REPORT ON A STUDY

OF THE ALEXANDRIA, VIRGINIA INCINERATOR

This report (SW-12ts) was written by

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F O R E W O R D

Incineration is an important method of solid waste processing in the United States, and although over 300 incinerators are in operation, little information on the performance of these units is available. It is therefore not surprising that the effects of incineration on the environment are little understood and frequently ignored.

An incinerator discharges effluents into the environment in three states: solid, liquid, and gaseous. The sources of these effluents are the processes of combustion, gas cleaning, and residue quenching. Any determination of the pollution contribution to the environment by incineration must be concerned with all these effluents.

The Bureau of Solid Waste Management, through the Division of Technical Operations, has initiated a testing program to characterize the performance of incinerators of different designs and configurations. The primary objectives of this program are to produce basic information that identifies the results of the incineration process and to develop reliable sampling methodology.

During the studies it is considered necessary to make a complete analysis of all features that affect the operation of the facility as well as those that influence its potential for environmental pollution. The operation of the facility is not altered in any way unless specific study objectives dictate a change. Therefore, no special effort is made to operate the facility at its design capacity; rather, it is tested at its "operating" capacity.

Reports from each study in this program will be prepared primarily for use by the management of the facility, although they will be available upon request to other interested technical personnel. Each report will contain only the data obtained during one individual study. Data comparisons with other studies will not be made in individual study reports. Summaries and comparisons of the data from all studies will be reported annually.

--RICHARD D. VAUGHAN, *Director*
Bureau of Solid Waste Management

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REPORT ON A STUDY OF THE ALEXANDRIA, VIRGINIA, INCINERATOR

The Division of Technical Operations of the Bureau of Solid Waste Management provides technical information and assistance to public and private agencies, organizations, and individuals throughout the country. In October 1967 Mr. Leroy Stone, Solid Waste Management Representative, Bureau of Solid Waste Management, Region III was contacted by the City of Alexandria, Virginia, regarding the possibility of having their incinerator tested. The city was interested in finding out if recently made changes in furnace operation had affected particulate emissions. Since the National Air Pollution Control Administration had conducted stack-emission tests in April 1967, before the changes in operation were made, a direct comparison would be possible.

Testing the incinerator would not only satisfy Alexandria's need for stack-emission data, it would also further the Division of Technical Operation's efforts to develop basic information about the environmental pollution potential of incinerators. A study was, therefore, conducted from May 18 to 25, 1968.

SUMMARY

The burning rate of each furnace during the study week, May 20-24, 1968, averaged 6.42 tons per hr, slightly more than rated capacity. The plant was designed to burn 6.25 tons of solid waste per hr per furnace, or 300 tons per day for both furnaces, with a heat content of 5,000 Btu per lb. Laboratory analysis revealed that the gross heat content available in the incoming solid waste averaged approximately 4,300 Btu per lb. Annual figures indicate, however, that based on a 5-day week, the plant burns an average of 250 tons per day. This can be explained partly by the fact that when the supply of solid waste is low, one furnace is shut down. When operating, however, the furnaces do burn close to design capacity.

The average particulate-emission rate with one furnace operating was 0.88 gr per standard cubic foot (scf) corrected to 12 percent CO_2. With both furnaces operating, the average emission rate was 1.12 gr per scf at 12 percent CO_2.

The National Air Pollution Control Administration had conducted stack-emission tests on the incinerator in April 1967, before an increase in underfire air was made to reduce slag buildup on the grates. The average of their three tests with both furnaces operating was 0.26 gr per scf at 12 percent CO_2.

All wastewater from the plant operation is discharged into the city sewer system. In both the residue-quench and fly ash scrubber systems, water is recirculated for 1 week before discharge. Makeup water is obtained from the city water supply. The extreme acidity that occurs in the fly ash scrubber water necessitates a soda ash neutralization system to protect equipment from corrosion.

The plant employs 24 full-time personnel to work the three shifts each day. Solid waste is burned Monday through Friday, and the plant is open until noon on Saturday to receive waste. The cost of plant operation was $4.90 per ton of solid waste burned. The total cost per ton, including depreciation came to $7.26.

Total weight-reduction efficiency of the incinerator was approximately 68 percent on a dry basis. The residue contained an average of 2.0 percent volatiles, and the fly ash had 13.9 percent volatiles. Total weight reduction of volatiles was approximately 99 percent. Approximately 99 percent of the available heat was released during incineration.

The operation of the plant was well managed. Complete records of the data taken from the instrumentation are kept on file for possible future reference. The working atmosphere was clean, and employees did their jobs effectively.

DESCRIPTION OF ALEXANDRIA, VIRGINIA, INCINERATOR

Operating Procedure

The Alexandria, Virginia, municipal incinerator is located in the southeastern section of the city at 5301 Wheeler Avenue. It was placed in operation in October 1966 and handles the solid waste generated by household, commercial, and industrial sources in Alexandria and Cameron Station. The total population served numbers about 100,000. Operating funds are provided from the municipal budget.

Plant operation is under the administrative control of the director of public works, but the plant superintendent is directly in charge of the day-to-day operation. The plant operates three shifts a day and requires 24 full-time employees. Both the foreman and the superintendent have offices at the plant. Employees understand their jobs and perform them efficiently.

All trucks using the incinerator are required to secure a tag that is valid for 1 year. When the tag is issued, the tare weight of the vehicle is recorded. A full-time operator is on duty during the hours the plant is open to receive solid wastes, and all incoming trucks are weighed on semi-automatic scales of 45,000-lb capacity. The residue and fly ash trucks leaving the plant while the operator is on duty are also weighed. Normally, estimates are made on the weights of residue and fly ash that are removed when the scales are closed. During the study, however, all fly ash and residue were weighed to enable reduction-efficiency calculations to be made.

The incinerator is open to receive solid waste from 7 am to 5 pm on weekdays, and from 6 am to 12 noon on Saturday. Both furnaces are fired up on Monday morning and are usually run continuously until Wednesday evening or Thursday morning, when one is shut down because the supply of solid waste is usually insufficient to keep both furnaces in operation all week. The furnace is fired up again Thursday evening or Friday morning, and both furnaces are run continuously until very early Saturday morning, when the pit is emptied. The solid waste coming in Saturday morning remains in the pit until operation begins Monday.

Inflammable liquids and hazardous dusts such as pulverized coal, flour, and sawdust are excluded from the incinerator. Any material that the plant foreman feels may be harmful to the operation is also rejected and hauled to a landfill.

Plant Layout

The incinerator is located in an industrially zoned area with no residences in the immediate vicinity. A fence with two lockable gates borders the entire plant, and the area (Figure 1) is well landscaped and free of litter.

