New York	Multiple-Hearth
Niagra County, New York	Multiple-Hearth
Rocky Mount, N. Carolina	Multiple-Hearth
Cleveland, Ohio	Multiple-Hearth
Youngstown, Ohio	Multiple-Hearth
Providence, Rhode Island	Multiple-Hearth
Arlington, Virginia	Multiple-Hearth

TABLE 2-2. INCINERATION FACILITIES CURRENTLY UNDER CONSTRUCTION IN THE U.S.

Location	Design Type
Decatur, Georgia	Electric
Gainsville, Georgia	Electric
Fall River, Massachusetts	Multiple-Hearth
Lynn, Massachusetts	Multiple-Hearth
St. Louis, Missouri	Multiple-Hearth
Watertown, New York	Fluid-Bed
Cranston, Rhode Island	Multiple-Hearth

For incinerators which have begun operations since 1978, the results of the survey are considered to be relatively complete. However, there is less certainty with respect to what percentage of incinerators currently under construction in the U.S. were identified in the survey since less emphasis was given to this question.

2.2.5 Growth in the Use of Incineration as a Sludge Disposal Technique

Since 1934, when incineration was first used as a sewage sludge disposal technique, over 400 incinerators have been constructed.[5] Over half of these were built between 1965 and 1975. The rate of growth of sewage sludge incineration declined sharply beginning in the mid 1970's, however.

The only source of information on the future growth of incineration of sewage sludge is the NEEDS data base. Since the main objective of the NEEDS survey is to quantify ongoing and future construction programs at wastewater treatment plants, the growth projections provided in the NEEDS data files are assumed to be reasonably accurate.

On the basis of plant surveys and demographic projections, NEEDS estimates that 63 sludge incineration facilities will be constructed between 1982 and 2000. Assuming a linear rate of growth, 18 incineration facilities would begin operating over the next five years. This would be roughly consistent with the rate of growth witnessed in both the 1973 to 1978, and 1978 to 1983, five year time frames. An estimate of approximately 18 new sludge incineration facilities over the next five years is also reasonably consistent with the available data on current construction programs.

2.3 PROCESS DESCRIPTIONS

2.3.1 Process Overview

Incineration is only one method of disposing of sludge generated by a system for treating municipal wastewater. The major processes involved in this treatment include sedimentation, filtration, digestion, chemical conditioning, and dewatering. From the standpoint of incineration, the most important aspect of these related treatment processes is their impact on the moisture and energy content of the sludge. Many of the processes which reduce the moisture content of wastewater sludge can also reduce the proportion of volatile elements to inert materials. Secondary treatment processes, such as anaerobic digestion, can significantly lower the energy content of the sludge. Most sewage sludges undergo a variety of individual treatments prior to the final conditioning and dewatering steps. Since sludge conditioning and dewatering are integral to the overall incineration process, they are briefly described below.

2.3.1.1 Sludge conditioning. Pre-thickened primary or combined primary and secondary sludges are chemically treated to enhance their dewatering characteristics. Chemical conditioning changes the colloidal structure of the sludge, causing particles to coagulate.[6] Absorbed water is released as voids are created by the coalescing particles.

A wide variety of chemicals have been used for conditioning sewage sludge. The most popular agents are ferric chloride, lime, aluminum chlorohydrate, and organic polymers. Depending on the level and type of pretreatment that the sludge has received, conditioners are added at a rate of between 1 and 12 percent of the dry sludge weight.

2.3.1.2 Sludge dewatering techniques. Dewatering is a critical step in the process of sludge incineration, since it reduces the thermal demand on the incinerators. Vacuum filtration, filter presses, belt filters and centifugation are the most widely used sludge dewatering technologies, although numerous other processes are available. The NEEDS data base lists nearly 1,200 vacuum filters, 242 centrifuges, 151 filter presses, and 36 "other" dewatering devices as currently in use at sewage treatment plants. Of the 23 incineration facilities installed since 1978, 11 employ vacuum filters, 5 are equipped with horizontal belt presses, 3 use centrifuges, and 4 have installed filter presses. Although these data are limited, the use of the relatively new belt press systems appears to be increasing.

Vacuum filtration is a technique that is applicable to all types of sewage sludge. The major equipment component is a cylindrical drum filter. Natural and synthetic cloth, coil springs, or wire mesh fabrics can all be used as the filter material. The drum is suspended above a vat of sludge and periodically dips into it. As the drum slowly rotates, part of the circumference is subjected to an internal vacuum. The vacuum draws water out through the filter medium. Prior to the next submergence into the sludge vat, the filter cake is scraped from the drum and deposited on a conveyor. The moisture content of the sludge cake is normally 70 to 80 percent. A range of from 60 to 86 percent final moisture content was reported for new facilities that use vacuum filters.

In a filter press, dewatering is accomplished by forcing the water from the sludge under elevated pressures. Various designs are available. The most common consists of a series of rectangular plates supported in a vertical position. Filters are placed over the recessed plates. Sludge is pumped into the space between the plates and the plates are then pressed against each other (60 to 225 lb/sq. in.) by hydraulic rams. The entire batch cycle takes from 1 to 3 hours to complete. Filter presses are capable of reducing the moisture content of the sludge to as low as 55 percent. In the survey of new plants, sludge cake moisture contents of from 65 percent to 75 percent were reported.

Horizontal belt filters are a relatively new approach to dewatering sewage sludge. One variant of these filters consists of two continuous belts placed one above the other. Chemically conditioned sludge is continuously fed between the two belts. Dewatering is accomplished in three separate zones. In the first, water is removed by the force of gravity. In the second zone, pressure is applied by a series of rollers located above the upper belt. Shear forces are applied in the final zone. The dewatered sludge cake is then removed from the belt by a scraper. Belt filters are designed to achieve approximately the same level of moisture removal as vacuum filters. However, the extent to which any dewatering technique can remove moisture from sewage sludge depends, in part, on the specific physical, chemical, and biological characteristics of the sludge. For example, a belt press filter recently installed at the incineration facility in Merrimack, New Hampshire, achieved a 78 percent final moisture content in the sludge compared to the 85 percent that was obtained from the vacuum filter system that had previously been used.[7] The results of the survey of new facilities gave a range of from 60 to 82 percent moisture in the sludge after being dewatered in a belt press.

Centrifuges are available in a variety of different design configurations including the horizontal, conical, solid bowl, basket, and disc types. Sludge is fed continuously into the centrifuge where it is subjected to centrifugal forces of up to 300 gravities. The sludge cake is discharged by a screw conveyor. Although centrifuges are capable of producing a sludge having a moisture content as low as 60 percent, this level of dewatering is usually not economically feasible.[8] The three facilities in the survey that employ centrifuges reported final moisture contents of from 60 to 70 percent.

2.3.2 Multiple-Hearth Furnaces

The basic multiple-hearth furnace design is nearly a century old, having been initially developed for roasting of mineral ores. An air-cooled variant of the original Herreshoff design has been used for incinerating sewage sludge since the 1930's.

2.3.2.1 Design characteristics Figure 2-2 illustrates the overall design of a multiple-hearth furnace. Multiple-hearth furnaces are cylindrically shaped and oriented vertically. The outer shell is constructed of steel and surrounds a series of horizontal refractory hearths. A hollow cast iron rotating shaft runs through the center of the hearths. Cooling air is introduced into the shaft by a fan located at its base. Attached to the central shaft are 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. Either 2 or 4 rabble arms extend into each hearth. Typically, the upper and lower hearths are fitted with 4 rabble arms, while only two are placed within the middle hearths. Burners, providing auxilliary fuel, are located in the sidewalls of the hearths.

The size of MHF's used for incineration of sewage sludge typically range from 6 hearth furnaces having an outer diameter of ∿ 6 ft. and a total effective hearth area of 85 sq. ft., to 12 hearth, 22 ft. diameter furnaces with hearth areas of over 3000 sq. ft.[9] Hearth loading rates range from

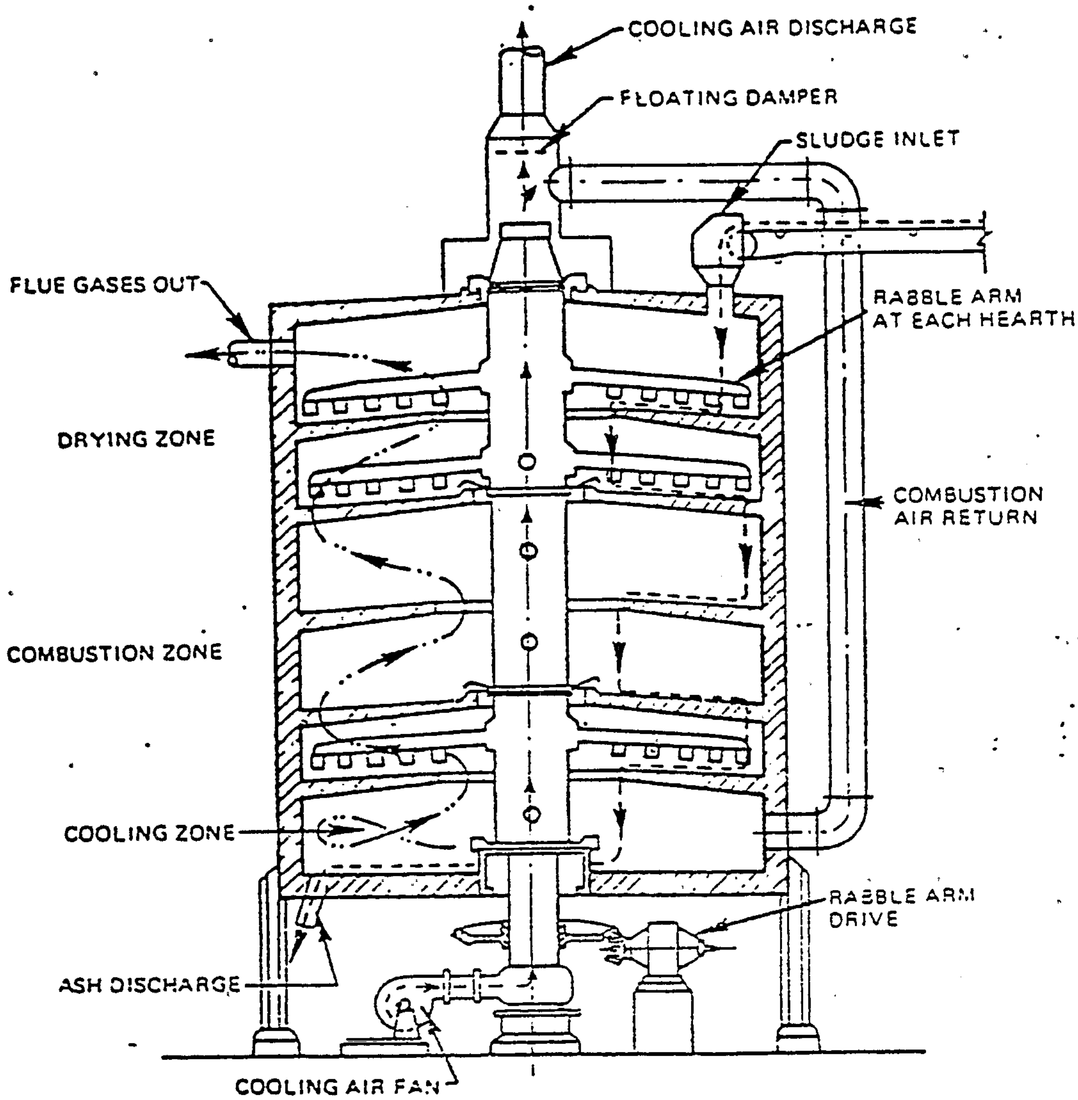

Figure 2-2. Cross-Sectional View of a Multiple-Hearth Sewage Sludge Incinerator

between 7 to 12 pounds of wet sludge per hour, per square foot. This corresponds to furnace capacities of from 600 pounds of wet sludge per hour up to 18 tons per hour.

2.3.2.2 Operating characteristics Partially dewatered sludge is fed into the periphery of the top hearth. The motion of the rabble arms rakes the sludge toward the center shaft where it drops through holes located near the edge 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 a sludge depth of about one inch is maintained in each hearth at the design sludge flow rate.

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 one of the middle hearths as well.

From the standpoint of the overall incineration process, multiple-hearth furnaces can be divided into three zones. The upperhearths comprise the drying zone where most of the moisture in the sludge is evaporated. The temperature in the drying zone is typically between 800 and 1400°F. Combustion occurs in the middle hearths (second zone) as the temperature is increased to about 1700°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.

Under proper operating conditions, 50 to 100 percent excess air must be added to a 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 addition 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 particulates and unnecessarily high fuel consumption..

Another important parameter in the operation of a multiple-hearth sewage sludge incinerator is the rate of feed of the sludge cake. Any sudden increase or decrease in load to the furnace can severely affect the performance of the incinerator.[10] A sharp increase in the rate of feed has been shown to lower the combustion zone in the furnace. This can subsequently lead to a decrease in temperature within the combustion zone and the potential for the fire to be extinguished. Conversely, a sudden decrease in furnace load can cause excessively high temperatures in the furnace with the attendant risk of damage to the refractories and rabble castings. The moisture content of the sludge feed must also be kept relatively constant for the same reasons.

Maintaining a uniform rate of feed into a MHF can be difficult, however. First, mechanical sludge dewatering devices are not capable of producing a sludge cake of perfectly uniform moisture content. Second, at most incineration plants, the sludge is fed directly from the treatment facility to the dewatering device, and then directly into the incinerator. Holding tanks are not usually available to independently control the rate of sludge input into the furnace. A related problem is that it may take up to an hour (or more) for the sludge to descend from the drying zone to the combustion zone in a multiple-hearth incinerator.[11] Thus, a change in the furnace load may not be noticed by the furnace operators in time to take corrective action. Moreover, there will be an additional delay before the incinerator responds to these corrective measures and operations become stable.

The speed at which the rabble arms are rotated can also have a critical impact on the operation of a multiple-hearth incinerator. Typically, the rotational speed can be varied between 0 and 3 revolutions per minute. As the speed of the rabble mechanism is increased, the rate of drying in the upper hearths is increased and the combustion zones tends to rise. Combustion will also tend to take place in a greater number of hearths. Experimental data have also demonstrated that the temperature of the hottest hearth will decrease as the speed of the rabble arm rotation is increased.[12] The opposite effects are observed when the speed of the rabble motion is decreased.

However, changes in the speed of rotation of the rabble arms will initially have just the opposite effects of those described above. For example, an increase in the rabble arm speed will initially create an internal increase in the load to the combustion zone. This will cause a temporary decline of the burning zone and an overall decrease in the temperature of the lower hearths. From 1 to 3 hours are required for a MHF to stabilize after the speed of the rabble arms is changed. Because of the transient furnace instabilities caused by such changes in the speed of the rabble motion, adjustment of rabble arm speed is not an effective means of controlling the process of combustion in a multiple-hearth incinerator.[13] Rather, the speed of the rabble movement should be set slow enough to form good furrows in the sludge, but fast enough to avoid crusting of the sludge in the upper hearths. The optimum speed is a function of the sludge moisture content and loading rate.

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

Theorectically, combustion can become self sustaining in a MHF when sludges having a heating value of at least 10,000 Btu/lb, a moisture content of less than 75 percent, and a volatile solids fraction of at least 60 to 65 percent are incinerated. However, under autogenous conditions the highest temperature in the furnace may only be about 900°F, which is insuffficent to completely destroy odor causing organics.[14] Even at minimum excess air rates, some auxilliary fuel must be burned in MHF's in order to maintain a minimum temperature of 1350°F for destruction of odoriferious materials.[15]

As discussed above, the operation of multiple-hearth sludge incinerators is complicated by the number of process variables involved, as well as by the transient nature of some of the responses observed when these variables are altered. As a means to establish guidelines for the operation of MHF incinerators, particulary for reducing the amount of fuel consumed, a substantial amount of both theorectical and empirical research has recently been conducted by the Indianapolis Center for Advanced Research (ICFAR).[16] Although the best mode of operating any incinerator is a function of numerous site-specific conditions, a number of general procedures have been established as the result of the ICFAR work. These operational guidelines include:

1. Utilization of shaft cooling air as combustion air;
2. Maintenance of sludge combustion on the lower burning hearths;
3. Use of only those burners located on, or immediately adjacent to, the combustion hearth(s);
4. Maintenance of rabble arm speed as slow as possible;
5. Minimization of air leakage into the incinerator;
6. Maintenance of sludge loading rates at, or below, design capacity, and;
7. Maintenance of excess air at 25 to 50 percent.

At incinerators where these procedures have been put into practice, fuel savings of from 30 to 70 percent have been attained.[17,18] Moreover, there are some indications that the operational procedures which result in reductions in fuel use also result in decreased emissions of particulates.[19] The relationship between operating procedures and particulate emissions is discussed in more detail in Chapter 3.

2.3.3 Fluidized-Bed Incinerators

Since its original development as a method for recovering catalysts in the oil refining industry, fluidized-bed technology has been applied to a wide range of industrial processes. The first fluidized-bed reactor, designed specifically for incineration of sewage sludge, was installed in 1961 in Lynwood, Washington.

2.3.3.1 Design characteristics. Figure 2-3 depicts the cross-section of a fluidized-bed sludge incinerator. Like multiple-hearth furnaces, fluidized-bed incinerators (FBF) are cylindrically shaped and oriented vertically. The outer shell is constructed of steel and is lined with refractory. Tuyeres are located at the base of the furnace within a refractory lined grid. A bed of sand, approximately 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 air is first passed through a heat exchanger where heat is recovered from the hot flue gases. Alternatively, ambient air can be injected directly into the furnace.

The physical dimensions of FBF units range from diameters of 6 to 25 feet. The corresponding range in the freeboard area is 30 to 525 square feet. Fluidized-bed incinerators have sludge loading rates of between 30 to 60 wet lb/hr/sq. ft. (roughly 5 times higher than multiple-hearth furnaces). Burning capacities of FBF units range from one-half to 15 tons of wet sludge per hour.

2.3.3.2 Operating characteristics. Partially dewatered sludge is fed into the lower portion of the furnace. Air injected through the tuyeres at pressures of from 3 to 5 psig, simultaneously fluidizes the bed of hot sand and the incoming sludge. Temperatures of 1400 to 1700°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.

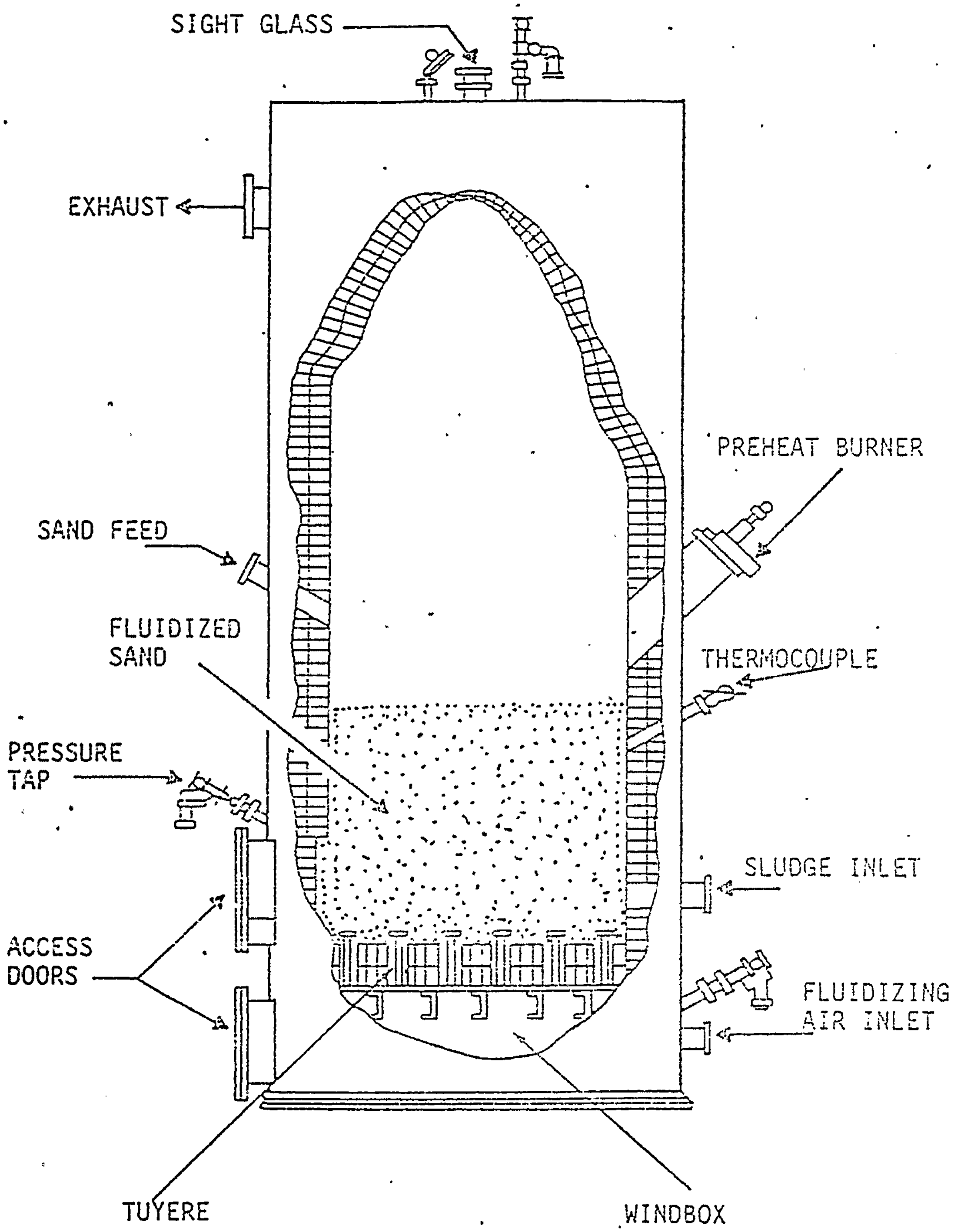

Figure 2-3. Cross-sectional View of a Fluid-bed Sewage Sludge Incinerator.

