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European Refuse Fired Energy Systems

Evaluation of Design Practices

Volume 7

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EUROPEAN REFUSE FIRED ENERGY SYSTEMS

EVALUATION OF DESIGN PRACTICES

Uppsala Plant
Sweden

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Volume 7

U.S. ENVIRONMENTAL PROTECTION AGENCY

1979

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TRIP REPORT

to

UPPSALA PLANT, SWEDEN

on the contract

EVALUATION OF EUROPEAN REFUSE-FIRED
STEAM GENERATION DESIGN PRACTICES

to

U.S. ENVIRONMENTAL PROTECTION AGENCY

May 3, 1978

EPA Contract Number: 68-01-4376

EPA RFP Number: WA-76-B146

by

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PREFACE

This trip report is one of a series of 15 trip reports on European waste-to-energy systems prepared for the U.S. Environmental Protection Agency. The overall objective of this investigation is to describe and analyze European plants in such ways that the essential factors in their successful operation can be interpreted and applied in various U.S. communities. The plants visited are considered from the standpoint of environment, economics and technology.

The material in this report has been carefully reviewed by the European grate or boiler manufacturers and respective American licensees. Nevertheless, Battelle Columbus Laboratories maintains ultimate responsibility for the report content. The opinions set forth in this report are those of the Battelle staff members and are not to be considered by EPA policy.

The intent of the report is to provide decision making information. The reader is thus cautioned against believing that there is enough information to design a system. Some proprietary information has been deleted at the request of vendors. While the contents are detailed, they represent only the tip of the iceberg of knowledge necessary to develop a reliable, economical and environmentally beneficial system.

The selection of particular plants to visit was made by Battelle, the American licensees, the European grate manufacturers, and EPA. Purposely, the sampling is skewed to the "better" plants that are models of what the parties would like to develop in America. Some plants were selected because many features envolved at that plant. Others were chosen because of strong American interest in co-disposal of refuse and sewage sludge.

The four volumes plus the trip reports for the 15 European plants are available through The National Technical Information Service, Springfield, Virginia 22161. NTIS numbers for the volumes and ordering information are contained in the back of this publication. Of the 19 volumes only the Executive Summary and Inventory have been prepared for wide distribution.

ORGANIZATION

The four volumes and 15 trip reports are organized the the following fashion:

VOLUME I

A EXECUTIVE SUMMARY

B INVENTORY OF WASTE-TO-ENERGY PLANTS

C DESCRIPTION OF COMMUNITIES VISITED

D SEPARABLE WASTE STREAMS

E REFUSE COLLECTION AND TRANSFER STATIONS

F COMPOSITION OF REFUSE

G HEATING VALUE OF REFUSE

H REFUSE GENERATION AND BURNING RATES PER PERSON

I DEVELOPMENT OF VISITED SYSTEMS

VOLUME II

J TOTAL OPERATING SYSTEM RESULTS

K ENERGY UTILIZATION

L ECONOMICS AND FINANCE

M OWNERSHIP, ORGANIZATION, PERSONNEL AND TRAINING

VOLUME III

P REFUSE HANDLING

Q GRATES AND PRIMARY AIR

R ASH HANDLING AND RECOVERY

S FURNACE WALL

T SECONDARY (OVERFIRE) AIR

VOLUME IV

U BOILERS

V SUPPLEMENTARY CO-FIRING WITH OIL, WASTE OIL AND SOLVENTS

W CO-DISPOSAL OF REFUSE AND SEWAGE SLUDGE

X AIR POLLUTION CONTROL

Y START-UP AND SHUT-DOWN

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Hans Nomann	Uppsala Managing Director
Hans Sabel	Uppsala Works Director

The authors wish to express our sincere thanks to these representatives for their very skilled assistance and kind hospitality.

UPPSALA STATISTICAL SUMMARY

Community Description:	
Area (square kilometers)	200
Population (number of people)	150,000
Key terrain feature	Rolling
Solid Waste Practices:	
Total waste generated (tonnes/year) (1975)	86,355
Waste generation rate (kg/person/day)	1.5
Lower heating value of waste (Kcal/kg) (estimated)	2,450
Collection period (days/week)	5
Cost of collection (local currency/tonne)	10 Skr
Use of transfer and/or pretreatment	No
Distance from generation centroid to:	
Local landfill (kilometers)	8
Refuse-fired steam generator (kilometers)	4
Waste type input to system	--
Cofiring of sewage sludge (yes or no)	No
Development of the System:	
Date operation began (year)	1961
Plant Architecture:	
Material of exterior construction	Brick
Stack height (meters)	100
Refuse-Fired Steam Generator Equipment:	
Mass burning (yes or no)	Yes
Waste conditions into feed chute:	
Moisture (percent)	--
Lower heating value (Kcal/kg) (estimated)	2,450
Volume burned:	
Capacity per furnace (tonnes/day)	84,84,108

Number of furnaces constructed	4
Capacity per system (tonnes/day) (maximum)	348
Actual per furnace (tonnes/day)	50
Number of furnaces normally operating	3
Actual per system (tonnes/day)	200
Use auxiliary reduction equipment (yes or no)	Yes
Pit capacity level full:	
(tonnes)	360
(m^3)	2400
Crane capacity (2):	
(tonnes)	0.6
(m^3)	4
Drive method for feeding grate	No feeder
Burning grate (Unit No. 4 only):	
Manufacturer	Bruun and Sorensen
Type	Sectional, rocking
Number of sections	3
Length overall (m)	8.1
Width overall (m)	2
Primary air-max (Nm^3/hr)	?
Secondary air-overfire air-max (Nm^3/hr)	?
Furnace volume (m^3)	50
Furnace wall tube diameter (cm)	None
Furnace heating surface (m^2)	None
Auxiliary fuel capability (yes or no)	No
Use of superheater (yes or no)	No
Boiler:	
Manufacturer	Maskinverkin
Type (No. 4 Unit only)	Nat. cir. water tube
Number of boiler passes	1
Steam production per boiler (kg/hr)	15,000
Total plant steam production (kg/hr)	40,000
Steam temperature (^{o}C)	138
Steam pressure (bar)	15
Use of economizer (yes or no)	No

Use of air preheater (yes or no)	No
Use of flue gas reheater (yes or no)	No
Cofire (fuel or waste) input	No
Use of electricity generator (yes or no)	No

Energy Utilization:

Medium of energy transfer	Hot water
Temperature of medium (°C)	120
Population receiving energy (number)	--
Pressure of medium (kg/m^2)	--
Return temperature (°C)	70

Pollution Control:

Air:

Furnace exit conditions:

Gas flow rate (Nm^3/hr)	
Furnace exit loading (mg/Nm^3)	15 to 38

SUMMARY

Until 1959, there was very little district heating in Uppsala, a city of 150,000, and no recovery from wastes. Then in 1960, the mayor and city council decided to build two large oil-fired district heating loops and a waste-to-energy plant to supply steam to generate hot water for a part of the demand. The first waste-burning boilers and furnaces began operating in 1961, with a burning capacity of 6 tonnes/hr (6.6 tons/hr). Two more furnaces were added in 1965 and 1971. About 50,000 tonnes are burned per year. A new remote pulverizing station and landfill handles industrial waste.

COMMUNITY DESCRIPTION

The city, which is over 1,000 years old with a population of about 150,000, stands 75 km (45 mi) northwest of Stockholm on a plain which is estimated to have been under shallow water as recently as 3,000 to 4,000 years ago as an aftermath of the Ice Age. The community has a long history of being in the forefront of knowledge. The University was 500 years old in 1977. Scheele discovered oxygen and chlorine there about 200 years ago. Linnaeus did most of his pioneering botanical research there.

Until 1863, Uppsala was a small town dominated by craft guilds which prevented growth and there was much poverty and unemployment. But in 1863, new Swedish laws ended the dominance of the craft guilds and the principle of free trade was established by law. The city then began to grow rapidly. The Uppsala City Council met for the first time in January, 1863. At the same time, municipal government began for 48 small neighboring communities. The last consolidation was in 1971 when seven rural districts joined. These together now (1978) form the municipality of Uppsala. There are 81 councillors, elected every 3 years. Nearly 2,000 citizens are on municipal boards and committees, and the city employs 10,000 people. The official city brochure* declares: "This story of the development of city government over the last 100 years is also the story of the rise of democracy in Swedish society and its development into a welfare state".

Figure 12-1 shows the Uppsala District Heating Network.

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* Uppsala, published by the City of Uppsala (1977).

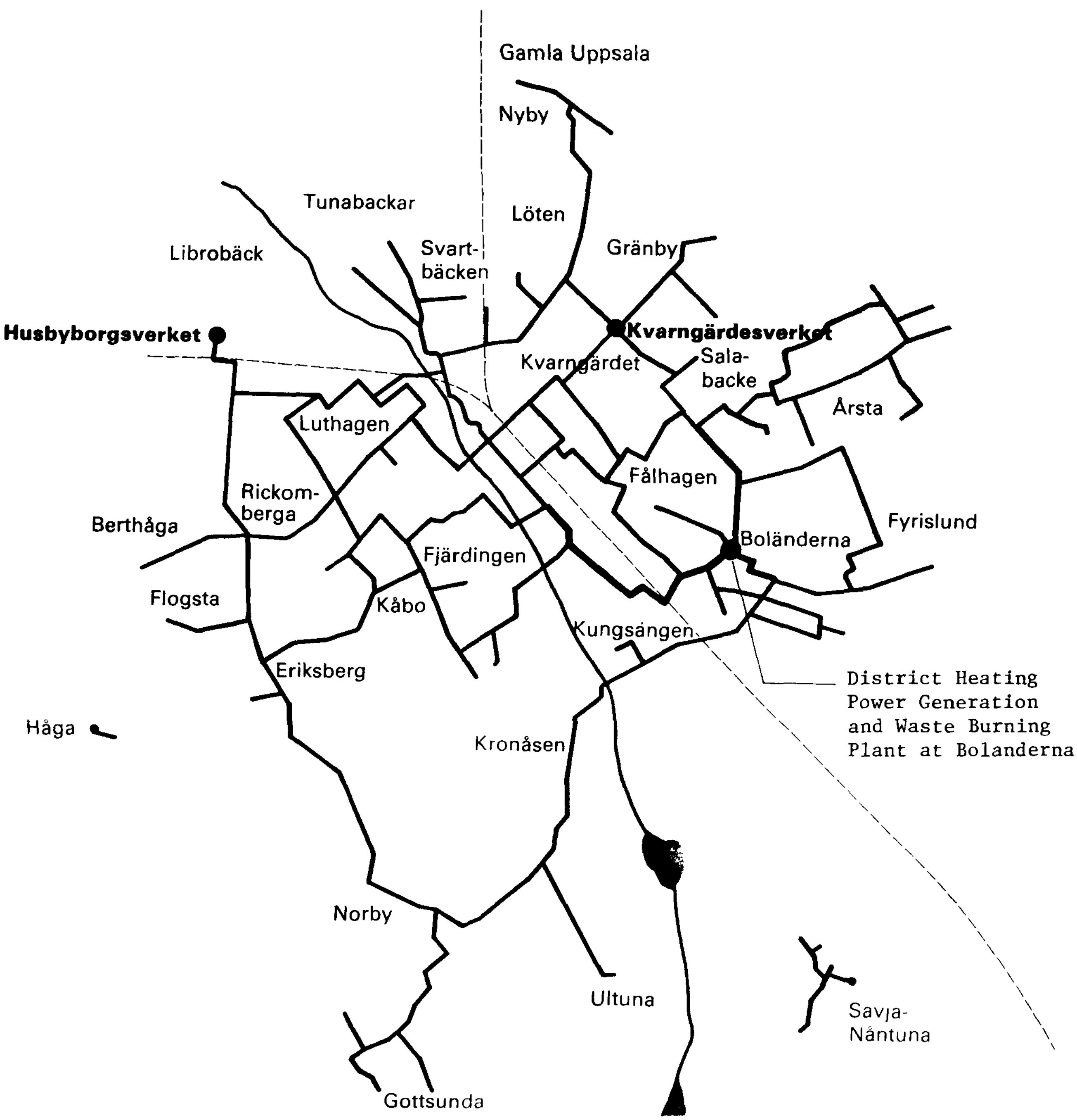

FIGURE 12-1. MAP OF HOT-WATER DISTRICT HEATING NETWORK AT UPPSALA SHOWING THREE MAIN HEATING PLANTS AND TWO SMALL ISOLATED PLANTS (COURTESY UPPSALA KRAFTVARME AB)

Industry

The service sector dominates Uppsala's industry and comprises 67 percent of the total employment. The largest industry, Volvo-Bagslogsverken, produces auto parts and outboard motors. Fortia-Pharmacia, the refuse plant's largest steam customer, has 1,250 employees and sends blood plasma substitutes worldwide. One quarter of the industrial employment is in workshop industries in graphics, food processing, wood, and cement products. Much active research is evolving new products.

SOLID WASTE PRACTICES

Solid Waste Generation

In 1975, the waste-burning plant received 51,355 tonnes (56,490 tons) of household and commercial waste. Since the Fall of 1972, industrial wastes have gone to the new Hovgarden Pulverizing Plant and sanitary landfill. Prior to then, such wastes were sent to several old landfills. The annual tonnage of such wastes was about 35,000 tonnes (38,500 tons) per year. This is expected to increase at the rate of 3 to 4 percent per year.

Discussions have been had with the cities of Enkoping, 30 km (18 mi) away, and Sigtuna, 20 km (12 mi) about possibly processing their waste at the Uppsala facilities.

Papermills in the vicinity are recycling some waste paper but at present, they have reached their limit in the amount they can use and the excess comes to the Bolanderna plant for burning.

Solid Waste Collection

The city street administration operates approximately 25 collection vehicles of 2 to 3 tonne capacity each which collect 5 days per week, once per week from each residence. Plastic bags are used which are generally deposited by the householder beneath some shelter to minimize moisture pickup. The trucks operate from 6:30 a.m. to 3:00 p.m. although their routes are generally completed by 1:00 p.m. The plant receives about 200 tonnes (220 tons) per day.

The total refuse to the plant of 51,355 tonnes (56,490 tons) in 1975 plus approximately 35,000 tonnes of industrial waste pulverized for the Hovgarden landfill, or a total of 86,355 tonnes (94,990 tons) in 1975. This amcunts to 236 tonnes/day (260 tons/day). For the population of about 150,000, this is 1.5 kg/person/day (3.37 lb/person/day).

Very little industrial waste is received at the Bolanderna plant as normally it goes to the pulverizer at Hovgarden. A bulky waste shear installed in 1970 will be described later.

Figure 12-2 shows the trend of annual waste input to the plant since 1969, when the input was only about 38,000 tonnes (41,800 tons). In 1974, it was 50,878 and in 1975, 51,355 tonnes (56,490 tons). There has been some discussion of bringing in more industrial waste after it is first pulverized at Hovgarden. Also, there have been some discussions toward receiving wastes from possible transfer stations at a number of distant communities as much as 70 km (43 mi) away. If these additional quantities are arranged, it is estimated tht 7-day, 24-hour operation could nearly double the capacity of the present facility.

At present, the maximum radius of collection is 30 km (18 mi), but about 90 percent of it is collected within a radius of 8 km (5 mi).

Solid Waste Disposal

The old landfills in the area are now being phased out and industrial and noncombustible waste goes to the Hovgarden pulverizing plant and landfill. The details of this site are described in an attractive brochure which is included in Appendix A.

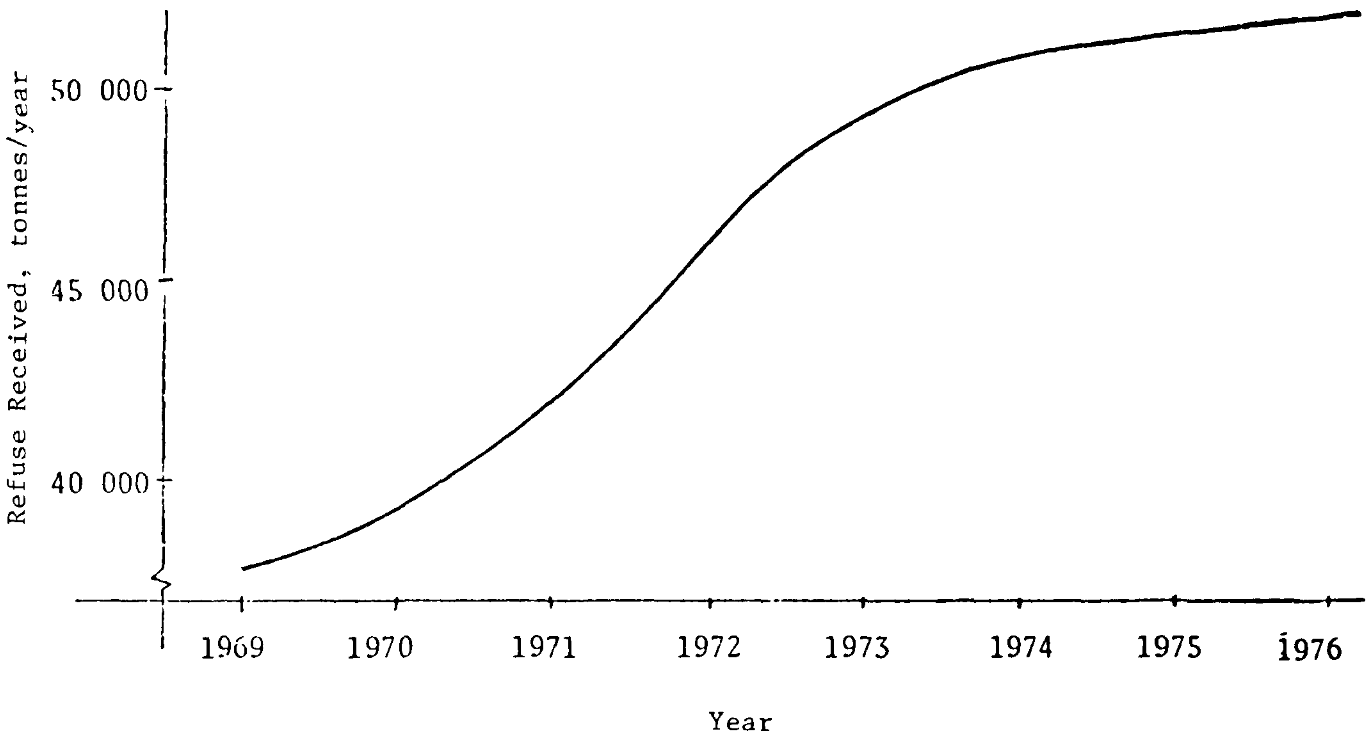

FIGURE 12-2. WEIGHT OF REFUSE RECEIVED ANNUALLY AT THE BOLANDERNA PLANT (COURTESY OF UPPSALA KRAFTVARME AB)

DEVELOPMENT OF THE SYSTEM

The Uppsala waste-to-energy plant is a part of a much larger environmental improvement and energy conservation program that was started by the City Council in 1960. In that year, it was decided to construct a plant for the production and distribution of district heat. The plans included also a thermal power station, an installation for the production of electrical and thermal energy, and a waste-to-energy plant.

The first delivery of heat was in August, 1961, from a portable oil-fired boiler, and the first permanent hot water generator at the Kvarngarde Plant began operating in September, 1962. Since then, expansion has materialized into a larger oil-fired hot water station in the Bolanderna Plant (built in three stages in 1965, 1968, and 1971) and into a peak load plant in Husbyborg (1975). Certain areas are still taken care of by portable oil-fired boilers until the expansion of the main network to these areas can be economically justified.