The plant structure is of conventional brick design with one storage pit and a covered, ventilated tipping area that can accommodate eight trucks at a time. The storage pit is 111 ft long, 23.5 ft wide and

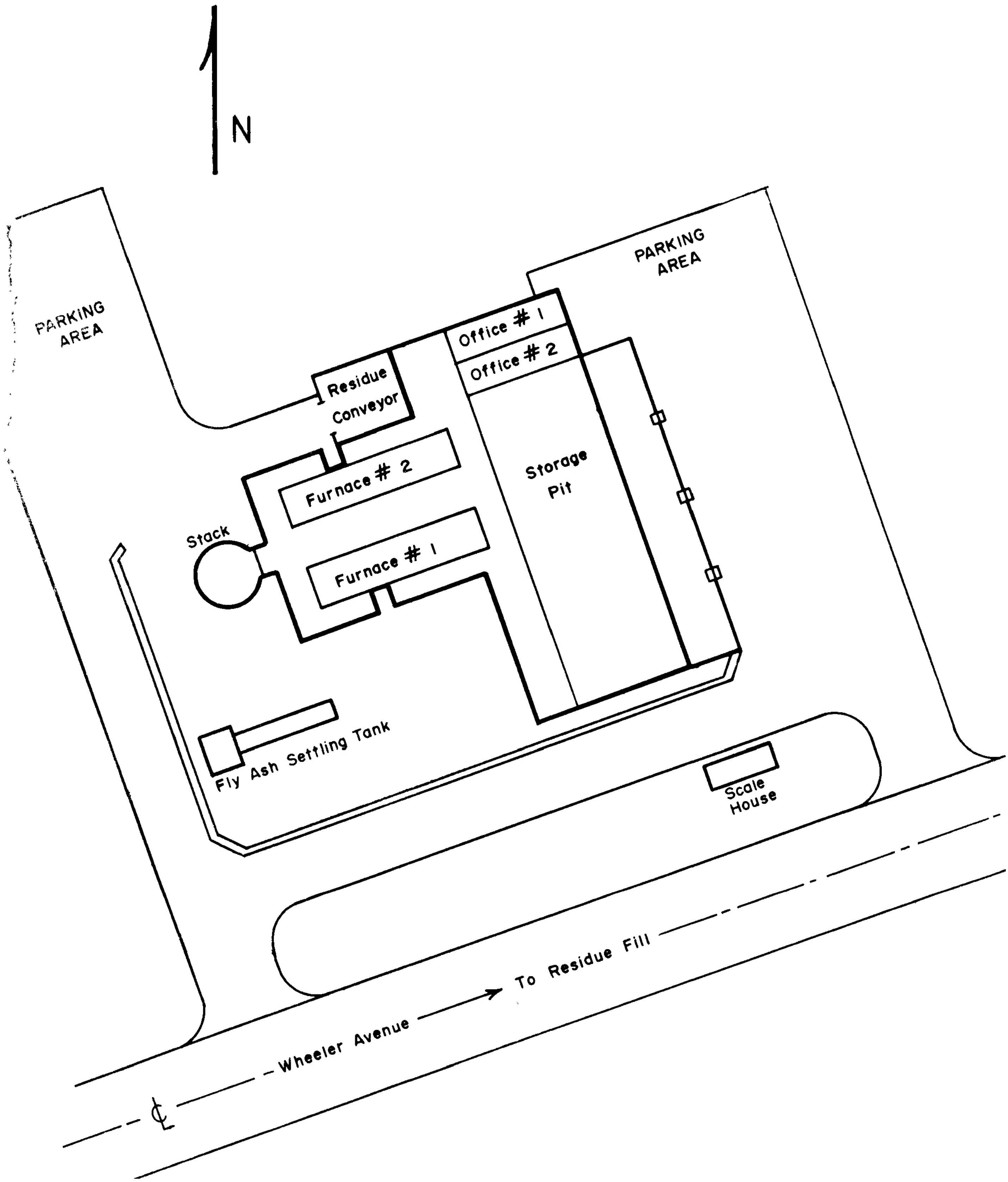

Figure 1. General layout of Alexandria, Virginia, incinerator.

32 ft deep. It has a level capacity of approximately 3,000 cu yd and is capable of storing 2 days of solid waste.

The building has four floors. A large meeting room and the residue dumping area are on the ground floor, the furnaces and offices are located on the second floor, the employee facilities are on the third floor, and the charging hoppers are located on the fourth floor.

The plant environment is very clean, with a charging floor, tipping area, furnace room, and residue-disposal area that are nearly dust and odor free. Temperatures are not excessive in any working area. Drinking fountains and soft-drink machines are located throughout the plant, and employees have access to a refrigerator and stove in their lunchroom. A large locker room is also available for employees to shower and dress.

Incinerator Design

Furnaces. The incinerator was designed to burn 300 tons per 24 hr of operation. The two identical, continuous-feed furnaces have rocking grates and a common 200-ft stack (Figure 2). Each is designed to burn 6.25 tons per hr, or 150 tons per day. The design was based on a solid waste heat content of 5,000 Btu per lb.

Combustion gases are partially cleaned by passing them through a water-spray baffle scrubber. Residue from both furnaces is water-quenched in a common tank and removed by conveyor. The highly acidic scrubber water is neutralized with soda ash before being pumped to a settling basin, where the resulting sediment is removed with a conveyor.