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 after-burner.[20]

From the standpoint of combustion, fluidization of the sludge has a number of advantages. First, the turbulence in the bed facilitates the transfer of heat from the hot sand particles to the sludge. Similarly, nearly ideal mixing is achieved between the sludge and the combustion air as a result of the greatly increased surface areas available. Finally, the sand provides a relatively uniform source of heat within the bed.

The most noticable impact of the better burning atmosphere provided by a fluidized-bed incinerator is seen in the amount of excess air required for complete combustion of the sludge. Fluidized-bed sludge incinerators can achieve complete combustion with 20 to 50 percent excess air. This is 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.

Controlling the rate of feed of the sludge into the incinerator is the most critical operating variable. There is an upper limit on the rate of heat transfer that can be achieved for a given quantity of sand. If the rate of sludge feed exceeds the burning capacity of the sand bed, combustion will not be complete. Similarly, either a rapid increase in the overall furnace load or in the total moisture content of the sludge will lead to coagulation of the sludge into heavy masses, depress the bed, and halt combustion. It is also important, for the same reasons, to ensure that an adequate residence time is available for the sludge to burn completely. However, due to their excellent mixing characteristics, as well as their short residence times, fluidized-bed sludge incinerators are less vulnerable than MHF's to fluctuations in the rate of sludge, and total moisture input into the furnace. Moreover, any disruption of combustion will occur almost immediately, and can be more easily detected and corrected by the operators of the furnace.

2.3.4 Electric Incinerators

The electric furnace is the newest of the technologies currently in commerical use for the incineration of sewage sludge. Most of these units were installed in the middle and late 1970's. The capacities of existing units are less than one ton of wet sludge per hour.

2.3.4.1 Design characteristics. Electric incinerators consist of a horizontally oriented, insulated furnace. A belt conveyor extends the length of the furnace. 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 pre-fabricated modules, which can be linked together to provide the necessary furnace length. A schematic of an electric sludge incinerator is provided in Figure 2-4.

2.3.4.2 Operating characteristics. 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 dryed and then burns 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.

2.3.5 Other Incinerator Designs

A number of other technologies have been used for incineration of sewage sludge including cyclonic reactors, rotary kilns, and wet oxidation reactors. These incinerators are no longer in widespread use, and will be only briefly described.

2.3.5.1 Cyclonic reactors. The cyclonic reactor is designed for small capacity applications. It is constructed of a cylindrical chamber that is lined with refractory. Preheated combustion air is introduced into the

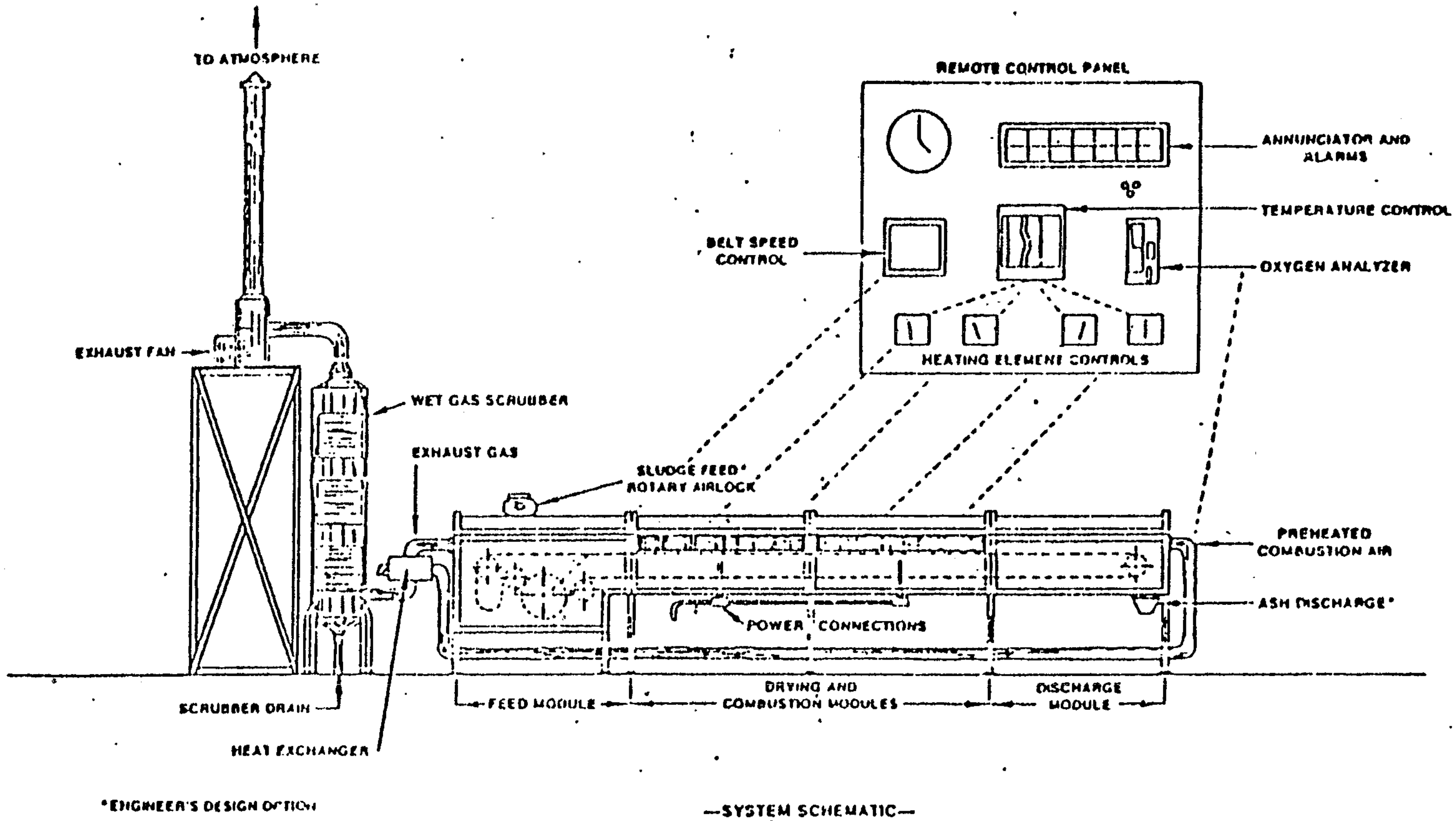

Figure 2-4. Cross-Sectional View of an Electric Sewage Sludge Incinerator

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.[21] The ash is removed with the flue gases.

2.3.5.2 Rotary kilns. Rotary kilns also have limited capacities (~1200 lb/hr). The kiln is inclined slightly to the horizontal plane, with the upper end receiving both the sludge feed and the combustion air. A burner is located at the opposite end of the kiln. The kiln rotates at a speed of about 6 inches per second. Ash is deposited into a hopper located below the burner.

2.3.5.3 Wet oxidation reactors. This process is not strictly one of incineration, but of oxidation at elevated temperature and pressure in the presence of water. Untreated sludge is first ground and mixed with a specified amount of compressed air. The mixture is then circulated through a series of heat exchangers before entering a pressurized reactor. The temperature of the reactor is held at from 350 to 600°F. Steam is usually used for auxilliary heat. The water and remaining ash are circulated out of the reactor and are finally separated in a tank or lagoon.

2.4 REGULATORY BACKGROUND

2.4.1 Selection of Sewage Sludge Incinerators for NSPS

Sewage sludge incinerators were originally selected for NSPS development in 1973 on the basis of their potential to emit significant quantities of particulate matter into the atmosphere. It was noted that less emphasis was given to retention of ash in sludge incinerators compared to other types of incineration units. Moreover, concern was expressed over the potential of sludge incinerators to emit "significant concentrations" of mercury and other toxic materials.[22] Although prior to 1973 all sludge incinerators in the U.S. were controlled with wet scrubbers, nearly all of these operated at low pressure drops (2 to 8 in. W.G.) with attendant low removal efficiencies. In addition, existing state and local regulations did not explicity apply to incineration of sewage sludge.

Prior to proposal of a NSPS for sewage sludge incineration, 15 plants having visible emissions of less than 10 percent opacity were visited. Each of these facilities were evaluated as to the feasibility of performing emissions measurements. Five locations were subsequently selected for testing: three multiple-hearth and two fluid-bed units. Four of the selected incinerators were controlled by low energy (2.5 to 6.0 in. W.G.) impingement-type scrubbers; one of the fluid bed units was equipped with a venturi scrubber operating at a pressure drop of 18 inches of water. The results of these stack tests are presented in Table 2-3. On the basis of these tests, a particulate emissions standard of 0.031 gr/dscf was proposed in 1973 for new sewage slude incinerators. An opacity limitation of 10 percent was also proposed.

2.4.2 Current NSPS for Sewage Sludge Incinerators

On February 28, 1974, the proposed standard was amended. It was felt that a standard based on the concentration of the particulate matter in the flue gases would lead to unacceptable error due to the difficulties in distinguishing between combustion air as opposed to dilution air in multiple-hearth furnaces. Thus, the promulgated standard for particulate matter was expressed on a mass basis, and set at 1.3 lb/ton of dry sludge input. The opacity standard was also changed from 10 percent to 20 percent. Sewage sludge incinerators are also subject to federal emission limits for mercury of 3200 grams per day.

The revised NSPS promulgated as Subpart O, Standards of Performance for Sewage Treatment Plants, applies to incinerators built or modified after June 11, 1973. Any incinerator that burn wastes consisting of more than 10 percent sewage sludge (dry), or charges more than 1000 kg of sewage sludge per day, is subject to the standard.

A facility is considered to have commenced construction on the date that a continuous program of construction starts, or on the date that a contractual agreement, including economic penalties for cancellation, is signed. Existing facilities that are modified in any way which increases the amount of particulate matter emitted, also become subject to the NSPS.

TABLE 2-3. SUMMARY OF EMISSIONS TESTING OF SEWAGE SLUDGE INCINERATORS FOR NSPS DEVELOPMENT

Facility	Incinerator[a] Type	Control[b] Device	Δ P (in. W.G.)	Capacity (lb/hr)	Feed Rate[c] (lb/hr)	Particulate Emissions, lb/ dry ton (gr/dscf) Run Number 1	2	3	Mean
A	FBF	V	18	1100	1100	1.06 (0.024)	0.207 (0.005)	0.177 (0.004)	0.481 (0.011)
B	MHF	P-PI	6	750	482	2.91 (0.025)	2.10 (0.020)	1.26 (0.017)	2.09 (0.021)
C	MHF	P-PI	6	900	270	1.14 (0.013)	4.16 (0.062)	1.34 (0.020)	2.21 (0.031)
D	FBF	P-PI	4	500	462	2.20 (0.055)	3.24 (0.079)	2.78 (0.055)	2.77 (0.062)
E	MHF	WC	2.5	2500	1220	3.18 (0.026)	1.16 (0.014)	4.07 (0.013)	2.80 (0.018)

a. FBF = Fluid-Bed; MHF = Multiple-Hearth
b. V = Venturi; P-PI = Perforated-Plate Impingement; WC = Wet Cyclone
c. average feed rate to the incinerator during stack tests

A device must be installed to measure the amount of sludge charged into the incinerator to within 5 percent accuracy. Access must also be provided for taking grab samples of the sludge. No provision is made in the existing standard for monitoring either particulate emissions (through periodic stack testing), or stack opacity, from sludge incinerators.

2.4.3 State Regulations

State regulations affecting sewage sludge incinerators were surveyed through written requests to the regional offices of EPA as well as by telephone contacts to State offices. No changes in these regulations were identified since the last NSPS review was conducted in 1978. The applicable State regulations are briefly discussed below.

Twenty-two states treat sewage sludge incinerators as a distinct source category. In these states, the federal NSPS is applied. Most other states have general standards that encompass incineration of all types of municipal wastes and refuse. These standards are usually less stringent than the existing NSPS for sludge incinerators.

In order to assess state requirements for monitoring emissions from sewage sludge incinerators, the regulations in 11 states were surveyed. Over 70 percent of all facilities currently incinerating sewage sludge in the U.S. are located in these 11 states. The results of this survey are provided in Table 2-4.

In six of the states, some provision is made to monitor either particulate emissions (through periodic stack tests) or opacity. In most of these six, however, the facilities affected by the monitoring requirement are to be determined on a case-by-case basis at the discretion of the Administrator. There is no indication, however, that this discretionary authority has ever been applied to sewage sludge incinerators in these states. The cut-off of 100 tons of particulate/year applied in California would exclude virtually all sludge incinerators.

Connecticut has a statutory requirement for the installation of a stack opacity recorder on all incinerators with a waste reduction capacity of more than 2000 pounds per hour. Opacity readings must be summarized and submitted to the Administrator on a quarterly basis. Connecticut does not,

TABLE 2-4. SUMMARY OF STATE MONITORING AND REPORTING REQUIREMENTS

State	Distinct SSI Category	Monitoring Requirement	Reporting Requirement	Facilities Affected
California	No	Emissions	Annual Summary	Any with >100 tons/years particulate emissions
Connecticut	No	Opacity	Quarterly Summary	Incinerators >2000 lb/hr
Louisiana	No	None	None	All NSPS facilities excluded from requirements
Massachusetts	Yes	Operating Procedures	Annual Summary	Sludge incinerators >1000 lb/hr
Michigan	Yes	Emissions	Administrative Discretion	Administrative Discretion
New Jersey	No	Emissions/Opacity	Administrative Discretion	Administrative Discretion
New York	Yes	None	None	None
Ohio	No	Emissions	Administrative Discretion	Administrative Discretion
Pennsylvania	No	Emissions	Administrative Discretion	Administrative Discretion
Virginia	No	None	None	None
Wisconsin	No	None	None	None

however, treat the incineration of sewage sludge as a distinct source category. Thus, the applicability of the requirements to sludge incinerators is not entirely clear.

Massachusetts is the only other State in the sample that has a monitoring requirement that would likely affect facilities incinerating sewage sludge. Massachusetts requires that a "Standard Operating Procedure" be developed prior to the granting of an operating permit. Although the exact content of the Operating Procedure is determined on a plant-specific basis, the procedure should detail how specific operating practices will minimize emissions. Operators of affected facilities are required to show conformity with these practices in an annual summary report to the Administrator.

Since only Connecticut and Massachusetts appear to have existing monitoring programs for sludge incinerators, personnel at both the state and local level were contacted in these states for further information. EPA's Region I office was also contacted for further details. The information obtained from these contacts is presented below.

Although Connecticut could legally require an operator of a sludge incinerator to install a device to continuously monitor and record stack opacity, this requirement is generally not excercised on sludge incinerators.[23] Opacity monitors have been found to not operate properly when placed in the stack of an incinerator. The major problem encountered in monitoring opacity is the moisture content of the incinerator flue gas. At typical incinerator stack gas temperatures of approximately 120°F, all of the moisture (10 to 30 percent) in the gas is condensed. A related problem is that the lens of the transmissometer can be easily fouled by solids and oils in incinerator flue gases.[24] The major manufacturer of opacity monitors confirms that they will not operate properly in such environments without prior dehumidification and reheating of the flue gas.[25] For these reasons, installation of opacity monitors on sewage sludge incinerators is generally not required, and no enforcement action has ever been taken in Connecticut on the basis of opacity recordings.

The Standard Operating Procedure (SOP) required by the State of Massachusetts is general, and does not follow any specific format.[26] Normally, only such information as shut-down procedures in case of scrubber malfunction, maintenance procedures and schedules, and operator training programs would be required. Each incinerator would, however, be treated on a case-by-case basis and more specific information on operating practices could potentially be required in certain instances. For example, if an incinerator fails an initial compliance test, and the reason for such failure can be correlated to specific operating parameters, the State may require that these parameters be monitored.[27] However, no specific instance could be identified where an incinerator was required to maintain and monitor a specific operating parameter within a specified range, or where an enforcement action has been initiated on the basis of an SOP report.

There is nonetheless, some interest in both Connecticut and Massachusetts to require more detailed monitoring of incinerator operating practices. Sludge moisture content and scrubber pressure drop have been cited as two variables that might be more closely monitored.[28] The primary objective in strengthening these requirements would be to improve inspection procedures. There are, however, no formal plans to institute a scheme to more closely monitor operating conditions at sludge incineration facilities.

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3.0 EMISSION CHARACTERISTICS, STATUS OF CONTROL TECHNOLOGY, AND COMPLIANCE STATUS OF SEWAGE SLUDGE INCINERATORS

3.1 INTRODUCTION AND SUMMARY OF FINDINGS

3.1.1 Introduction

The objective of this chapter is to investigate the emission characteristics of sewage sludge incinerators and to evaluate their ability to meet the existing NSPS of 1.3 pounds of particulate per ton of dry sludge input. This evaluation is focused on the compliance experience of incinerators which have begun operating during the past five years. The compliance experience of sludge incinerators installed prior to 1978 has been previously reviewed.[1]

The types of technologies employed to control particulate emissions from sludge incinerators are identified and discussed in Section 3.2. Trends over the past ten years in the types of control technologies most widely used are discussed. The type of control device most widely used since 1978 is described in detail.

Section 3.3, discusses uncontrolled emission characteristics of sewage sludge incinerators. The impact that the quality of the sludge feed, as well as the manner in which the incinerator is operated, can have on uncontrolled emission rates is also assessed in this section.

In Section 3.4 the capability of sewage sludge incinerators to comply with the existing NSPS is addressed. First, the results of the review conducted in 1978 are briefly summarized. Second, the compliance experience of incinerators installed since 1978 are presented and evaluated.

The potential of sewage sludge incinerators to emit toxic substances is briefly reviewed in Section 3.5.

In the final section of this chapter an estimate is made of the national emissions of particulates from incinerators that are expected to be installed between 1985 and 1990.

3.1.2 Summary of Findings

Multiple-hearth and fluidized-bed incinerators that have begun operating over the past five years commonly employ combination venturi/impingement-tray scrubbers to control particulate emissions. In most cases, these scrubbers are operated at total pressure drops of approximately 30 inches of water. The standard could likely be achieved at pressure drops of less than 30 in. W.G., although higher pressure drops are commonly employed to account for typically wide variations in the particulate loading at the scrubber inlet.

Over the past ten years there has been a distinct trend toward the nearly exclusive use of combination venturi/impingement-tray scrubbers to control emissions from multiple-hearth incinerators. Prior to 1978 only about 20 percent of multiple-hearth incinerators were equipped with venturi/impingement-tray scrubbers. All but three of the 17 multiple-hearth incinerators installed after 1978 utilize this technology, however. Three of the four new fluidized-bed incinerators are also equipped with combination venturi/ impingement-tray control devices. Although all electric incinerators installed since 1978 utilize a venturi, only one of these is followed by an impingement-tray scrubber.

The average pressure drop for all scrubbers installed after 1978 is approximately 25 in. W.G. This is higher than the average pressure drop of 19 in. W.G. for the control devices in use when the NSPS was reviewed in 1978. The trend toward increasing pressure drops for scrubbers applied to sludge incinerators reflects the wide variability in the amount of particulates that potentially may enter the scrubber, rather than widespread difficulties in meeting the NSPS. Emissions from most of the incinerators installed after 1978 are well under the NSPS limit. Moreover, several incinerators equipped with control systems operating at considerably lower pressure drops have achieved the NSPS.

Uncontrolled rates of particulate emissions from sewage sludge incinerators are highly variable. On the basis of the available data, uncontrolled emissions can range from less than 10 lb/dry ton input to over 400 lb/dry ton. Variability in the quality of the sludge feed, as well as the manner in which an incinerator is operated, are responsible for the variability observed in uncontrolled emissions from sludge incinerators. There is some evidence to suggest that uncontrolled emissions can be decreased by improving incinerator operating practices. However, no quantitative correlation has been identified between any specific operating parameter(s) and uncontrolled particulate emissions.