In the waste incineration plant, which began operating at Bolanderna in 1961, the steam produced is used to heat water for district heating. The initial installation of two furnaces rated at 3 tonnes/hr and supplying hot gas to two waste heat boilers was built in 1960 by Kochum-Landsverk and began operation in 1961. A third similar but larger (3.5 tonne/hr) was added in 1965. A fourth furnace system, burning 5 tonnes/hr and feeding a third boiler, began operation in 1970. This newer installation built by Bruun and Sorensen is the principal subject of this report.

Two smaller incinerators burn separately biological wastes and contaminated dextrose solution from the Fortia-Pharmacia plant. The hot waste gases from the latter are mixed with those from the larger furnaces ahead of the waste heat boilers. The useful thermal energy recovered from all wastes, about 34 Gwhr* (thermal) (122,471 GJ) in 1975, is only a small part, 2.5 percent, of the total energy produced by the entire system, 1,373 Gwhr, but its recovery results in a much more acceptable solution to the solid waste problem than the old landfills. Also, in the summer, a major fraction of the hot-water needs of the community are met with energy derived from the solid wastes.

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* Gigawatt-hours equals 1 billion watt-hours.

An added part of the environmental improvement program in 1971 was the Hovgarden pulverizing plant and fully controlled landfill which could well serve as a model for future residue-disposal designs (see Appendix A).

In the 1950's, at the site of the new pulverizing plant, there was a compost plant. However, a market was not developed for the compost. Hence, the decision was made in 1960 to burn the household wastes and later, in 1970, to build the pulverizing plant for industrial wastes.

The waste-to-energy plant was designed by the engineering staff of the Uppsala Thermal Power Company (Uppsala Kraftvarme AB). This is unusual for Sweden where normally the city engages a consulting engineering firm to design, purchase, and supervise construction.

PLANT ARCHITECTURE

The Bolanderna incineration system is incorporated in the large district heating plant at that site. Figure 12-3 shows the main brick structure which is dominated by the unusual 100 m (328 ft) chimney comprised of 10 separate flues serving the heating boilers, the four main incinerators, and two small specialized waste incinerators without heat direct recovery.

Figure 12-4 shows the plan of the Bolanderna facility. At the lower part of the plan, Items 6, 7, and 8, are the incinerators. The chimney, Item 5, is adjacent to the main power plant, Item 2; hence, elevated duct work, not shown, conducts the incinerator exhaust gases to the chimney, a distance of 160 m (100 ft).

The approach to the facility is dominated visually by the four huge oil-storage tanks in a line parallel to the main highway. These tanks reflect a system policy which is to maintain enough oil for a year's heating operation. The daily expense of financing and operating this large storage enters into the total operating cost of the district heating system.

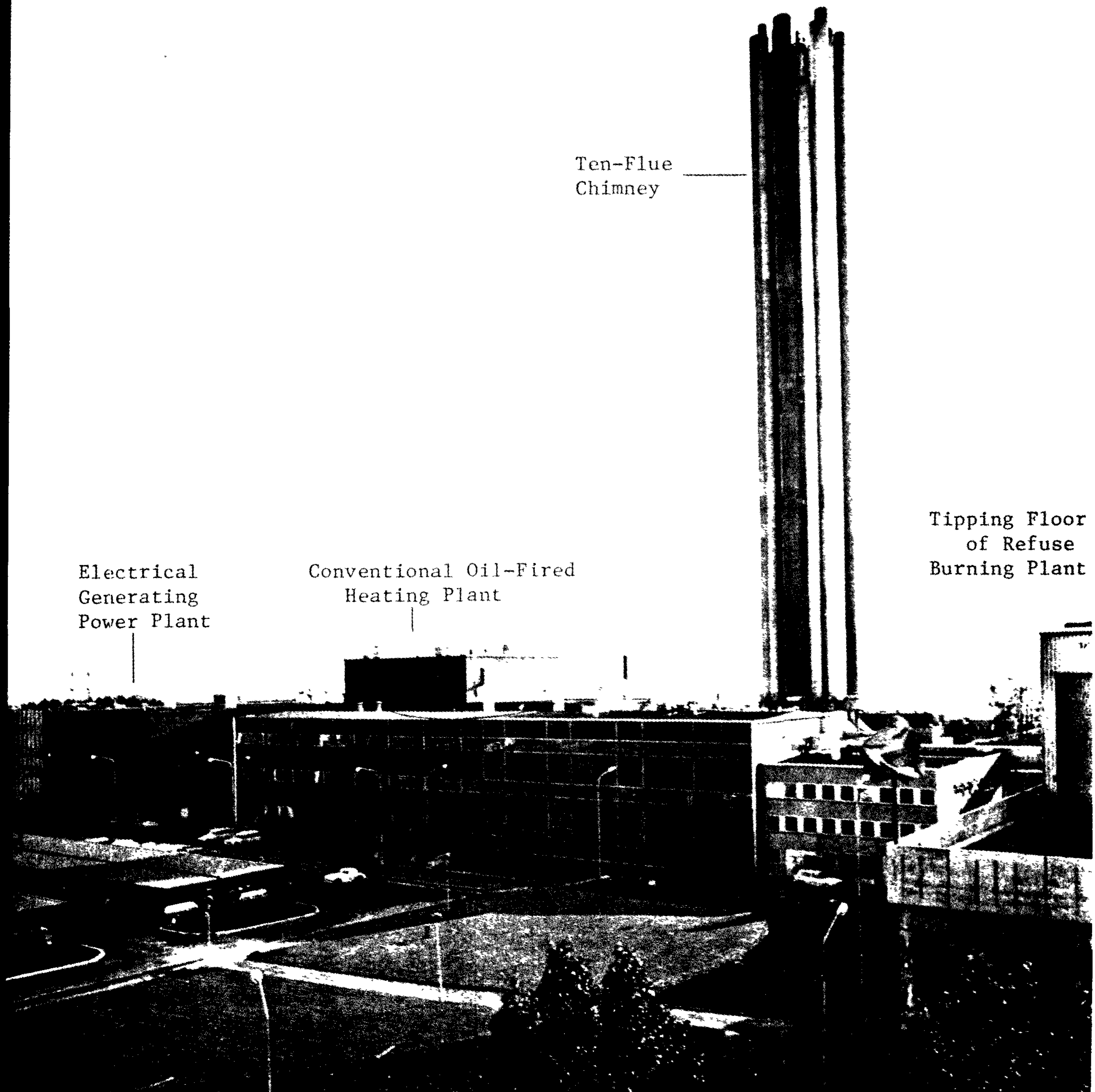


FIGURE 12-3. DISTRICT HEATING AND INCINERATION PLANT AT BOLANDERNA
(COURTESY UPPSALA KRAFTVARME AB)

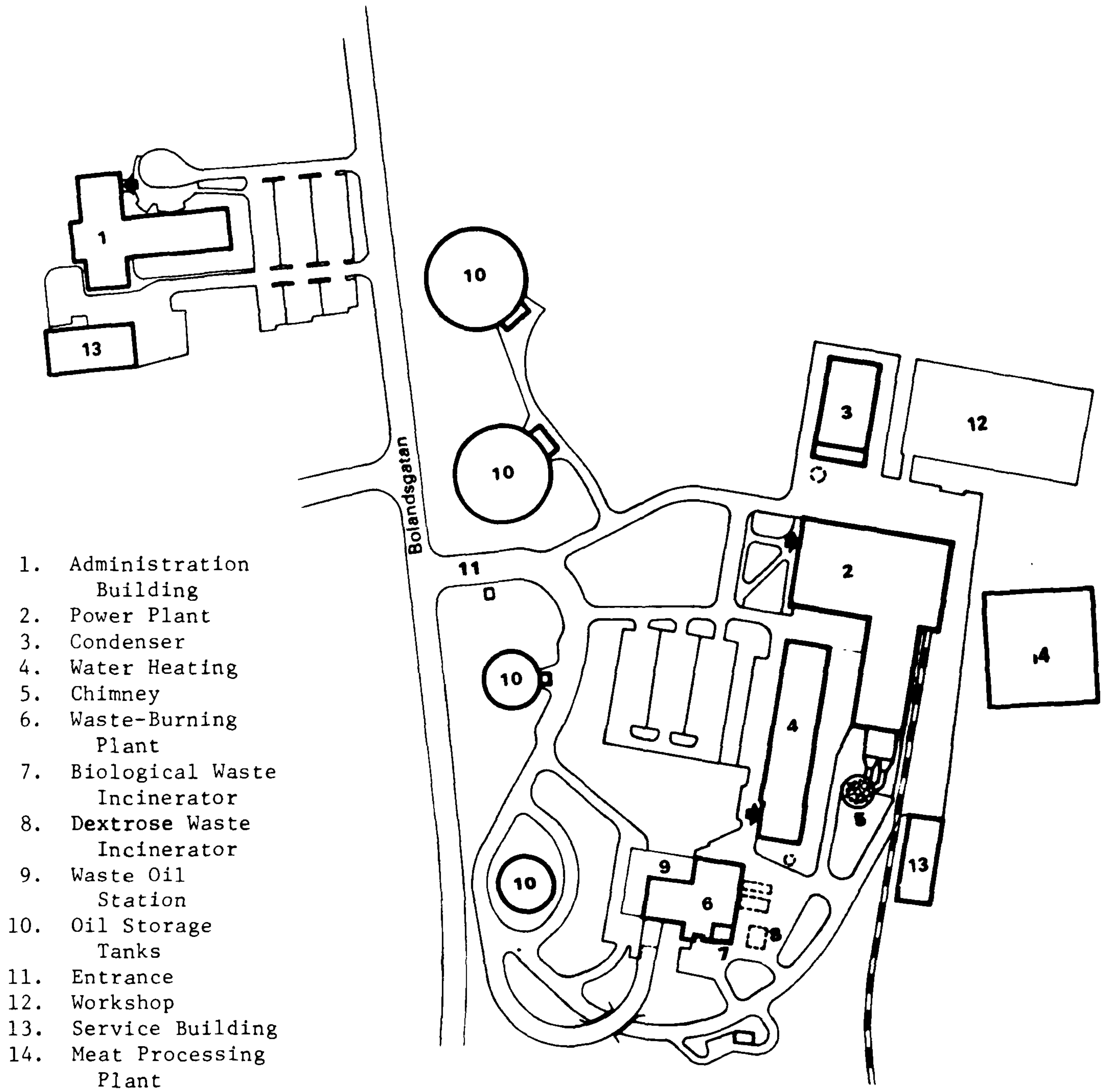


FIGURE 12-4. PLAN OF BOLANDERNA FACILITY FOR DISTRICT HEATING AND SOLID WASTE BURNING (Courtesy Uppsala Kraftvarme AB)

REFUSE-FIRED STEAM GENERATOR

Refuse delivered to the plant is weighed as the trucks arrive, their weight and tare being recorded by means of plastic identification cards issued to the drivers. The scale is sensitive to 20 kg (44 lb). A few trucks are weighed through manual operation of the scale. Some difficulty with the weigh system was encountered at first because of the weather effects on the recording system. The system was made by Stathmos-Lindell.

The new tipping floor is elevated about 10 m (33 ft) above ground level. Figure 12-5 shows the gently sloped helical ramp, installed in 1971, outside the structure. The original tipping floor was near ground level but was elevated to enable a larger bunker for greater storage capacity.

Figure 12-6 shows the plant arrangement. The cranes and bunker serve all four furnaces but only No. 4, the newest, the Bruun and Sorensen furnace system, is shown in this figure.

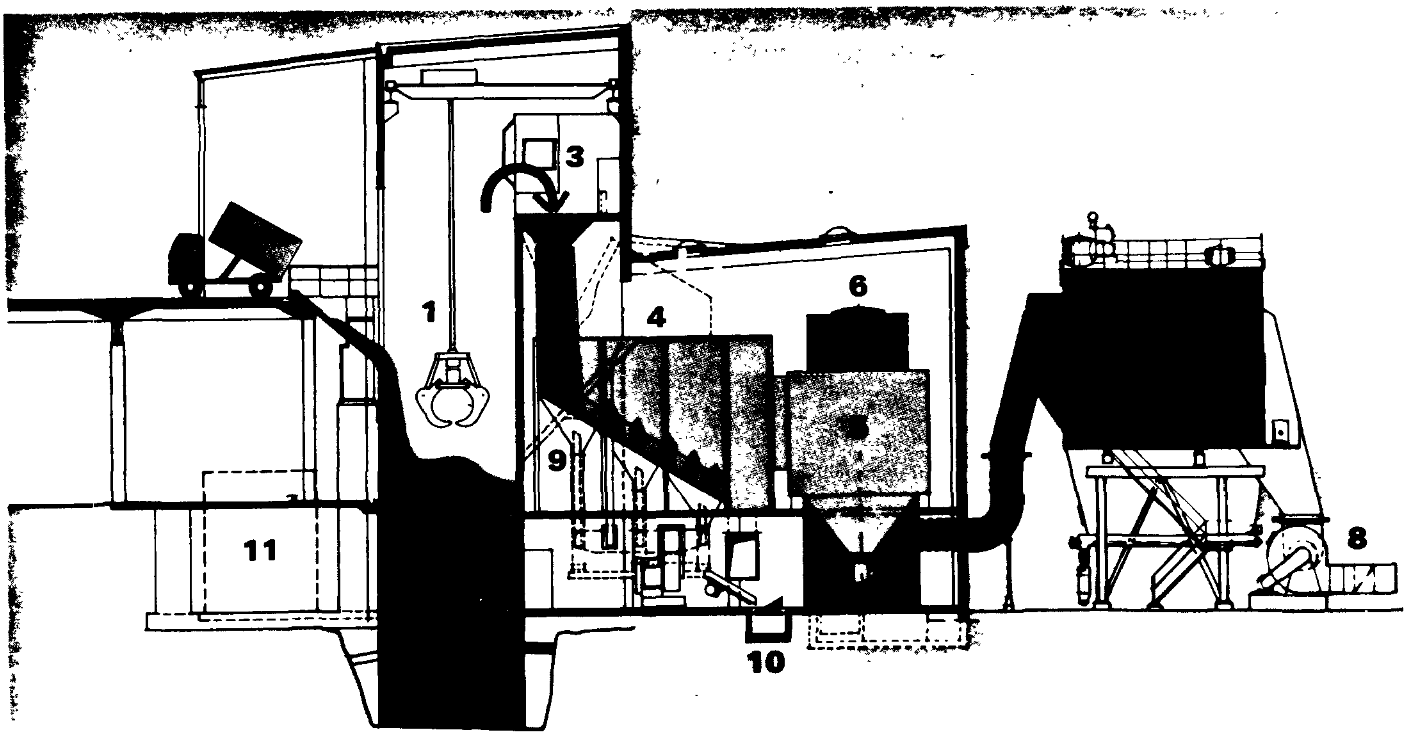
Refuse Storage and Retrieval

The maximum refuse storage volume of the bunker is $2400 m^3$ ($3140 yd^3$). At a density of $150 kg/m^3$ ($252 lb/ft^3$), this represents a storage of 360 tonnes (396 tons), which is about one day supply if all four furnaces operated at full rated capacity which is about 360 tonnes/day (400 tons/day).

Figure 12-7 shows a scissors type of hydraulically driven shear which is provided adjacent to hopper No. 4 for reduction of bulky refuse. It is fed by the crane operator who also operates the shear by remote control. As will be discussed later, the system fed by the fourth hopper tends to receive more of the highly combustible refuse. The shear will accept pieces up to 4 m (13 ft) across and reduces them to about 0.3 m (1 ft) pieces.

When the fourth boiler furnace system was added in 1971, a second crane was added and a new crane control room was positioned near the shear and between hoppers No. 3 and No. 4, shown earlier in Figure

FIGURE 12-5. TRUCK ENTRANCE RAMP TO UPPSALA. THIS WAS ADDED IN 1971 TO ENABLE OPERATION WITH A MUCH DEEPER BUNKER WHICH MORE THAN DOUBLED REFUSE STORAGE CAPACITY (BATTELLE PHOTOGRAPH)



1. Crane and Bucket
2. Refuse Bunker
3. Crane Operator's Station
4. Furnace
5. Afterburner Chamber
6. Steam Boiler
7. Electrostatic Precipitator
8. Induced Draft Fan
9. Primary Air Zones
10. Residue Conveyor
11. Waste Oil Tank

FIGURE 12-6. ARRANGEMENT OF UPPSALA PLANT
(COURTESY BRUUN AND SORENSEN)

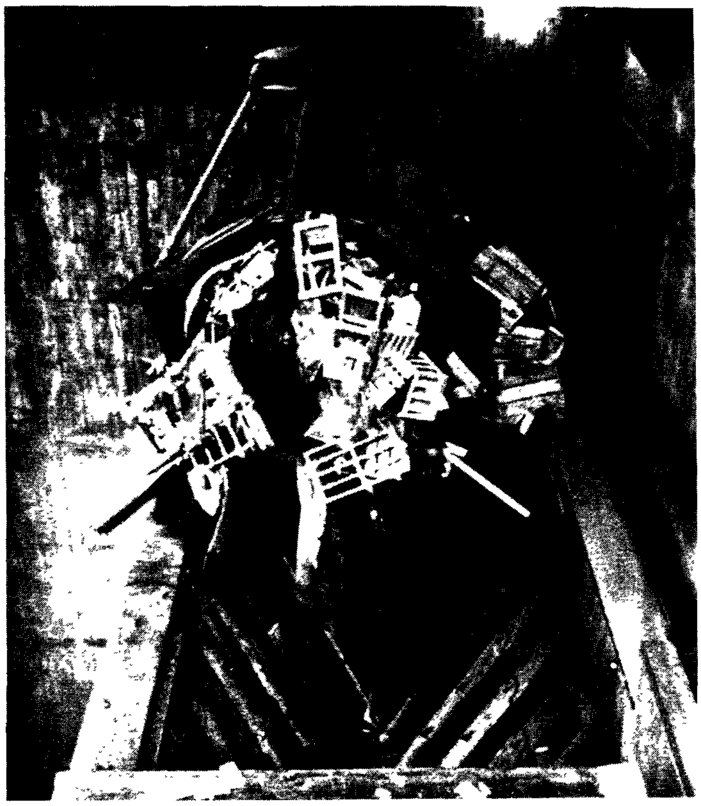


FIGURE 12-7. SCISSORS-TYPE HYDRAULICALLY DRIVEN SHEAR ADJACENT TO HOPPER 4 (COURTESY OF BRUUN AND SORENSEN)

12-5, above the hopper. The crane bucket is positioned semi-automatically above any hopper selected by the crane operation.

Figure 12-8 shows safety railings at the tipping chute. A portion of the bulky waste shear is in the background.

Figure 12-9 shows the component arrangement of the Uppsala plant. The original three furnaces installed in 1960 are manifolded to feed hot gas to either of two steam boilers. The fourth furnace, installed in 1970, serves a third, larger boiler. The nominal capacities of the components are as follows:

	tonnes/hr	tons/hr	tons/day
Furnace 1	3.0	3.3	72
Furnace 2	3.0	3.3	84
Furnace 3	3.5	3.9	84
Furnace 4	5.0	5.5	108
TOTAL REFUSE CAPACITY	14.5	16.0	348
Boiler 1	10.0	11.0	--
Boiler 2	15.0	16.5	--
Boiler 3	15.0	16.5	--
TOTAL STEAM CAPACITY	40.0	44.0	88,000 lb/hr

However, these total capacities are only ratings as the plant was not intended to and never operates all components at full capacity. Usually some components are down for service. The actual average plant burning rate for 1976, 51,000 t/d was the equivalent of an average rate of about 200 tons/day based on a 5-day week. This is about 52 percent of rated capacity.

Figure 12-10 shows a partial elevation of the new portion of the plant added in 1971.