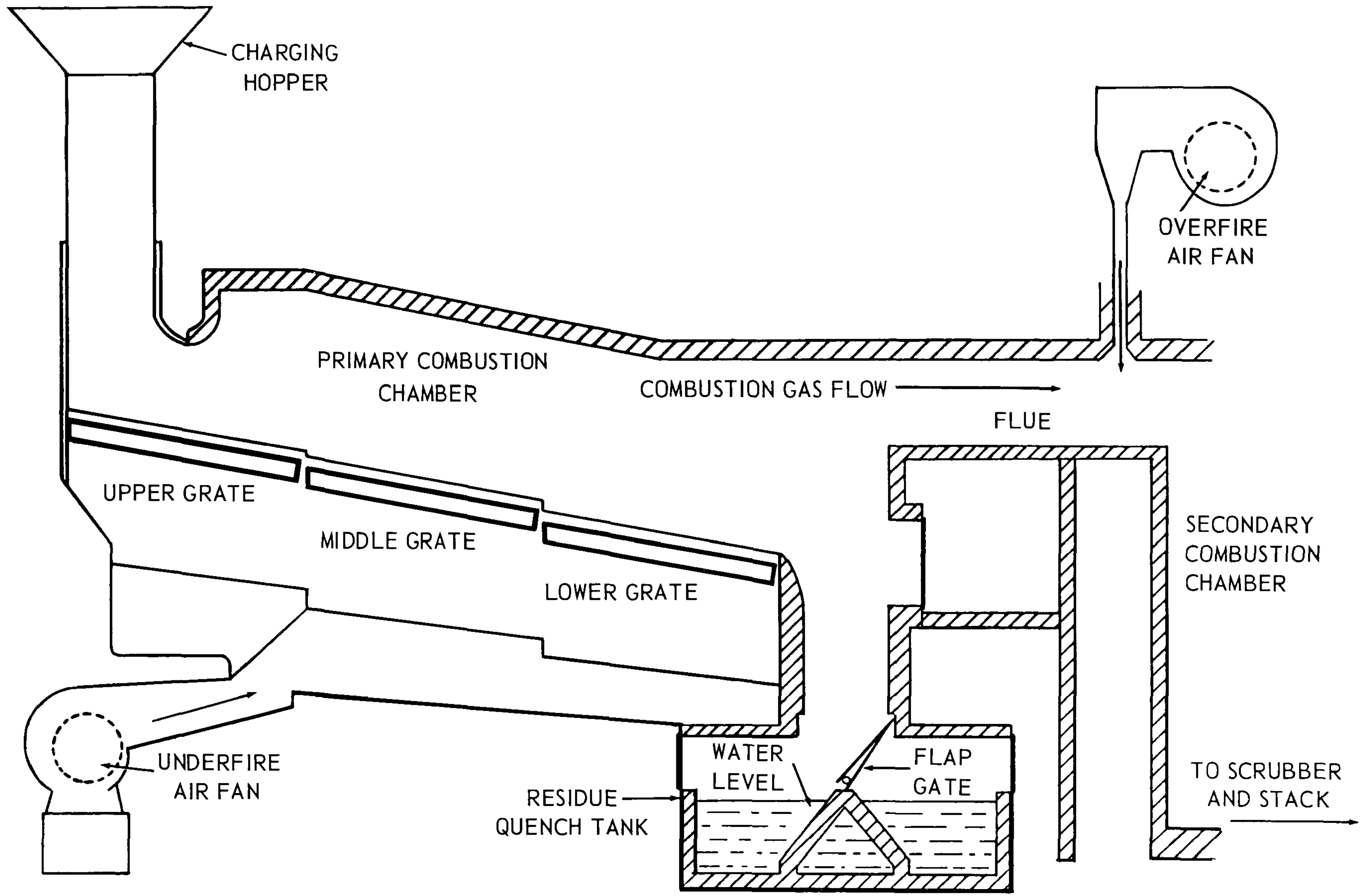

Figure 2. Furnace schematic of Alexandria, Virginia, incinerator.

The furnace chambers were manufactured by Plibrico.* The primary combustion chamber is approximately 34 ft long, 8 ft wide, and 8 ft high. The brick refractories are 8 in. thick.

An automatic hydraulic system controls the three separate sections of grates (manufactured by Flynn and Emrich), which can be set to rock at various speeds and in various cycles. The grates nearest the residue-quench tank are usually run one-fifth as fast as the middle grates. The first section of grates is essentially for drying, and most of the burning occurs on the next two sections. Approximately 30 min are required for solid waste to pass from the charging hoppers to the residue-quench tank.

A thermocouple located in the secondary combustion chamber is connected to a buzzer alarm that rings when the temperature exceeds 1,450 F. Operating experience has shown that when this temperature is reached in the secondary combustion chamber, the temperature is high enough in the primary chamber to cause slagging and refractory deterioration. Adjustments are then made in grate speeds and/or auxiliary air to lower the temperature.

Each furnace is equipped with underfire and overfire air fans that are rated at 19,000 cfm each, with the dampers fully open. The underfire air fan is usually run with the damper half open, which is equal to about 75 percent of the available fan capacity. Overfire air fans are usually operated with the dampers one-eighth open, which is equal to about 20 percent of the fan capacity. A 200-ft stack

*The mention of commercial products does not imply endorsement by the U.S. Public Health Service.

provides the necessary natural draft for removal of combustion gases from the combustion chamber.

Charging System. Solid waste is charged into the furnace hoppers with a 2.5-cu-yd grapple attached to a P & H overhead crane of 4-ton capacity. A standby crane is not available. The operator sits in an enclosed moving cab and feeds each furnace through separate charging hoppers. The solid waste is fed both by gravity and by the movement of the furnace grates from the charging hoppers, through the charging chutes, and into the furnaces. The charging chutes are water-cooled to protect them from excessive heat buildup.

Air Pollution Control Equipment. After the combustion gases leave the primary combustion chamber they pass through a flue into the secondary combustion chamber before entering the spray-baffle scrubber (Figure 3). A set of pressurized nozzles spray water down the firebrick baffle walls from above. The combustion gases make two 90° turns while passing through the baffle walls, thus causing the particulates to impinge upon the wetted surfaces where some are entrained in the water droplets. Water is pumped through the scrubber system at a rate of 500 gpm. The scrubber water, laden with fly ash, is processed through a fly ash settling basin and pumped back to a sump tank for recirculation. Before entering the settling basin, however, the water is treated with soda ash to reduce the extreme acidity of the water. Sedimentation and neutralization are the only treatments the scrubber water receives before its once-a-week discharge into the city sewer system. Replacement and make-up water come from fresh city water. Make-up water is pumped through

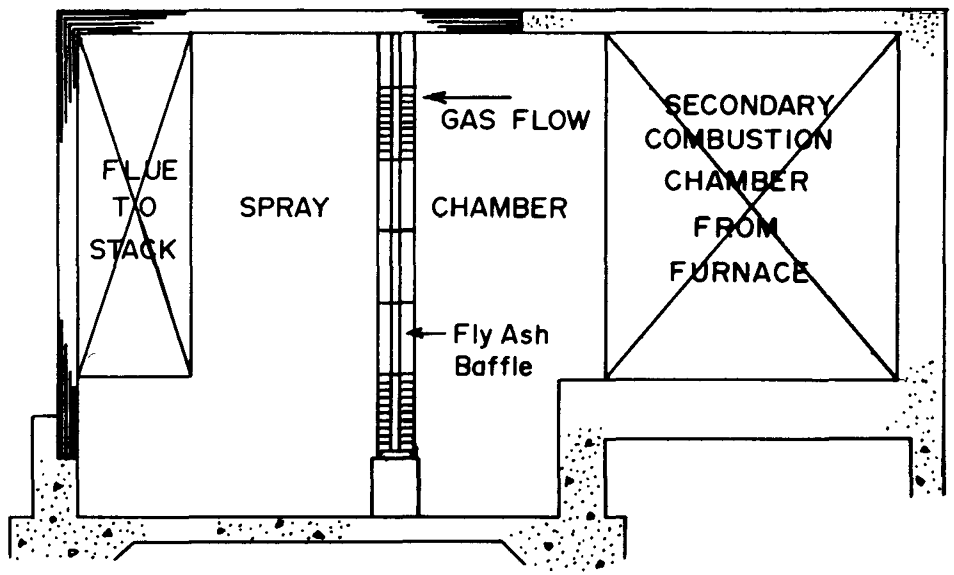

Figure 3. Scrubber schematic of Alexandria, Virginia, incinerator.

the charging chute cooling system before it is utilized in the scrubber and residue-quench systems.

Residue and Fly Ash Removal Systems. The residue from each furnace falls off the last section of grates into a common quench tank where it is removed by conveyor to a truck. The plant is equipped with a reserve quench tank and conveyor system. A movable flap gate diverts the residue to one system or the other, and in this way, plant operation is not impeded if a conveyor fails. The water from the residue-quench tank is recirculated at a rate of 300 gpm from a sump tank that is separate from the scrubber-water sump tank. The material that settles out in the sump tank is removed Monday morning when fresh water is added. The residue-quench water, untreated except for sedimentation, is discharged into the city sewer system at this time.

The sludge from the bottom of the fly ash settling basin is removed by conveyor to a truck. Both residue and fly ash were weighed during the study, then hauled to a disposal site located on Wheeler Avenue about ½ mile from the plant. The disposal site is leveled off and covered about four times a year.