New sewage sludge incinerators, when correctly operated and equipped with an appropriate control device, can achieve the existing New Source Performance Standards. Of the 17 multiple-hearth incinerators that have begun operating in the past five years, 12 are officially in compliance with the NSPS. Four new units have not yet been tested. The remaining multiple-hearth incinerator, located in Providence, Rhode Island, has demonstrated the capability to meet the NSPS during unofficial tests, but has not yet officially complied with the standard. All of the four fluidized-bed sludge incinerators installed since 1978 are in compliance with the standard. Of the four electric incinerators installed since 1978, two were unable to achieve the NSPS. However, both of these units are equipped with scrubbers operated at very low pressure drops of 8 to 10 inches W.G. One electric incinerator is officially in compliance, while another has not yet been tested.

Sewage sludge incinerators also emit potentailly toxic trace elements. Data for 12 sewage sludge incinerators indicate that emissions of trace elements are highly variable. For example, controlled emissions of cadmium ranged from 0.003 lb/dry ton sludge to 0.06 lb/dry ton. Overall, the highest controlled trace element emissions were for lead, which can range from 0.002 up to 0.16 lb/dry ton sludge, and averaged 0.05 lb/ton. Data on uncontrolled trace element emission rates from 6 incinerators averaged 0.03 lb/ton for cadmium, 0.18 lb/ton for chromium, 0.08 lb/ton for nickel, 0.45 lb/ton for lead, and 0.02 lb/ton for arsenic. The efficiency of control devices in removing trace elements from incinerator flue gases is generally less than that for total particulates. For the six incinerators tested, control efficiencies were lowest for lead (average = 63 percent) and for cadmium (average = 83 percent). There is no apparent correlation between the pressure drop of the control devices and their corresponding removal efficiencies for trace elements.

It is estimated that an additional 245,000 dry tons of sludge will be incinerated annually at 18 new wastewater treatment plants by the year 1990. Assuming a maximum particulate emission rate of 1.3 lb/dry ton sludge, the increase in national particulate emissions from sewage sludge incinerators would be 160 tons in 1990.

3.2 EMISSION CONTROLS APPLIED TO SEWAGE SLUDGE INCINERATORS

Particulate emissions from sewage sludge incinerators have historically been controlled by wet scrubbers. The most obvious reasons for this are that a sewage treatment plant provides a relatively inexpensive source of scrubber water (plant effluent is used) and a system for treatment of the scrubber effluent is available (spent scrubber water is fed to the head of the treatment plant for solids removal). In addition, a long history of scrubber applications has demonstrated success in meeting pollution control standards for particulate matter. This section identifies the types of particulate matter emission controls applied to sludge incinerators and focuses on the controls which are currently most widely used.

3.2.1 Control Technologies Applied Prior to 1978

Table 3-1 shows the estimated distribution of emission controls applied to sludge incinerators prior to 1978. As Table 3-1 indicates, a wide variety of emission controls were applied to all types of incinerators prior to 1978. The types of controls shown in Table 3-1 range from low pressure drop spray towers and wet cyclones (pressure drops from 4 to 9 inch W.G.), to higher pressure drop venturi scrubbers and venturi/impingement-tray scrubbers (pressure drops from 12 to 40 inch W.G.). In general, the lowest pressure drop scrubbers were utilized prior to proposal of the NSPS in the early seventies. The most widely used type of control device applied to multiple-hearth incinerators was the impingement-tray scrubber. Combination venturi/impingement-tray scrubbers were most widely applied to fluidized-bed incinerators. Most electric incinerators used venturi scrubbers.

TABLE 3-1. DISTRIBUTION OF EMISSION CONTROL TECHNOLOGIES APPLIED TO SELECTED SEWAGE SLUDGE INCINERATORS PRIOR TO 1978[2]

Control Type	Applications to Incinerators: Total Number	Applications to Incinerators: Percent of Total	Range of Pressure Drops (in. w.g.)
Multiple Hearth Incinerators			
Impingement Tray	21	40	6 - 9
Venturi	12	22	15 - 32
Venturi/Impingement Tray	11	20	15 - 35
Spray Tower	4	10	4 - 9
Wet Cyclone	3	5	3 - 4
Venturi/Wet Cyclone	2	3	15
Total	53		
Fluidized Bed Incinerators			
Venturi/Impingement Tray	15	68	12 - 40
Impingement Tray	5	23	4
Venturi	2	9	17 - 18
Total	22		
Electric Incinerators			
Venturi	4	57	4 - 9
Impingement Tray	2	29	6 - 9
Venturi/Wet Cyclone	1	14	12
Total	7		

3.2.2 Control Technologies Applied After 1978

Table 3-2 shows the distribution of emission control technologies applied to sewage sludge incinerators built since 1978. The data presented in this table were collected as part of the survey described in Chapter 2. The control device installations included in Table 3-2 represent all 25 of the new incinerators identified in this study as being built since 1978.

Table 3-2 shows that most of the sewage sludge incinerators installed since 1978 are equipped with venturi/impingement-tray scrubbers. Before 1978, only 20 percent of the multiple-hearth incinerators used venturi/impingement-tray scrubbers, but after 1978, this number increased to nearly 90 percent. Three of the four new fluidized-bed incinerators are also equipped with combination venturi/impingement-tray scrubbers. New electric incinerators are controlled predominantly by individual venturi scrubbers.

Pressure drops for the venturi/impingement scrubbers shown in Table 3-2 range from 10 to 45 inch W.G. In general, this represents an increase in pressure drop over the same type of scrubber used prior to 1978. The following section presents a brief process description for a typical venturi/impingement-tray scrubber system.

3.2.3 Venturi/Impingement-Tray Scrubber Description

Figure 3-1 presents a simplified diagram of a typical venturi/impingement-tray scrubber. As the figure shows, 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 travelling 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, it passes into a flooded elbow where the stream velocity decreases allowing the water and gas to separate. Most venturi

TABLE 3-2. DISTRIBUTION OF EMISSION CONTROL TECHNOLOGIES APPLIED TO SEWAGE SLUDGE INCINERATORS AFTER 1978

Control Type	Total Number	Percent of Total	Range of Pressure Drops (in. w.g.)
Multiple Hearth Incinerators			
Venturi/Impingement-Tray	15	88	10 - 45
Fabric Filter	1	6	-
Impingement Tray	1	6	10
Total	17		
Fluidized Bed Incinerators			
Venturi/Impingement-Tray	3	75	42
Venturi	1	25	DNR[a]
Total	4		
Electric Incinerators			
Venturi	3	75	8 - 10
Venturi/Impingement-Tray	1	25	10
Total	4		

[a]Data Not Recorded

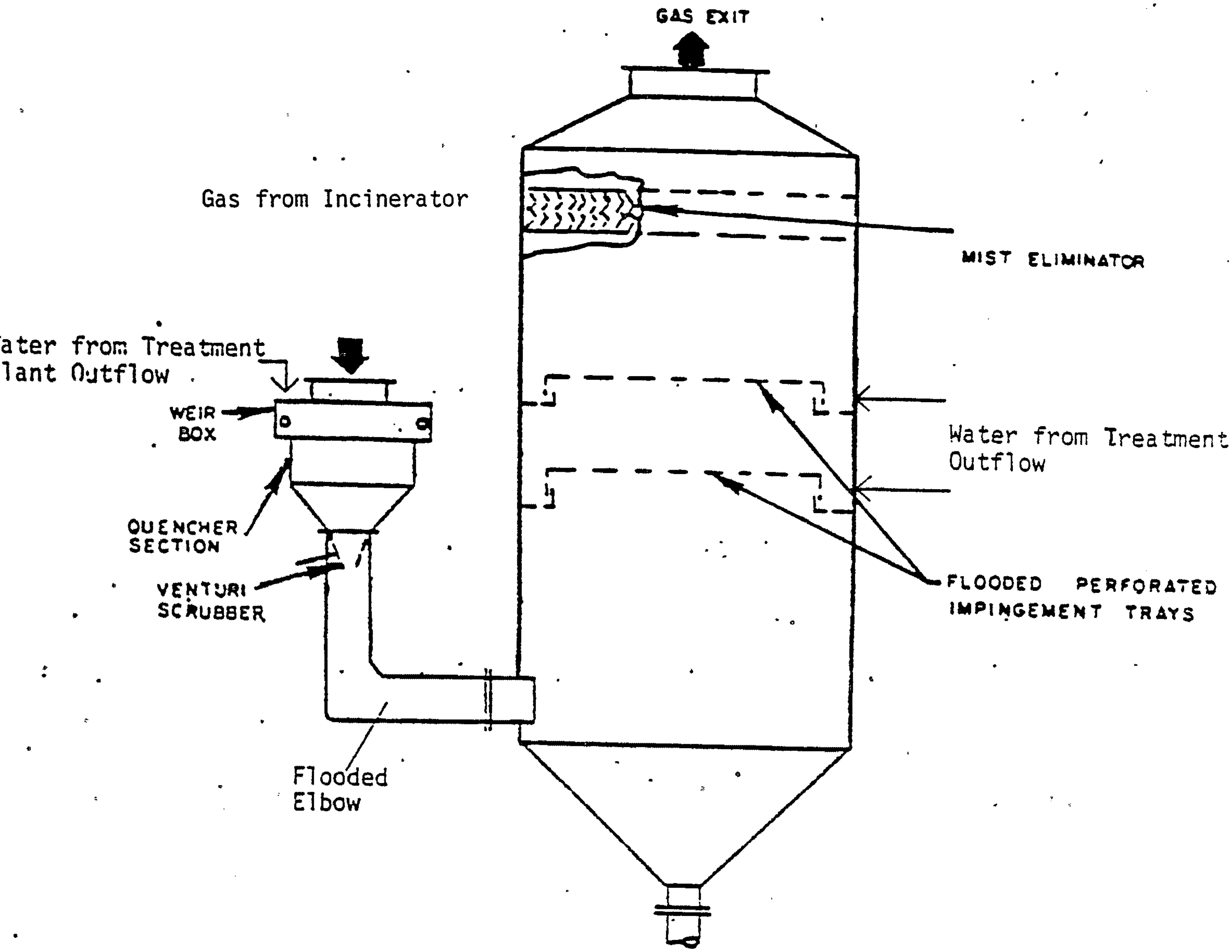

Figure 3-1. Cross-Sectional View of a Venturi/Impingement-Tray Scrubber

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.

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 mist eliminator to reduce the carryover of water droplets in the stack effluent gas. The impingement section can contain from 1 to 4 trays, but most systems for which data are available have 2 or 3 trays.

Although pressure drop information for individual components of the venturi/impingement-tray scrubber system is limited, available data show that the impinger section usually accounts for just under one-third of the overall scrubber pressure drop. As shown in Table 3-2, overall pressure drops range from 10 to 45 inch W.G. Individual impingement-tray tower pressure drops range between 5 and 10 inch W.G.

As noted earlier, scrubber water consists of effluent from the water treatment plant. The total solids content of the inlet scrubber water depends on the performance of the water treatment plant. Design data for one plant built after 1978 indicates a permissible total solids content of 1 to 5 percent.[3]

3.3 UNCONTROLLED EMISSIONS FROM SEWAGE SLUDGE INCINERATORS

The following section describes the uncontrolled emission characteristics of sewage sludge incinerators. The discussion focuses on (1) the differences in emission characteristics for the three major types of incinerators, and (2) the factors affecting uncontrolled emissions.

3.3.1 Uncontrolled Emission Characteristics of Sludge Incinerators

Uncontrolled particulate emission rates can vary widely depending on the type of incinerator, the volatiles and moisture content of the sludge, and the overall operating practices employed. Generally, uncontrolled particulate emissions from fluidized-bed incinerators are the highest because suspension burning results in most 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.

Since particulate loadings at the scrubber inlet are not normally measured during compliance testing, uncontrolled emissions data are limited. The available data are presented in Table 3-3. Both relatively new, as well as older, incinerators are represented in the table.

For the 21 multiple-hearth incinerators listed in Table 3-3 uncontrolled particulate emission rates range from about 5 lbs/dry ton sludge input to over 450 lb/ton. The average emission rate for the 21 multiple-hearth incinerators is 89 lb/ton. Both of the incinerators with the highest uncontrolled emission rates burn a sludge having relatively low percentage of volatile solids. Nonetheless, in order to emit 450 lb/ton, a large percentage of the inert materials would have to be discharged with the furnace exhaust. As is discussed below, much of the ash from these incinerators was probably being suspended by incoming air and emitted with the flue gas. If the two incinerators having the highest emission rates, Indianapolis #2 and MERL D, are excluded, the average uncontrolled emission rates for the multiple-hearth incinerators listed in Table 3-3 decreases to 51 lb/dry ton sludge input.

Uncontrolled emission rates for the 12 fluidized-bed incinerators listed in Table 3-3 range from 18 to 342 lb/dry ton input with an average of approximately 88 lb/ton. The results obtained from the incinerators in Lynwood and Edmonds, Washington, are notable in that they demonstrate the wide fluctuations in uncontrolled emissions that can occur from a single incinerator, burning a sludge of relatively constant volatiles and moisture content, at a relatively constant loading rate.

The data available for electric incinerators indicate a range of uncontrolled particulate emissions of from 3 to 17 lb/ton with an average of 11.2 lb/ton.

TABLE 3-3. UNCONTROLLED EMISSION DATA FOR SEWAGE SLUDGE INCINERATIONS

Name/Location	Capacity (dry lb/hr)	Sludge Moisture (%)	% Volatiles in Sludge Solids	Emission Rate (lb/dry ton sludge)
Multiple-Hearth Incinerators:				
Williamsburg # 1[a]	975	88	89	23.02
Williamsburg # 2[a]	1165	88	90	15.29
Indianapolis # 1[b]	4900	65[c]	30[c]	292.59
Indianapolis # 2[b]	4900	65	30	454.57
Indianapolis # 3[b]	4900	65	30	73.15
Indianapolis # 4[b]	4900	65	30	43.54
Indianapolis # 5[b]	4900	65	30	59.22
Indianapolis # 6[b]	4900	65	30	73.15
Indianapolis # 7[b]	4900	65	30	73.15
Indianapolis # 8[b]	4900	65	30	43.54
Decatur, GA[b]	850	DNA[d]	DNA	26.92
Savannah, GA[b] # 1[b]	5250	DNA	DNA	30.49
Savannah, GA[b] # 2[b]	5250	DNA	DNA	18.29
MERL A[e]	2822	74	42	00.5

TABLE 3-3. (continued)

Name/Location	Capacity (dry lb/hr)	Sludge Moisture (%)	% Volatiles in Sludge Solids	Emission Rate (lb/dry ton sludge)
MERL B[e]	3080	80	57	10.20
MERL C[e]	5390	75	52	17.4
MERL D[e]	5980	75	29	450.8
MERL E[e]	3521	70	33	4.9
MERL F[e]	2065	73	49	11.3
Merrimack, NH # 1[f]	2170	85	DNA	31.52
Merrimack, NH # 2[f]	1770	86	DNA	36.93
AVERAGE,		73	43	89.07
Fluidized-Bed Incinerators:				
Lynwood, WA (A)[g]	220	75[c]	86[c]	187.00
Lynwood, WA (B)[g]	220	75	86	21.30
Lynwood, WA (C)[g]	220	75	86	342.00
Lynwood, WA (D)[g]	220	75	86	85.80
Lynwood, WA (E)[g]	220	75	86	67.80
Lynwood, WA (F)[g]	220	75	86	55.60
Lynwood, WA (G)[g]	220	75	86	46.40

TABLE 3-3. (continued)

Name/Location	Capacity (dry lb/hr)	Sludge Moisture (%)	% Volatiles in Sludge Solids	Emission Rate (lb/dry ton sludge)
Edmonds, WA (A)[g]	500	DNA	DNA	18.34
Edmonds, WA (B)[g]	500	DNA	DNA	66.0
Edmonds, WA (C)[g]	500	DNA	DNA	55.20
MERL J[e]	2955	DNA	67	19.10
AVERAGE		75	84	87.69
Electric Incinerators:				
Shirco (A)[h]	500	84	45	3.00
Shirco (B)[h]	1200	83	65	10.1
Shirco (C)[h]	1200	83	65	14.8
Shirco (D)[i]	400	85	50	17.0
AVERAGE		84	56	11.23

a) Reference 4
b) Reference 5
c) Average for entire facility
d) Data not available
e) Reference 6
f) Reference 7
g) Reference 8
h) Reference 9
i) Reference 10

3.3.2 Factors Affecting Uncontrolled Particulate Emission Rates From Sewage Sludge Incinerators

There are numerous factors that may influence the amount of particulate matter that is discharged from a sludge incinerator including characteristics of the sludge and operating practices. Since 1978 attempts have been made to identify correlations between these factors and emission rates, but for the most part, no quantitative correlations have been found.[11] It is important to note that the operating variables of a sludge incinerator are very closely inter-related. With the data presently available, it is virtually impossible to delineate precisely individual cause and effect relationships. Nonetheless, although the relationships between operating parameters and uncontrolled emission rates cannot not be quantified, they are discussed here in a qualitative manner.

3.3.2.1 Sludge characteristics. The two major characteristics of sewage sludge which may, directly or indirectly, affect the rate of uncontrolled emissions from sludge incinerators are the moisture content and the percent of volatile solids in the sludge feed. As the moisture content of the sludge increases, or as the volatile solids content decreases, more fuel is required to burn the sludge. As more fuel is consumed, the amount of air flowing through the incinerator is also increased. Higher air flow rates increase the opportunity for particulate matter to be entrained within the exhaust gases. Sludges having a low percentage of volatile solids compound this problem by also increasing the quantity of inert materials present.

The moisture content of the sludge can also have an indirect effect on particulate emissions by making it more difficult to obtain a correct drying profile within a multiple-hearth incinerator. As mentioned in the preceding chapter, too rapid drying can lead to severe turbulence in the upper hearths. A high degree of turbulence in the drying hearth(s) might also increase the amount of solids that become entrained in the exhaust gases.

Although the moisture content and volatile solids content of the sludge can affect uncontrolled emissions, no direct correlation is clearly evident between these parameters. For example, the two incinerators located in Merrimack, New Hampshire, listed in Table 3-3, burn a sludge having a very high moisture content. The uncontrolled emissions from these furnaces, however, were less than the average for the total number of multiple-hearth furnaces listed. Similarly, uncontrolled emissions from the MERL B incinerator were very low, although this unit burns a relatively high moisture content sludge.

3.3.2.2 Ash discharge system. One aspect of the design of multiple-hearth incinerators that has been clearly related to uncontrolled emission rates is the ash discharge system.[12] In some multiple-hearth incinerators air is allowed to enter into the ash drop hole at the base of the furnace. This allows virtually all of the fines in the ash to be suspended and drawn back into the incinerator. The unusually high uncontrolled particulate emission rates measured at both the Indianapolis #2 and MERL D incinerators were probably caused by this problem.[13,14]

3.3.2.3 Operating practices. A number of incinerator operating practices have the potential to impact uncontrolled emissions from sewage sludge incinerators. These include, but are not limited to, (1) sludge feed rate, (2) excess air rate, (3) rabble arm speed, (4) combustion zone location, (5) burner use profile, and (6) combustion air flow geometry. The delivery of a consistent quality and quantity of sludge is key in maintaining steady state incinerator operations. However, no single operating variable can have a totally independent effect on emissions. For example, combustion zone location is influenced strongly by both the sludge feed rate and the rabble arm speed, as well as by the burner use profile. Achieving optimum operating conditions within a sludge incinerator requires an optimization of many individual and closely inter-related parameters.

Operating practices have only been indirectly implicated as a factor that may affect uncontrolled emission rates. There are only two documented cases (discussed below) where changes in operating procedures have led to reduced emissions from sewage sludge incinerators. However, in both of these instances, emissions measurements were made at the outlet, rather than the inlet, of the control devices. Thus, it is not absolutely certain that the emission reductions achieved were due entirely to decreases in the amount of particulate being discharged from the furnace. Operational changes could also potentially lead to reduced emission rates by improving the efficiency of the scrubber. Scrubber efficiency will be affected by the particle size distribution, the velocity of the furnace exhaust gas, as well as by the concentration of the particulate matter in the exhaust gas. However, it is unlikely that changes in operating practices could result in major decreases in controlled emissions by increasing the efficiency of the control device alone; any major decrease in the controlled emission rate would imply a corresponding decrease in the total quantity of particulates entering the scrubber.

The first case where operational modifications have led to reduced emissions was at the Indianapolis incinerators. The operational changes were performed by the Indianapolis Center for Advanced Research (ICFAR) and were primarily directed toward reducing the fuel consumption of the incinerators.[15]

The program instituted by ICFAR was based on theoretical analysis of combustion kinetics, parametric data, and on data obtained from operational trial runs. The result of these analyses was specific operating ranges for key incinerator operating variables. For the Indianapolis incinerators (eight identical multiple-hearth furnaces with eight hearths each) the following operating conditions were specified:

1. Maintain excess air at 25 to 50 percent.
2. Utilize cooling air from the center shaft for combustion air.
3. Maintain sludge combustion on hearth 6.
4. Utilize burners on hearth 6 only; if additional fuel is required utilize hearth 4 burners.
5. Maintain sludge cake loading to design rates (7 tons/hour).
6. Employ slowest possible shaft speed (0.6 rpm).
7. Maintain furnace draft of .02 to .04 inches of water.