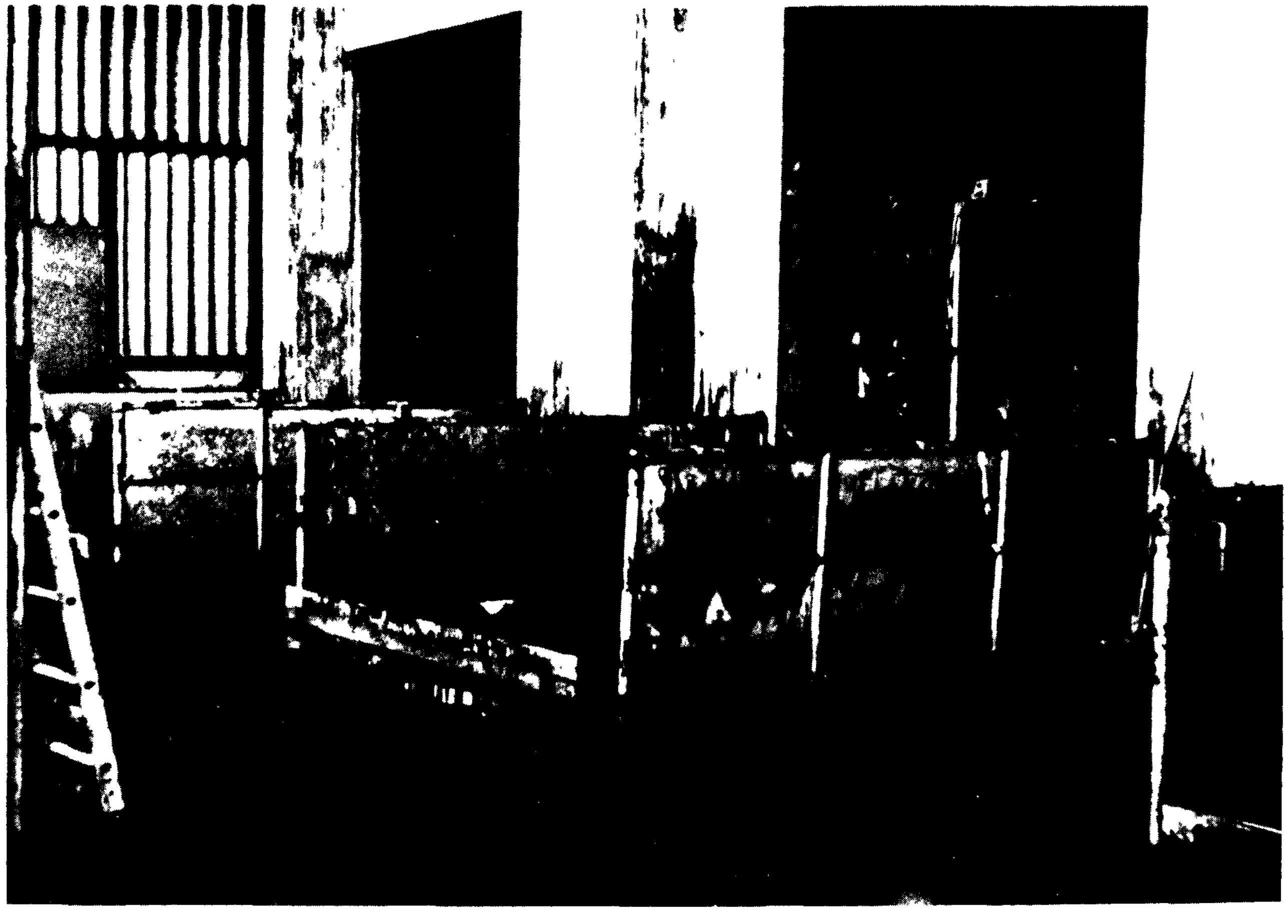


FIGURE 12-8. SAFETY RAILINGS AROUND TIPPING CHUTES. NOTE BULKY WASTE SHEAR IN BACKGROUND LEFT OF CENTER (Battelle Photograph)

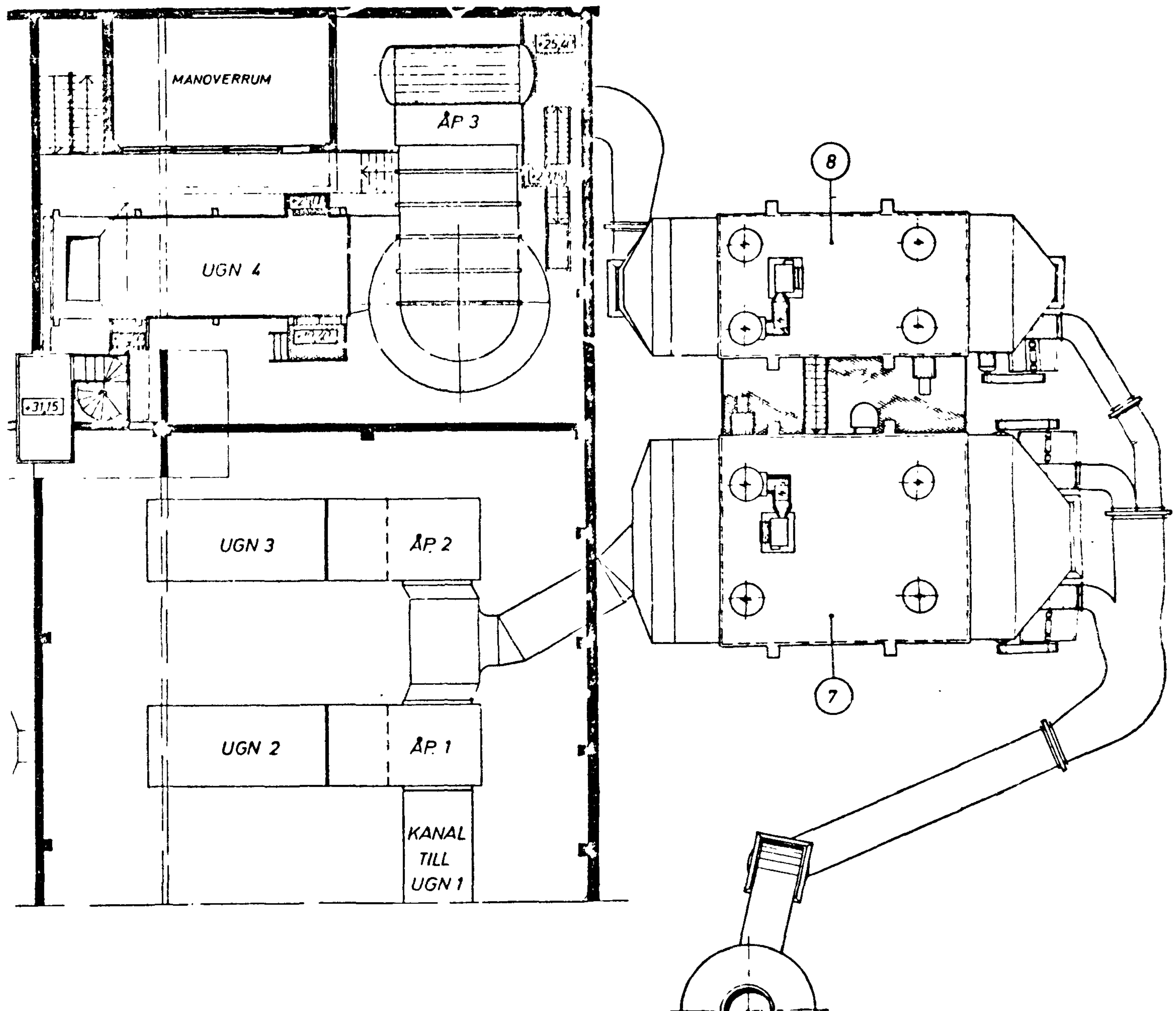


FIGURE 12-9. ARRANGEMENT OF COMPONENTS OF BOLANDERNA INCINERATOR PLANT (COURTESY OF UPPSALA KRAFTVARME AB)

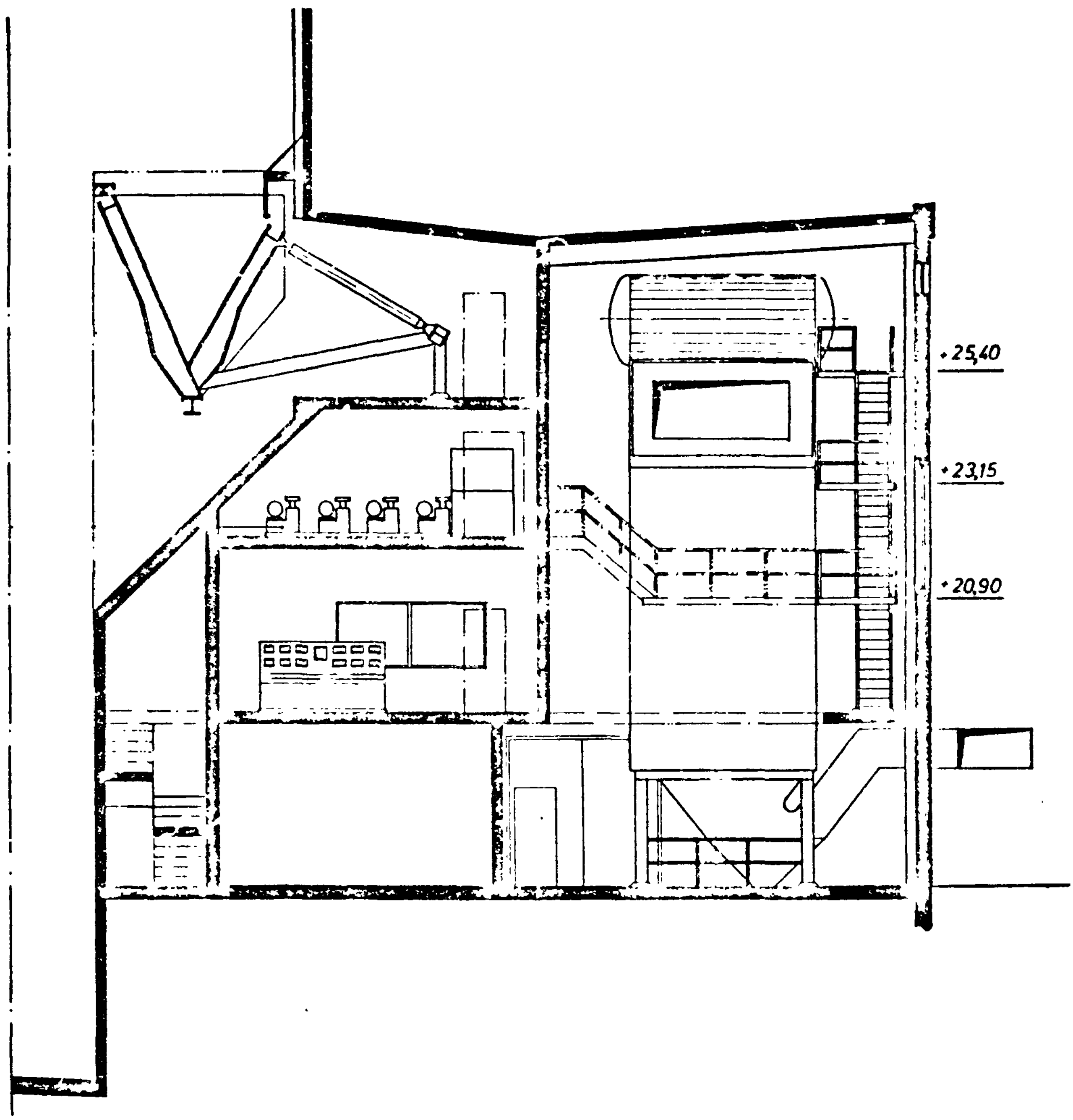


FIGURE 12-10. PARTIAL SECTION OF UPPSALA PLANT SHOWING IN UPPER LEFT THE SCISSORS TYPE SHEAR FOR BULKY REFUSE, THE HYDRAULIC PUMP ROOM, CONTROL ROOM FOR FURNACE NO. 4, AND AFTERFURNACE CHAMBER (COURTESY OF BRUUN & SORENSEN)

Heat Input

No measurements of refuse heat value have been made for the Uppsala plant. The design of the newer unit, No. 4, was based on a value of 2,450 kcal/kg (4,410 Btu/lb) (13,257 kJ/kg). The original three furnaces installed by Kockum-Landsverk in 1960 were based on a heat value of 2,200 kcal/kg (3,960 Btu/lb) (9,211 kJ/kg).

Furnace Hopper

Figure 12-11 shows the Brunn and Sorensen installation. The vertical outwardly tapered steel refuse chute feeds directly onto the sloping grate without assistance by any feed mechanism except the feeding action of the grate itself. For the first three furnaces built by Kockum-Landsverk (now a part of Volund), the feed chutes are not provided with dampers to control burnback. Instead, the height of the gravity-packed refuse in the chute is depended upon as a seal. However, with furnace No. 4 installed in 1970, the confinement of the existing roof structure and the height of the top of the Brunn and Sorensen grate imposed an upper limit on the length of the feed chute. Thus, to control burnback in the chute, a double flap damper was installed. The operators have had no problem with burnback.

Figure 12-12 shows a view into the empty hopper where a thin line of flame is visible between the mating halves of the flap damper.

Burning Grate in Furnace No. 4

This plant does not use a refuse feeder to feed the refuse on to the grate. This grate is a 30-degree sloping sectional grate depicted in Figure 12-13. As shown in the lower three sketches of the figure, the grate sections oscillate rotationally in a coordinated rocking motion such that the burning refuse is induced to cascade downward along the sloping grate in a wave-like motion, thus slowly agitating the fuel bed so as to prevent compaction, voids, and consequent irregularity in air flow. The

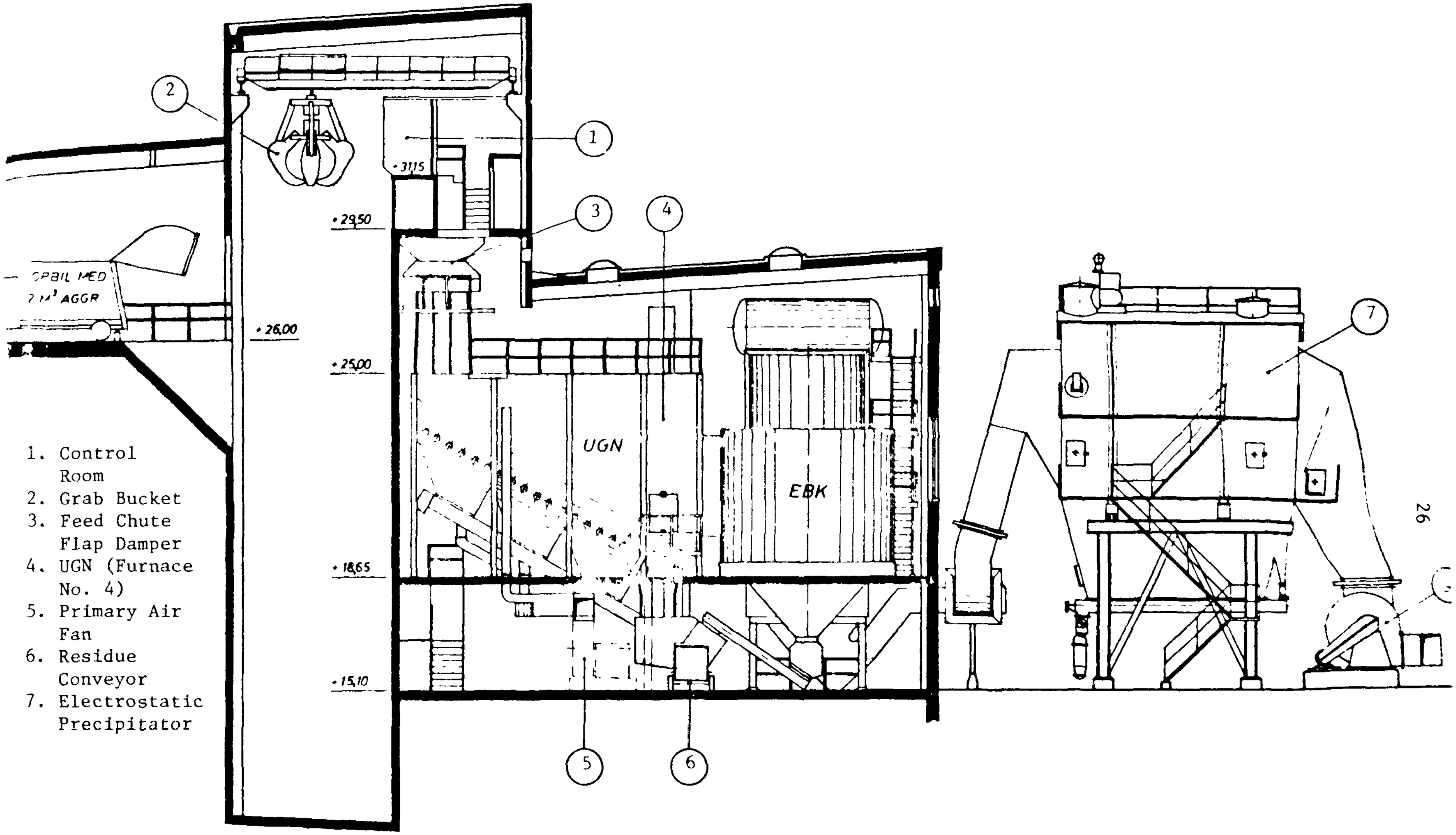


FIGURE 12-11. CROSS SECTION OF FURNACE NO. 4 AND BOILER NO. 3 AT UPPSALA (COURTESY OF BRUUN AND SORENSEN)

FIGURE 12-12. EMPTY FEED HOPPER SHOWING LINE OF FLAME BENEATH DOUBLE FLAP DOORS AT UPPSALA (Battelle Photograph)

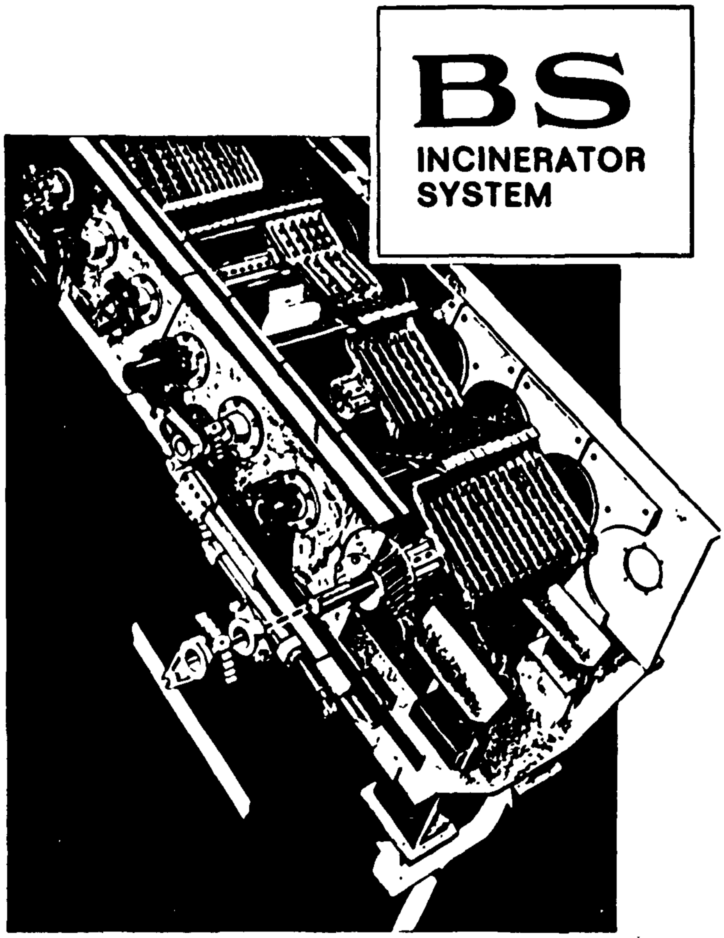


FIGURE 12-13. SKETCHES OF GRATE ACTION (COURTESY OF BRUUN AND SORENSEN)

motion of each grate section is controlled by an adjustable timer.