Instrumentation. The incinerator is equipped with an upright Honeywell instrument panel located on the furnace floor between the two furnaces. Controls for regulating the hydraulic grates are located on each furnace. The instrument panel contains continuous-recording circular charts that record readouts of temperatures for each secondary combustion chamber as well as the temperature in the stack. Underfire and overfire air-pressure gauges are located on the instrument panel. Air flow is regulated by adjusting the dampers. The stack draft and the vacuum between the breeching and the combustion chambers are indicated on gauges located on the instrument panel. A continuous-recording circular chart indicating smoke opacity is also on the panel. Manual readings of water temperature in the water-cooled charging chutes are taken hourly with a thermometer to indicate possible heat buildup in the chutes.

Each furnace is controlled by an operator who monitors the instrument panel and makes necessary adjustments in grate speeds and overfire and underfire air to keep combustion as efficient as possible. If temperatures in the secondary combustion chamber become too high (about 1,450 F), a buzzer alarm rings and necessary adjustments are made. The degree of burnout in the residue is observed to determine whether grate speeds should be changed to vary the residence time of the solid waste in the furnace. The furnace temperature and the completeness of combustion can also be regulated by varying the overfire and underfire air. These methods are used in combination to obtain the desired operating conditions. Readings are taken every hour from all instrumentation and filed for future reference. The charts from the continuous recorders are also kept on file.

Maintenance

Minimal corrective maintenance has been required in most aspects of plant operation, but problems with clinker buildup on the grates did develop soon after the plant was opened. The problem was alleviated by increasing the underfire air rate. The increase in underfire air resulted in excessive fly ash blowover into the secondary combustion chamber, which reportedly lowered the pH in the scrubber water. To prevent the acidic water from corroding the pumping and settling basin equipment, a soda ash neutralization system was added. This treatment takes place after the water is drained from the scrubbers and before it enters the settling basin. The cost of the treatment is about $2,500 per yr. When the cost of the grate replacement is compared to the cost of the neutralization system after the underfire air rate was changed, the expenditure was certainly justified. However, as discussed later under Results, the increased underfire air probably did substantially increase stack emissions. During the first year and a half of operation, a total of 98 grate sections were replaced, but most of them were required before the changes in the underfire air rate were made. Each grate section costs $240 and requires about 1 hr to replace.

Routine maintenance work is done on Monday mornings before the furnaces are fired. The only other maintenance that has been required has been patchwork on the refractories and frequent repairs on the smoke opacity meter.

METHODS AND PROCEDURES

The methods and procedures used in this study were designed to give an overall view of the potential for air, water, and land pollution that the incinerator has on the surrounding environment. The study was also undertaken to provide information on the characteristics of solid wastes.

During the week of the tests, the incinerator was operated normally, which meant that one furnace was shut down on Thursday, May 23. Four stack tests were performed while both furnaces were operating; two were performed with one furnace operating. Sampling of all effluents was done simultaneously.

Input and Output Measurements

All incoming solid waste is weighed on the incinerator scale before it is dumped into the storage pit. Efforts were made to obtain a more accurate measurement of the charging rate while stack tests were being conducted by weighing the grapple loads on a platform scale before they were charged into the furnace. Difficulties were encountered in keeping the crane cables slack and in keeping the solid waste in the grapple while weighing, thus making it impossible to gather more definitive data.

The average charging rate over the study week was determined by dividing the total number of furnace operating hours into the number of tons of solid waste received and burned from May 18 to 24, 1968. The residue and fly ash were also weighed during the study week to determine the reduction efficiencies.

Sampling Techniques

Incoming Solid Waste. Samples of incoming solid waste were taken on Monday, Tuesday, and Wednesday. The solid waste samples were obtained by dumping a partial grapple load of what was considered typical waste (determined by visual inspection) onto a plastic drop cloth on the charging floor. The sample was then separated into the following nine categories:

Combustibles:

- Food wastes
- Garden wastes
- Paper products
- Plastics, rubber, and leather
- Textiles
- Wood

Noncombustibles:

- Metal products
- Glass and ceramic products
- Ash, dirt, and rocks

After separation, materials in each of the categories were weighed. The total sample weight was then calculated, and the percent by weight of each category was determined. Using these percentages, a 10- to 15-lb sample was reconstituted by weight from the combustible categories. Noncombustibles were assumed inert and were excluded from this sample to make the laboratory grinding less troublesome. Laboratory analysis of the sample included determinations of moisture content, heat content, percent volatiles, and percent ash. The analysis indicated that adequate precautions to protect against moisture loss were not taken, thus making it necessary to estimate the moisture content. Once the sample was well mixed and dried, the volatile and ash analyses were performed on a portion of the sample according to procedures outlined in Appendix A of Tentative Methods of Analysis of Refuse and Compost in Municipal Refuse Disposal.[1] The heat content was determined on a well mixed, dry portion of the sample in the Parr Adiabatic Calorimeter by the method outlined in the Parr Instrument Company's Manual Number 130.[2]

Residue. Furnace residue samples were taken on Tuesday, Wednesday, and Thursday of the test week for determination of burning efficiency. Approximately 15 gal of residue were caught in a 30-gal drum as it was discharged from the residue conveyor. The sample was allowed to dry for several hours and was then separated by hand into three categories: metals, glass and rocks, and unburned combustibles and fines.

After the larger pieces of unburned combustibles (glass, metal, and rock) were removed, the remainder of the sample was sifted through a ½-in. mesh screen to remove the fines. The weight of each category was recorded, and all the unburned combustibles and fines were returned to the laboratory for analysis. The remainder of the sample was discarded and assumed to contain no heat, moisture, or volatiles. Laboratory analysis of the residue was the same as for the incoming solid waste except that the moisture content was determined from one sample taken from the conveyor in a 6-gal plastic container that was tightly sealed to guard against moisture loss during shipment to the laboratory.

Fly Ash. Fly ash samples were taken from the fly ash conveyor. A 1-gal composite sample was taken for the 3 days of stack testing and was returned to the laboratory for the same analyses that were made on the solid waste and residue.

Stack Effluent. The majority of time and effort during the week was devoted to sampling the stack effluent. Monday was spent in setting up the sampling equipment. Two tests were made on both Tuesday and Wednesday when both furnaces were operating, and two tests were made on Thursday when only one furnace was operating.

The two stack sampling ports were located 100 ft above the ground and 180 degrees apart. Equipment was set up on a catwalk located at this level. Twelve points across the diameter of the stack were sampled during each test. Each point was sampled for 5 min, making a total sampling time of 1 hr. Six of the points were sampled from each port. Approximately 15 min were required to move the sampling probe between the ports during the test. The sampling was done approximately 10 stack diameters up from the top of the breeching at the base of the stack. The maximum velocity head encountered during testing was 0.32 in. of water. A 3/8-in. diameter nozzle was used on the sampling probe. Two particulate collection boxes were required per test because of plugging problems encountered with the glass fiber filters. The plugging occurred because of particulate buildup on the filter, which prevented maintenance of isokinetic sampling conditions.

The procedures used in stack sampling are described in the publication Specifications for Incinerator Testing at Federal Facilities[3] and the addendum to that publication. The particulate samples returned to the laboratory were analyzed according to the procedures outlined in that publication.