In addition, the program instituted by ICFAR called for installation of instruments to monitor sludge flow rate, oxygen levels in the furnace exhaust, and fuel flow rates. Control systems were also installed to remotely control fuel and air supply into the incinerators. Finally, a detailed operating manual was devised and used in conjunction with on-site operator training in the new operating mode.

Over an eight month, full scale, plant demonstration, fuel use was reduced by 34 percent after the new operating program was begun. Moreover, subsequent testing showed particulate emissions to have decreased by approximately 70 percent compared to those measured before the fuel saving program was instituted. In more detailed follow-up studies on incinerator #2, an attempt was made to find direct correlations between emissions and individual incinerator operating parameters. No consistent correlations were found, however, although the lowest emissions overall occurred at the slowest rabble arm speed. ICFAR concluded that additional tests were required to fill the void that exists in the analytical and operational understanding of how incinerator operating modes affect particulate emissions.

ICFAR instituted a similar operating program for the multiple-hearth incinerator located in Providence, Rhode Island. As will be discussed in the following section, the Providence incinerator failed to meet the NSPS during initial compliance testing; controlled emissions averaged 3.20 lb/dry ton sludge input during the first test in October 1980. The objective in initiating the new operating mode at Providence was to reduce both fuel consumption and particulate loadings to the scrubber. After the ICFAR procedures were initiated in the spring of 1982, along with general improvements in the condition of the plant, fuel consumption decreased by about 70 percent. Controlled particulate emissions were reduced by nearly 85 percent on the basis of an unofficial test conducted in July 1982, and by 50 percent on the basis of an official test performed in August 1982. Similar to the Indianapolis incinerators, emission reductions of this magnitude suggests that the rate of uncontrolled particulate release was significantly reduced as the result of changes in incinerator operating practices. The experience at Providence will be discussed in more detail in the following section.

Some additional insights into the relationship between operating parameters and uncontrolled emission rates have been obtained from work carried out by EPA's Municipal Environmental Research Laboratory (MERL). In tests conducted on ten sewage sludge incinerators, reductions in gas velocity were shown to reduce the amount of particulate discharged from the furnace. The average particle size also decreased with decreasing gas velocity, however. Although rabble arm speed adjustments were not shown to have any effect on the amount of particulate discharged from the furnace, there were some indications that decreasing rabble arm speed may result in increases in the average particle size. Thus, lowering the speed of the rabble arms may serve to compensate for the lower average particle sizes obtained when steps are taken (by lowering excess air or sludge feed rates) to reduce gas velocities.

3.4 ACHIEVABILITY OF THE STANDARD

In this section the achievability of the current NSPS for sewage sludge incinerators is assessed on the basis of the experience that facilities affected by the NSPS have had in complying with the standard. First, the compliance experiences of facilities installed prior to 1978 will be briefly summarized. In addition, some follow-up studies performed in response to the results obtained from the earlier review of the standard in 1978 will be summarized. Second, the compliance experience of incinerators installed after 1978 will be addressed.

3.4.1 Compliance Experience of Incinerators Installed Prior to 1978

The compliance experience of 26 incinerators was addressed in the 1978 review of the NSPS.[17] Table 3-4 lists these incinerators, and provides information on sludge characteristics, the types of control devices employed, as well as the emission levels achieved.

Of the 26 incinerators, 4 multiple-hearth units were unable to meet the standard. Of these four, however, only the failure of the Merrimack, New Hampshire #2 incinerator to meet the standard could not be reasonably explained, although some evidence implied that the high moisture content of the sludge burned at Merrimack might be responsible.[17] Between 1977 and

TABLE 3-4. SUMMARY OF EMISSIONS DATA FOR INCINERATORS REVIEWED IN 1978

Type[a]	Name/Location	Sludge Moisture (%)	Control Device[b]	Pressure Drop (in. W.G.)	Emissions Pounds/dry ton input
MHF	Chicopee, MA # 1	79	V-I	25	1.17
MHF	Chicopee, MA # 2	74	V-I	25	0.92
MHF	East Fitchburg, MA	83	I	3	3.50
MHF	Manchester, MA # 1	85	V	DNA[c]	0.39
MHF	Manchester, MH # 2	85	V	DNA	0.60
MHF	Merrimack, NH # 1	84	V-I	30	1.25
MHF	Merrimack, NH # 2	84	V-I	30	1.34
MHF	Upper Blackstone, MA # 1	74	V-I	27	0.98
MHF	Upper Blackstone, MA # 2	74	V-I	32	0.79
MHF	Upper Blackstone. MA # 3	74	V-I	25	1.50
MHF	Erie, PA # 1	80	V-I	24	0.97
MHF	Erie, PA # 2	80	V-I	24	0.57
MHF	Morrisville, PA	71	V-I	12	2.00
FBF	Tyrone, PA	77	V	22	0.20
MHF	Hopewell, VA	50	DNA	DNA	0.91
MHF	Maryville, TN	81	V-I	20	0.64
MHF	Granite City, IL	78	DNA	DNA	0.67[d]
MHF	Cincinnati, OH # 1	66	I	7	1.01
MHF	Cincinnati, OH # 2	67	I	8	0.56
MHF	Cincinnati, OH # 3	68	I	8	0.77
MHF	Lawton, OK	79	DNA	DNA	0.90
MHF	Missouri, KS # 2	80	V-I	18	0.99

TABLE 3-4. (continued)

Type[a]	Name/Location	Sludge Moisture (%)	Control Device[b]	Pressure Drop (in. W.G.)	Emissions Pounds/dry ton input
ELF	Plano, TX # 1	DNA	V-I	9	0.92
ELF	Plano, TX # 2	DNA	V-I	9	1.27
ELF	Richardson, TX	DNA	DNA	DNA	1.30
FBF	Longview, WA	50	V	30	DNA
	Average	76		19	1.04 0.87[e]

a MHF = Multiple-hearth; FBF = Fluidized-Bed; ELF = Electric
b V = Venturi scrubber; I = Impingement-tray scrubber
c DNA = Data Not Available
d Estimate
e Excludes E. Fitchburg, Blackstone # 3 and Morrisville (see note below)

Exclusions:

E. Fitchburg - excluded because impingement scrubber operated at 3 inches ΔP (not considered technology needed to meet NSPS).

Upper Blackstone #3 - excluded because problems were occurring with the vacuum filter used to dewater sludge and furnace feed was not uniform. This created a difficulty in maintaining combustion on the proper hearth.

Morrisville, PA - test report questions the accuracy of the feed scale. Indicates that feed was occuring while scale was reading zero.

1979 a number of modifications were made to the scrubber. These included alteration of the separator system to increase gas velocity through the mist eliminator, decrease of the venturi throat diameter, and the addition of four impingement plates within the cyclonic separator housing. The success of these modifications in reducing emissions from the Merrimack incinerators is shown in Table 3-5.[19] As can be seen in Table 3-5, both incinerators eventually were able to demonstrate compliance with the NSPS once the pressure drops of the control devices were increased to 40 to 42 in. W.G.

On the basis of the data collected during the 1978 review, no quantitative correlation could be established between controlled emission rates and either the pressure drop of the scrubber or the moisture content of the sludge. As can be seen in Table 3-4, some incinerators were able to achieve the standard at relatively low pressure drops. For example, the three incinerators in Cincinnati, Ohio, demonstrated compliance while using impingement-tray scrubbers operating at pressure drops of less than 10 in. W.G. In addition, some plants burning a sludge of relatively high moisture content (Maryville, TN, for example) easily met the standard with control devices operating at moderate pressure drops.

In order to examine whether correlations between operating variables and controlled emissions would become apparent if a larger data base were used, a follow-up study was initiated.[20] For this study, detailed data were collected on 60 sludge incinerators. However, no strong correlations could be found between emissions and either scrubber pressure drop, sludge moisture content, or sludge loading rate. Figure 3-2 shows the relationship found between emissions from multiple-hearth incinerators and the pressure drop of the control devices. The moisture content of the sludge is also shown. As can be seen, the relationship is highly scattered and no correlation is apparent.

Although no quantitative correlation has been generally established between emissions and scrubber pressure drop, this does not imply that the pressure drop of a control device has no impact on particulate emissions. For any given incinerator, and any given scrubber, emissions will increase as the pressure drop is decreased. Inversely, emissions can be decreased by

TABLE 3-5. SUMMARY OF EMISSIONS DATA FOR INCINERATORS 1 AND 2 AT THE MERRIMACK SITE

Date	Sludge Moisture (%)	Incinerator Number	Emissions (lb/dry Ton)	Scrubber Pressure Scrubber Drop (In. W.G.)	Operational Changes or Modifications Implemented Prior to Testing
5-77	84	1	3.04	25	None
	83	2	3.07	25	
9-77	85	1	1.94	33	Increased pressure drop on existing scrubber. Reduced lime feed in sludge dewatering.
	86	2	1.94	33	
10-77	84	1	1.87	32	Modified mist eliminator.
	82	2	1.48	32	
3-78	83	1	1.25	40	Modified venturi to increase maximum pressure drop to 40 inches W.G.
	84	2	1.34	40	
8-78	83	2	1.60	38	None
1-79	86	2	0.99	42	New impingement plates added.

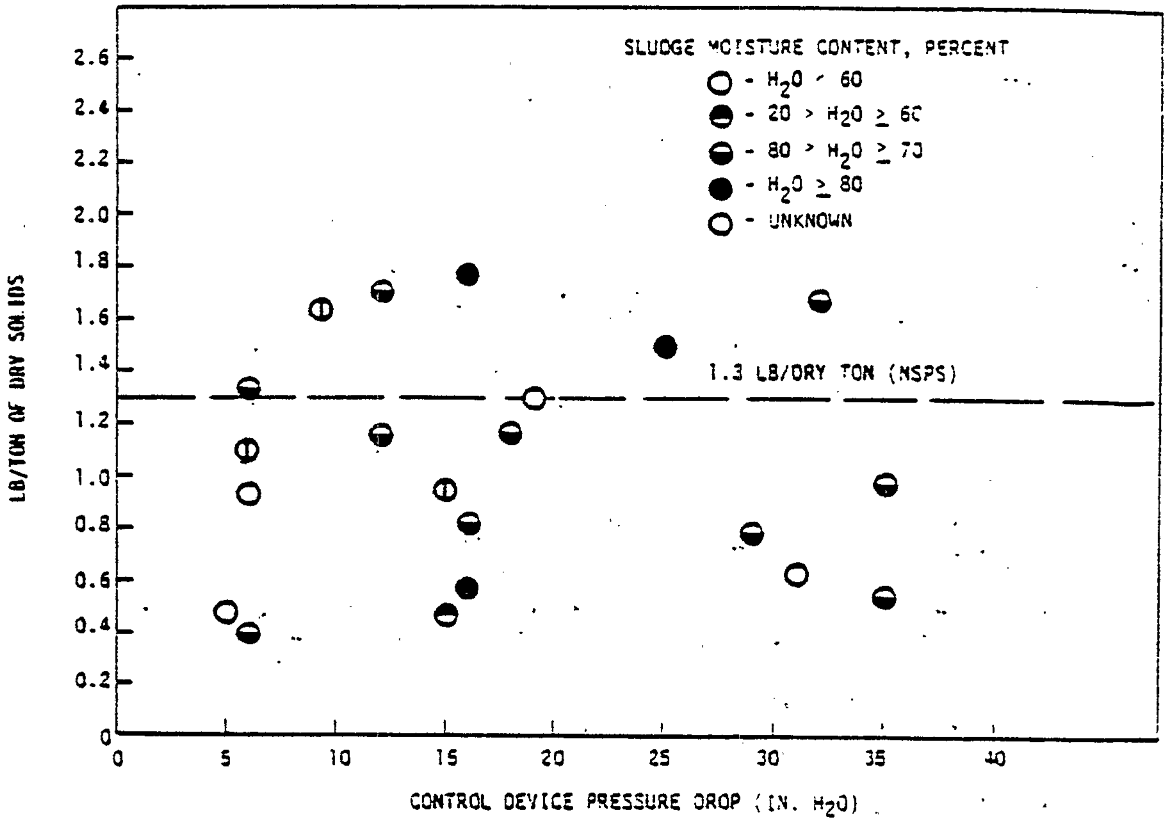

Figure 3-2. Multiple-Hearth Incinerator Emissions Versus Scrubber Pressure Drop

increasing the pressure drop of the scrubber (as seen in Table 3-5), at least until the particle size cut-off for the scrubber is reached. The analysis discussed in the preceeding paragraphs only indicates that there is no specific emission rate (lb/dry ton sludge) that can be universally correlated with a specific pressure drop.

3.4.2 Compliance Experience of Incinerators Installed After 1978

Sewage sludge incinerators that have come under the NSPS since 1978 are listed in Table 3-6. Information is provided on the types of control devices used, sludge characteristics, and emission rates achieved by these incinerators.

Of the 17 multiple-hearth incinerators listed in Table 3-6, 12 are in compliance with the NSPS. Four new units have not yet been tested. Only the incinerator located in Providence, Rhode Island, has failed to achieve the NSPS. The Attleboro incinerator did, however, fail to meet the standard during initial compliance tests. All four of the fluidized-bed incinerators installed since 1978 have achieved the NSPS. Of the four electric incinerators listed in Table 3-6, only one is in compliance with the standard. One electric incinerator has not yet been tested. Incinerators that have failed to meet the standard are discussed in more detail in Section 3.4.2.1.

The average particulate emission rate achieved by all new multiple-hearth incinerators is 0.76 lb/dry ton of sludge input. If the Providence incinerator is excluded, the average emission rate for facilities in compliance is 0.67 lb/ton. This is approximately one-half of the allowable standard. The pressure drops of the scrubbers employed to meet the standard ranged from 10 to 45 in. W.G. The average pressure drop for all 17 multiple-hearth incinerators is about 28 in. W.G. Apparently, however, many of the multiple-hearth incinerators listed in Table 3-6 could have achieved the standard at lower pressure drops. In one instance, Youngstown, Ohio, the standard is being met with a scrubber operating at a pressure drop of only 10 in. W.G.

The average emission rate for the fluidized-bed incinerators that have come under the NSPS since 1978 is 0.74 lb/ton. The pressure drops of the

TABLE 3-6. COMPLIANCE STATUS OF SLUDGE INCINERATORS THAT HAVE BEGUN OPERATING SINCE 1978

Name/Location	Sludge Moisture (%)	Control Device[a]	Pressure Drop (in. W.G.)	Emissions lb/dry ton sludge
Multiple Hearth Incinerators:				
Marietta, GA	61	V-I	26	1.00
Oahu, HW	73	V-I	26	Not Tested
Cedar Rapids, IA	70	V-I	30	1.10
Covington, KY	60	FF	NA[b]	0.48
Attleboro, MA	65	V-I	33	0.51
Battle Creek, MI	81	V-I	30	Not Tested
St. Paul, MN #1	67	V-I	30-35	0.30
St. Paul, MN #2	67	V-I	30-35	0.85
Atlantic City, N.J.	66	V-I	30	0.67
Amherst, NY	65	V-I	38-45	0.99
Niagra, NY	65	V-I	31	Not Tested
N. Tonawanda, NY	66	V-I	32	0.40
Rocky Mount, NC	60	V-I	27	0.67
Cleveland, OH	70	V-I	10	Not Tested
Youngstown, OH	72	I	10	0.29
Providence, RI	66	V-I	30	1.69
Arlington, VA	65	V-I	29-36	0.20[c]
Average	67		28	0.76
Fluidized Bed Incinerators:				
Kansas City, KA	70	V	DNR[d]	0.99
Independence, MO	65	V-I	30	0.70
Erie County, NY #1	75	V-I	42	0.75
Erie County, NY #2	75	V-I	42	0.28
Average	70		36	0.74

TABLE 3-6. (continued)

Name/Location	Sludge Moisture (%)	Control Device[a]	Pressure Drop (in. W.G.)	Emissions. lb/dry ton sludge
Electric Incinerators:				
Petersburg, AK	82	V	8	3.83
Wrangle, AK	83	V	9	1.23
Cynthiana, KY	65	V-I	10	1.60
Bay County, MI	65	V	10	Not Tested
Average	74		9	2.22
Average (all plants)	70		24	1.24

a V-I = Venturi/Impingement Scrubber; FF = Fabric Filter; I = Impingement scrubber; V = Venturi scrubber
b NA = Not Applicable
c Preliminary Test Result
d DNR = Data Not Recorded

scrubbers employed to meet the standard were between 30 and 42 in. W.G. As is the case for multiple-hearth incinerators, however, the standard could evidently be achieved by these units at more moderate pressure drops.

For the three new electric incinerators that have been tested, the average emission rate is 2.22 lb/ton. However, the control devices in use at each of these facilities operate at low pressure drops (average = 9 in. W.G.). This is significantly less than the pressure drop that would considered be Best Available Control Technology (BACT) for sewage sludge incinerators.[21]

3.4.2.1 Discussion of incinerators that have failed to achieve the NSPS. In this section the experience at the Providence incinerator is addressed in more detail. Since the Attleboro incinerator failed to pass its original compliance tests, the experience there will also be briefly reviewed. Because neither of the two electric incinerators that have failed to meet the standard are equipped with BACT, these units will not be considered in an assessment of the achievability of the standard.

The incinerator located in Attleboro, Massachusetts, is a seven hearth unit with a rated sludge capacity of 3,350 lb/hour (dry basis). The incinerator burns both sludge and scum from primary and secondary wastewater treatment processes. The maximum design feed rate of the scum is 1.4 gallons/minute. Operation of the incinerator is controlled by a computer, and is designed for completely automatic operation.

The Attleboro incinerator failed to achieve the NSPS when first tested in December of 1981. Failure to meet the standard was due to a breakdown of the computer while the test was in progress.[22] Once the problem with the computer control system was rectified, a second series of tests were conducted in February of 1983. The incinerator was also unable to achieve compliance during this second series of tests, however. The main problem encountered during this test was in the scum feeding mechanism.[23] Originally, the scum was atomized and injected into hearths four and six. Besides a number of mechanical problems associated with the scum atomization and injection systems, the scum injected into hearth four was not being completely combusted. At the time of the test, it was determined that if the scum were injected into hearth six only, without atomization, then the incinerator would be able to achieve the standard.[24] The incinerator was retested in this mode in May 1983, and demonstrated compliance with the NSPS.

The incinerator located in Providence, Rhode Island, is multiple-hearth design (nine hearths) and a rated capacity of from 2.2 to 2.8 dry tons of sludge per hour. Design specifications call for a sludge moisture content of 72 to 78 percent with a volatile solids content of 55 to 75 percent. The incinerator was originally constructed in 1959. Extensive renovations were made to the incinerator beginning in the late 1970's. These modifications were severe enough to bring the unit under the NSPS at that time.

Compliance testing was initially conducted in October 1980. Measured emissions averaged 3.20 lb/dry ton input during these tests. None of the three separate test runs showed emissions to be within the NSPS. During subsequent investigations, a number of problems were identified which could have contributed to the failure of the incinerator to achieve the standard. Many of the burners were not functioning properly, and some were not operating at all. In addition, numerous instrumentation and control systems were out of order, including the center shaft speed alarm, the temperature recorder, and the high/low alarms for the ash slurry tank.[25] The volatiles content of the sludge burned during the test was only 50 to 55 percent, which was slightly lower than the minimum design specifications. The sludge loading rate was also only about 65 percent of design capacity. Most likely as a result of the poor sludge quality and the reduced loading rate, combustion was not occurring on the proper hearths. The scrubber inlet water was also very dirty due to either a dirty water strainer or to an exceptionally high total solids content in the treatment plant effluent (no quantitative measurements of the scrubber water solids content were made at the time of the test).[26] It also was noted in the test report that the paint used to coat the interior of the stack was peeling off during testing and collecting in the sampling train.[27] Finally, during the 1980 tests an oil-fired afterburner was in use which could have also contributed to excessive particulate emissions.[28]

As noted previously in the section on uncontrolled emission characteristics, subsequent to the initial compliance testing, a number of incinerator modifications and operational changes were made in an effort to improve control of the incineration system and to reduce emissions. Many of these changes were performed in consultation with ICFAR. The following system modifications and operational changes were initiated after the 1980 test:

1. A temporary oxygen monitor was installed upstream of the control device to aid operators in controlling the furnace.
2. Inoperative burners were replaced, and other burners adjusted.
3. A sludge feed rate indicator was installed in the control room.
4. The sludge dewatering process was changed to a 24 hour cycle to increase the dewatering efficiency of the filter presses and to ensure a more consistent quality feed to the incinerators.
5. All existing instruments and controls were repaired and calibrated.
6. An operating procedure was developed to maintain combustion on the proper hearths.
7. An on-site operator training program was instituted.
8. The scrubber system was inspected and all necessary maintenance carried out.