The moving part of the grate is formed of three sections with six horizontal shafts in each section. The grate bars are fixed to the shafts. Figure 12-14 shows two typical grate bars which are 0.5 m (1.6 ft) long. The lower bar in the figure is 50 mm (2 in) wide. The upper one is a new design of bar which is 100 mm (4 in) wide. Recent experience at Horsens, Denmark with a test section of the newer bar revealed that fine ash is less likely to adhere in the interstices between the bars; hence, less cleaning is required to maintain the gaps free for uniform air flow. New bars have been installed in all of the first grate section, and it is planned to change also the other two grate sections. The new and old bars are cast by a Swedish affiliate of Bruun and Sorensen using an alloy of 23 percent chromium, 1.5 percent silicon. 0.2 percent nickel, and 0.25 percent molybdenum. They are guaranteed for 10,000 hours.

The grate is 2 m (6.5 ft) wide and 8.1 m (26.6 ft) long with a total area of 16.2 m^2 (174.3 ft^2). At the rated capacity of 5 tonnes/hr (5.5 tons/hr), this provides a burning rate of 308.6 $kg/m^2/hr$ (63.1 $lb/ft^2/hr$), a typical burning rate in many plants. However, this is only an average, and since the plant does not operate at high rate at night, peak burning rates probably are much higher.

The burned residue falls from the end of the grate into a sprayed quench chute which drops it then onto a series of vibrating conveyors shown in Figure 12-15.

No details were obtained on the grates in the three older furnaces except that it was pointed out that the steel support members between the grate steps are water cooled. This uses about 10,000 m^3/yr of city water (3,002,600 gal/yr). Some of this water is then used for spray quenching the grate residue.

The primary air supply to the first three furnaces is not zoned. In the fourth furnace, there are three separate zones, manually adjustable.

Furnace Wall

As with many small refuse-fired furnaces, these four furnaces are not water cooled. Their completely refractory construction has been

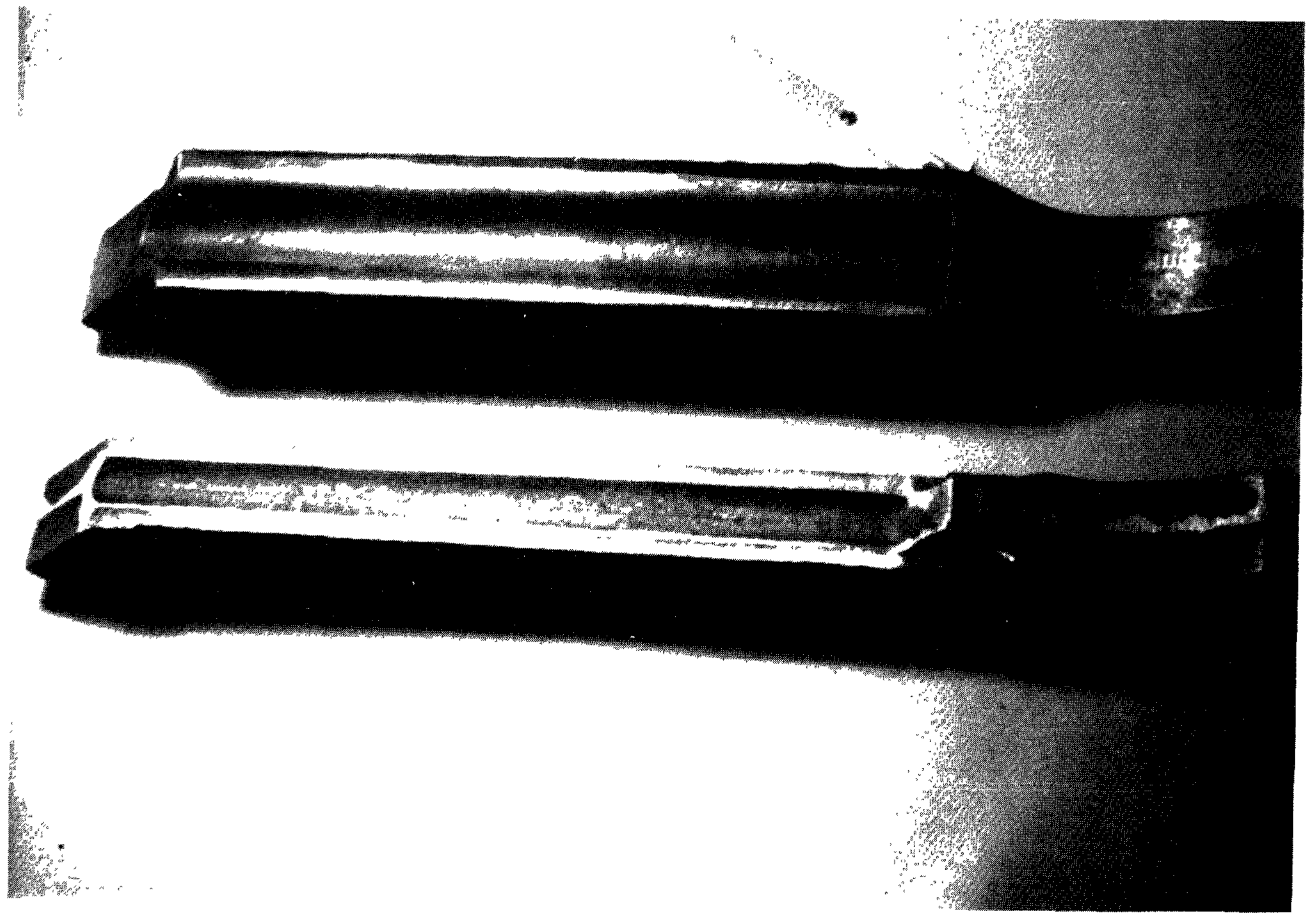


FIGURE 12-14. BRUUN AND SORENSEN CAST ALLOY GRATE BARS. THE OLDER BAR IS SHOWN BELOW. THE NEWER, WIDER BAR IS ABOVE (Battelle Photograph)

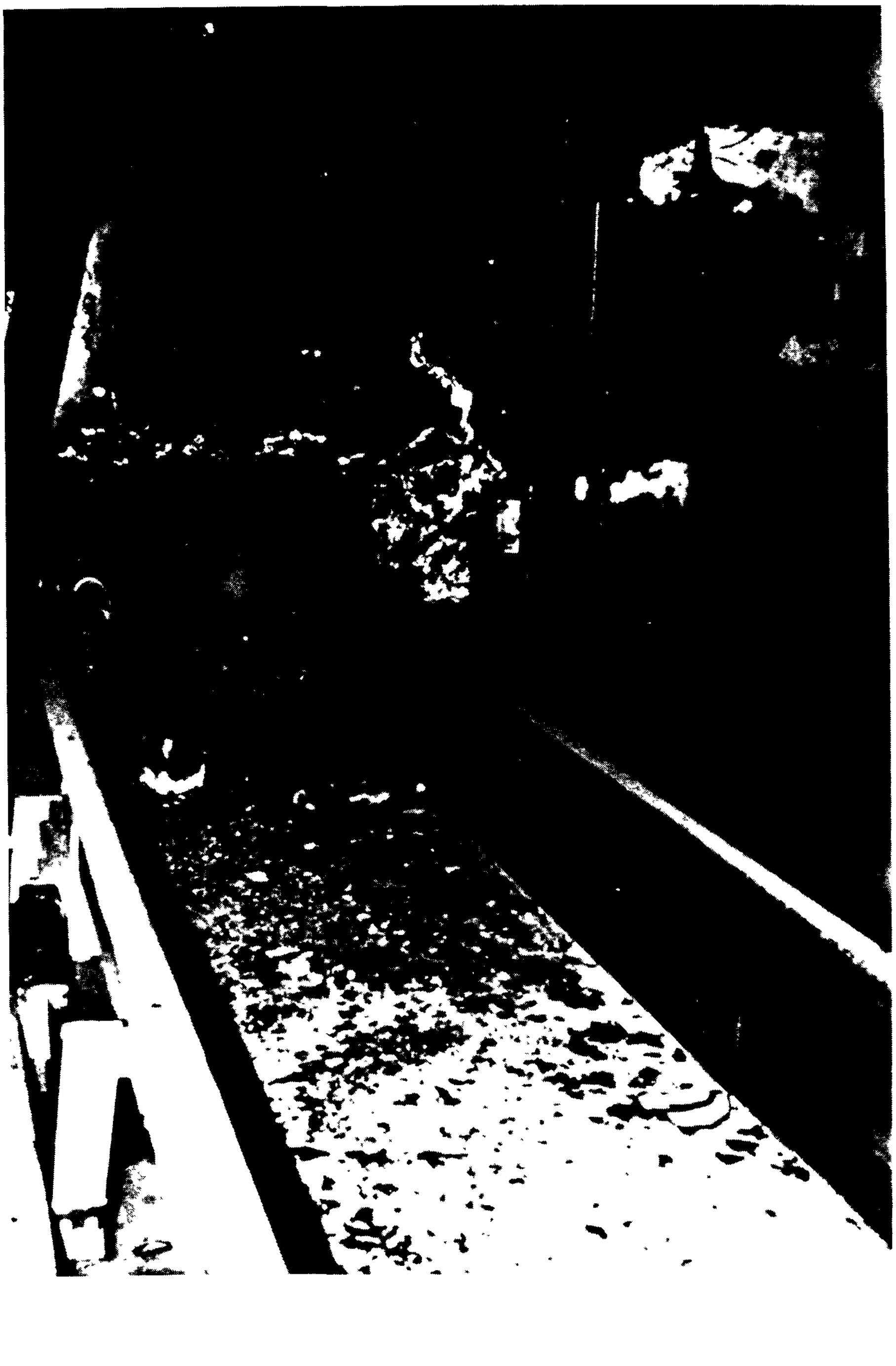


FIGURE 12-15. FURNACE BOTTOM ASH CHUTE DISCHARGING INTO ASH VIBRATING STEEL CONVEYOR AT UPPSALA (Battelle Photograph)

satisfactory except for a major error in installation of too-widely spaced support anchors in Furnace No. 4, which has caused much breakage and some occasional collapse of firebrick but has now been corrected. The revision was partly at the owner's expense in the form of labor and partly at the expense of Bruun and Sorensen for the new refractory and more closely-spaced hangers.

Figure 12-16 shows the interior of the new No. 4 furnace and grate before firing. The width of the furnace is 2 m (6.5 ft) and the grate length, almost all of which is shown, is 8.1 m (16.6 ft). At the far end of the photograph is the offset opening where the hot gases leave the furnace at about 1,000 C (1,832 F) and make a tangential entry beyond into the aftercombustion chamber. The height of the roof arch above the lowest end of the grate is approximately 6 m (19.7 ft). The volume of the furnace is about 50 m^3 (1,765 ft^3). The volume of the refractory-lined aftercombustion chamber is also 50 m^3 (1,765 ft^3). That chamber has an internal diameter of 4.6 m (15 ft) and an external diameter of 5.3 m (17.4 ft). The gases leave the chamber at its top.

In Figure 12-16, immediately above the grate, is a very dark wall area on both sides that consists of cast iron plates cooled only by radiation and convection to the surroundings. These plates are used to resist erosion by the motion of the burning refuse against the wall. The cast iron surface extends upward about 500 mm (20 in) above the grate. For community refuse, it has been Brunn and Sorensen's experience that air cooling or water cooling of these plates are unnecessary. For furnaces burning highly combustible industrial refuse, water cooling of the plates is used.

Immediately above the cast iron wear plates in Figure 12-16 is a narrow band of silicon carbide brick. These also resist erosion, will stand much higher temperature than cast iron, and have the desirable characteristic of resisting the adherence of molten slag.

The remainder of the furnace wall is built of Hoganas firebrick, tradenamed "Krona", which is rated to withstand 1,600 C (2,912 F). Originally, the first three furnaces were lined with "Chamotte" brick which is a naturally occurring clay which becomes a high-grade refractory when fired. However, it is expensive: 14 Skr/brick ($2.80 @ 5 Skr/$). All

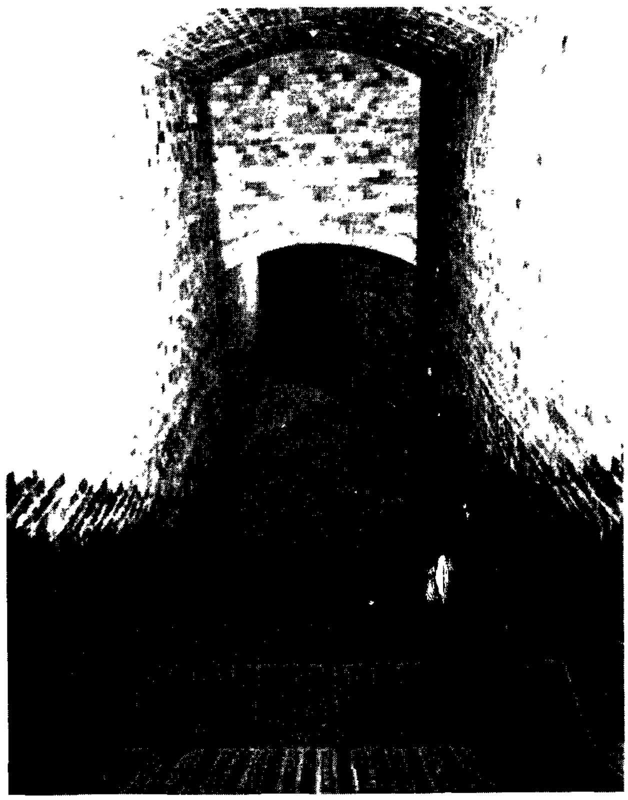


FIGURE 12-16. INTERIOR OF FURNACE NO. 4 BEFORE FIRING (COURTESY OF BRUUN AND SORENSEN)

four furnaces are now built of Krona, which costs about 4 Skr/brick ($0.80). The wall thickness for Furnaces 1 through 3 is 1-1/2 brick. Furnace No. 4 is only one brick thick. This causes a higher rate of heat loss which helps prolong the life of the refractory. Figure 12-17 shows a view upward above the grate in Furnace No. 1. The slag adhering to the wall does not accumulate to much greater thickness and is considered a protection for the refractory.

Figure 12-18 shows a similar thin slag coating on the roof arch in Furnace No. 1.

Similar slag deposits were observed in Furnace No. 4. At some points, the deposit appeared to have been hot enough to flow down the wall but no erosion nor massive slag buildup was evident.

There is no slag accumulation in the aftercombustion chamber following Furnace No. 4.

Heat Release Rate

In Furnace No. 4, the rated input of 5 tonnes/hr (5.5 tons/hr) into 50 m^3 (1,765 ft^3) of furnace volume corresponds to a heat release rate (at 2,450 kcal/kg) (4,410 Btu/lb) of 245,000 kcal/m^3/hr (27,494 Btu/ft^3/hr) (1,025 kJ/m^3/h). This is a relatively high heat release rate but there are three factors that mitigate its intensity: (1) part of the burning and heat release occurs in the aftercombustion chamber, (2) the relatively thin refractory wall helps to cool the furnace although, of course, at a price in terms of energy efficiency, and (3) the furnace is not operated steadily at rating. On the other hand, each time rating is reached for a time and then burning is reduced, the refractory wall is subject to considerable expansion and contraction. However, since the early problem with inadequately spaced wall anchors was corrected, there has been little wall maintenance required. The walls in the older three furnaces are patched every 3 months and during the annual 2-week plant maintenance period.

Figure 12-19 shows the exterior of Furnace No. 2.

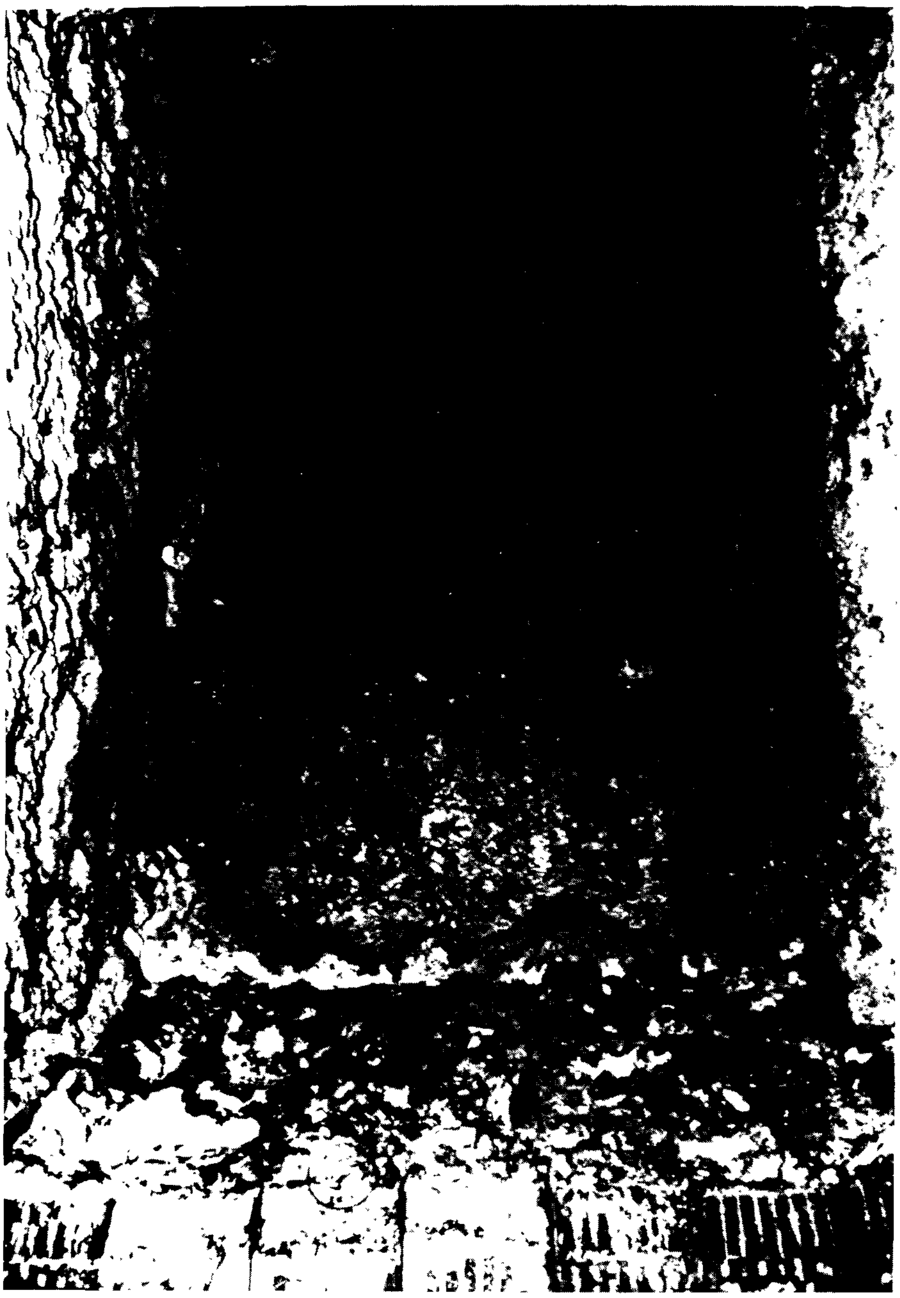


FIGURE 12-17. INSIDE OF OLDER TWO-GRATE FURNACE AT UPPSALA
(Battelle Photograph)