Liquid Effluent. Liquid samples of 1 liter were taken from the residue quench tank and the fly ash settling basin during each day of stack sampling. Half of each sample was collected during the morning tests and half during the afternoon tests. It was not possible to collect samples of the scrubber water before the neutralization process. The samples were sealed, labeled, and returned to the laboratory for determination of solid, chemical, and biological characteristics. The samples were analyzed according to procedures outlined in Standard Methods for Examination of Water and Waste Water.[4] Separate grab samples were collected and delivered to the Alexandria Sanitation Department where BOD tests were performed.

RESULTS

Overall Plant Efficiency

During the week of the study, 1,271.8 tons of solid waste were received and burned. With the furnaces operating a total of 198 hours, the average burning rate was 6.42 tons per furnace per hour. The storage pit was emptied before and after the study week, and all incoming solid waste and solid effluents were weighed during the week. The burning rates of the furnaces could not be determined on a daily basis because burning was not continuous and the solid waste was not completely burned until the end of the week. The moisture contents for the residue and fly ash were obtained from single samples taken for that purpose. Laboratory data for the moisture content of the incoming solid waste were unrealistically low (5 to 15 percent), considering that the wastes were visibly wet. This indicates that not enough precaution had been taken in sealing the sample containers for shipment back to the laboratory. An estimated moisture content of 20 percent was assumed for all calculations (Table 1).

The overall weight reduction efficiency for the week was approximately 68 percent, weight reduction in volatiles was approximately 99 percent, and the percentage of heat released was approximately 99. These calculations are shown in Appendix C.

TABLE 1

INCINERATOR PERFORMANCE DATA

Date	Input			Output						Operating time (hours)	
	Solid waste received (tons)	Moisture content* (%)	Dry weight of solid waste (tons)	Wet residue (tons)	Moisture content† (%)	Dry weight of residue (tons)	Wet fly ash (tons)	Moisture content† (%)	Dry weight of fly ash‡ (tons)	Furnace no. 1	Furnace no. 2
5-18-68	87.5	20	70.0	---	---	---	---	---	---	---	---
5-19-68	---	---	---	---	---	---	---	---	---	---	---
5-20-68	296.5	20	237.2	82.8	24.5	62.5	5.8	69.4	1.8	12.5	12.5
5-21-68	255.4	20	204.3	97.3	24.5	73.5	5.2	69.4	1.6	24.0	24.0
5-22-68	213.9	20	171.1	71.5	24.5	54.0	7.2	69.4	2.2	24.0	19.0
5-23-68	213.2	20	170.6	73.7	24.5	55.6	5.7	69.4	1.7	24.0	6.0
5-24-68	205.3	20	164.2	74.2	24.5	56.0	7.1	69.4	2.2	24.0	24.0
5-25-68	---	---	---	---	---	---	---	---	---	2.0	2.0
Total	1,271.8	---	1,017.4	399.5	---	301.6	31.0	---	9.5	110.5	87.5

*Assumed.
†Determined from one sample taken specifically for a moisture determination.
‡From settling basin only. The dry fly ash (particulates) from the stack totaled 9.2 tons as determined from the stack emission data.

Stack Tests

A total of six stack tests was conducted during the study week. The results of the particulate emissions tests are expressed in three different ways (Table 2.)

A spectrographic analysis of the particulate matter collected on the filter paper used during the stack tests was conducted to determine the metallic elements present in the stack effluent. The most prominent elements were aluminum, lead, tin, and zinc, but none were present in great quantity.

Because a qualified smoke reader was not available during the study and the smoke opacity meter on the instrument panel was not functioning, a comparison of the Ringlemann number to particulate loadings could not be made.

The National Air Pollution Control Administration had conducted stack-emission tests on the incinerator in April 1967, before the increase in underfire air was made to reduce slag buildup on the grates. The average of their three tests with both furnaces operating was 0.26 gr per scf at 12 percent carbon dioxide, which may be compared with this study's average of 1.12 gr per scf at 12 percent carbon dioxide with both furnaces operating (Table 2). The increased turbulence caused by the additional underfire air appears to have increased particulate emissions by a factor of approximately four. The sampling techniques and equipment used for the two studies were identical except that the National Air Pollution samples were taken at only two points along the stack diameter, compared with the 12 points used during this study.

TABLE 2

STACK EFFLUENT DATA

Test	CO_2 in stack gases	Feed rate (tons/hr)	Particulate emissions: Gr/scf* at 12% CO_2	Particulate emissions: Lb/hr	Particulate emissions: Lb/ton of charged waste
Both furnaces normal:					
Test no. 1 (5-21)	4.2	12.84	0.97	193	15.0
Test no. 2 (5-21)	3.5	12.84	1.67	264	20.5
Test no. 3 (5-22)	3.3	12.84	0.83	128	10.0
Test no. 4 (5-22)	3.1	12.84	1.02	160	12.4
Average	---	---	1.12	186	14.5
One furnace normal:					
Test no. 5 (5-23)	4.3	6.42	0.73	89	13.8
Test no. 6 (5-23)	3.2	6.42	1.03	100	15.7
Average	---	---	0.88	95	14.8

*Standard conditions: 70 F, dry and 29.92 in. Hg.

Incoming Solid Waste and Residue Composition

A total of seven samples was separated (Table 3) on an as received basis into nine categories during the week of the study. Three residue samples were separated to determine their composition during the week of the study (Table 4).

Heat Contents and Burning Efficiency

Laboratory analysis to determine heat content was performed on the incoming solid waste, residue, and fly ash by standard bomb calorimetry (Table 5). The data for the solid waste are representative of the solid waste as received at the incinerator. Data for the fly ash and residue are on a dry basis. Appendix A shows the methods for calculating the data for the solid waste, and Appendix B shows the methods for calculating the data for the residue and fly ash.

For the three samples analyzed, the incoming solid waste had an average gross heat content of 4,320 Btu per lb. This is below the 5,000-Btu-per-lb design heat-release rate, but the heat content can fluctuate considerably because of seasonal variation in solid waste composition. The furnace residue had an average gross heat content of about 200 Btu per lb, and the composite fly ash sample contained 180 Btu per lb.

The laboratory analyzed the combustible portion of the solid waste samples for the percent volatiles and ash (Table 6). The noncombustibles were discarded in the field after their percentage by weight of the total sample had been determined. The percent volatiles and ash for the total