After these changes were performed, the Providence incinerator was unofficially tested. Emissions during those tests averaged 0.65 lb/dry ton sludge input; one-half of the allowable NSPS limit and an 80 percent reduction from the results obtained in the 1980 test. On the basis of these results, an official compliance test was conducted three weeks later in August 1982. However, during the August test the incinerator failed to meet the allowable emission limitation.

The results of all three separate emission tests performed on the Providence incinerator are summarized in Table 3-7. Important operating variables as measured during these tests are also provided. The most noticeable difference between the 1980 tests and those performed in 1982 is the quantity of fuel consumed. Prior to initiation of the fuel conserving operational mode, the Providence incinerator burned, on average, 34 gallons

TABLE 3-7. SUMMARY OF EMISSIONS TESTS ON INCINERATOR IN PROVIDENCE, RHODE ISLAND

Test Date	Emissions (lb/ton)	Feed Rate (dry tons/hr)	Sludge Moisture (%)	Scrubber ΔP (in. W.G.)	Gas Velocity (ft/min)	Gas Flow (dscfm)	Fuel Flow (gal/ton sludge)
10/1/80	2.43	1.75	76.4	31.0	2280	21,500	107[a]
10/1/80	4.12	1.81	75.7	31.5	2310	21,800	93[a]
10/2/80	3.04	1.82	77.0	30.8	2320	21,900	106[a]
Average	3.20	1.79	76.4	31.1	2300	21,700	102[a]
7/21/82	0.70	3.07	65.2	31.8	1615	15,100	3.00
7/22/82	0.56	3.01	68.9	35.6	1645	15,300	9.41
7/22/82	0.67	3.05	69.3	32.7	1200	10,700	13.39
Average	0.65	3.04	67.8	33.4	1490	13,700	8.60
8/10/82	1.29	2.60	70.1	29.4	1540	14,250	4.61
8/10/82	3.03	2.51	67.8	30.7	1800	16,950	7.97
8/10/82	0.74	2.18	71.9	30.6	1470	13,780	15.54
Average	1.67	2.43	69.9	30.2	1600	15,000	9.37

a Afterburner in use.

of No. 2 fuel oil per ton of sludge feed. After the operational changes were made, average fuel use declined to less than 10 gal/ton. Flue gas flow rates decreased as less fuel was required to burn the sludge. The average gas flow rate during the 1982 test was 70 percent of what it was in 1980. The data in Table 3-7 also indicate that the changes made in the dewatering cycle were successful in reducing the moisture content of the sludge. The average sludge moisture content during the 1980 test was 76.4 percent, compared to average moisture contents of 67.8 percent and 69.9 percent during the July and August, respectively, 1982 tests. Finally, during the 1982 tests, the sludge feed rate was within design capacity while in the 1980 test sludge was being fed to the incinerator at less than minimum design loadings.

The Providence incinerator failed to meet the NSPS during the August 1982 test, owing to the sharp increase in emissions during Run No. 2. There were, however, repeated upsets in the operation of the incinerator while the test was in progress. These upsets were, for the most part, caused by external factors that ultimately interfered with the operation of the incinerator. One impact of these upsets on the operation of the incinerator is reflected in the air flow rates. As discussed earlier, an increase in the air flow rate through the incinerator should result in some increase in the amount of particulate discharged from the furnace. During run No. 2 of the August 1982 test, the average flue gas flow rate was nearly 20 percent higher than it was during the first run, and emissions increased substantially. The problems encountered during the August test are reviewed below, and are based on the conclusions drawn by the operators of the Providence incineration facility.[29]

Prior to the test, the incinerator had been operated only intermittently due to continuing mechanical problems with the incinerator and associated equipment. On the day of the test, sludge was first fed to the incinerator only five hours before the test was scheduled to begin. Plant personnel felt that this was insufficient time for the incinerator to stabilize, especially at the required feed rates.

Approximately one minute after the start of the first run an electrical problem caused all of the burners in the incinerator to go out of service. In the ten minutes it took to correct the problem, the operation of the incinerator became even less stable. A further failure of the electrical system occurred approximately one-half hour later. While the problem was being repaired, all power to the circuit was shut-off. Many of the incinerator control systems were tied to this circuit, including the oxygen analyzer and the sludge scale. The operators of the incinerator, however, were not informed that the power to these instruments had been cut. As a result, a number of incorrect control responses were made, further disrupting the overall operation of the furnace.

Problems were also experienced with the dewatering system during the first test run. Due to a problem with a sludge feed pump, two of the vacuum filters went off-line causing the sludge feed to be reduced by about 50 percent for a short period of time. While the sludge feed was interrupted, there was a noticeable increase in stack gas opacity.

The various problems experienced while the first run was in progress carried over to the second test run. Several of the burners were not operating which limited the operator's control of the furnace. Continuing problems with the sludge feed pumps led to an unsteady rate of feed to the furnace. The major problem occurring in the second run, however, was caused by waste oil which had inadvertently been stored in one of the sludge holding tanks. Just prior to the start of run No. 2, the operators began to feed the furnace with the sludge from this tank. The presence of the waste oil caused periodic flare-ups in the furnace. Sludge began to burn in the drying hearths. In order to control these flare-ups, the airflow through the incinerator was increased by opening up the access doors on the upper hearths. This was estimated to cause a three- to five-fold increase in the air flow through the system. When the air flow was increased, carbon particles which had built up inside the exhaust system were dislodged. Whenever the system air flow was increased, there was a corresponding increase in visible emissions.[30]

In summary, the Providence incinerator and its associated systems were not in good working condition when first tested in 1980 for compliance with the NSPS. A program was subseqently carried out to upgrade the equipment at the plant and to improve the overall operation of the facility. This program was successful in reducing fuel consumption and in reducing particulate emissions, as evidenced by the unofficial test conducted in July, 1982. During the August compliance test, a series of equipment failures prevented the incinerator from reaching a stable level of operation. For the most part, these failures were unusual and can not be considered as representative of typical operating conditions at the facility. In absence of the problems experienced during the August test, the Providence incinerator could be reasonably expected to achieve the NSPS.

3.5 EMISSIONS OF TRACE ELEMENTS FROM SEWAGE SLUDGE INCINERATORS

As noted in Chapter 2, one of the original basis of the development of the NSPS for sewage sludge incinerators was their potential to emit toxic trace elements into the atmosphere. In this section, data on trace element emissions from sludge incinerators are presented and briefly discussed.

3.5.1 Data Sources and Methods of Analysis

Relatively limited data are available on trace element emissions from sludge incinerators. The most complete set of data available is that assembled by EPA's Municipal Environmental Research Laboratory (MERL) from tests on ten incinerators.[31] In these tests sampling was conducted at both the inlet and the outlet of the control device. Thus, the MERL data includes measurements of both controlled and uncontrolled trace element emissions. Complete data are available for only 6 of the 10 incinerators tested, however.

MERL employed a Source Assessment Sampling System (SASS). Since only one sampling train was available, measurements at the scrubber inlet and outlet were not made simultaneously. This could potentially introduce significant error into the data, because release of trace elements from sludge incinerators can be highly variable over relatively short periods of time. The particles collected in the front end of the SASS train were separately digested and analyzed for trace element content using a spectrophotometer system with an inductively coupled argon plasma source.

Another set of data on trace element emissions from sludge incinerators was developed from tests conducted by EPA's Environmental Sciences Research Laboratory (ESRL).[32] Four sludge incinerators were tested by ESRL. A standard EPA Method 5 sampling train was employed. Samples were collected at the outlet of the control device only. Analysis of the particulates (probe and filter catch) for trace element composition was performed through X-ray fluorescence spectrophotometry.

The final data presented in this section are for the incinerator installed in Atlantic City, New Jersey.[33] The Atlantic City unit is relatively new, having been installed after 1978. The trace element content (cadmium and lead only) of the particulates collected during compliance testing were measured using standard X-ray fluorescent techniques.

3.5.2 Uncontrolled Emissions of Trace Elements

Table 3-8 summarizes the data collected by MERL on uncontrolled emissions of trace elements from six sewage sludge incinerators.

The uncontrolled rate of particulate emissions are provided for reference. The highest uncontrolled trace element emissions from the six incinerators were for lead (Pb). Lead emissions ranged from 0.03 lb/ton to 1.77 lb/ton. Average uncontrolled Pb emissions (0.45 lb/ton) were more than double those for chromium. Uncontrolled emissions of cadmium (Cd) ranged from 0.002 lb/dry ton sludge to 0.07 lb/ton. The average rate of uncontrolled Cd emissions was 0.03 lb/dry ton. Uncontrolled chromium (Cr) emissions were higher, ranging from 0.007 lb/ton to 0.63 lb/ton (average = 0.18 lb/dry ton). Uncontrolled emissions of Nickel (Ni) averaged 0.08 lb/dry ton, but were as high as 0.33 from incinerator D. Arsenic (As) emissions were generally negligible, with the exception of incinerator A which emitted 0.64 lb/dry ton sludge. Four of the six incinerators, however, showed uncontrolled arsenic emissions of less than 0.001 lb/ton. Overall, incinerators A and D had the highest rates of uncontrolled trace element emissions.

TABLE 3-8. UNCONTROLLED TRACE ELEMENT EMISSIONS FROM SEWAGE SLUDGE INCINERATORS

Name/Location	Incinerator Type[a]	Sludge Feed (dry lb/hr)	Uncontrolled Emission Rates (lb/dry ton sludge)					
			Particulates	Cd	Cr	Ni	Pb	As
MERL A	MHF	3825	80.5	0.0427	0.3382	0.1610	0.5943	0.6442
MERL C	MHF	4405	17.4	0.0709	0.0889	0.0840	0.0903	0.0008
MERL D	MHF	1587	450.8	0.0586	0.6268	0.3337	1.7721	0.0243
MERL E	MHF	2970	4.9	0.0047	0.0071	0.0035	0.1563	0.0004
MERL F	MHF	3499	11.3	0.0147	0.0038	0.0015	0.0263	0.0004
MERL J	FBF	3849	19.1	0.0016	0.0127	0.0114	0.0522	0.0007
AVERAGE			97.3	0.0322	0.1796	0.0750	0.4486	0.2236

a MHF = Multiple-hearth furnace; FBF = Fluidized-bed furnace

3.5.3 Controlled Trace Element Emissions

Data on controlled emissions of trace elements from sewage sludge incinerators are presented in Table 3-9.

As in the case of the data on uncontrolled emissions, controlled lead emissions are the highest of all the trace elements analyzed. Controlled lead emissions ranged from 0.002 lb/ton to 0.16 lb/ton, and averaged 0.05 lb/ton for all 12 tests. Controlled emissions of cadmium averaged approximately 0.01 lb/dry ton sludge for the 12 incinerators listed. This is about one-third of the average uncontrolled emission rate for cadmium. Average controlled emissions of chromium are four percent of the average uncontrolled rate. Average controlled emissions of nickel are also about four percent of the average uncontrolled rate. In all cases, controlled emissions of arsenic were negligible. The arsenic emission rate of 0.02 lb/ton reported for incinerator MERL C is probably in error since the uncontrolled As emission rate reported for this incinerator was 0.0008 lb/ton. As mentioned earlier, however, the inlet and outlet samples were not collected simultaneously. Thus, the arsenic emission rate during the outlet sampling could have conceivably been higher than it was when the measurements were made at the scrubber inlet.

The various data sources are in relatively good agreement for controlled cadmium emissions. Controlled cadmium emissions ranged from 0.003 to 0.06 lb/ton, with an average emission rate of 0.01 lb/ton. The cadmium data from the Atlantic City incinerator illustrate the variability in emission rates that can occur from an individual incinerator.

The data for controlled chromium and nickel emissions are also reasonably consistent. Chromium emissions range from 0.0002 lb/ton to 0.03 lb/ton; nickel emissions range from 0.0002 lb/ton to 0.008 lb/ton.

The lead emissions rates reported for both the ESRL incinerators and the Atlantic City incinerator are generally lower than those given in the MERL data. The highest reported controlled emission rate for lead is 0.16 lb/dry ton.

TABLE 3-9. CONTROLLED TRACE ELEMENT EMISSIONS FROM SEWAGE SLUDGE INCINERATORS

Name/Location	Incinerator Type[a]	Sludge Feed (dry lb/hr)	Controlled Emission Rates (lb/dry ton sludge) Particulates	Cd	Cr	Ni	Pb	As
MERL A	MHF	2824	1.43	0.0195	0.0074	0.0062	0.1552	0.0002
MERL C	MHF	5381	1.33	0.0104	0.0078	0.0039	0.0534	0.0209
MERL D	MHF	2586	3.46	0.0059	0.0076	0.0055	0.1577	0.0004
MERL E	MHF	3519	0.26	0.0012	0.0003	0.0002	0.0565	0.0000
MERL F	MHF	2064	1.18	0.0009	0.0017	0.0004	0.0243	0.0002
MERL J	FBF	2954	0.07	0.0000	0.0002	0.0003	0.0002	0.0000
ESRL O	MFH	4277	0.92	0.0030	0.0071	-	0.0373	-
ESRL P	MHF	3836	3.43	0.0024	0.0024	0.0082	0.0778	-
ESRL Q	FBF	1850	0.23	0.0003	0.0006	-	0.0051	-
ESRL R	MHF	4167	2.25	0.0624	0.0074	-	0.0707	-
Atlantic City, NJ	MHF	2180	1.15	0.0075	-	-	0.0054	
Atlantic City, NJ	MHF	2180	0.49	0.0017	-	-	0.0035	
AVERAGE			1.35	0.0096	0.0072	0.0035	0.0539	0.0002

a MHF = Multiple-hearth furnace; FBF = Fluidized-bed furnace

3.5.4 Control Efficiencies for Trace Element Emissions

Using the MERL data, the efficiency of control devices in reducing emissions of trace elements from sewage sludge incinerators can be estimated. In Table 3-10 both the type, and the operating pressure drops, of control devices in use on the MERL incinerators are listed. The overall control efficiencies for particulate emissions are shown, and these can be compared to the control efficiencies calculated for the five trace elements.

Based on average data only, control efficiencies for trace metals are less than those for total particulates. The lowest control efficiency is for lead emissions, which average 63 percent. The next lowest removal efficiency, 83 percent, is for cadmium.

There are, however, significant variations among individual incinerators. In some cases, trace elements are controlled more efficiently than total particulates. For example, the calculated removal efficiency of nickel for incinerator MERL C, 95 percent, is higher than the 91 percent calculated for particulates as a whole. There is also significant variability within individual trace element categories. The removal efficiency of both cadmium and chromium ranges from about 55 percent to about 90 percent. An even greater variability is seen in the percent reduction in lead emissions that can be achieved by typical control devices. There is no apparent correlation between scrubber pressure drop and either control of trace elements or control of total particulates.

3.6 NATIONAL EMISSIONS FROM SEWAGE SLUDGE INCINERATORS

Estimates from the NEEDS Survey discussed in Chapter 2 indicate that an increase of 3,713 million gallons per day of wastewater will flow into new treatment plants equipped with incinerators between 1982 and the year 2000. Assuming a linear increase, a 1,031 million gallons per day increase is estimated to occur for 18 new incineration facilities between 1984 and 1989. For an average sludge production of 0.65 dry tons per million gallons of wastewater (see Section 2.2.2), the flow of sludge into new incineration facilities is estimated to be 245,000 dry tons in the year 1989. Assuming all new incinerators produce particulate emissions at a rate equal to the

TABLE 3-10. CONTROL EFFICIENCIES FOR TRACE ELEMENT EMISSIONS FROM SEWAGE SLUDGE INCINERATORS

Name/Location	Incinerator Type[a]	Control Device Type[b]	Pressure Drop (in. W.G.)	Removal Efficiencies (%) Particulate	Cd	Cr	Ni	Pb	As
MERL A	MHF	I	10	98.69	54.41	97.81	96.15	73.89	99.96
MERL C	MHF	I	16	90.61	85.38	91.21	95.38	40.82	-2630.35[c]
MERL D	MHF	I	6	98.73	89.99	98.79	98.36	91.10	98.29
MERL E	MHF	V-I	20	93.78	74.49	95.49	93.98	63.87	90.78
MERL F	MHF	V-I	20	93.82	93.98	54.76	76.08	7.33	43.83
MERL J	FBF	V-I	16	99.70	99.01	98.78	97.66	99.60	99.05
AVERAGE			15	95.89	82.88	89.47	92.94	62.77	86.38

a) MHF = Multiple-hearth furnace; FBF = Fluidized-bed furnace
b) I = Impingement-tray scrubber; V-I = Venturi/Impingement-tray scrubber
c) Outlet loadings calculated to be higher than inlet loadings

current standard (1.3 lb/dry ton sludge), national particulate emissions from all new incinerators are estimated to be 160 tons in 1990. Based on a weighted average uncontrolled particulate emission rate for all incinerators of 52 lb/dry ton sludge, national emissions from new sludge incinerators would be approximately 6,400 tons if the NSPS were not in place.

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4.0 CONTROL COSTS

4.1 INTRODUCTION AND SUMMARY

4.1.1 Introduction

This chapter presents the costs of controlling particulate emissions from sewage sludge incinerators. Section 4.2 presents the details of the cost components. The capital and annualized costs for a range of multiple-hearth and fluidized-bed sewage sludge incinerator sizes are presented in Section 4.3. Cost effectiveness of controlling particulate emissions from these incinerators is presented and discussed in Section 4.4.

4.1.2 Summary of Findings

The cost effectivness of controlling particulate emissions from sewage sludge incinerators is estimated to range from $191 to $1743 per ton removed. These costs are based on conservative capital cost estimates for venturi/impingement-tray scrubbers operating at pressure drops of from 20 in. W.G. to 40 in. W.G. Cost effectiveness is most sensitive to incinerator size. The highest cost effectiveness was calculated for a 500 dry lb/hr fluidized-bed incinerator equipped with a venturi/impingement-tray scrubber operating at a pressure drop of 40 in. W.G. The total cost impact of operating at lower pressure drops is very small, on the order of $10 per ton of particulate removed for each 10 in. change in pressure drop. For equivalent size incinerators, the cost effectiveness of reducing particulate emissions from fluidized-bed incinerators is less than that from multiple-hearth incinerators.

4.2 COST COMPONENTS

The estimated control costs for sewage sludge incinerators are based on the most prevalent control system applied to incinerators built since 1978; the venturi/impingement-tray scrubber. Flue gas from the incinerator is first ducted to a variable throat venturi scrubber. In the venturi the dust particles agglomerate with the scrubbing liquid. The gas stream then passes through a flooded elbow which agglomerates the larger, heavy droplets. An impingement scrubber cools the gas, further reduces particulates, and eliminates mist with a mist eliminator. The gas then passes onto the stack. A more detailed description of a typical venturi/impingement scrubber system was presented in Chapter 3.

The equipment specifications for the control system costed in this Chapter are shown in Table 4-1. Equipment and materials specifications were based on information supplied by vendors of these control devices, and on specifications for actual plants. For the range of pressure drops assumed for the variable throat venturi (12 to 22 in. W.G.), 3/16 inch type 316 stainless steel was recommended.[1] Data supplied by another vendor of these systems confirmed that 3/16 inch type 316 stainless steel would be used for both the venturi and impingement-tray scrubbers.[2] Material specifications for circulation tanks, piping, fans, pumps, and ducting are consistent with design data for actual plants using similar control systems.[3,4,5]

The individual capital cost components and the general methodology used for calculating total capital costs are presented in Table 4-2. Direct capital costs consist of the basic and auxiliary equipment costs in addition to the labor and material required to install the equipment. Indirect costs are those costs that are not attributable to specific equipment items. Contingencies are also included in total capital costs to compensate for unpredicted construction costs and other unforeseen expenses.

Equipment costs for the venturi scrubber, flooded elbow and the fan were calculated using cost equations from "Capital and Operating Costs of Selected Air Pollution Control Systems" (GARD).[6] The equipment costs for the impingement scrubber, scrubber water circulation tanks, ducting, piping, and pumps were calculated using information contained in the EPA report "Costs of Uncontrolled Non Fossil Fuel-Fired Boilers and PM Controls Applied to these Boilers".[7] The installation factors for all equipment were also based on this report, and are presented in Table 4-3. These factors are multiplied by the equipment cost to yield the installation cost for each incinerator.