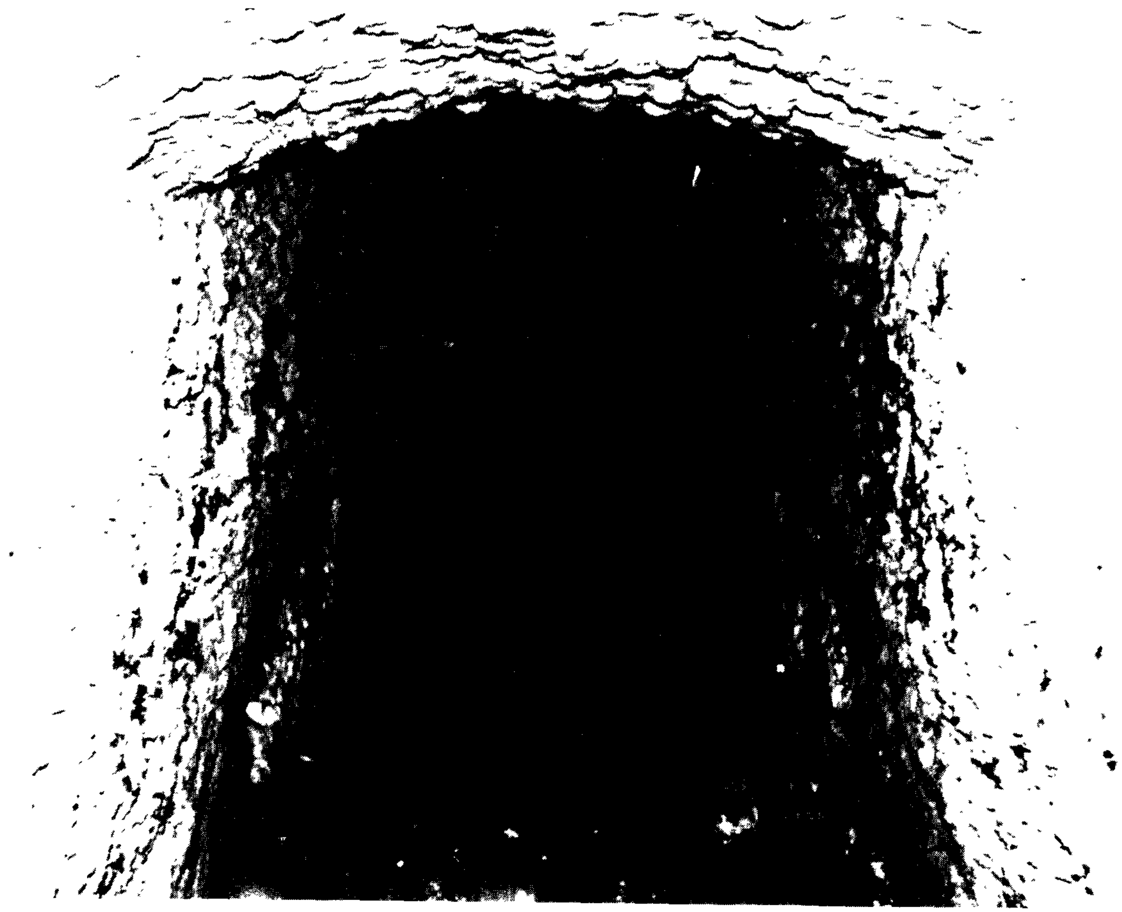


FIGURE 12-18. OLDER FURNACE LOOKING TOWARD THE FEED CHUTE AND DRYING GRATE AT UPPSALA (Battelle Photograph)

FIGURE 12-19. REAR OF FURNACE NO. 2 AT UPPSALA (Battelle Photograph)

Boiler

All three boilers serving the four furnaces are water-tube boilers producing saturated steam at 15 bar (217.6 psia) (1,500 kPa). Saturation temperature is 138 C (389 F). The first two boilers use forced circulation. Boiler No. 3, built by Maskinverken, Kallhall, Sweden, under a license from Combustion Engineering Co. of Windsor, Connecticut, U.S.A., uses natural circulation. The boiler capacities are:

	tonne/hr	lb/hr
No. 1	10	22,000
No. 2	10	22,000
No. 3	15	33,000
TOTAL	40	88,000

As seen earlier in Figure 12-9, the three boilers and four furnaces are cross manifolded so that various combinations can be operated. However, all three boilers and all four furnaces are rarely operated all at the same time.

Boiler No. 3, the newest boiler, is formed of an outer enclosure of wall tubes plus banks of horizontal convection tubes.

All three boilers are cleaned continuously by falling aluminum pellets. Figure 12-20 shows a part of the pellet recirculation system. The pellet storage bin holds 30 kg (66 lb) of pellets. Owing to attrition, about 15 kg (33 lb) of pellets must be added per month. The melting point of the pellets is about 750 C (1,382 F). The maximum gas temperature entering the boiler is about 700 C (1,292 F). Incidentally, with 1,000 C leaving the furnace and 700 C entering the boiler, this 300 C cooling represents a substantial energy loss in passing through the aftercombustion chamber but, at the same time, undoubtedly contributes to the slag-free trouble-free operation of that chamber as a gas mixing, burning, and dust removal device.

About every 3 weeks, it is necessary to clean dust accumulations up to 50 mm (2 in) thick at the entrance to Boiler No. 3. The deposit is

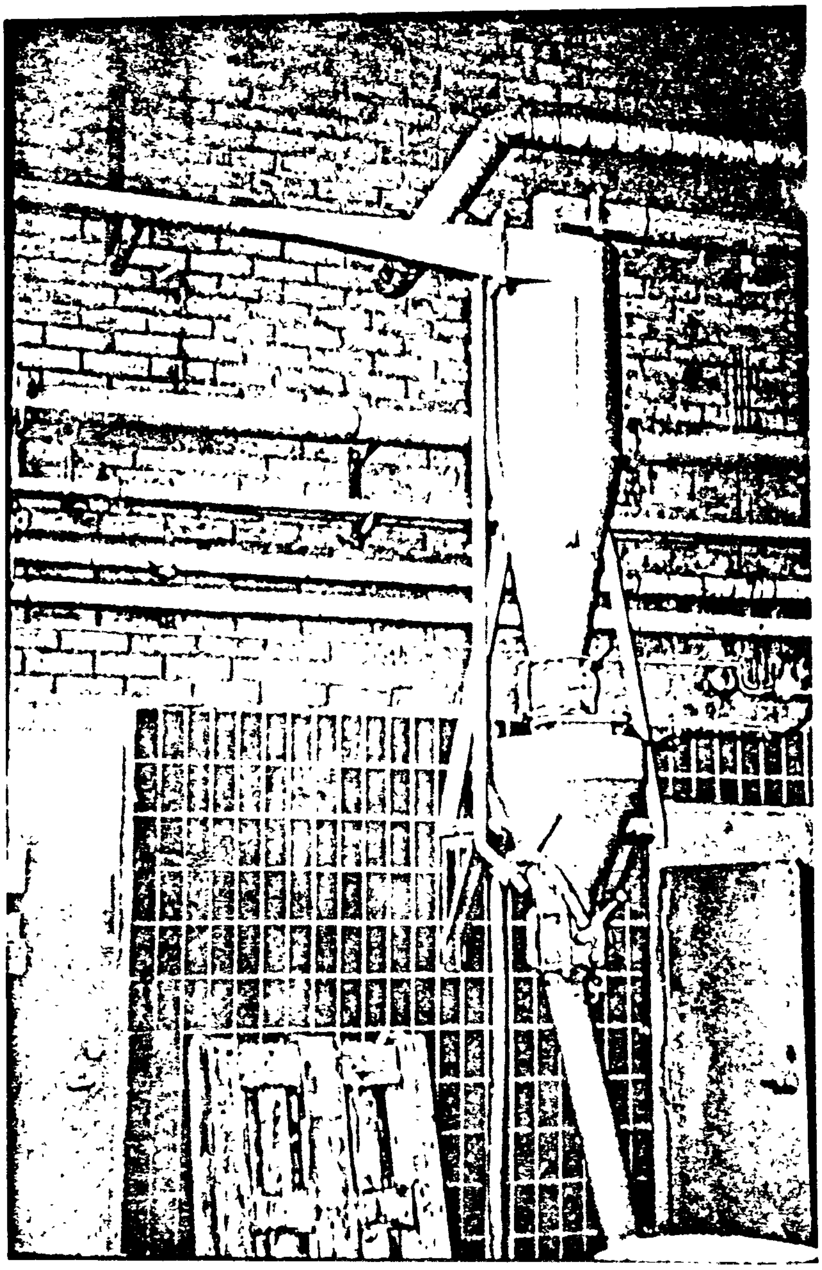


FIGURE 12-20. SHOT PELLET CLEANING FEED SYSTEM AT UPPSALA (Battelle Photograph)

easily brushed away and steam jets will be tried to remove it more easily. No other boiler cleaning is required.

The boiler feedwater is treated and supplied from the main oil-fired boiler plant.

The average steam production rate is 2.44 kg/kg refuse.

Primary Air

For Furnaces No. 1 through 3, there is a single primary air zone. For Furnace No. 4, there are three zones.

Secondary Air

For all furnaces, the secondary air is supplied by the primary air blower. In Furnaces No. 1 through 3, there is only one sidewall secondary air port 250 by 500 mm (10 by 20 in) controlled manually as needed. In Furnace No. 4, the secondary air is automatically regulated bya smoke density meter.

Auxiliary Incinerators

Figure 12-21 shows the two small auxiliary incinerators at the plant. The oil-fired pathological waste unit receives bags of waste fed semi-automatically from a carrousel shown on top of the chamber. The incinerator for contaminated liquid dextrose is an oil-fired horizontal, refractory chamber. The exhaust gases from the dextrose unit are passed through Boiler No. 3 for heat recovery.

Figure 12-22 shows, in the foreground, the building which houses the dextrose incinerator. The horizontal, round duct above the building conveys that incinerator's exhaust gases to Boiler No. 3 for heat recovery.

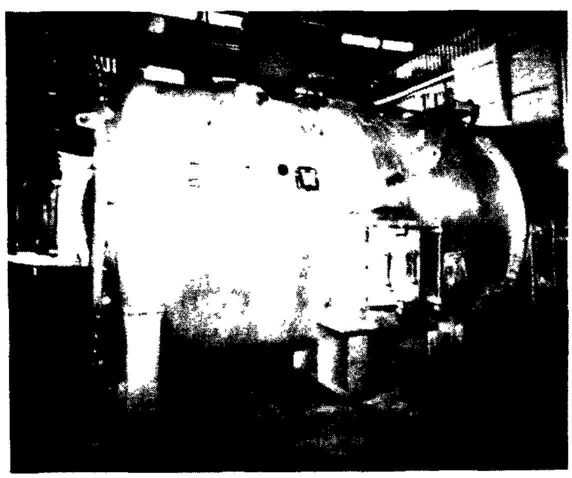


FIGURE 12-21. AUXILIARY WASTE INCINERATORS AT UPPSALA. THE TOP PHOTOGRAPH SHOWS A PATHOLOGICAL WASTE INCINERATOR WHICH RECEIVES BAGS OF WASTE FROM A CAROUSEL ON TOP OF THE CHAMBER. THE LOWER PHOTOGRAPH SHOWS THE HORIZONTAL OIL-FIRED INCINERATOR FOR CONTAMINATED DEXTROSE (COURTESY UPPSALA KRAFTVARME AB)

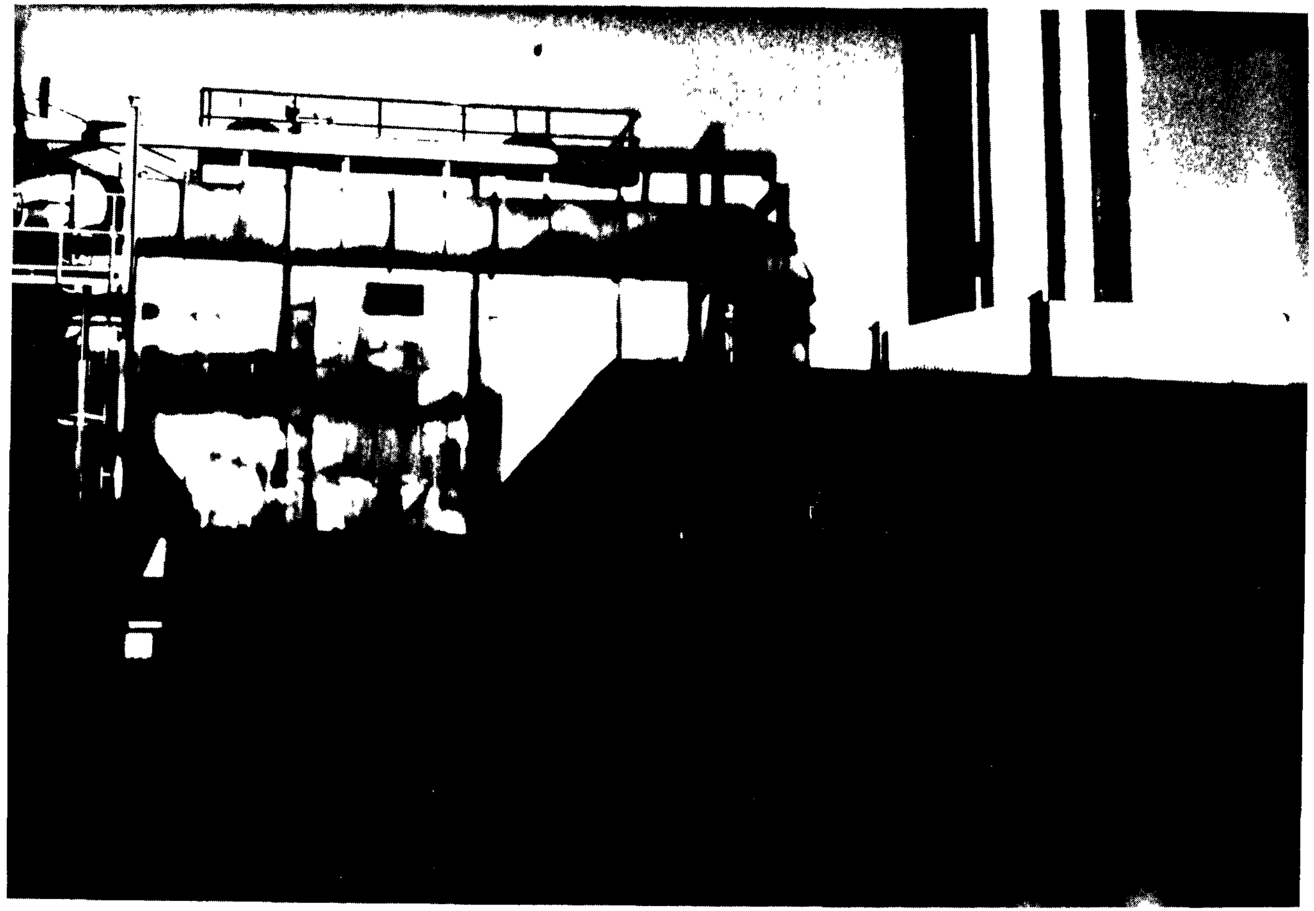


FIGURE 12-22. AUXILIARY INCINERATOR BUILDING IN FOREGROUND SHOWING ROUND HORIZONTAL DUCT WHICH CONVEYS THE EXHAUST GASES TO BOILER NO 3 FOR HEAT RECOVERY (Battelle Photograph)

ENERGY UTILIZATION

About half of the energy from refuse is used as hot water in district heating. The other half goes as 15 bar (217 psia) saturated steam to 10 industrial customers. The largest of these is the Fortia-Pharmacia Plant which has 1,250 employees and uses about 30 tonnes (66,000 lb/hr) of steam/hour. The district hot water system receives water at 120 C (248 F) and returns it at 70 C (158 F). Some of the return water serves as condensor cooling water for the turbo-electric generators in the adjacent oil-fired power plant.

Other steam customers are a meat packing factory, two bakeries, and a laundry. About 75 percent of the residences in the dense part of Uppsala are connected to the district heating system. It is hoped to increase this to 95 percent by 1980. In 1975, the length of distribution system was 160 km (100 mi).

Figure 12-23 shows the central panel in the oil-fired district heating plant at the Bolander plant.

Figure 12-24 shows the control panel for the newest incinerator--No. 4.

Figure 12-25 shows the installation of heated water tubing for snow melting at Uppsala.

FIGURE 12-23. CONTROL PANEL IN THE OIL-FIRED DISTRICT HEATING PLANT AT BOLANDERNA, UPPSALA (Battelle Photograph)

FIGURE 12-24. CONTROL PANEL FOR BOLANDERNA FURNACE NO. 4, UPPSALA
(Battelle Photograph)

FIGURE 12-25. INSTALLATION IN UPPSALA OF ROADWAY TUBING SYSTEM FOR SNOW MELTING (COURTESY UPPSALA KRAFTVARME AB)

POLLUTION CONTROL EQUIPMENT

Originally in 1962, this plant had only mechanical dust collectors for air pollution control. Then at the time the fourth furnace was installed in 1970, two electrostatic precipitators were installed serving all furnaces, as seen earlier in Figure 12-7. An unusual feature of Precipitator No. 1 serving Furnaces No. 1 through 3, is that it is followed by a multiple cyclone dust collector because of concern that large flakes of charred paper would escape the precipitator. There are 200 cyclones, each 200 mm (7.9 in) in diameter. However, similar cyclones were not included in Precipitator No. 2 because the aftercombustion chamber following No. 4 furnace usually breaks and burns any such large flakes before they reach the precipitator.

Table 12-1 shows the results of performance tests on No. 2 precipitator in 1972. The resulting particle emission rate of 15 to 38 mg/Nm^3 (0.0066 to 0.017 grains/scf) is well within the Swedish (Statens Naturvardsverk) standard of 85 mg/Nm^3.

The second precipitator has required almost no maintenance. Only one electrode has needed replacement in 5 years. There is some wet corrosion of the steel expansion joints in the long duct leading outdoors from the precipitators to the chimney. These joints have, therefeore, been replaced by heavy-coated nylon fabric. However, in the precipitator serving the first three boilers, 100 electrodes have been replaced since 1971 due to corrosion.

The dust hoppers are heated and when the system is not operating, a fan circulates air in the hoppers to prevent moisture buildup.

Figure 12-26 shows the exterior of Precipitator No. 1. Figure 12-27 shows the ducts leading the exhaust gases to the chimney.

Residue Disposal

Figure 12-28 shows the discharge end of the vibrating conveyor. Figure 12-29 shows the precipitators and long horizontal ducts leading to the base of the chimney. Figure 12-30 shows the detachable residue hoppers on rollers for collection of the residue for truck disposal.