TABLE 3

COMPOSITION OF SOLID WASTE

Component	Date sampled														Total for week
	5-20-68		5-20-68*		5-20-68		5-21-68		5-21-68*		5-22-68*		5-22-68		
	lb	%	lb	%	lb	%	lb	%	lb	%	lb	%	lb	%	
Combustibles:															
Food waste	35.0	4.8	6.0	2.3	14.0	7.9	35.0	12.1	22.0	6.9	15.0	6.0	4.0	2.9	6.1
Garden waste	106.0	14.4	3.0	1.2	5.0	2.8	18.0	6.2	34.0	10.7	24.0	9.5	19.0	13.7	8.4
Paper products	384.0	52.3	167.0	63.5	97.0	54.8	139.0	47.9	182.0	57.4	158.0	62.9	93.0	67.1	58.0
Plastic, rubber, leather	21.0	2.9	12.0	4.6	7.0	3.9	19.0	6.6	3.0	1.0	4.0	1.6	3.0	2.2	3.3
Textiles	37.0	5.1	13.0	4.9	3.0	1.7	17.0	5.8	9.0	2.8	1.0	0.4	1.5	1.1	3.1
Wood	20.0	2.7	4.0	1.5	2.0	1.2	8.0	2.8	4.0	1.3	0.0	0.0	0.5	0.4	1.4
Subtotal	603.0	82.2	205.0	78.0	128.0	72.3	236.0	81.4	254.0	80.1	202.0	80.4	121.0	87.4	80.3
Noncombustibles:															
Metal	64.0	8.7	19.0	7.2	17.0	9.6	30.0	10.3	23.0	7.3	20.0	8.0	9.0	6.5	8.2
Glass and ceramics	47.0	6.4	34.0	12.9	26.0	14.7	16.0	5.5	20.0	6.3	15.0	6.0	7.0	5.0	8.1
Ash, rocks and dirt	20.0	2.7	5.0	1.9	6.0	3.4	8.0	2.8	20.0	6.3	14.0	5.6	1.5	1.1	3.4
Subtotal	131.0	17.8	58.0	22.0	49.0	27.7	54.0	18.6	63.0	19.9	49.0	19.6	17.5	12.6	19.7
Total	734.0	100.0	263.0	100.0	177.0	100.0	290.0	100.0	317.0	100.0	251.0	100.0	138.5	100.0	100.0

*Representative portions of the combustible fractions of these samples were returned to the laboratory for analysis.

sample (combustibles and noncombustibles) were calculated from laboratory values by assuming that the noncombustibles contained no moisture, were completely ash, and contained no heat.

TABLE 4

COMPOSITION OF RESIDUE SAMPLES*

Component	Date of sample 5-21-68 lb	%	5-22-68 lb	%	5-23-68 lb	%	Average %
Unburned combustibles and fines	31	49.2	31.8	50.6	38	57.6	52.5
Metal	9	14.3	10.0	15.9	9	13.6	14.6
Glass	23	36.5	21.0	33.5	19	28.8	32.9
Total	63	100.0	62.8	100.0	66	100.0	100.0

*Data on a wet basis although the samples were allowed to drain.

TABLE 5

SOLID WASTE, RESIDUE, AND FLY ASH HEAT CONTENTS

Date	Solid waste (Btu/lb, as received basis)	Residue (Btu/lb, dry basis)	Fly ash* (Btu/lb dry basis)
5-20-68	4,140	---	
5-21-68	4,260	180	
5-22-68	4,550	170	
5-23-68	---	250	
Average	4,320	200	180

*A composite sample was analyzed.

TABLE 6

VOLATILE AND ASH CONTENT
(Dry basis)

Material and date tested	Volatiles (%)	Ash (%)
Incoming solid waste:		
May 20	65.4	34.6
May 21	69.0	31.0
May 22	70.3	29.8
May 23	---	---
Average	68.2	31.8
Residue:		
May 21	1.8	98.2
May 22	1.8	98.2
May 23	2.3	97.7
Average	2.0	98.0
Fly ash:		
May 21-23*	13.9	86.1

*One composite sample was analyzed.

The same procedure was used to determine the volatiles and ash in the total residue sample, because only the unburned combustibles and fines were returned and analyzed in the laboratory. The percentages of glass and of rocks and metals were determined in the field, and these two categories were then discarded. The fly ash sample was returned in its entirety.

Liquid Effluents

Laboratory analysis was also performed on the fly ash scrubber water and the residue quench water (Table 7). The residue quench water is recirculated at the rate of 300 gpm, and the fly ash scrubber water is

TABLE 7

LIQUID EFFLUENT ANALYSIS

Sample and date tested	5 day BOD (ppm)	Temperature (°C)	pH	Total dissolved solids (mg/l)	Total suspended solids (mg/l)	Chloride (mg/l)	Phosphate (mg/l PO_4)	Sulfate (mg/l SO_4)	Alkalinity (mg/l $CaCO_3$)	Hardness (mg/l $CaCO_3$)
Fly ash scrubber water:*										
May 21	6.8	77	4.8	7818	370	3077	15.0	1125.0	16	2440
May 22	6.2	79	6.2	9364	398	3722	11.5	1350.0	24	2780
May 23	13.5	66	6.5	9332	208	3821	13.5	1275.0	28	2676
Average	8.8	74	---	8838	325	3543	13.0	1250.0	23	2632
Residue quench water:										
May 21	10.1	48	11.3	3084	1534	949	37.3	155.0	744	1204
May 22	32.7	49	11.2	3213	1124	770	39.3	145.0	820	1100
May 23	104.3	35	11.5	1678	1258	320	38.5	65.0	592	636
Average	49.0	44	---	2658	1305	679	38.3	121.7	719	980

*Taken after soda ash neutralization.

recirculated at 500 gpm. Both systems are drained and flushed at the end of each week and replenished with fresh water from the city water supply. The acidic water from the fly ash scrubber is neutralized with soda ash and is then circulated through a settling basin, where the entrained fly ash is removed. This water is then pumped to the sump tank for recirculation. As stated earlier, it was impossible to get a sample before the soda ash neutralization process. The residue quench water is recirculated from a separate sump tank with no settlement except that which takes place in the conveyor tank and in the sump tank itself.

The wastewater from the incinerator is discharged to the city sewer system for treatment. No additional treatment other than the soda ash neutralization and sedimentation is performed on the process water before discharge.

Cost Analysis

The total annual cost for incinerating 65,000 tons of solid waste was $472,082 (Table 8), yielding a unit cost of $7.26 per ton. This figure includes both operating costs, depreciation, and interest costs. The operating cost amounted to $4.90 per ton, or 67.5 percent of the total. Interest and depreciation costs amounted to $2.36 per ton, or 32.5 percent of the total.

The capital cost of the plant was $1,978,740, excluding the cost of land. The depreciation cost was calculated by using a 25-year plant life and straight-line depreciation. The yearly interest was determined

TABLE 8

TOTAL ANNUAL COST

Item	Cost	Percent of total
Annual operating cost:		
Direct labor	$197,500	41.9
Utilities	20,000	4.2
Parts and supplies	32,950	7.0
Vehicle operating expenses	7,200	1.5
External repair charges	6,250	1.3
Disposal charges	2,000	0.4
Overhead	52,800	11.2
Subtotal	318,700	67.5
Annual financing and ownership costs:		
Plant depreciation	79,149	16.8
Vehicle depreciation	9,675	2.0
Interest	64,558	13.7
Subtotal	153,382	32.5
Total annual cost	472,082	100.0

by retiring the bond over the 25-year plant life at an interest rate of 3.2 percent.

The operating costs were analyzed by breaking them into functional cost centers: receiving, volume reduction, and effluent handling and treatment (Figure 4). Operations involved in each cost center are also shown. The cost breakdown by cost center is shown in Table 9.