TABLE 4-1. EQUIPMENT SPECIFICATIONS FOR VENTURI/IMPINGEMENT-TRAY SCRUBBER CONTROL SYSTEM

EQUIPMENT	SPECIFICATIONS
Venturi Scrubber	3/16" inch thick 316 stainless steel, automatic variable throat venturi Includes: Venturi, elbow, pumps, controls, quencher
Impingement Scrubber	3/16" inch thick 316 stainless steel Includes: Impingement scrubber, mist eliminator
Venturi Scrubber Circulation Tank	5 minute liquid holdup time, 304 stainless steel storage tanks Includes: Storage tanks
Fan & Auxiliaries	Radial tip centrifugal fan (60 hp), carbon steel Includes: Fan motor, and starter, dampers, V-belt drive
External Scrubber Water Piping	100 ft length of pipe, 304 stainless steel, Schedule 40
Impingement Scrubber Water Pump	20 ft piping height; centrifugal, open, drip proof, Stainless steel. Includes: Pump, motor, and starter (and a spare)
Ducting	30-40 ft of straight ducting; 10 gauge stainless steel. Includes: Ducting

TABLE 4-2. CAPITAL COST COMPONENTS

(1) Direct Costs

  Equipment
+ Installation
  Total Direct Costs

(2) Indirect Costs

  Engineering - 10% of direct costs
  Construction and Field Expense - 10% of direct costs
  Construction Fees - 10% of direct costs
  Start Up Costs - 2% of direct costs
+ Performance Costs - 1% of direct costs
  Total Indirect Costs - 33% of direct costs

(3) Contingencies - 20% of (Total Indirect Costs + Total Direct Costs)

(4) Total Capital Cost = Total Indirect Costs + Total Direct Costs & Contingencies

TABLE 4-3. EQUIPMENT INSTALLATION FACTORS[a]

Equipment Item	Installation Cost Factor
Wet Scrubber	0.68
Circulation Pump	1.49
Circulation Tank	0.93
Fan	1.18
Ducting	1.6
External Piping	0.1[b]

[a]Items included in installation cost are the following:

(1) freight and taxes
(2) foundations and supports
(3) erection and handling
(4) electrical
(5) internal piping
(6) insulation
(7) painting

[b]Estimated from Guthrie, "Process Plant Estimating, Evaluation and Control", p. 462.

The operating and maintenance (O&M) cost components are listed in Table 4-4. Direct O&M costs include operating and maintenance labor, supervision, spare parts, and electricity used for pumps, fans, and controls. Indirect operating costs include payroll and plant overhead which are based on some key O&M cost components (direct labor, supervisory labor, maintenance labor, and spare parts).

Telephone contacts with each of the 23 incineration facilities installed since 1978 indicated that capacity utilization ranges from about 60 to 120 percent. A mid-point value of 80 percent (7008 hours/year) was assumed to calculate annual operating costs. Direct labor was assumed to be 2 man-hours/shift and maintenance labor 1 man-hour/shift.[8] Supervisory labor was estimated to be 15 percent of the direct labor costs. The unit costs used for O&M cost calculations are shown in Table 4-5.

Total annualized costs are the sum of the annual O&M costs and the annualized capital charges. The annualized capital charges include the payoff of the capital investment (capital recovery), general and administrative costs, taxes, and insurance.

Table 4-6 presents the methods used to calculate the individual annualized capital charges. The capital recovery cost is determined by multiplying the capital recovery factor, which is based on the real before tax interest rate and the equipment life, by the total capital cost. For this analysis a 10 percent real interest rate and a 15 year equipment life are assumed. This translates into a capital recovery factor of 13.15 percent. The real interest rate of 10 percent was selected as a typical constant dollar rate of return on investment to provide a basis for calculation of capital recovery charges. Table 4-6 also presents the methods used to calculate the other annualized capital charges.

4.3 CAPITAL AND ANNUALIZED COSTS

This section presents the capital and annualized costs for the control system discussed in Section 4.2. The costs for controlling particulate emissions from multiple-hearth incinerators of various sizes are discussed in Section 4.3.1. In Section 4.3.2 the control costs for fluidized-bed incinerators of various sizes are presented.

TABLE 4-4. OPERATING AND MAINTENANCE COST COMPONENTS

(1) Direct Operating Costs

Direct Labor
Supervision
Maintenance Labor
Spare Parts
\+ Electricity

Total Direct Operating Costs

(2) Indirect Operating Costs

Payroll - 30% of (Direct Labor + Supervision Labor + Maintenance Labor)
\+ Plant - 26% of (Direct Labor + Supervision + Maintenance Labor + Spare Parts)

Total Indirect Operating Costs

(3) Total Annual Operating and Maintenance Costs
= Total Direct + Total Indirect Operating Costs

TABLE 4-5. UNIT COSTS USED IN O&M COST CALCULATIONS

	January 1983 $
Utilities	
Electricity[a]	$0.0503/kwh
Labor	
Direct Labor[b]	$11.75/man-hr
Supervision Labor[c]	$15.28/man-hr
Maintenance Labor[d]	$14.34/man-hr

[a] Monthly Energy Review, April 1983.

[b] Average of Chemical & Allied Products and Petroleum direct labor wages. Monthly Labor Review, April 1983.

[c] Estimated at 30 percent over direct labor rate.

[d] Estimated at 22 percent over direct labor rate.

TABLE 4-6. ANNUALIZED COST COMPONENTS

(1) Total Annualized Cost = Annual Operating Costs + Capital Charges

(2) Capital Charges = Capital recovery + miscellaneous (G&A, taxes and insurance)

(3) Calculation of Capital Charges Components

A. Capital Recovery = Capital Recovery Factor (CRF) x Total Capital Cost

$$CRF = \frac{i\ (1 + i)^n}{(1 + i)^n - 1}$$

i = interest rate

n = number of years of useful life of control system

Item	n	i	CRF
Control System	15	10	0.1315

B. G&A, taxes and insurance = 4% of total capital cost

4.3.1 Multiple-Hearth Incinerator Control Systems

Table 4-7 shows the operating parameters for the model multiple-hearth incinerators, and associated control systems. Capital and annualized costs were calculated for model multiple-hearth incinerators of sizes ranging from 0.5 dry ton sludge/hour to 4.0 dry ton sludge/hour. This size range represents the majority of multiple-hearth incinerator sizes. Operating parameters for the model control systems for multiple-hearth incinerators were developed from design data for actual plants, from contacts with equipment vendors, and from theoretical calculations. The moisture content and volatile solids content of the sludge represent typical values for currently operating incinerators (see Chapter 3). Excess air rates, flue gas flow rates, and liquid flow rates are based on design data for two recently installed incinerators as well on information provided by vendors.[9,10,11,12] Operating parameters were initially developed for the 1.0 dry ton/hr model plant, and scaled linearly up or down.

As discussed in Chapter 3, scrubber pressure drops for the sewage sludge incinerators built since 1978 range from 10 to 45 inch W.G. Costs were calculated for three cases of scrubber pressure drop: 20, 30, and 40 inches W.G. However, since a variable throat venturi is assumed here, capital costs were estimated for a fan capable of operating at the highest pressure drop for any given incinerator size. Although the capital costs for a fan with a maximum operating capability corresponding to a pressure drop of 20 in. W.G. would cost about 30 percent less than a fan designed for a 40 in. pressure drop, this cost difference would have a negligible impact on total annualized costs. The fan power requirements do vary according to pressure drop, however.

Table 4-8 shows the details of the capital cost estimates. Attempts were made to verify the capital cost estimates with vendor quotes and costs for actual systems. For the 1.0 ton/hr model plant, one vendor quote was about $60,000.[13] However, some of the equipment components included in the estimates (instrumentation and control systems, ducting, piping, etc.) were not included in the vendor quote. Another vendor quote for the 1.0 ton/hour model plant was $125,000 (also exclusive of instrumentation and control).[14] The capital cost of a similar control system installed at an actual plant

TABLE 4-7. OPERATING PARAMETERS FOR MODEL MULTIPLE-HEARTH SEWAGE SLUDGE INCINERATORS AND CONTROL SYSTEMS

Incinerator Capacity (dry ton sludge/hr)	0.5	1.0	2.0	4.0
Excess Air (%)	75	75	75	75
Sludge Moisture Content (%)	70	70	70	70
% Volatiles in Sludge Solids	70	70	70	70
Gas Flow to Venturi (acfm)	6,000	12,000	24,000	48,000
Gas Flow out of Impingement (acfm)	2,250	4,500	9,000	18,000
Temperature into Venturi (°F)	800	800	800	800
Temperature out of Impingement (°F)	120	120	120	120
Liquid Flow into Precooler(gpm)	20	40	80	160
Liquid Flow into Venturi (gpm)	25	50	100	200
Liquid Flow into Impingement (gpm)	88	175	350	700

TABLE 4-8. CAPITAL COSTS FOR MODEL MULTIPLE-HEARTH INCINERATOR CONTROL SYSTEMS (JANUARY 1983 $)

Incinerator Capacity (Dry Tons Sludge/Hr)	0.5	1.0	2.0	4.0
Venturi Scrubber	75,900	83,800	97,800	113,900
Impingement Scrubber	15,500	26,000	43,800	73,700
Venturi Circulation Tank	4,000	5,900	8,600	12,600
Fan & Auxiliaries	17,000	17,500	18,500	30,900
Ducting	5,500	7,300	10,000	13,800
Piping	2,200	3,100	5,300	7,900
Pump	3,800	4,100	4,900	7,800
Total	123,900	147,700	188,900	250,600
Total Direct Cost (Equipment + Installation)	224,500	266,500	339,000	470,900
Indirect Cost	74,100	87,900	111,900	155,400
Contingencies	44,900	53,300	67,800	94,200
Total Installed Capital Cost	343,500	407,700	518,700	720,500

was $128,000.[15] Thus, the cost estimates presented in Table 4-8 are considered to be reasonable, but somewhat conservative.

Table 4-9 presents the details of the annualized costs. The capital, operating, and annualized costs for all incinerator sizes are summarized in Table 4-10. As seen from the table, the annualized cost increases as the incinerator size increases. However, for a given incinerator size, annualized costs change very little as the scrubber pressure drop increases. The small increase in annualized costs is due to the increased fan energy and pumping requirements associated with increasing pressure drop.

4.3.2 Fluidized-Bed Incinerator Control Systems

Cost analysis was performed for five fluidized-bed incinerator sizes. The incinerator sizes range from 0.25 dry ton/hour to 4.0 dry ton/hour. The model plant parameters for the fluidized-bed incinerators are shown in Table 4-11. An excess air rate of 35 percent, and an exit gas temperature of 1500°F was assumed for the model fluidized-bed incinerator. The flue gas flow rates are the same as those developed for the multiple-hearth furnaces, but have been adjusted to reflect the lower excess air rates, and higher furnace exhaust temperatures, typical of fluidized-bed sludge incinerators.

Capital and annualized costs were calculated for scrubber pressure drops of 20, 30, and 40 inches. The details of the capital costs are presented in Table 4-12. The annualized costs are shown in Table 4-13. The capital, operating, and annualized costs for all fluidized-bed incinerator sizes are presented in Table 4-14. Once again, the annualized costs increase with incinerator size, but remain relatively constant for a given incinerator size as the pressure drop changes.

4.4 COST EFFECTIVENESS OF CONTROLS

Cost effectiveness of the control system was calculated for multiple-hearth and fluidized-bed incinerators at 20, 30 and 40 inches of pressure drop. The controlled particulate emission rate was assumed to be the NSPS limit (1.3 lb/dry ton sludge). The uncontrolled particulate emission rate (51 lb/dry ton) for multiple-hearth incinerators is the average of 19 incinerators (see Table 3-3). The uncontrolled emission rate

TABLE 4-9. ANNUALIZED COSTS FOR MODEL MULTIPLE-HEARTH INCINERATOR CONTROL SYSTEMS (JANUARY 1983 $)

	Incinerator Capacity (dry tons/hr)			
	0.5	1.0	2.0	4.0
Electricity				
Fan:				
ΔP = 20"	2,800	5,600	11,300	22,600
ΔP = 30"	4,200	8,500	16,900	33,900
ΔP = 40"	5,600	11,300	22,600	45,200
Pumps:	700	1,100	1,800	3,200
Total Labor Cost	41,200	41,200	41,200	41,200
Total Direct Operating Cost (including spare parts)				
ΔP = 20"	57,100	60,400	66,800	79,500
ΔP = 30"	58,600	63,300	72,400	90,800
ΔP = 40"	66,100	66,100	78,100	102,100
Indirect Operating Costs	26,300	26,300	26,300	26,300
Total Annual Operating Costs				
ΔP = 20"	83,500	86,700	93,100	105,800
ΔP = 30"	84,900	89,600	98,700	117,100
ΔP = 40"	86,300	92,400	104,400	128,400
Capital Recovery	45,200	53,600	68,200	94,700
G&A, Taxes and Insurance	13,700	16,300	20,700	28,800
Total Capital Charges	58,900	69,900	88,900	123,500
Total Annualized Costs				
ΔP = 20"	142,400	156,600	182,000	229,300
ΔP = 30"	143,800	159,500	187,600	240,600
ΔP = 40"	145,200	162,300	193,300	251,900

TABLE 4-10. CAPITAL, OPERATING, AND ANNUALIZED COSTS FOR MULTIPLE-HEARTH SEWAGE SLUDGE INCINERATOR CONTROL SYSTEMS (January 1983 $)

Incinerator Capacity (Dry Ton Sludge/Hr)	Capital Costs ($1000)			Operating Cost ($1000/yr)			Annualized Cost ($1000/yr)		
	ΔP = 20"	30"	40"	ΔP = 20"	30"	40"	ΔP = 20"	30"	40"
0.5	343.5	343.5	343.5	83.5	84.9	86.3	142.4	143.8	145.2
1.0	407.7	407.7	407.7	86.7	89.6	92.4	156.6	159.5	162.3
2.0	518.7	518.7	518.7	93.1	98.7	104.4	182.0	187.6	193.3
4.0	720.5	720.5	720.5	105.8	117.1	128.4	229.3	240.6	251.9

TABLE 4-11. OPERATING PARAMETERS FOR MODEL FLUIDIZED-BED SEWAGE SLUDGE INCINERATORS AND CONTROL SYSTEMS

Incinerator Capacity (Dry Ton Sludge/Hr)	0.25	0.5	1.0	2.0	4.0
Excess Air (%)	35	35	35	35	35
Sludge Moisture Content (%)	70	70	70	70	70
Sludge Volatiles Content (% Solids)	70	70	70	70	70
Gas Flow to Venturi (acfm)	3,375	6,750	13,500	27,000	54,000
Gas Flow out of Impingement (acfm)	875	1,750	3,500	7,000	14,000
Temperature into Venturi (°F)	1,500	1,500	1,500	1,500	1,500
Temperature out of Impingement (°F)	120	120	120	120	120
Liquid Flow into precooler (gpm)	10	20	40	80	160
Liquid flow into venturi (gpm)	13	25	50	100	200
Liquid flow into impinger (gpm)	44	88	175	350	700

TABLE 4-12. CAPITAL COSTS FOR MODEL FLUIDIZED-BED INCINERATOR CONTROL SYSTEMS (JANUARY 1983 $)

Incinerator Capacity (Dry Tons Sludge/Hr)	0.25	0.5	1.0	2.0	4.0
Venturi Scrubber	66,400	87,900	90,000	105,000	136,000
Impingement Scrubber	8,600	14,400	24,300	40,900	68,700
Venturi Circulation Tank	2,600	4,000	5,900	8,600	12,600
Fan & Auxiliaries	17,000	17,100	17,500	18,500	30,900
Ducting	4,800	5,500	7,300	10,000	13,800
Piping	1,700	2,200	3,100	5,300	7,900
Pump	3,000	3,400	4,100	5,000	7,800
Total	104,100	134,500	152,200	193,300	277,700
Total Direct Cost (Equipment + Installation)	190,000	242,100	274,200	346,300	449,600
Indirect Cost	62,700	79,900	90,500	114,300	164,900
Contingencies	38,000	48,400	54,800	69,300	99,900
Total Installed Capital Cost	290,700	370,400	419,500	529,900	764,400

TABLE 4-13. ANNUALIZED COSTS FOR MODEL FLUIDIZED-BED INCINERATOR CONTROL SYSTEMS (JANUARY 1983 $)

	Incinerator Capacity (Dry Tons/Hr)				
	0.25	0.5	1.0	2.0	4.0
Electricity					
Fan:					
P = 20"	1,100	2,200	4,400	8,800	17,600
P = 30"	1,600	3,300	6,600	13,200	26,400
P = 40"	2,200	4,400	8,800	17,600	35,100
Pumps:	500	700	1,100	1,800	3,200
Total Labor Cost	41,200	41,200	41,200	41,200	41,200
Total Direct Operating Costs (including spare parts)					
P = 20"	55,300	56,600	59,200	64,300	74,500
P = 30"	55,800	57,700	61,400	68,700	83,200
P = 40"	56,400	58,800	63,600	73,100	92,000
Indirect Operating Costs	26,300	26,300	26,300	26,300	26,300
Total Annual Operating Costs					
P = 20"	81,600	82,900	85,500	90,600	100,800
P = 30"	82,100	84,000	87,700	95,000	109,600
P = 40"	82,700	85,100	89,900	99,400	118,300
Capital Recovery	38,200	48,700	55,200	69,700	100,500
G&A, Insurance, Taxes	11,600	14,300	16,800	21,200	30,600
Total Capital Charges	49,800	63,500	72,000	90,900	131,100
Total Annualized Cost					
P = 20"	131,400	146,400	157,500	181,500	231,900
P = 30"	131,900	147,500	159,700	185,900	240,700
P = 40"	132,500	148,600	161,900	190,300	249,400

TABLE 4-14. CAPITAL, OPERATING, AND ANNUALIZED COSTS FOR FLUIDIZED-BED SEWAGE SLUDGE INCINERATOR CONTROL SYSTEMS

Incinerator Capacity (Dry Ton Sludge/Hr)	Capital Costs ($1000)			Operating Cost ($1000/yr)			Annualized Cost ($1000/yr)		
	ΔP = 20"	30"	40"	ΔP = 20"	30"	40"	ΔP = 20"	30"	40"
0.25	290.7	290.7	290.7	81.6	82.1	82.7	131.4	131.9	132.5
0.5	370.4	370.4	370.4	82.9	84.8	85.1	146.4	147.5	148.6
1.0	419.5	419.5	419.5	85.5	87.7	89.9	157.5	159.7	161.9
2.0	529.9	529.9	529.9	90.6	95.0	99.4	181.5	185.9	190.3
4.0	764.4	764.4	764.4	100.8	109.6	118.3	231.9	240.7	249.4

for fluidized bed incinerators (88 lb/dry ton) is the average of 11 emission tests (see Table 3-3).

The cost effectiveness was calculated by dividing the annulized costs ($/yr) by the emission reduction achieved (tpy) by the control system to yield the cost to remove one ton of particulates. The cost effectiveness increased slightly with increasing pressure drop and decreased significantly with increasing incinerator capacity as shown in Table 4-15 for multiple-hearth control systems and Table 4-16 for fluidized-bed control systems.

At equivalent incinerator capacities and pressure drops, fluidized-bed control systems have lower cost effectiveness. Multiple-hearth cost effectiveness ranged from $329 to $1669 per ton removed and fluidized-bed cost effectiveness ranged from $191 to $1743 per ton removed. The 0.25 dry ton/hr fluidized-bed control system had the highest cost effectiveness since emission reduction is strongly influenced by incinerator size.

TABLE 4-15. COST EFFECTIVENESS OF MULTIPLE-HEARTH SEWAGE SLUDGE INCINERATOR CONTROL SYSTEMS (UNCONTROLLED PM = 51 LB/TON, CONTROLLED PM = 1.3 LB/TON)

Incinerator Capacity (Ton Dry Sludge/Hr)	Uncontrolled Emissions (tpy)	Controlled Emissions (tpy)	Emissions Reduction (tpy)	Cost Effectiveness ΔP ($/ton removed)		
				20"ΔP	30"ΔP	40"ΔP
0.5	89	2	87	1637	1653	1669
1.0	179	5	174	900	917	933
2.0	357	9	348	523	539	555
4.0	715	18	697	329	345	361

TABLE 4-16. COST EFFECTIVENESS OF FLUIDIZED-BED SEWAGE SLUDGE INCINERATOR CONTROL SYSTEMS (UNCONTROLLED PM = 88 LB/TON; CONTROLLED PM = 1.3 LB/TON)

Incinerator Capacity (Ton Dry Sludge/Hr)	Uncontrolled Emissions (tpy)	Controlled Emissions (tpy)	Emissions Reduction (tpy)	Cost Effectiveness ΔP ($/ton·removed)		
				20"ΔP	30"ΔP	40"ΔP
0.25	77	1	76	1729	1736	1743
0.50	154	2	152	963	970	978
1.0	308	5	303	520	527	534
2.0	617	9	608	299	306	313
4.0	1233	18	1215	191	198	205

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5.0 COINCINERATION OF SEWAGE SLUDGE AND MUNICIPAL REFUSE

5.1 INTRODUCTION AND SUMMARY OF FINDINGS

5.1.1 Introduction

At the present time, an NSPS has not been developed specifically for incinerators that coincinerate sewage sludge and municipal refuse. A procedure has been developed by EPA for use in determining whether facilities coincinerating are subject to Subpart E (municipal incinerators) or Subpart O (Sewage sludge incinerators) of the New Source Performance Standards.[1]

In this chapter the technologies available for coincinerating sludge and solid wastes are described. Former, as well as current coincineration projects in the U.S. are reviewed. In addition, the technical, economic, and institutional factors most likely to affect the growth of coincineration are overviewed. The effect that coincineration has on particulate emissions is also addressed.