TABLE 12-1. PERFORMANCE TEST DATA ON PRECIPITATOR NO. 2 SERVING FURNACE NO. 4 (COURTESY OF UPPSALA KRAFTVARME AB)

	Test 1	Test 2	Test 3
Date (1972)			
Time of Day	8:08 a.m.- 9:41 a.m.	11:00 a.m.- 1:46 p.m.	2:51 p.m.- 4:30 p.m.
Waste Burning Rate, kg/h	4,560	4,560	4,560
Steaming Rate, kg/h	11,500	15,100	14,900
Gas Flow Rate, Nm^3/sec	8.13	8.13	8.13
Gas Flow Rate, Nm^3/hr	29,300	29,300	29,300
Gas Flow Velocity, m/sec	0.71	0.71	0.71
Gas Temperature in Precip., C	205	208	208
Gas Temperature before Precip., C	210	216	218
Moisture, Volume Percent	--	13	11
Humidity, Percent	--	0.7	0.6
Dew Point, C	--	51	48
CO_2 Leaving Boiler, Percent	7.5	9.9-10.1	9.3-9.4
CO_2 Entering Precipitator, Percent	8.0	9.7	8.0
Draft After Boiler, mm Water	58	70	69
Damper Position, Percent	35	36	34
Precipitator Voltage, kv	31.7	33.5	32.5
Plate Current, mA/m^2	0.33	0.33	0.33
Primary Current, A	55.7	55.7	55.8
Dust Loading			
Wet Gas, Entering, mg/Nm^3	0.694	0.815	0.687
Wet Gas, Leaving, mg/Nm^3	0.013	0.017	0.034
Dry Gas, Entering, mg/Nm^3	0.789	0.937	0.772
Dry Gas, Leaving, mg/Nm^3	0.015	0.020	0.038
Collection Efficiency, Percent	98.13	97.91	95.06
Dust Collection Rate, kg/h	22.9	22.9	22.9

FIGURE 12-26. ELECTROSTATIC PRECIPITATORS RETROFITTED FOR UNITS #1 AND #2 OUTSIDE AT UPPSALA (Battelle Photograph)

FIGURE 12-27. DUCTS LEADING TO BASE OF TEN FLUE CHIMNEY AT UPPSALA (Battelle Photograph)

FIGURE 12-28. VIBRATING STEEL CONVEYOR DUMPING BOTTOM AND FLY ASH INTO CONTAINER AT UPPSALA (Battelle Photograph)

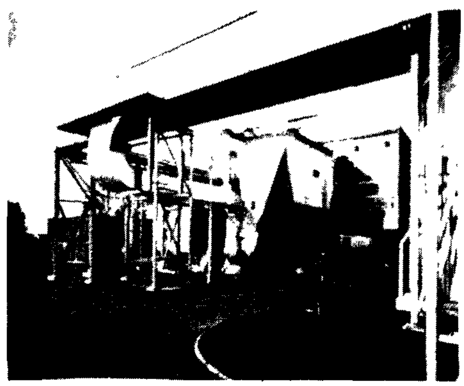


FIGURE 12-29. PRECIPITATORS AT UPPSALA AND LONG HORIZONTAL DUCTS LEADING TO THE BASE OF THE MULTIFLUE CHIMNEY (COURTESY UPPSALA KRAFTVARME AB)

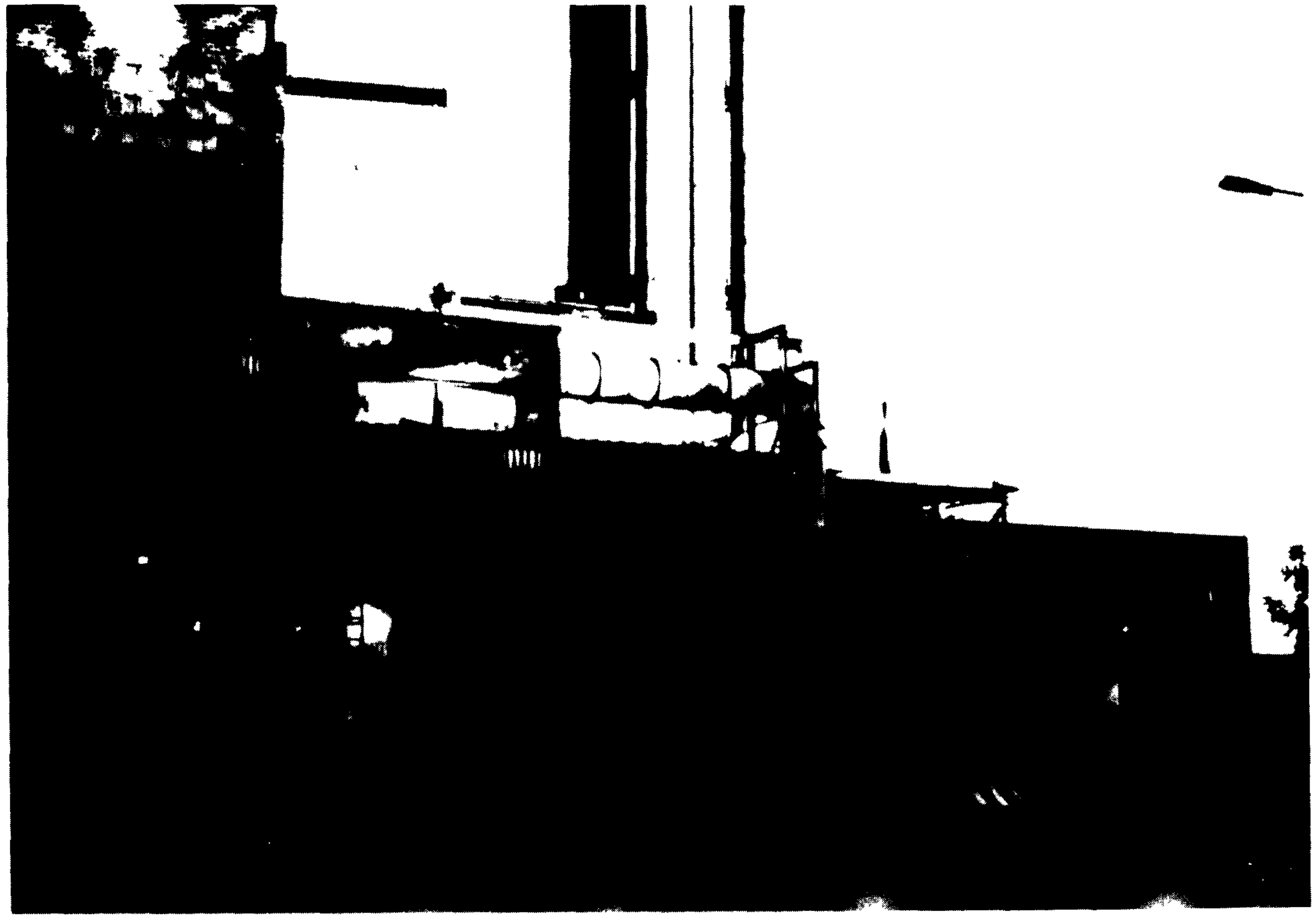


FIGURE 12-30. DETACHABLE ASH HOPPERS ON AUTOMATIC ROLLER SYSTEM AT UPPSALA (Battelle Photograph)

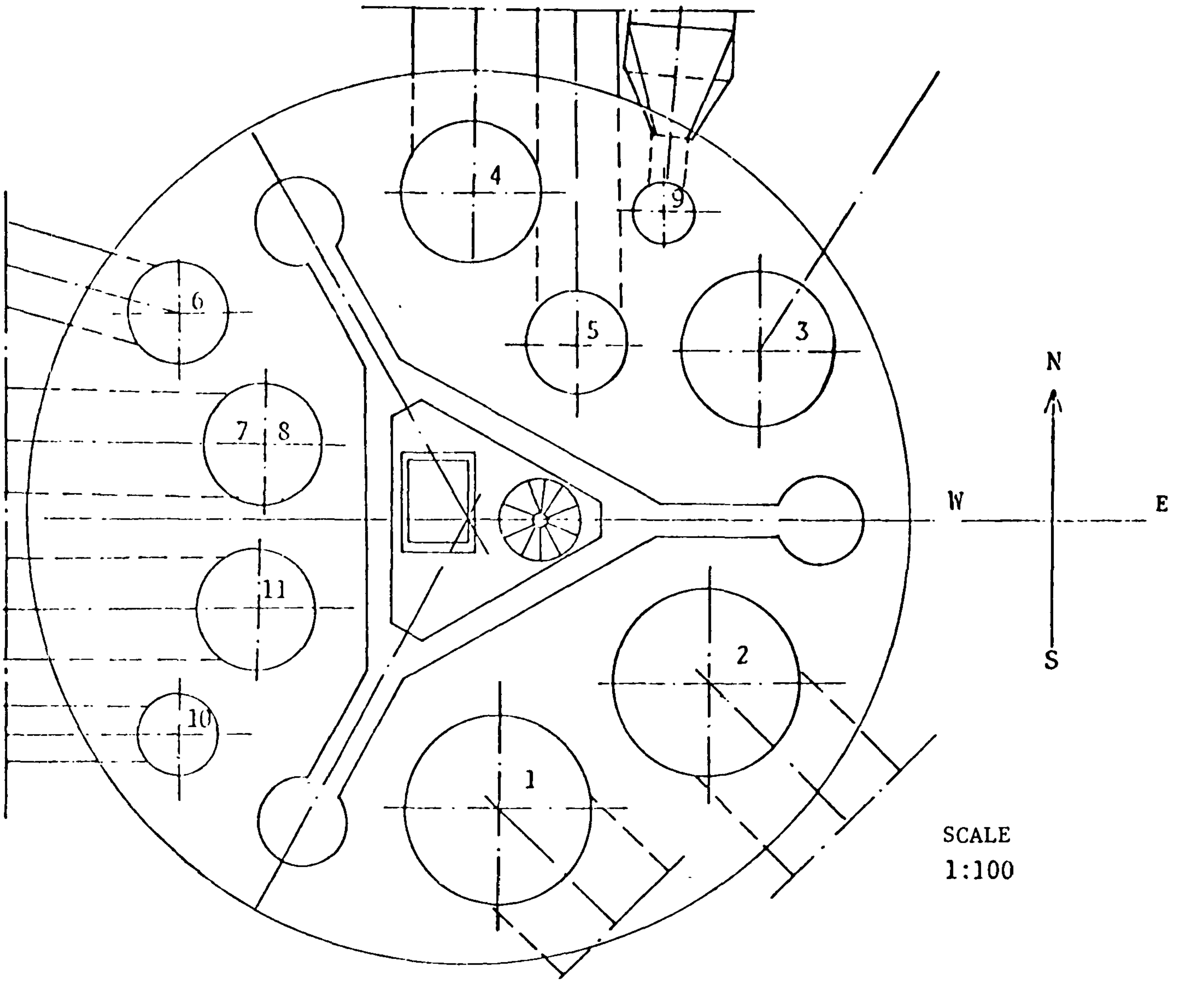
The quenched residue is hauled 4.4 km (7 mi) to the Hovgarden landfill, which is described in Appendix A.

Chimney

Figure 12-2 earlier showed the unusual chimney 100 m (328 ft) tall. It consists of 10 insulated, corten steel tubes supported from a reinforced concrete framework. The flues serve many different boilers and furnaces at the installation.

Figure 12-31 shows the cross-section of the flue arrangement within the chimney. The base of the tubes are fastened to a concrete platform 15 m (49 ft) above the ground. The tube stays connecting them to the support frame utilize sliding joints to allow for thermal expansion. The insulation on the tubes is 200 mm (7.9 in) thick encased in corrugated aluminum.

So far, there has been little maintenance required. A crane at the top enables a workman to be lowered inside idle tubes for inspection and repair.



Flue No.	Facility Served	Internal Diameter, Meters	Dimensions of Connected Duct Width x Height, Meters
1	Power Boiler	2.75	2.2 x 3.6
2	Power Boiler	2.75	2.2 x 3.6
3	Spare	2.25	--
4	Heating Boiler 5 and 6	2.00	1.8 x 2.5
5	Heating Boiler 4	1.45	1.2 x 1.8
6	Heating Boiler 3	1.45	1.2 x 1.8
7&8	Heating Boiler 1 and 2	1.65	1.5 x 1.8
9	Steam Boiler	0.90	1.6 x 0.5
10	Refuse Boiler 1	1.20	0.8 x 1.8
11	Refuse Boiler 2	1.70	1.5 x 1.8

FIGURE 12-31. CHIMNEY TUBE ARRANGEMENT AT UPPSALA (COURTESY UPPSALA KRAFTVARME AB)

POLLUTION CONTROL ASSESSMENT

The exceptionally low emission measured from the precipitators and the unusually thorough design of the Hovgarden shredder and landfill described in Appendix A combine to make this an exemplary system environmentally.

A new regulation of the national environmental control agency, Statens NNaturvardsverket (SNV), requires that any plant emitting more than 40 mg/Nm^3 of total acid equivalent must undertake studies to seek feasible means for control. The acid equivalent discharged at Uppsala appears to be near to that upper limit. HCl ranges from 14 to 79 mg/dry Nm^3 measured at 6.4 percent CO_2. This is much lower than measured elsewhere in Sweden.

Wastewater is sent to the sewage treatment plant at a treatment cost of 2 Sk/m^3 ($0.0015/gal).

Table 12-2 shows the results of gaseous emission measurements in 1974 at Uppsala by the laboratory staff of Aktiebolaget Atomenergi. The data are for the emissions from Furnaces 1, 2, and 3. The sampling point was 5 m (16 ft) ahead of the precipitator. A six-point traverse was made during each test across a square duct about 1 m (3.3 ft) square.

The SO_2 results shown in Table 12-2 were stated to be comparable to other Swedish results established in the government publication, "Atmospheric Pollution Problems in Waste Materials Incineration", Publication No. 1969:6 by Statens Naturvardsverk. However, the HCl emissions in Table 12.2 were stated to be about half those measured elsewhere. This type of variation is not uncommon in refuse burning. The amount of HCl discharged depends greatly on the amount of pvc burned.

TABLE 12-2. **RESULTS OF GASEOUS EMISSION MEASUREMENTS FROM ORIGINAL THREE FURNACES AT UPPSALA (APRIL 23, 1974) (COURTESY UPPSALA KRAFTVARME AB)**

Test Number	1	2	3	4
Time of Day	9:00-9:45	9:57-10:47	11:00-11:48	12:---12:45
Steam Production Rate, tonnes/hr	22.4	22.4	22.4	23.9
Gas Volume Sampled, Nm^3	0.106	0.111	0.078	0.103
CO_2, Percent Dry Gas	6.4			
O_2, Percent Dry Gas	10.4			
SO_2, mg/Nm^3, Dry Gas	110	110	210	60
SO_2, mg/Nm^3 corr. to 10 Percent CO_2	170	170	330	90
HCl, mg/Nm^3, dry gas	73	79	34	14
HCl, mg/Nm^3, corr. to 10 Percent CO_2	114	124	53	22

Note: 1 mg/Nm^3 SO_2 = 0.378 ppm SO_2.
1 mg/Nm^3 HCl = 0.672 ppm HCl.

EQUIPMENT PERFORMANCE ASSESSMENT

Table 12-3 shows the 1974 and 1975 operating results for the entire Uppsala district heating and power system. In 1975, the waste burning plant produced 80 Gwh (58.9×10^6 Gcal) (273×10^6 MBtu) in the form of saturated steam at 15 atm (220 psia). This was 5.4 percent of the total heat production in the entire system.

The waste burning plant achieved its energy recovery and waste disposal function with minimal cost.

TABLE 12-3. OPERATING DATA FOR THE UPPSALA ENERGY SYSTEM FOR 1974 AND 1975 (COURTESY UPPSALA KRAFT-VARME AB)

	1974	1975
Electricity Production, Gwh	313	520
Hot Water From Power Plant, Gwh	655	1,020
Hot Water From Three Heating Plants[(a)], Gwh	463	206
Hot Water From Central Heating Plant, Gwh	24	34
Steam Production From Waste, Gwh	80	81
Steam Production From Others[(b)], Gwh	41	32
Heat From Heat Exchanger, Gwh	38	30
Total Production (Hot Water + Steam), Gwh	1,263	1,373
Delivery of Hot Water From Four Plants, Gwh	1,017	1,166
Delivery of Hot Water From Central Plant, Gwh	22	31
Delivery of Steam (Pharmacia, Farmek, KVV), Gwh	56	59
Oil Consumed:		
Power Plant (for Power), m^3	36,943	62,834
Power Plant (for Hot Water), m^3	63,303	99,930
Three Heating Plants for Hot Water[(a)], m^3	44,580	21,453
Central Heating Plant, m^3	2,987	4,034
Bolandsverket Plant for Steam, m^3	4,128	3,296
Total Oil Burned, m^3	115,643	129,051
Specific Oil Consumption (Three Plants + Power Plant), Mwh/m^3	9.3	9.6
Specific Oil Consumption, Central Plant, Mwh/m^3	7.4	7.7
Oil From Coastal Terminal to Storage, m^3	173,179	188,182
Waste Burned, tonne	50,878	51,355
Waste Plant Evaporation Rate, kg/kg	2.44	2.44

TABLE 12-3. (Continued)

	1974	1975
Length of District Heating System, m	164,201	189,656
Volume of Hot Water Circulated, m^3	13,486	15,386
Income		
From Hot-Water Customers, 1,000 Skr	63,355	73,801
From Steam Customers, 1,000 Skr	2,588	2,898
From Delivery of Refuse, 1,000 Skr	1,888	1,693
Rate of Income From Heat Customers, ore/kwh[(c)]	6.10	6.17
Tipping Fee, Skr/tonne	37.11	33.62

(a) The three heating plants are: Bolandsverket, Kvarngardesverket, and Husbyborgs Verket (see map on page 7).

(b) Other small steam sources are Sunrod and Kymmene.

(c) 1 skr = 20 ore.

PERSONNEL AND MANAGEMENT

Chief Engineer, Hans Nyman, directs the overall plant through his staff, Hans Nordstrom, Plant Engineer, and Karl-Eric Berg, Works Engineer, and an assistant works engineer.

The plant does not now operate on weekends. The work-week is now 38.5 hours with 170 hours per month. Every ninth week, each worker works for shorter days. The regulation 4-week vacation will be extended to 5 weeks in 1978.

On the three daily shifts, there are five workers as follows:

- Crane operator
- Slag and residue handler
- Boiler-furnace operator
- Scale operator
- Mechanic (and on call for scale).

There is a possibility that more refuse will be coming from neighboring cities. To handle the extra volume, 7-day operation will be planned for which it is expected nine additional workers will be needed, three for each of three weekend shifts.

ENERGY MARKETING

Figure 12-32 illustrates schematically how the energy from refuse is integrated into the much larger district heating system operated by the Uppsala Kraftvarme AB (Uppsala Power Heat Corp.). The bulk of the energy required for the system is obtained from the burning of oil in a 200 mw power plant and in the central heating plants. At the bottom of Figure 12-23 is depicted the refuse-fired steam plant which supplies some steam for heating water for the central heating system plus process and heating steam to a number of industrial plants including the Fortia-Pharmacia, a meat packing house, two bakeries, and a laundry.

Table 12-4 shows the input-output data for the power and heating complex at Uppsala for the month of October, 1977. The steam-to-refuse production ratio of 2.26 is slightly lower than the average for this plant.

The total energy input for the month from oil was about 110 x 10^3 Gcal (assuming 10 Gcal/m^3) (39.7 MBtu)*. The enthalpy of the 12,056 tonnes (13,262 tons) of steam produced by the refuse plant was 667 Kcal/kg (1,200 Btu/lb) or a total refuse-to-energy output of 8,300 Gcal. This is 8.0 percent of the oil energy input to the system for October, 1977.

Figure 12-33 shows the installation of additional hot water piping at Uppsala.

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* 150,200 Btu/gal.