The total annual cost of repair and maintenance (Table 10) for the three cost centers was $76,747. These repair and maintenance costs (labor, parts, external charges, and overhead) were allocated to each of the cost

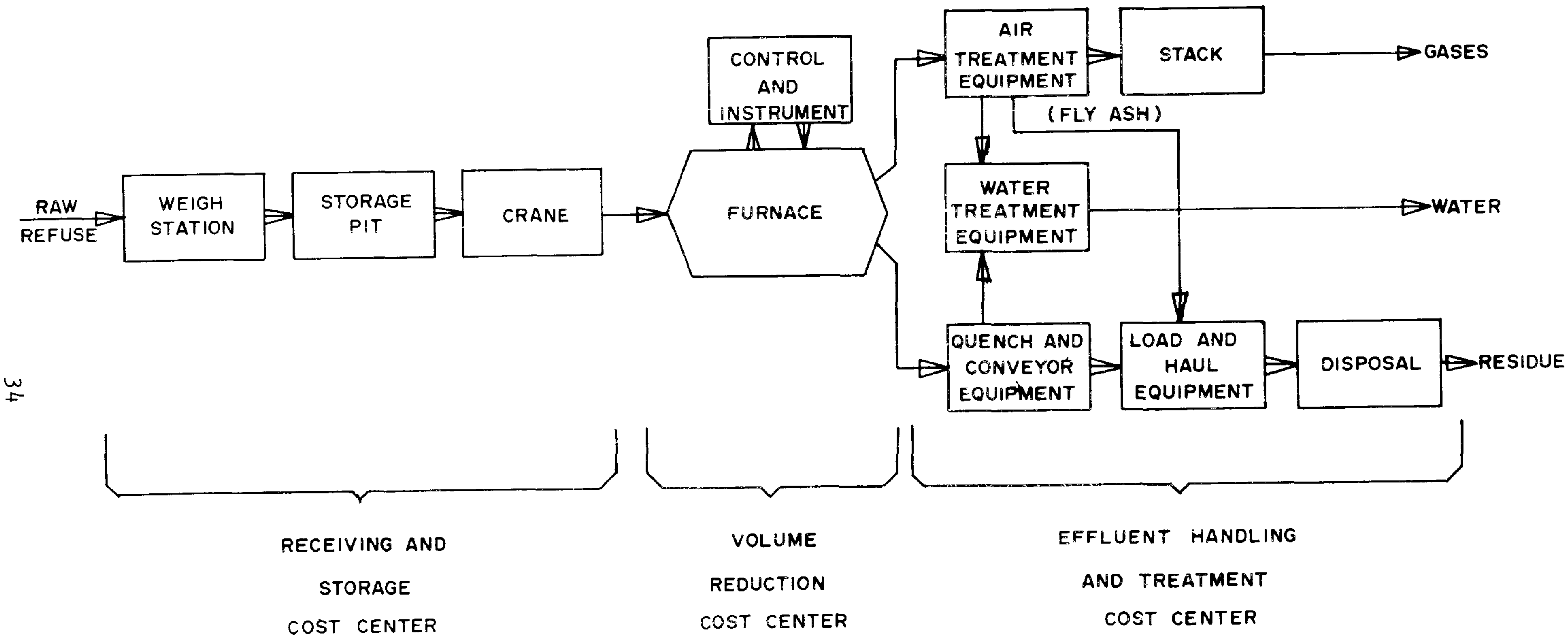

Figure 4. Incinerator cost centers, Alexandria, Virginia.

TABLE 10

BREAKDOWN OF ANNUAL REPAIR AND MAINTENANCE COST

Item	Cost	Percent of total
Actual charge:		
Labor	$29,625	38.6
Parts	32,950	42.9
External charges	6,250	8.2
Overhead	7,922	10.3
Total	76,747	100.0
Cost center:		
Receiving	9,112	11.9
Volume reduction	56,826	74.0
Effluent handling and treatment	10,809	14.1
Total	76,747	100.0

of 250 tons. Because the plant was designed to burn 300 tons a day, a projection was made to estimate what the change in cost would be if the plant were operated at design capacity (Table 11). Although the total annual cost would increase from $472,082 to $485,762, savings would be made on a unit cost basis. The greatest savings on a per-ton basis would be in direct labor, since no additional men would be required, and in financing and ownership costs. The total cost per ton would be reduced from $7.26 to $6.22.

TABLE 11

COST PROJECTIONS FOR FULL CAPACITY

Item	Actual burning rate (250 tons/day)		Projected, full-capacity burning rate (300 tons/day)	
	Total cost	Cost per ton	Total cost	Cost per ton
Annual operating cost:				
Direct labor	$197,500	$3.04	$197,500	$2.53
Utilities	20,000	0.31	24,000	0.31
Parts and supplies	32,950	0.51	39,540	0.51
Vehicle operating expenses	7,200	0.11	8,640	0.11
External repair charges	6,250	0.09	7,500	0.10
Disposal charges	2,000	0.03	2,400	0.03
Overhead	52,800	0.81	52,800	0.67
Subtotal	318,700	4.90	332,380	4.26
Annual financing and ownership cost:				
Plant depreciation	79,149	1.22	79,149	1.01
Vehicle depreciation	9,675	0.15	9,675	0.12
Interest	64,558	0.99	64,558	0.83
Subtotal	153,382	2.36	153,382	1.96
Total annual cost	472,082	7.26	485,762	6.22

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APPENDICES

APPENDIX A

Example Calculations for the Ash, Volatile, and Heat Content of the Solid Waste

Using the data from the laboratory analyses of the solid waste sample collected on May 20, 1968, these calculations show the methods used to calculate the ash, volatile, and heat content of the total sample.

The laboratory analyses (Table A-1) were performed on a dry basis. The moisture contents shown are inaccurate and it was assumed that the solid waste contained 20 percent moisture. For the following calculation, the assumptions were made that the noncombustibles contained no moisture, no heat, and were considered as "ash."

TABLE A-1

PROXIMATE ANALYSES OF THE COMBUSTIBLE PORTION OF THE SOLID WASTE SAMPLES

Date sample collected	Moisture (%)	Volatile (%)	Ash (%)	Heat (Btu/lb)
5-20-68	8.8	90.2	9.8	7145
5-21-68	18.5	86.9	13.1	7090
5-22-68	16.8	93.0	7.0	7530

The moisture content of the combustibles is calculated by the following method:

$$\text{Percent moisture in total sample} = \left(\frac{\text{lb combustibles}}{\text{lb waste}}\right)\left(\frac{\text{lb moisture}}{\text{lb combustible}}\right) 100.0$$

$$20.0 \text{ (assumed)} = (0.78)\left(\frac{\text{lb moisture}}{\text{lb combustible}}\right) 100.0$$

$$\frac{\text{lb moisture}}{\text{lb combustible}} = \frac{20.0}{100.0\ (0.78)} = 0.256$$

Because the volatile and ash fractions are calculated on a dry basis, the percent combustibles must be converted to a dry basis by means of the following equation:

$$\text{Percent dry combustibles} = \left(\frac{\text{lb wet combustibles} - \text{lb moisture in combustibles}}{\text{dry sample wt}}\right) 100.0$$

These calculations are summarized in Table A-2.

TABLE A-2

CONVERSION OF THE SEPARATION DATA TO A DRY BASIS

Component	Wet weight		Moisture		Dry weight	
	(lb)	(%)	(%)	(lb)	(lb)	(%)
Combustibles	205.0	78.0	25.6	52.5	152.5	72.4
Noncombustibles	58.0	22.0	0.0*	0.0	58.0	27.6
Total sample	263.0	100.0	20.0*	52.5	210.5	100.0

*Assumed.