5.1.2 Summary of Findings

No technology has ever been developed for the express purpose of combined incineration of sewage sludge and municipal refuse. Four different approaches to coincineration can be distinguished: 1) combustion of dewatered sludge in a refuse incinerator; 2) combustion of pre-dried sludge in a refuse incinerator, and; use of prepared municipal refuse (refuse derived fuel); in either 3) a multiple-hearth sludge incinerator or 4) a fluidized-bed sludge incinerator. All of the major techniques for combined incineration have been tried in the U.S.

Over the past 30 years, 23 facilities in the U.S. have coincinerated refuse and sewage sludge. Only one facility is currently operating on a regular commercial basis, 18 have been shut down, and the remaining 4 have reverted to single purpose incineration. In addition, 6 coincineration facilities were being planned during the mid 1970's. Of these, only one has started up. One is still being considered, but plans for the remaining four facilities have been dropped.

A variety of operational and maintenance problems have plagued virtually every coincineration facility in the U.S. It has proved difficult to maintain combustion in refuse incinerators when partially dewatered sludge is added. Although thermal drying of the sludge mitigates combustion-related problems, the dryers themselves are subject to plugging, corrosion, and odors, as well as fire and explosion. Technical obstacles to burning refuse-derived fuel in conventional multiple-hearth or fluidized-bed sewage sludge incinerators include the reliability of refuse preparation systems and control of combustion.

The process of planning and implementing new coincineration projects in the U.S. is often hampered by organizational differences between those groups responsible for disposing of sludge and refuse. Whereas sewage sludge management authority is vested in centralized, public bodies, the collection, transport, and disposal of municipal refuse is usually managed by a combination of decentralized public and private bodies. These organizational differences detract from the achievement of the level of integration in municipal waste management programs necessary for the implementation of coincineration facilities. Moreover, the criteria employed in siting a sludge treatment and disposal plant are essentially different from those used in locating a refuse incinerator.

Very little data are available on particulate emissions from combined incineration of sewage sludge and municipal refuse. Some evidence indicates that uncontrolled emissions from refuse incinerators may increase when sludge is coincinerated. Operating a multiple-hearth unit in a pyrolysis mode does not appear to offer any significant reduction of uncontrolled emissions when prepared municipal refuse is used for fuel. It is doubtful that all of the various approaches to coincineration will have similar emission characteristics, although this is a topic deserving further investigation.

Despite the general lack of technical success with coincineration projects, the costs of combined incineration of sewage sludge and municipal refuse are still attractive when compared to the costs of burning these wastes separately. Coincineration is also attractive from the standpoint of energy conservation. Thus, the incentives to coincinerate are still clear. Yet until the various technical problems and uncertainties are overcome, little growth in the use of coincineration can be expected over the next five years.

A number of regulatory issues have been identified. First, the separate NSPS's for municipal and sludge incinerators are not expressed in the same units, and the conversion from a concentration- to a mass-based standard is not straight-forward. Second, in the existing proration procedure, a discontinuity exists when an incinerator is burning equal amounts of sludge and refuse. Third, neither standard addresses the case where an incinerator is operated in a pyrolysis mode. Finally, Subpart E includes a minimum size cut-off, while Subpart O applies to all incinerator sizes.

5.2 DESCRIPTION OF COINCINERATION TECHNOLOGIES

Any incinerator that is capable of burning either sewage sludge or municipal refuse separately could feasibly burn both wastes simultaneously. No technologies have been, or are being, developed specifically for purposes of combined incineration, however. Thus, coincineration technology can be classified, at the most general level, according to whether the incinerator was originally designed for burning refuse or sludge. On the other hand, successful coincineration sometimes requires modification of the incinerator itself, and/or a pretreatment of the waste beyond that which would be required if the waste were burned separately. When these additional considerations are taken into account, four distinct categories of coincineration technology emerge. An additional (fifth) classification can be made on the basis of whether or not the incinerator is operated in a pyrolysis, or starved-air combustion mode. These categories are discussed below.

5.2.1. Incineration of Dewatered Sludge in a Conventional Refuse Incinerator

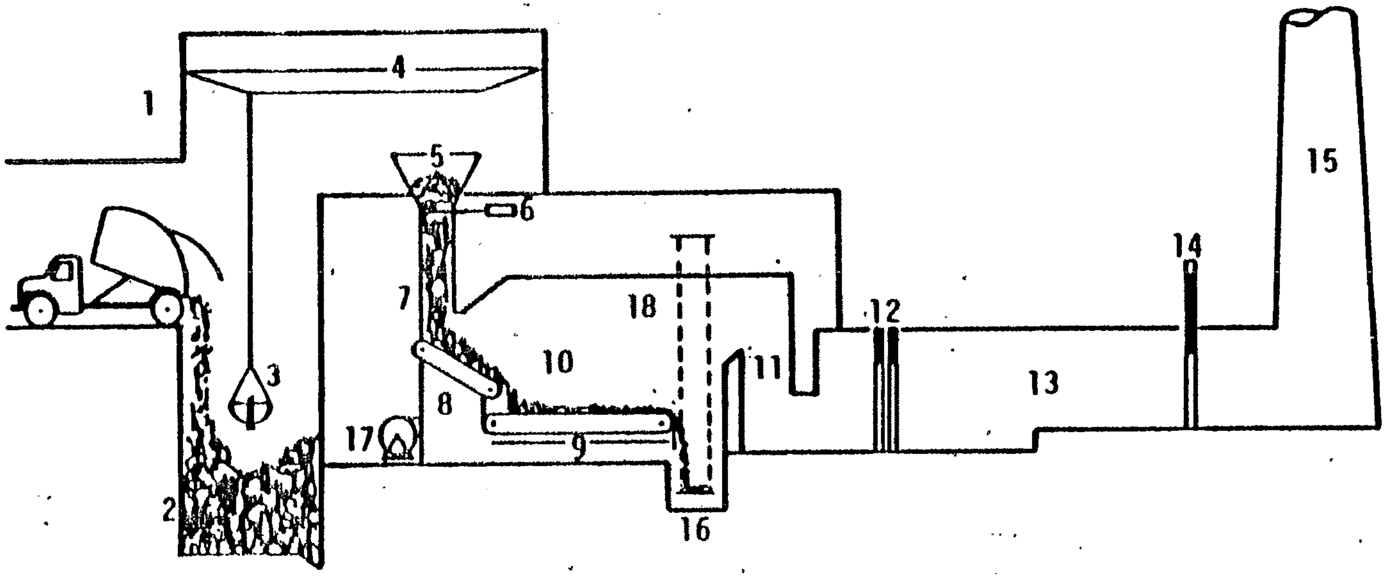
The oldest, simplest, and most direct method of achieving combined incineration is to burn partially dewatered sludge (i.e., 70 to 80 percent moisture content) in a conventional municipal refuse incinerator. Figure 5-1 depicts a typical mass-burning refuse incinerator. This approach can be further subdivided on the basis of the type feeding mechanism employed. The sludge can be fed separately into the furnace by either spraying it into the combustion chamber or by dumping it onto the grate. Alternatively, the sludge can be mixed with the refuse prior to entering the incinerator.

Although this approach has the advantage of simplicity, it has not proved to be very successful. The major problem encountered with this technique relates to combustion. Conventional incinerators usually provide insufficient residence time for the sludge to burn completely. In addition, too little heat is generated from the burning refuse to evaporate the moisture and combust the sludge. These problems are compounded by difficulties in distributing the sludge evenly within the furnace. For the most part, this approach has proved unsuccessful both in this country and in Europe, although two future projects in the U.S. are expected to use it.

5.2.2. Coincineration of Pre-dried Sludge in a Conventional Refuse Incinerator

As a means to overcome the problems associated with burning sludge directly in a refuse incinerator, a number of facilities have installed systems to dry the sludge to less than 20 percent moisture content before it enters the furnace. A wide variety of different drying systems have been employed. Flue-gas heated direct contact dryers, steam heated rotary dryers, flash evaporaters, spray dryers, and multi-effect evaporators have all been utilized in the past. The dried sludge is then mixed with the refuse at a ratio of approximately 10 parts refuse to each part sludge and fed into the incinerator.

This method has been relatively successful. Pre-drying mitigates the combustion problems associated with the use of only partially dewatered sludges. Also, separation of the drying process from the combustion process simplifies furnace operations. Nonetheless, this technique has not been entirely devoid of problems. A major difficulty has been the prevention of rapid corrosion in the dryers. Clogging and general handling problems have



1. INCINERATOR
2. STORAGE PIT
3. GRAP BUCKET
4. BRIDGE CRANE
5. CHARGING HOPPER
6. HOPPER GATE
7. WATER-COOLED HOPPER
8. FEEDING AND DRYING STOKER
9. BURNING STOKER
10. PRIMARY COMBUSTION CHAMBER
11. SECONDARY COMBUSTION CHAMBER
12. GAS-CLEANING CHAMBER
13. FLUE
14. DAMPER
15. STACK
16. ASH CONVEYOR
17. FORCED-DRAFT FAN
18. REFACTORY ENCLOSURES

Figure 5-1. Cross-Sectional View of a Mass-Burning Municipal Refuse Incinerator also been encountered with the dried sludge. Odors given off by the dryers (particularly direct contact dryers) have been another obstacle. Flash evaporators are unattractive because of the potential for explosions to occur. Nonetheless, the majority of the facilities currently coincinerating in Europe, as well as the only commercially operating plant in the U.S., can be classified within this category.

5.2.3. <u>Combustion of Refuse in a Multiple-hearth Sludge Incinerator</u>

In this arrangement, prepared municipal refuse is used in place of fossil fuels for burning sludge in a multiple-hearth furnace (MHF). Preparation of the raw refuse entails the mechanical separation of non-combustibles and subsequent shredding of the remaining organic portion into uniform particle sizes. The refuse derived fuel (RDF) thus obtained can be further treated chemically to produce a fine powder or pressed into briquettes or pellets. The RDF is then either mixed with the sludge and fed together into the top of the incinerator, or fed separately into one of the lower hearths.

Although at least three units of this type operate in Europe, it has not been fully demonstrated in the U.S. Some testing has been done at a demonstration facility in Contra Costa County, California. Based on limited operating data, the major problem with this design is controlling the rate of combustion in the incinerator. Localized overheating caused by periodic intense heat release from the RDF can lead to structural failures in the rabble shaft castings. To compensate for the higher heat release rate associated with co-burning RDF, a greater volume of cooling air is required. At higher than design air flow rates, the movement of the sludge and refuse through the hearths could be impeded. Besides installation of all of the facilities required to produce the RDF, substantial modifications to the incinerator itself are necessary in order to coincinerate.

The major benefit associated with this type of system would be the reduction in fuel costs for sludge incineration. Fuel costs represent the largest share of the total annualized costs of operating MHF incinerators.

5.2.4. <u>Combustion of RDF in a Fluidized-Bed Sludge Incinerator</u>.

This approach is analogous to that described above, except that coincineration would take place in a fluidized-bed sewage sludge incinerator

(FBF). The RDF can either be introduced into the furnace as dry pellets, fluff, or powder, or alternatively the refuse can be pulped into a slurry having a 40 to 45 percent moisture content and sprayed into the furnace along with the sludge. Both the wet and dry systems have been demonstrated in the U.S.

Compared to coincineration in a multiple-hearth incinerator, use of a FBF offers a number of advantages. Foremost is that combustion is more easily controlled in a fluid-bed, and furnace operation is less vulnerable to changes in the sludge feed rate or moisture content, due to both the excellent mixing characteristics and longer residence time typical of these incinerators.

As in the case of MHF's, however, significant modification has to be made to the incinerator in order to burn RDF. Beside the addition of a feeding mechanism, a system for separating inert RDF materials that build up in the sand bed is required. The interior of the furnace shell must also be protected from the corrosive condensation of HCl and HF gases evolving from combustion of plastic materials.

5.2.5. Starved-Air Combustion (Pyrolysis)

With the exception of fluidized-bed furnaces, all of the incineration techniques reviewed above can be operated in a starved-air or pyrolysis mode. Thus, this category represents not so much a distinct technology type as it does a general operating technique, applicable to a number of alternative technology configurations. Four incinerators, specifically designed to operate as pyrolytic reactors, are presently under development.

These incinerators include the Purox^R (Union Carbide), Torrax^R (Carborundum), Landgard^R (Monsanto), and the Flash Pyrolysis (Occidental) systems. Both the Purox and Torrax processes are based on a vertical shaft reactor design; the Landgard system utilizes a rotary kiln. All of these technologies are being developed primarily as municipal refuse incinerators. Each, however, has also been considered as a possible coincineration technology and some testing has been conducted on them in this mode.

In a conventional refuse incinerator, combustion under starved-air conditions is the most common operating technique. Generally, however, combustion air is added at only slightly less than stoichiometric rates. The off-gases from the furnace are then combusted in an afterburner. The smaller, modular refuse incinerators that have been widely utilized since the early 1970's are almost always designed to operate under starved-air conditions.

Operating a multiple-hearth sewage sludge incinerator in a pyrolysis mode is a technique that was developed specifically for purposes of coincinerating refuse. As described earlier, the major problem encountered in coincinerating in these furnaces is controlling the rate of combustion. By operating the furnace as a pyrolysis reactor, these problems are effectively overcome. During a series of comprehensive tests conducted on a MHF at the Contra Costa County demonstration project, operating the furnace in a pyrolysis mode emerged as the preferred means of co-burning refuse with sewage sludge.[2] The major manufacturers of multiple-hearth furnaces also recommend that the unit be operated in a pyrolysis mode when coincinerating municipal refuse.[3] Other benefits associated with this approach are an increased furnace capacity and the capability for pyrolysis to become autogenous with sludges having a low solids content.

For all types of pyrolysis, the major disadvantage is the greatly increased complexity of the system. The furnaces must be well sealed against air infiltration, the interior linings must be highly corrosion resistant, and additional controls and instrumentation are required. Moreover, to be economically viable these systems must be able to recover and utilize the energy content of the off-gases. Heat recovery systems add to the overall complexity and capital costs of the facility. Finally, a greater volume of residual ash and char is produced when wastes are processed by pyrolysis rather than incineration.

5.3 REVIEW OF COINCINERATION PROJECTS IN THE U.S.

All of the available techniques for combined incineration of sewage sludge and municipal refuse have been, at one time or another, tried in the U.S. in either commercial- or pilot-scale plants. No single approach has emerged as a definitively "best" technique, although burning pre-dried sludge in a conventional refuse incinerator has been attempted most often.

A comprehensive listing of former, present, and planned coincineration projects in the U.S. is provided in Table 5-1. Only one facility, at Stamford, Connecticut, is currently coincinerating on a regular commercial basis. The facility in Glen Cove, New York, is in a start-up phase. Out of the total 32 facilities listed, 18 units that formerly were coincinerating have been shut-down or abandoned completely and four facilities have reverted to single-purpose incineration. Of the six major coincineration projects being considered during the mid 1970's, only the Glen Cove facility is currently operative. The municipal incinerator in Harrisburg, Pennsylvania, plans to begin burning sludge sometime in the next year.

In quite a few cases, plants that have shut down have done so for technical reasons. Operating problems have plagued some of the new, as well as the older, coincineration facilities. The Ansonia, Connecticut, Duluth, Minnesota and Holyoke, Connecticut, plants have each experienced equipment failures. Even the Stamford plant has been unable to coincinerate on a continuous basis since the facility began operating in 1975. New pyrolysis reactors have yet to demonstrate a sufficient level of operating reliability when processing refuse alone, and the feasibility of coincinerating in these units is still open to question.[4]

5.4 ECONOMIC AND INSTITUTIONAL CONSIDERATIONS

From the standpoint of annualized operating costs, coincinerating sludge and refuse appears to be an attractive waste management approach in situations where landfilling or other disposal options are unavailable. In contrast, there are numerous institutional barriers to coincineration that can mitigate the economic incentives for co-disposal.

5.4.1 Costs for Coincineration

The most comprehensive assessment of the costs of coincineration was conducted in 1976.[5] In this study, the costs for separate incineration of sludge and refuse were compared to the costs of four combined incineration systems. Costs for non-thermal disposal options are also used for comparison. The coincineration designs considered included a multiple-hearth unit burning RDF, a Torrax pyrolysis shaft furnace, and two

TABLE 5-1. SUMMARY OF COINCINERATION FACILITIES IN THE U.S.

Location	Capacity	Design Parameters	Operating History	Current Status
Contra Costa County, California	1200 tpd MRF 160 tpd RDF 95 tpd sludge	MHF sludge Incinerator/Pyrolysis Mode	Planned; Feasability Study completed	Abandoned Plans For Coincineration
San Diego, California	DNA	Flash Pyrolysis (Occidental Test Facilty)	DNA	DNA
Ansonia, Connecticut	40 tpd MRF 13 tpd sludge	Mass burning MRF Incinerator Sludge Pre-dried	Ceased operations in 1977 due to fire.	Burns Refuse Only. Sludge is dried and landfilled
Stamford, Connecticut	360 tpd MRF 10 tpd sludge	Twin Rocking-Grate MRF Incinerators	Began operations in 1975.	Still coincinerating
Waterbury, Connecticut	300 tpd MRF	Twin Mass-burning MRF Incinerators; Sludge Flash-Evaporated	Began operations in 1951. Ceased burning sludge in 1975.	Shut down in 1978
West Albany, Indiana	160 tpd MRF	Twin Traveling-Grate MRF Incinerators Sludge Flash-Evaporated	Began operating in 1959	Abandoned
Louisville, Kentucky	850 tpd MRF	Reciprocating-Grate MRF Incinerators Sludge Flash-Evaporated	Began operating in 1959	Burns MRF only
Auburn, Maine	150 tpd MRF 10 tpd sludge	Consumat Modular MRF Incinerators Sludge Pre-dried	Groundbreaking Scheduled for 1979	Plans Abandoned
Baltimore, Maryland	DNA	Landgard Rotary Kiln (Monsanto Test Facility)	DNA	DNA
Frederick, Maryland	DNA	Mass-Burning MRF Incinerator Sludge Dewatered	Coincineration Unsuccessful	Abandoned

DNA = Data Not Available

TABLE 5-1. SUMMARY OF COINCINERATION FACILITIES IN THE U.S. (Continued)

Location	Capacity	Design Parameters	Operating History	Current Status
Holyoke, Massachusetts	225 tpd MRF 10 tpd sludge	Twin Fixed-Grate MRF Incinerators	Began operating in 1965	Shut down in 1976
Lansing, Michigan	DNA	MHF Sludge Incinerator	Attempted to Coincinerate	Burns sludge only
Trenton, Michigan	DNA	Mass-Burning MRF Incinerator Sludge Flash-Evaporated	Began operations in 1964. By 1975, sludge dried and landfilled	Shut down
Duluth, Minnesota	160 tpd RDF 70 tpd sludge	FBI sludge Incinerator Sludge Pre-dried	Began operating in 1979 Shut down due to explosion	Burns sludge only. No plans to resume coincineration
Minneapolis/St. Paul, Minnesota	400 tpd MRF 60 tpd sludge	Rotary kiln in Pyrolysis Mode	Planned for 1980 Start-up	Plans Abandoned in 1976
Vicksburg, Mississippi	DNA	Rotary kiln	DNA	Abandoned
Glouchester City, New Jersey	DNA	Rotary kiln	DNA	Abandoned
Tenafly, New Jersey	DNA	Mass-burning MRF Incinerator Sludge Flash-Evaporated	DNA	Shut-down
Glen Cove, New York	250 tpd MRF 25 tpd sludge	Twin Reciprocating-Grate MRF Incinerators Sludge Dewatered	Began operating in 1983	In Start-up
Newburg, New York	DNA	Mass-burning MRF Incinerators Sludge Flash-Evaporated	Began operating in 1970, Redesigned in 1974.	Abandoned
Orchard Park, New York	DNA	Torrax Air-Blown Shaft Furnace (Carborundum Test Facility)	DNA	DNA

DNA = Data Not Available

TABLE 5-1. SUMMARY OF COINCINERATION FACILITIES IN THE U.S. (Continued)

Location	Capacity	Design Parameters	Operating History	Current Status
Waterville, New York	DNA	Mass-burning MRF Incinerator Sludge Flash-Evaporated	Began operating in 1940	Abandoned
Franklin, Ohio	150 tpd RDF 30 tpd sludge	FBI Incinerator MRF Wet-Pulped	Began operating in 1971	Shut-down in 1979
Bloomburg, Pennsylvania	DNA	Mass-burning MRF Incinerator Sludge Flash-Evaporated	Began operating in 1953	Abandoned
Harrisburg, Pennsylvania	720 tpd MRF 50 tpd sludge	Twin Waterwall MRF Incinerators Sludge Dewatered	Expected start-up in 1979	Not burning sludge. Coincineration expected for 1984
Hershey, Pennsylvania	DNA	Mass-burning MRF Incinerators Sludge Dewatered	Operated from 1963 to 1972	Abandoned
Whitemarsh, Pennsylvania	75 tpd MRF 6 tpd sludge	Mass-burning MRF Incinerator Sludge Dewatered	DNA	Abandoned
Georgetown, South Carolina	DNA	Rotary kiln	DNA	Abandoned
Memphis, Tennessee	2400 tpd MRF 1225 tpd sludge	MRF Conversion to RDF MHF Incinerator in Pyrolysis Mode	Feasability Studies Completed	Plans Abandoned
South Charleston, West Virginia	200 tpd MRF	Purox Oxygen-Blown Shaft Pyrolysis Furnace (Union Carbide)	Began testing in 1975	Refuse only
Kewashum, Wisconsin	25 tpd MRF	Mass-burning MRF Incinerator	Began operating in 1954	Abandoned
Neenah-Menash, Wisconsin	150 tpd MRF	Twin Traveling-Grate MRF Incinerators Sludge Flash-Evaporated	Began operating in 1958	Shut-down in 1959

DNA = Data Not Available

systems based on the use of a conventional refuse incinerator with pre-drying (either direct or indirect) of the sludge.