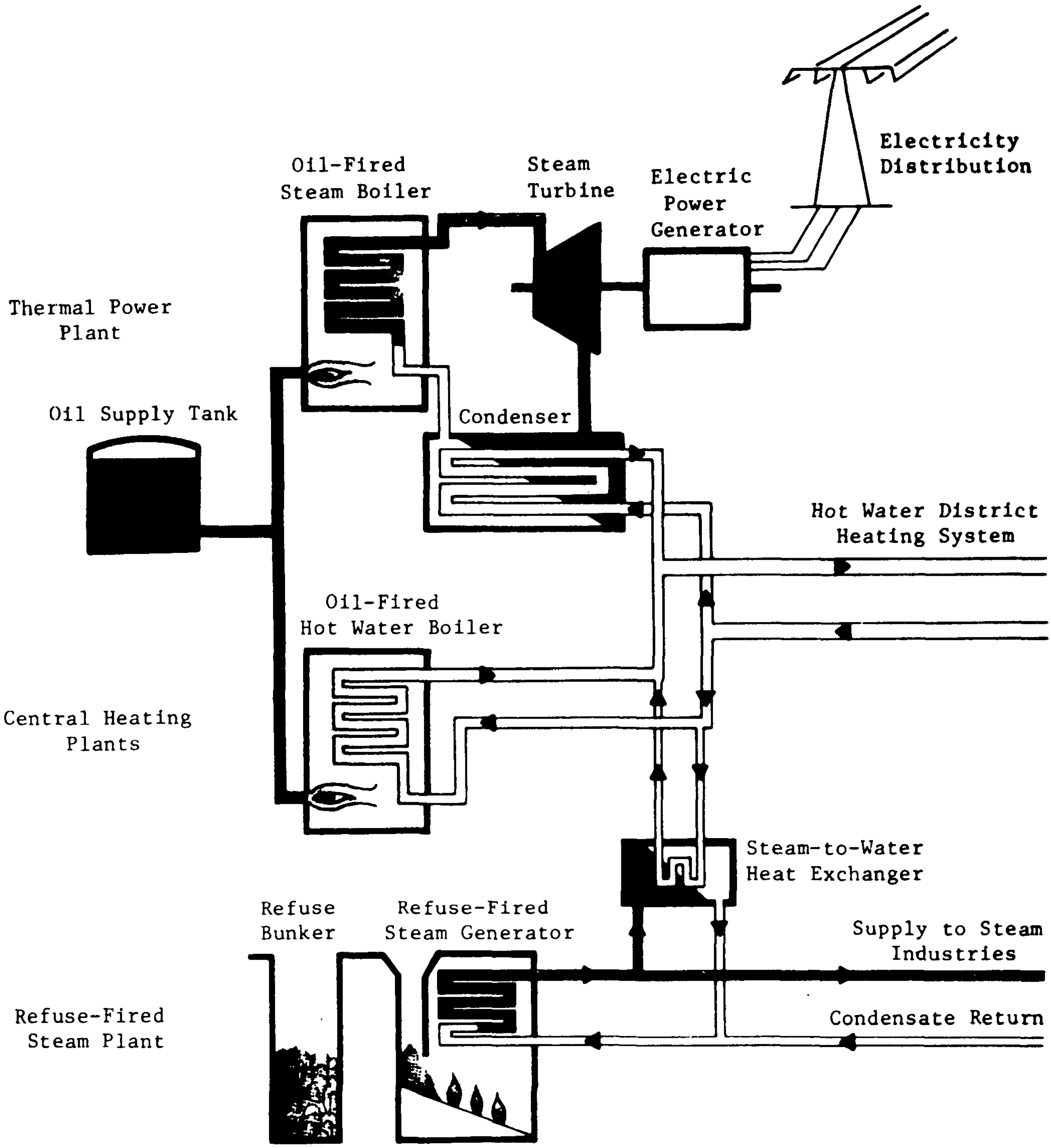


FIGURE 12-32. SCHEMATIC OF UPPSALA HEATING SYSTEM
(COURTESY UPPSALA KRAFTVARME AB)

TABLE 12-4. TYPICAL AUTUMN MONTH OPERATION DATA FOR UPPSALA HEAT POWER COMPANY, OCTOBER, 1977

Total Oil Consumed, m^3	10,994.2
Refuse Burned, tonne	5,342
Steam Produced, tonne	
Refuse Plant	12,056.0
Other Steam Boilers (from oil)	3,333.7
Electricity Consumed by Refuse Plant, kwh	368,960
Steam-to-Refuse Production Ratio	2.26
Electricity Produced, Mwh	29,494.8
Oil Consumed in Electricity Generation, m^3	3,353
Electricity Consumed in Power Plant, kwh	151,316
Total Steam Delivered, tonne	12,231
Steam Used Internally, tonne	3,158.7
Condensate Returned, tonne	3,463.2
Electricity Consumed in Pumping	
District Heating Water, kwh	875,900
Waste Oil Received, kg	37,620
Waste Oil Burned, kg	0
Biological Wastes Received, kg	2,604
Oil Consumed for Boiler wastes, m^3	2,800
Dextrose Waste Received, kg	0

FIGURE 12-33. INSTALLATION OF HOT WATER DISTRIBUTION PIPING
(COURTESY UPPSALA KRAFTVARMEWERKE AB)

ECONOMICS

The costs of the various stages of construction of the Uppsala waste plant were approximately as follows:

	Million Skr	Thousand $
1962 Furnaces 1 & 2 by Kockum-Landsverk and Boiler 1	3.4	850
1965 Furnace 3 by Kockum-Landsverk and Boiler 2	1.0	250
1971 Furnace 4 by Bruun & Sorensen and Boiler 3	4.0	1,000
1971 New Crane	0.15	38
1971 Precipitators	1.3	325
1971 Bulky Waste Shear	0.2	50
1971 New Ramp to Increse Bunker Depth	1.0	150
TOTAL	11.05	2,763

NOTE: This report uses two monetary conversion factors: (1) 1962-1972 costs @ 4 Skr/$; and (2) 1974-1978 expenses and revenues @ 5 Skr/$.

The plant operating management estimates that replacement in 1977 of the whole system would cost about 60 million Skr ($12 million @ 5 Skr/$).

In 1973, the original chimney was replaced at a cost of about 1 million Skr ($250,000).

Operating Costs

For the year 1976, the following owning and operating costs were paid for processing 52,040 tonnes (57,244 tons) during the year:

	Thousand Skr	Thousand $, (@ 5 Skr/$)
Amortization (15 years, 10%)	1,547	309
Staff Salaries and Wages	768	154
Fringe Benefits (Including Pension)	323	65
Repair and Maintenance	933	187
Building Maintenance and Cleaning	80	16
Electricity Consumption	280	56
Administration	232	46
TOTAL OWNING AND OPERATING COST	4,163	833

This resulted in a unit cost for 1976 of 80 Skr/tonne ($14.54/ton @ 5 Skr/$).

Revenues

As already shown in Table 12-3, for 1974 and 1975 the tipping fees were:

- 1974: 1,888,000 Skr for 50,878 tonnes or 37.1 Skr/tonne
- 1975: 1,693,000 Skr for 51,355 tonnes or 34.0 Skr/tonne.

This is the equivalent of $6.75 and $6.18 per short ton, respectively. As already stated, the 1976 operating cost was 80 Skr/tonne ($14.54/ton). No data were obtained on revenue from the portion of the district heat load supplied by the waste plant, but the above data would indicate that the income from that source would amount to about $8.00/ton (44 Skr/tonne) of waste. Plant staff indicated that the costs for heating are adjusted periodically to approximately support actual owning and operating costs.

Figure 12-34 shows the past and expected future trend of the net cost to the heating system of operating the refuse-to-energy plant. The cost in 1976 is shown to have reached a recent peak of about 44 Skr/tonne. In the future, the curve predicts a steep reduction in cost to the heating system because the expected rise in foreign oil prices will enhance the value of the heat from the refuse. The prediction curve is calculated from the following equation:

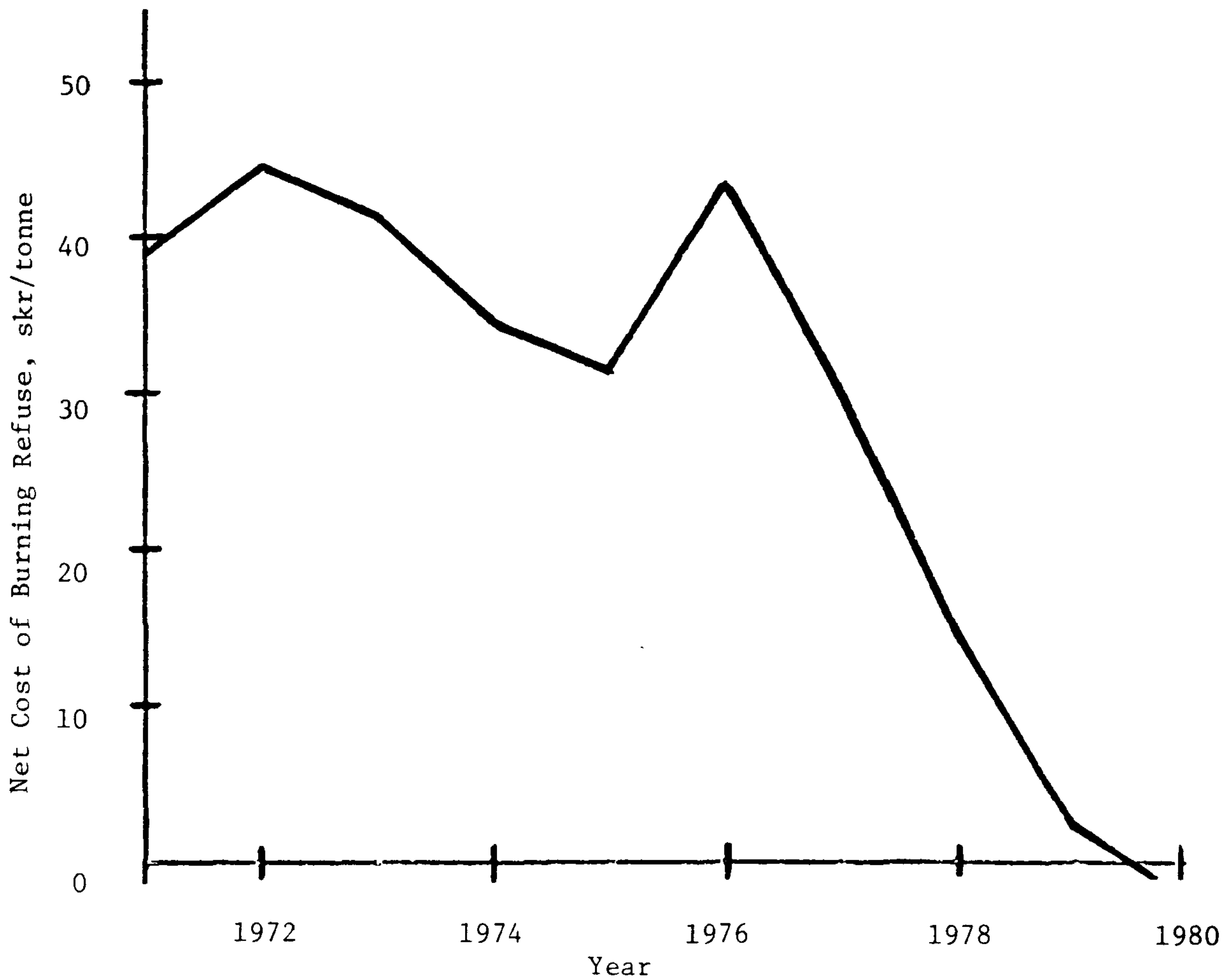


FIGURE 12-34. PAST AND PREDICTED TREND OF NET OPERATING COST OF REFUSE BURNING PLANT AFTER CREDIT IS TAKEN FOR THE VALUE OF HEAT RECOVERED (COURTESY UPPSALA KRAFTVARME AB)

$$\frac{\text{Annual Cost of Plant Operation}}{\text{Annual Refuse Burned}} - KB = \text{net cost to heating system.}$$

where:

B = cost of oil (48 Skr/m^3 in November, 1975)

and:

k = empirical factor relating heat from refuse to heat from heavy oil considering inherent efficiencies of utilization

k = 0.15 to 0.16 depending on plant conditions and volume of waste.

Thus, for the year 1979, processing 50,000 tonnes, if the total operating cost is 90 Skr/tonne and the cost of heavy oil has risen to 600 Skr/m^3, the net cost will be zero:

90 - 0.15 (600) = 0 Skr/tonne.

In November, 1975, the cost of oil delivered at the coastal terminal at Gavle was 350 Skr/tonne (about 350 Skr/m^3). Interest on the storage of 1 year's oil supply was 40 Skr. Tax was 50 Skr. Thus, the total oil cost then was 485 K/m^3.

Table 12-5 shows the electrical and heating charges for a typical residence served by the total Uppsala system. The three columns are for an electrically heated residence and two hot-water-heated ones based on an old oil cost and a new (lower) oil cost according to the formula discussed above. However, the portion of this revenue example which actually flows to the waste-to-energy plant is not revealed in the table. At a 1976 operational cost of 80 Skr/tonne of refuse and an evaporation rate of 2.44, that operational cost would be 33.79 Skr/tonne steam ($6.14/short ton @ 5 Skr/$).

TABLE 12-5. COMPARISON OF COSTS FOR ELECTRICITY AND DISTRICT HEAT FOR A NEWLY BUILT RESIDENCE CONNECTED TO THE UPPSALA KRAFTVARME AB (FROM A TABULATION PREPARED BY JANS ERIKSSON, VARMVERKET, SEPTEMBER 27, 1976)

External Surface of Residence Including Basement: 109 m^2 (1,173 ft^2)

Maximum Heat Load: 12.5 Mcal/h (52.3 MJ/h) [49,600 Btu/h]

Equivalent Electrical Load: 15 kw.

	Electric Heat	Old District Heat Rate, kwh (thermal)	New Rate, kwh (thermal)
Heat Consumption	27,600	29,800	29,800
Household Electricity Consumption	4,500	4,500	4,500
TOTAL	32,100	34,300	34,300
Fees (Skr)	Cost	Cost	Cost
Fixed Charge	--	1,103	1,340
Consumption Charge	--	1,435[a]	1,284[b]
Reduced Charge Bonus	--	2,538	2,236
Electrical Subscriber Fee	900	230	230
Power Consumed Cost	2,247[c]	450[d]	450[d]
Tax	642	90	90
SUM OF OPERATION COSTS	3,789	3,308	3,306
Facility Costs (Skr)			
Installation Cost for Heat	7,000	14,000	14,000
District Heat Connection Charge	--	3,100	4,850
Electricity Connection Charge	2,000	2,000	2,000
Sum of Connection and Installation	9,000	19,100	20,085
Ten-Year Prorated Annual First Cost	900	1,910	2,009
Forty Percent Tax on Annual First Cost	360	764	804
Summary of Total Annual Cost (Skr)			
Tax	360	764	804
Operation Cost	3,789	3,308	3,306
TOTAL	4,149	4,072	3,810
TOTAL IN $ @ 5 Skr/$	$829.80	$814.40	$762.00

(a) Based on a cost of heavy oil of 400 Skr/m^3 (30 ¢/gal).
(b) Based on a heavy oil cost of 359 Skr/m^3 (27 ¢/gal).
(c) Electricity cost of 7 ore/kwh (0.7 Skr/kwh) (7 ¢/kwh).
(d) Electricity cost of 10 ore/kwh (1 Skr/kwh) (10 ¢/kwh).

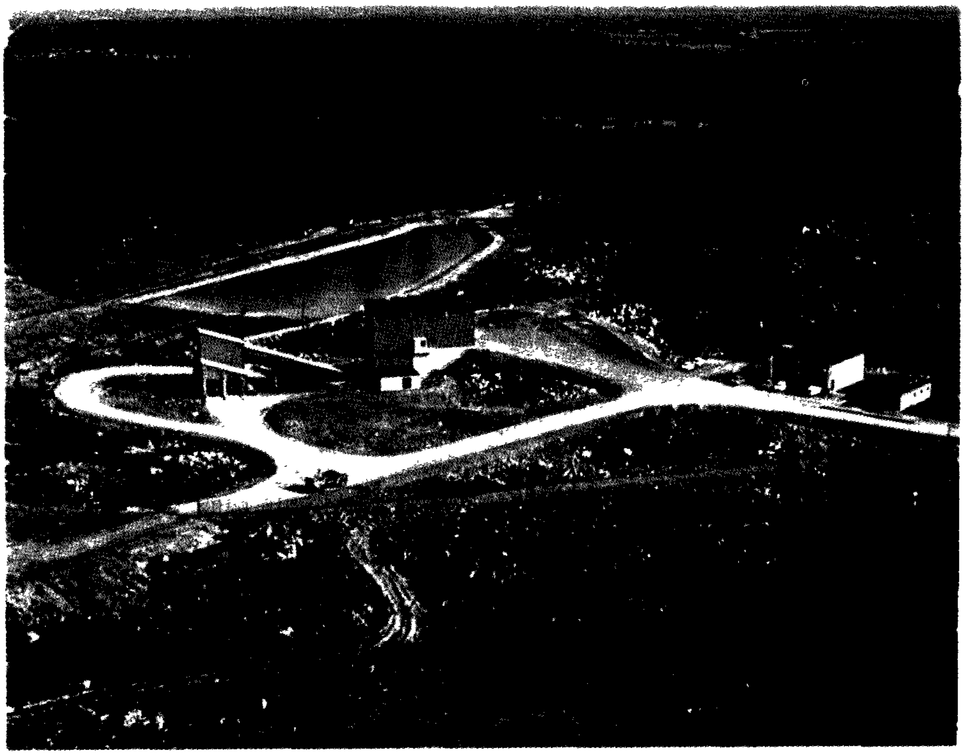
FINANCE

Of the total of 11.05 million Skr ($2,763,000 @ 5 Skr/$) of the original capital cost, 3.4 million Skr was borrowed from commercial lending sources. An additional 6.7 million Skr was financed from reserves from previous operations of the heating system. Out of present operations, it is planned to build up a reserve for the community of about 3 million Skr.

The refuse burning plant is to be amortized over 15 years at a nominal interest rate of 10 percent. Plant staff remarked that they would find it difficult to imagine operating the facility as a private enterprise.

APPENDIX A

PULVERIZING PLANT FOR CONSTRUCTION AND INDUSTRIAL WASTE AT UPPSALA



The Hovgården Pulverizing Plant

Uppsala

During the last few decades, Uppsala's refuse has either been burnt in a incinerator plant or tipped at a number of different sites. Tipping has involved great sanitary and hygienic problems.

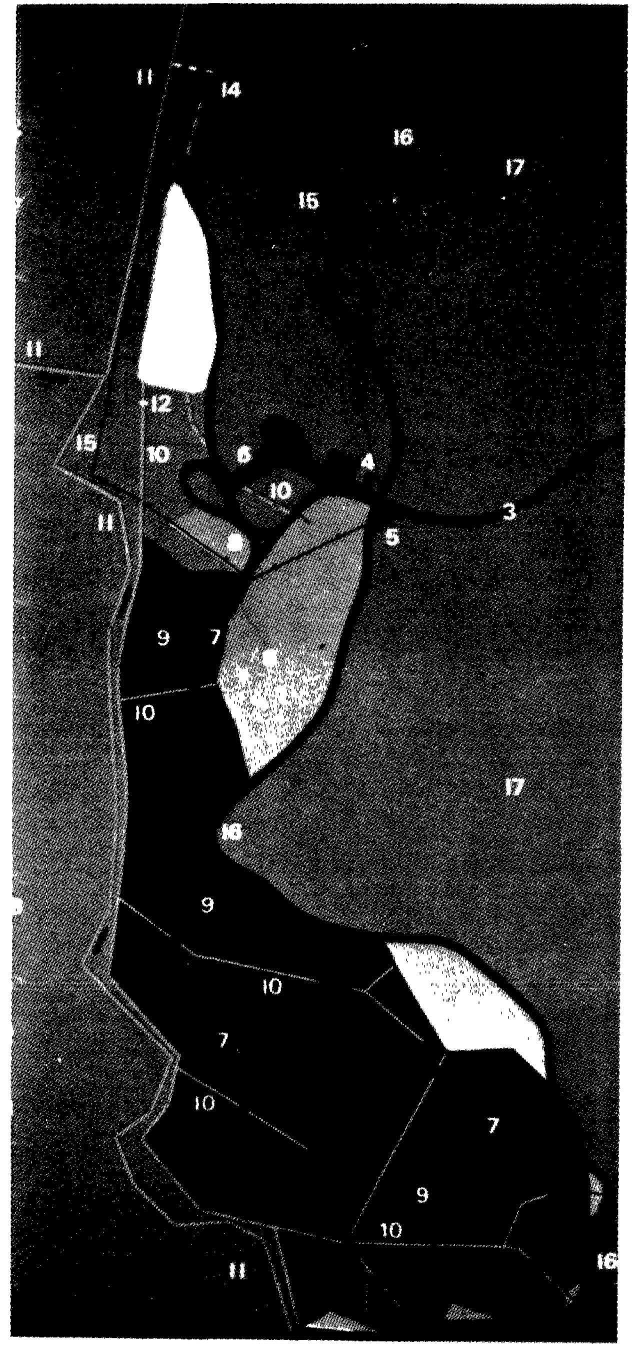
At an early stage, the aim of the Uppsala City Council was to treat the refuse in a technically and hygienically correct manner at reasonable cost. For this reason, the incinerator plant at Boländerna was built in 1962. It is here that all the household refuse is incinerated.