The percent volatiles and ash are calculated by the following method:

$$\text{Percent volatiles in total sample} = \left(\frac{\text{lb volatiles}}{\text{lb dry combustibles}}\right)\left(\frac{\text{lb dry combustibles}}{\text{lb dry waste}}\right) 100.0$$

$$\text{Percent volatiles in total sample} = (0.902)(0.724)\ 100.0 = 65.4$$

$$\text{Percent ash in total sample} = 100.0 - \text{percent volatiles}$$

$$\text{Percent ash in total sample} = 100.0 - 65.4 = 34.6$$

The laboratory reports the heat content on a dry basis for the combustibles only, thus the moisture content and the noncombustibles in the total sample must be considered when calculating the heat content of the total sample. The heat content of the total sample on an "as received basis" was calculated by the following method:

$$\text{Heat content in total sample} = \left(\frac{\text{Btu}}{\text{lb dry combustibles}}\right)\left[1 - \left(\frac{\text{\% moisture in total sample} + \text{\% noncombustibles in total sample}}{100.0}\right)\right]$$

$$\text{Heat content in total sample} = 7145\left[1 - \left(\frac{20.0 + 22.0}{100.0}\right)\right] = 7145\ (0.58) = 4140$$

APPENDIX B

Example Calculations for the Ash, Volatile, and Heat Content of the Residue and Fly Ash

Using the data from the laboratory analyses (Table B-1) of the residue sample taken on May 21, 1968, these example calculations show the methods used to calculate the moisture, ash, volatile, and heat content of the total sample. For each sample, only the fines and unburned combustibles were returned for laboratory analyses. The laboratory volatile, ash, and heat content data are on a dry basis.

TABLE B-1

PROXIMATE ANALYSES OF THE UNBURNED COMBUSTIBLES AND FINES

Date sample collected	Moisture (%)	Volatile (%)	Ash (%)	Heat (Btu/lb)
5-21-68	24.4	4.2	95.8	437
5-22-68	20.6	4.1	95.9	383
5-23-68	29.9	4.8	95.2	513

An additional sample was taken on May 22, 1968 which was analyzed for moisture only. It contained 24.5 percent moisture and is the value used in the efficiency calculations (Appendix C) and was assumed representative of the residue.

Because the remaining calculations are on a dry basis, the separation data (Table 4) must be converted to a dry basis by means of the following equation:

$$\text{Percent dry component} = \left(\frac{\text{lb wet component - lb moisture in wet component}}{\text{total dry sample wt}}\right) 100.0$$

It was assumed that all the moisture was in the fines and unburned combustibles and that the glass and metals were dry. These calculations are summarized in Table B-2.

TABLE B-2

CONVERSION OF RESIDUE SEPARATION DATA TO A DRY BASIS

Component	Wet weight (lb)	Wet weight (%)	Moisture (%)	Moisture (lb)	Dry weight (lb)	Dry weight (%)
Fines and unburned combustibles	31	49.2	24.4	7.6	23.4	42.2
Glass and rocks	23	36.5	0.0*	0.0	23.0	41.6
Metal	9	14.3	0.0*	0.0	9.0	16.2
Total sample	63	100.0	12.1	7.6	55.4	100.0

*Assumed.

The percent volatiles and ash are calculated by the following method:

$$\text{Percent volatiles in total sample} = \left(\frac{\text{lb volatiles}}{\text{lb dry fines and unburned combustibles}}\right)\left(\frac{\text{lb dry fines and unburned combustibles}}{\text{lb dry residue}}\right) 100.0$$

$$\text{Percent volatiles in total sample} = (0.042)(0.422)\ 100.0 = 1.8$$

$$\text{Percent ash in total sample} = 100.0 - \text{percent volatiles}$$

$$\text{Percent ash in total sample} = 100.0 - 1.8 = 98.2$$

The heat content is calculated on a dry basis by the following method:

$$\text{Heat content in total sample} = \left(\frac{\text{Btu}}{\text{lb dry fines and unburned combustibles}}\right)\left(\frac{\text{lb dry fines and unburned combustibles}}{\text{lb dry residue}}\right)$$

$$\text{Heat content in total sample} = (437)(0.422) = 180$$

The volatile and ash contents of the fly ash as reported by the laboratory were on a dry basis. Therefore, no adjustment is needed. The heat content, however, was reported as 1,290 Btu/lb on a moisture and ash free basis. The following calculation is used to adjust this value to only a dry basis:

$$\text{Heat content in total sample} = \left(\frac{\text{Btu}}{\text{lb dry volatiles}}\right)\left(\frac{\text{lb dry volatiles}}{\text{lb dry fly ash}}\right)$$

$$\text{Heat content in total sample} = (1{,}290)(0.139) = 180$$

APPENDIX C

Plant Efficiency Calculations

These calculations show the methods used to calculate the percent weight reduction, the percent volatile reduction, and the percent heat released. The following data were used:

Solid waste	Particulate	Fly ash	Residue
1,271.8 tons wet	186 lb/hr	31.0 tons wet	399.5 tons wet
20 percent moisture		69.4 percent moisture	24.5 percent moisture
1,017.4 tons dry		9.5 tons dry	301.6 tons dry
68.2 percent volatiles		13.9 percent volatiles	2.0 percent volatiles
4,320 Btu/lb		180 Btu/lb	200 Btu/lb
198.0 hr of burning time			

Weight reduction:

$$\text{Percent weight reduction} = \left[1 - \left(\frac{\text{dry residue wt} + \text{dry particulate wt} + \text{dry fly ash wt} + \text{dry wt of wastewater solids*}}{\text{dry wt of solid waste}}\right)\right] 100.0$$

$$= \left[1 - \left(\frac{301.6 + \frac{(186)(198)}{2,000} + 9.5}{1,017.4}\right)\right] 100.0 = \left[1 - \left(\frac{329.5}{1,017.4}\right)\right] 100.0 = 67.6$$

Volatile reduction:

$$\text{Percent volatile reduction} = \left[1 - \left(\frac{\text{wt of dry volatiles in residue} + \text{wt of dry volatiles in particulates*} + \text{wt of dry volatiles in fly ash} + \text{wt of dry volatiles in wastewater solids*}}{\text{dry wt of volatiles in solid waste}}\right)\right] 100.0$$

$$= \left[1 - \left(\frac{(0.02)(301.6) + (0.139)(9.5)}{(0.682)(1,017.4)}\right)\right] 100.0 = \left[1 - \left(\frac{7.4}{693.9}\right)\right] 100.0 = 98.9$$

Heat released:

$$\text{Percent heat released} = \left[1 - \left(\frac{\text{heat content of dry residue} + \text{heat content of dry particulates*} + \text{heat content of dry fly ash} + \text{heat content of wastewater solids*}}{\text{heat content of solid waste}}\right)\right] 100.0$$

$$= \left[1 - \left(\frac{(200)(301.6)(2,000) + (180)(9.5)(2,000)}{(4,320)(1,271.8)(2,000)}\right)\right] 100.0$$

$$= \left[1 - \left(\frac{1.21 \times 10^8 + 0.03 \times 10^8}{109.9 \times 10^8}\right)\right] 100.0 = 98.9$$

*Not measured.