The principal conclusion of this analysis was that for all combustion technologies considered, coincineration had the lowest annualized costs. All four combined incineration systems were shown to be less costly to build and to operate when compared to the costs for incinerating these wastes separately. Burning dried sludge in a mass-burning refuse incinerator was the lowest cost option. However, all types of incineration involved higher costs than land or ocean disposal.

The capital costs of constructing a coincineration facility could, nonetheless, be prohibitive to many municipalities. For example, the capital cost of a multiple-hearth furnace burning refuse derived fuel was estimated to be nearly four times higher than the same furnace burning fuel oil.

5.4.2. Institutional Factors Affecting Coincineration

Institutional issues embody a number of complex legal, organizational, and administrative factors which relate to wastewater and solid waste management. These factors often serve to discourage combined disposal of municipal sewage sludge and refuse.

Water- and solid waste-related management programs have evolved along different paths. While water quality programs were initiated through public action, solid waste handling and disposal has remained predominantly a private concern. Water quality management programs are highly centralized within public bodies. In contrast, solid waste management is much less centralized, with authority vested in various groups, some private and some public. Moreover, different aspects of solid waste removal, collection, transport, processing, storage, and disposal can be controlled by different bodies. These organizational differences alone are obstacles to integrating municipal waste management and planning.[6] From the perspective of those responsible for municipal refuse management, there is no real incentive to engage in a coincineration project, especially when refuse disposal is carried out by private companies.[7]

Siting a codisposal facility creates numerous problems since the criteria by which potential sites are judged are not mutual. The location of a sewage treatment plant is determined by hydrological boundaries. Collection and disposal of municipal refuse is organized according to municipal boundaries. Rarely do these locational parameters overlap. Furthermore, while transportation is a critical concern in handling refuse, it has little relevance to the treatment and disposal of sewage sludge.

5.5 PROSPECTS FOR GROWTH OF COINCINERATION

Little growth in coincineration is likely to occur over the next five years because coincineration has yet to be widely demonstrated as a reliable disposal technique. The failure of the vast majority of the systems put into operation in the past has clearly impeded the widespread acceptance of the technology. Other than the plants currently operating in Stamford, Connecticut and Glen Cove, New York, only the facility planned for Harrisburg, Pennsylvania, has a high probability of entering commercial service within the next few years.

Countering these technical uncertainties, however, are the economic incentives to coincinerate refuse and sewage sludge. With the rise in the costs for fossil fuels over the past five years, these incentives have become stronger. Also, the economics of incineration relative to land disposal should diminish as a result of increased regulation and declining availability of disposal sites.[8]

5.6 EMISSION CHARACTERISTICS OF COMBINED SLUDGE AND MUNICIPAL REFUSE INCINERATION

Very little data are available on the particulate emission characteristics of coincineration facilities. On the basis of the data that are available, no overall generalizations can be drawn as to the impact that combined burning has on emissions compared to incineration of the wastes separately. However, given the wide variability in both the types of technologies available for coincineration and the control devices used on these technologies, as well as the differences in the types of waste burned, it is doubtful that emissions will show similar characteristics. This is a topic requiring further investigation.

5.6.1 Control Technologies Used.

While wet scrubbers are normally used on sewage sludge incinerators, a variety of different control systems are currently being used on refuse incinerators. Of the approximately 45 municipal refuse incinerators currently operating in the U.S., about 23 are equipped with electrostatic precipitators (ESP), 15 use wet scrubbers, baghouses are in use at two plants, and the rest are controlled with either mechanical separators or a combination of control devices. Each of the three coincineration facilities expected to be operating in 1985 are equipped with ESP's.

5.6.2 Emission Test Data

Emissions tests were performed in 1977 on the multiple-hearth sludge incinerator located at the Central Contra Costa Sewage Treatment Plant in California. The incinerator was modified to burn prepared municipal refuse in combination with sewage sludge. In addition, provisions were made to operate the unit in either an incineration or pyrolysis mode. Both the relative amounts of RDF and sewage sludge entering the furnace, as well as the location at which the wastes entered the furnace, were varied during the test program. These parameters are summarized for each individual test run in Table 5-2. Particulate emissions were measured (EPA Method 5) at both the inlet and the outlet of the afterburner. Although the incinerator is equipped with a scrubber, no sampling was conducted on the scrubber inlet.

The results of these tests are summarized in Figure 5-2. The individual runs have been grouped according to the ratio of refuse to sludge burned during the test. There is no apparent difference in the uncontrolled emission rate of incineration as opposed to pyrolysis, although the emissions from pyrolysis are controlled somewhat better by the afterburner. This is most likely a function of the difference in the average size of the particles leaving the furnace, which were generally larger when it was operated in the pyrolysis mode. No emissions tests were performed on the furnace when it was incinerating sludge alone.

TABLE 5-2. WASTE FEED RATES AND METHOD DURING TESTS ON CONTRA COSTA MULTIPLE-HEARTH INCINERATOR

Run Number	Mode[a]	Waste Feed Point Top Hearth	Waste Feed Point Third Hearth	Waste Feed Rate (dry) RDF lb/hr	Waste Feed Rate (dry) Sludge lb/hr	Waste Feed Rate (dry) Total lb/h	Ratio RDF/Sludge
5A	I	Blended	-	595	521	1116	1.1
8C	I	Sludge	RDF	2282	213	2495	10.7
8D	I	Sludge	RDF	2282	213	2495	10.7
11E	I	-	Blended	438	325	763	1.4
11F	I	-	Blended	438	325	763	1.4
17G	I	Sludge/RDF	RDF	2046	295	2341	6.9
19H	P	Sludge	RDF	2762	288	3050	9.6
19I	P	Sludge	RDF	2762	288	3050	9.6
26I	P	Blended	-	2502	374	2876	6.7
29N	P	Blended	-	1982	510	2492	3.9
31P	P	Sludge	RDF	2563	438	3001	5.9

[a]I = Incineration; P = Pyrolysis

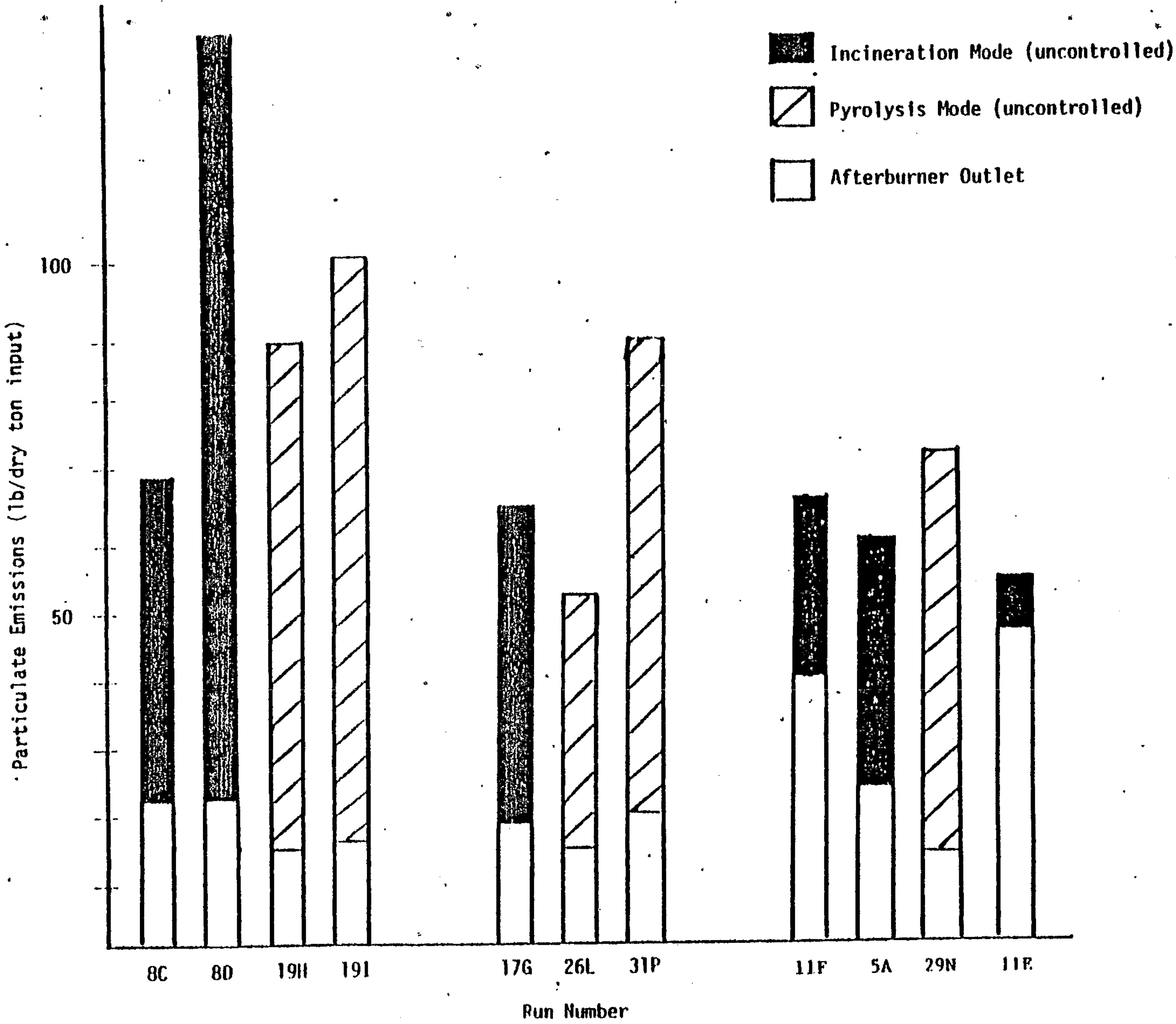


Figure 5-2. Summary of Emissions Tests on the Contra Costa Multiple-Hearth Incinerator.

Although particulate emissions appear to decline as the ratio of RDF to sludge declines, this trend could also be a function of how the sludge is charged into the incinerator. The uncontrolled rate of particulate release is generally higher when the sludge is charged separately into the top hearth (runs 8C, 8D, 19H, 19I, and 31P). In the other runs the sludge was first blended with the RDF before it entered the top of the incinerator.

Two sets of emissions data were obtained for refuse incinerators coincinerating sludge. The first set is from the Waterbury, Connecticut, facility.[9] This incinerator is a batch-fed, mass-burning, refuse incinerator with a capacity of about 150 tons/day. The sludge was first flash-evaporated and then burned in suspension in the secondary combustion chamber. The ratio of refuse to sludge was approximately 3.5:1. Emissions where controlled by a spray-baffle scrubber. The Waterbury unit was not tested in accordance with EPA Method 5 procedures.

A Consumat modular refuse incinerator was tested while coincinerating sewage sludge.[10] The sludge was first dried in an indirect steam dryer to a 20 to 25 percent moisture content. The dried sludge was not mixed with the refuse, but rather dumped into the hopper on top of the refuse. Approximately equal portions of sludge and refuse were burned. The incinerator is not equipped with a scrubber. Afterburners are employed to control particulate and odorous emissions.

The data from these two tests are displayed in Figure 5-3. For the Waterbury facility, no difference can be discerned between the controlled particulate emissions when refuse is burned separately in contrast to combined incineration. There is, however, a noticable increase in the emissions from the Consumat incinerator when dried sludge is burned, over that observed for refuse alone.

5.7 REGULATORY ISSUES

As mentioned earlier, there is currently no NSPS that applies explicity to coincineration. In the few cases where new facilities subject to NSPS have been built, the emission limit has been determined on an ad hoc basis. Table 5-3 shows the procedure that has been employed in making these determinations.

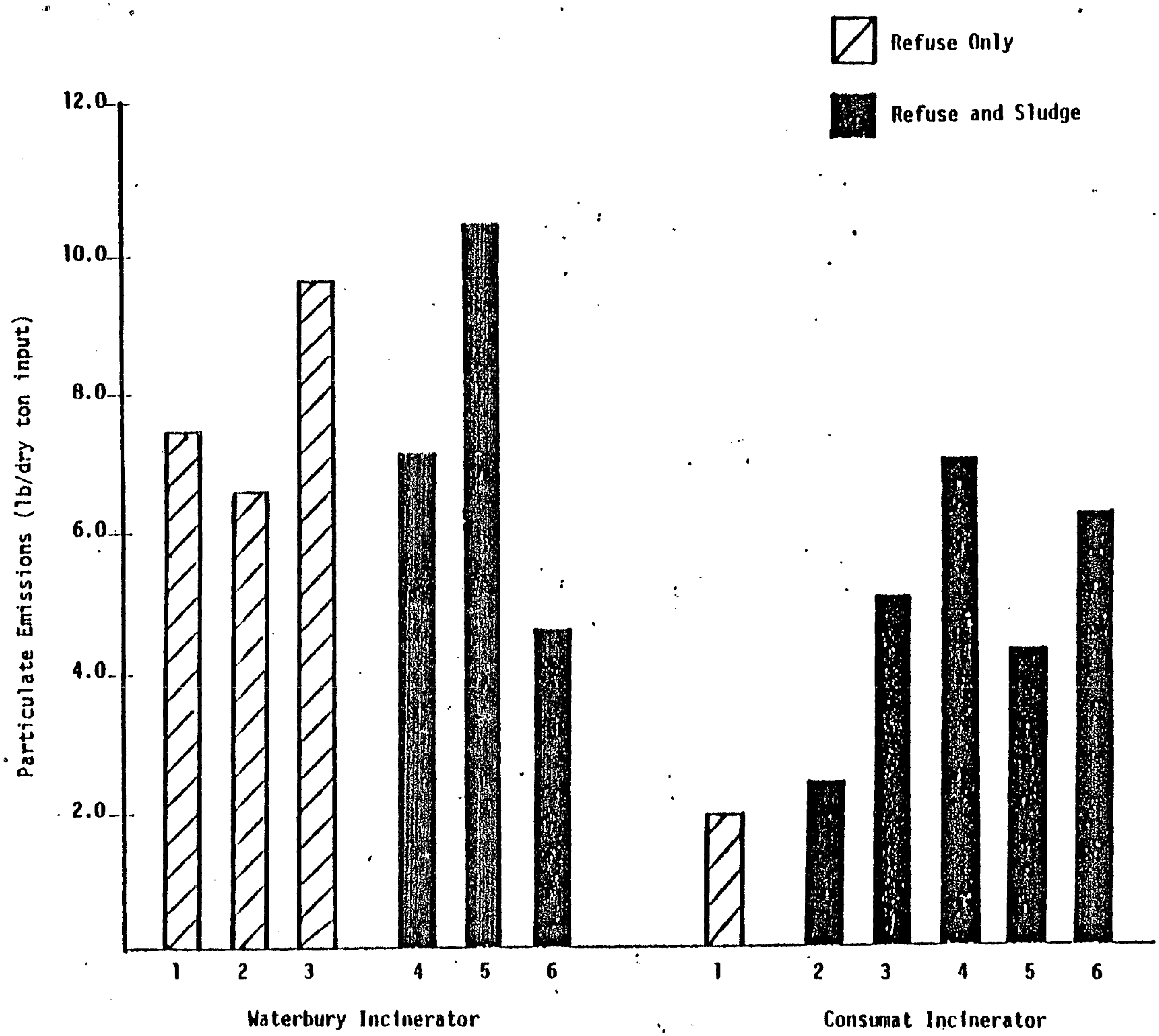


Figure 5-3. Summary of Particulate Emissions from Two Municiple Refuse Incinerators

TABLE 5-3. CURRENT BASIS FOR DETERMINING THE APPLICABILITY OF THE NSPS TO INCINERATORS

Sewage Sludge (Percent)	Municipal Refuse (Percent)	Incinerator Charging Rate (tons/day)	Applicable Subpart[a)]
100	0	any rate	Subpart O
51 - 100	0 - 49	> 50 total waste	Prorated, O/E[b)]
0 - 50	50 - 100	> 50 total waste	Subpart E
0	100	< 50 municipal refuse	None
1 - 99	1 - 99	< 50 total wastes, > 1.1 sewage sludge	Subpart O
11 - 99	1 - 89	< 50 total wastes, ≤ 1.1 sewage sludge	Subpart O
0 - 10	90 - 100	< 50 total wastes, ≤ 1.1 sewage sludge	None

a) Subpart O: 1.3 lb particulate/dry ton sludge input; Subpart E: 0.08 grains/dry standard cubic foot flue gas

b) DSSE determination (E-7), May 17, 1976, allows a prorated standard based on the percentage of each waste consumed.

There are a number of inconsistencies within this scheme. First, as noted in the 1978 review of the sewage sludge incineration standards, there exists a discontinuity when an incinerator is burning 50 percent municipal waste and 50 percent sludge.[11] Also as noted in the 1978 review, the separate standards are not expressed in the same units; the conversion from a concentration- to a mass-based standard is not always straight-forward.

Additional gaps in the coverage of the existing regulations are also apparent. For example, neither Subpart E nor Subpart O addresses the applicability of the standard when an incinerator is operated in a pyrolysis mode. In at least one instance, a planned solid waste pyrolysis project was exempted from the NSPS on this basis.[12]

The fact that the existing NSPS for refuse incinerators has a minimum size cut-off (50 ton/day), while no cut-off is given for sludge furnaces, raises a number of questions in terms of the equity of the current procedure for applying the Subparts. For example, a large 250 ton/day refuse incinerator burning 75 ton/day of sludge would have to meet a less stringent standard than a 45 ton/day incinerator burning 5 ton/day sludge.

Finally, in some instances, it is not clear whether the percent contribution of sludge to the total incinerator charge rate is to be calculated on a wet or dry basis.

Because of the lack of sufficient emission data, the differences between alternative coincineration techniques, and the differences between the two standards, it is not possible to resolve these issues in this study.

5.7.1 NSPS Applied to Former, Existing, and Planned Coincineration Facilities

Various determinations have been made in the past as to which NSPS should apply to coincineration. Of the facilities that were formerly coincinerating, only the Holyoke, Massachusetts, and Duluth, Minnesota incinerators were subject to the NSPS. In both instances, the incinerators were required to meet either the most stringent applicable NSPS (subpart O), or to meet an emission limit based on a proration of the two applicable subparts in a manner acceptable to the Administrator.[13,14]

Each of the three coincineration projects expected to be operating over the next five years will be required to meet different emission limits. The planned coincineration facility in Harrisburg, Pennsylvania, is considered an existing facility, and will not be subject to the NSPS. The incinerator will remain subject only to the state emission limit of 0.1 grains/dscf (corrected to 12 percent CO_2) for existing municipal incinerators. An emissions test will be performed, however, once the incinerator begins to burn sludge.[15]

Although the incinerators in Stamford, Connecticut, were built in 1975, and therefore are subject to the NSPS, the emission limit currently applied to the facility is the State emission limit for existing sources of 0.4 lb particulate/ 1000 lb flue gas. Emissions tests are currently being planned, however, to determine which Subpart of the NSPS that the incinerator is to be subject to. If the Stamford facility is determined to qualify under Subpart O, then this Subpart will be applied.[16]

Presently, no final determination has been made as to which Subpart will be applied to the Glenn Cove, New York, coincineration facility. A test program is currently underway, and a final determination will be made at the conclusion of these tests.[17]

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16. ABSTRACT

Review of Standards to control emissions from new and existing sewage sludge incinerators. This document contains information on the background and authority regulatory alternatives considered and the economic impacts of the proposed regulations.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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