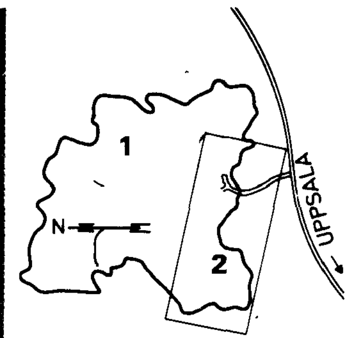
The Hovgården pulverizing plant and dumping area came into operation in the autumn of 1971. This plant makes possible a further extension step by step, concurrently with the improvements in the technical facilities and the requirements of environmental conservation.

Uppsala, May 1972

Ola Nyquist
Chairman of the City Council

HÅLL SVERIGE RENT





1. The Hovgården catchment area and future tipping area
2. The present tipping area
3. Approach road to the refuse works
4. Weigh-house, staff buildings and garage
5. Area for refuse containers
6. Pulverizing plant
7. Roads in the tipping area
8. Tipping area for excavated material and broken stone
9. Tipping area for refuse
10. Drainage system for polluted water
11. Drainage system for clean water
12. Measuring weir
13. Compensation reservoir
14. Purifying plant
15. Fence
16. Boundary of catchment area
17. Forest areas not affected by tipping
18. Future tipping area

INDUSTRIAL AND CONSTRUCTIONAL WASTES (EXCL. ASHES)

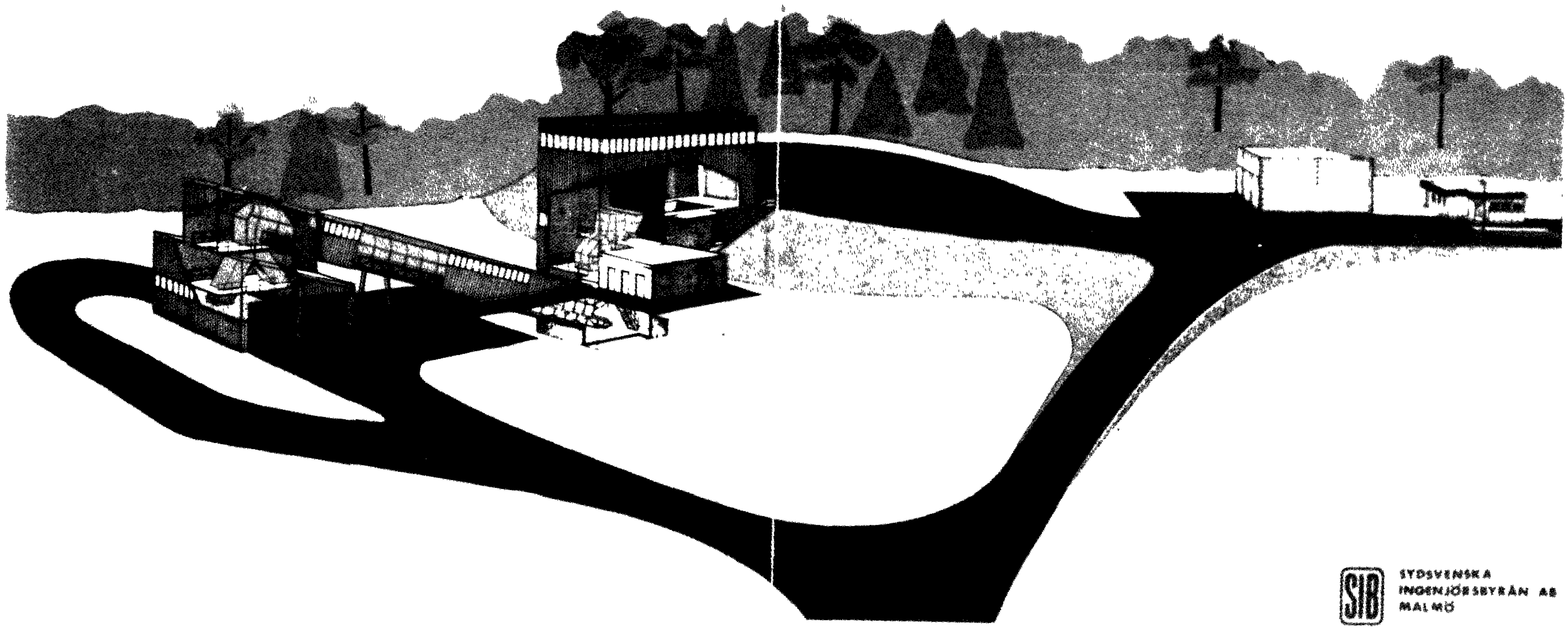
The Hovgarden pulverizing plant now deals with all building and industrial refuse etc from the whole of the Uppsala municipality. Previously the refuse went to several tips in the municipal area, the main one being the former industrial tip at Vedyxa. The quantity of refuse which has been tipped here is shown in the above diagram. These former tips will gradually be shut down and the land will be restored. In future, all refuse will be destroyed by sending the chemical waste etc. to a *central destructor, the combustible refuse to the incinerator plant and* other refuse to the Hovgarden pulverizing plant.

The refuse which comes to the pulverizing plant is weighed. In connection with the weighing, a decision is made as to whether the refuse shall be crushed or go directly to the dumping area. The industrial and building refuse, which is difficult to treat, is crushed in the pulverizing plant. Water is added in varying quantities, depending on the humidity of the refuse, which is then laid out in the dumping area to decompose.

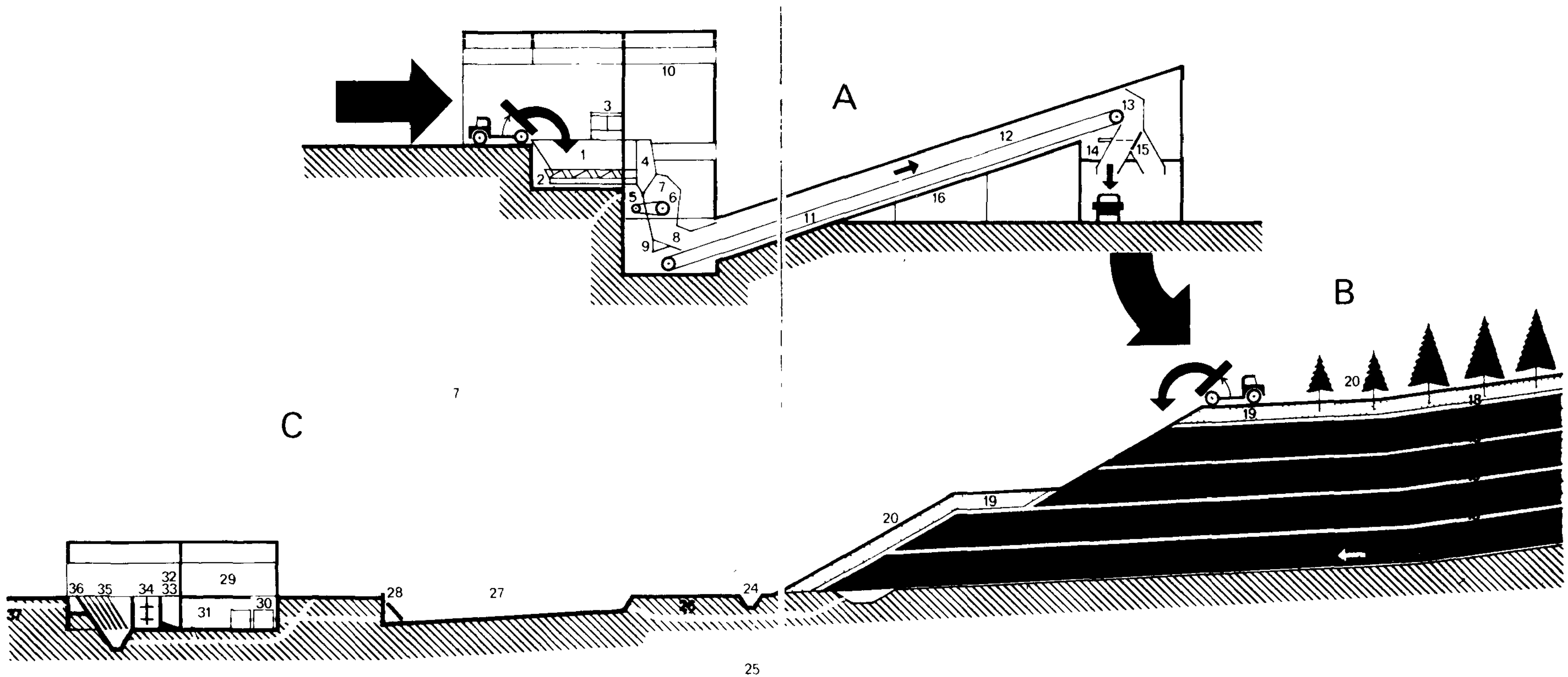
Several advantages are obtained from this pre-treatment, for example, an immediate and substantial reduction in the volume of the refuse, which makes it easier to handle. The biological process is started *more rapidly than in conventional dumping.* The risk of fire is almost completely eliminated, because the dumping is compact. Vermin, such as rats, gulls, etc are absent. Moreover, by using a special dumping plan and effective drainage, it is possible to control the polluted water from the dumping area. This polluted water is led by a drainage channel into a reservoir (compensation reservoir), in which a certain amount of pre-sedimentation and aeration takes place. The foul water is then pumped into a high-grade chemical purifying plant for treatment, before being discharged to the receiver.

In the latter half of the 1970s, it is calculated that the quantity of refuse received at the Hovgarden refuse works will increase by about 3-4% annually (see the diagram above). When necessary, the works can therefore simply be supplemented by additional pulverizing plants. Space has also been reserved for any future alternative solutions.

The consultants for the design and building of the pulverizing plant, the garage, the staff buildings and the weigh-house were Sydsvenska Ingenjorsbyran, Malmo, and for the compensation reservoir and purifying plant Vattenbyggnadsbyran, Stockholm.



The Hovgården refuse works in broad outline



A Pulverizing plant

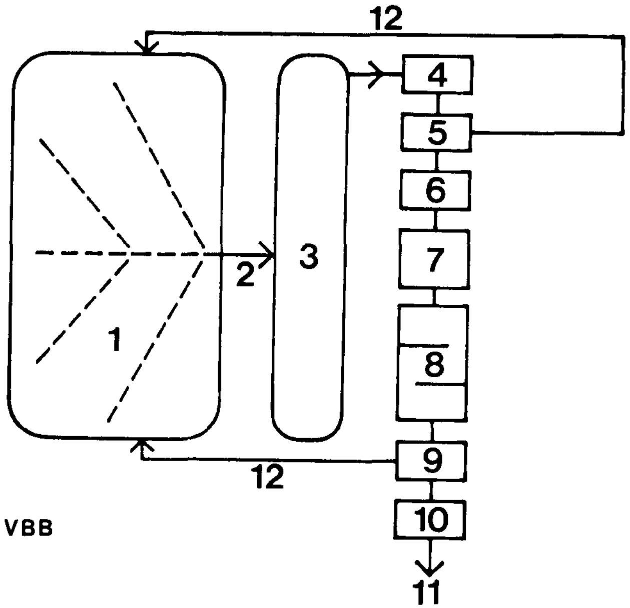
1. Charging hopper
2. Vibrating chute
3. Control room
4. Inlet cover
5. Electric motor for driving the pulverizer
6. Pulverizer
7. Pipe for sludge from purifying plant
8. Discharge cover
9. Vibrating chute
10. Telpher
11. Rubeer conveyor belt (36 m long)
12. Conveyor-belt cover
13. Unloading pit
14. Bascule motor
15. Bascule
16. Collecting chute with scraper for overflow

B Dumping area

17. Rows of refuse, height 2-2.5 m, width 20-30 m
18. Inert covering material, water-permeable, thickness about 0.2 m
19. Inert covering material, including layer of topsoil, thickness about 0.5 m
20. Clean surface water
21. Draining material
22. Polluted water
23. Covered stone drain for foul water (dimensions 4 × 4 m)
24. Drain for clean water
25. Clean water by-passes the purifying plant
26. Measuring weir

C The purifying plant

27. Compensation reservoir for polluted water
28. Oil separator
29. Chemical section in purifying plant
30. Tanks containing chemicals surrounded by embankments
31. Pump room
32. Sumps
33. Dosage box for chemicals
34. Flocculation basins
35. Lamellar-sedimentation basins with sludge pockets
36. Chlorine contact basin
37. Outgoing purified water



VBB

The polluted water from the tipping area (1) is led via special drains (2) to a reservoir (3). At the inlet to this reservoir, the volume of incoming water is measured continuously. The reservoir has a capacity of 15 000 m³. It is also fitted with aeration devices. A certain amount of biological activity and sedimentation takes place in this reservoir. Any oil on the water is removed by a specially designed conveyor (4). From the compensation reservoir, the water is pumped at a constant rate to the automatic chemical purifying plant. This plant has a capacity of 20 litres per second and is divided into two separate units. The capacity can be increased to 30 litres per second. The plant comprises sumps (5), chemical-adding unit (6), mixing chamber (7), flocculation basins (8), sedimentation basins (9) and chlorine contact basin (10). The purified water is chlorinated with sodium hypochlorite before it runs out into an oxidation ditch 200 m long (11).

The sedimentation basins are designed for lamellar sedimentation on the counter-flow principle, with a double-sided intake, central sludge removal to the crushing plant (12) and divided clear-water withdrawal.

Ferric chloride is used to induce precipitation. Sodium hydroxide is used to adjust the pH. The chemicals used for the precipitation process can easily be varied. Moreover it is possible to purify the water chemically in two different steps, using different chemicals for precipitation.

General data

Exemption from the consent of the Concessions Committee for Environmental Conservation obtained from the National Environment Protection Board	June 1970
City Council grants funds	June 1970
Designing and planning work	June–Dec. 1970
Stage I started	October 1970
Stage II started	February 1971
Pulverizing plant in operation	August 1971

Total dumping area	2.3 km²
Distance from city centre	12 km
Calculated capacity of dumping area	
Period I	7.0 million m³ (25–30 years)
Period II	5.0 million m³ (15–20 years)
Total cost of plant and buildings, including value-added tax	6.2 million kronor (approx. 496,000)

Technical data

Weighbridge	
Toledo Reliance, weighing capacity	32,000 kg
Pulverizing plant	
Tipping pocket, volume	50 m³
Pulveriser: Hazemag, type AP 4 80 MFA	
Motor, electric	160 kW
Crushing capacity	30 tons hour

Compensation reservoir	15,000 m³
Purifying plant	
High-grade chemical plant with lamellar sedimentation, capacity	Phase 1: 20 l s Phase 2: 30 l/s

Staff

Chief engineer	1
Operating staff	4

Administration

Uppsala Municipal Services Division, Cleaning Department

Builder

Uppsala Municipal Services Board

Participants in designing and planning

Consultants

1. Roads, open spaces, culverts, tipping areas, etc. — Uppsala Municipal Services Division
2. Architectural design, building construction, machinery design, etc. — Sydsvenska Ingenjorsbyran, Malmo
3. Purifying plant and compensation reservoir — Vattenbyggnadsbyran, Stockholm
4. Electrical designs — Elektrokonsult, Uppsala

Machinery suppliers

1. Pulverizing plant, including unloading gear — Hazemag AG, Munster, West Germany
2. Weighing equipment — Toledo-Reliance AB, Stockholm
3. Telpher equipment — Transportkonstruktioner AB, Stockholm
4. Machinery, pumping equipment, etc in purifying plant — Nordiska Varme Sana, Goteborg

Building contractors

Stage I — Nils P. Lundh AB, Vasteras
Stage II — Vag- och Vattenbyggnads AB, Svenssons Stensätteri, Uppsala

Electrical contractors

(a) High-tension installation — Byggproduktion AB, Uppsala
(b) Low-tension installation — Karnes El AB, Uppsala

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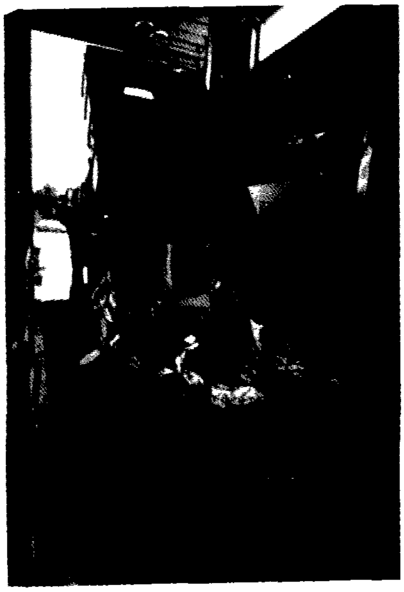
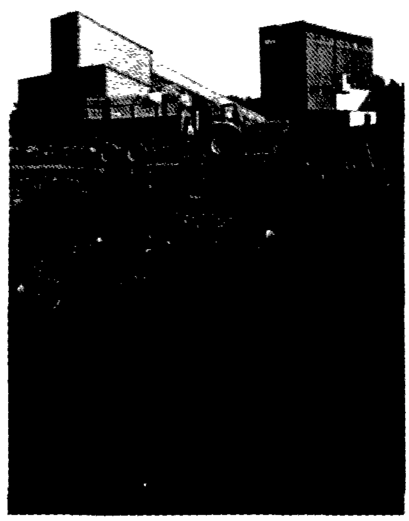
1. Weighing



2. Tipping into a charging hopper

3. The pulverizing room

4. The crushed and moistened refuse is transported to the dumping area



CONVERSION FACTORS

English Units Versus SI (and Metric) Units

To Convert From	To Get	Multiply by	To Convert From	To Get	Multiply by
feet	meters	0.3048	meters	feet	3.281
square feet	square meters	0.0929	square meters	square feet	10.76
cubic feet	cubic meters	0.0283	cubic meters	cubic feet	35.31
inches	millimeters	25.4	millimeters	inches	0.0394
cubic yards	cubic meters	0.7646	cubic meters	cubic yards	1.308
barrels (oil)	cubic meters	0.15899	cubic meters	barrels (oil)	6.290
miles	kilometers	1.609	kilometers	miles	0.6214
square miles	square kilometers	2.589	square kilometers	square miles	0.3861
acres	square kilometers	0.004047	square kilometers	acres	247.1
acres	hectares	0.4047	hectares	acres	2.471
gallons	cubic meters	0.003785	cubic meters	gallons	264.2
ton (short)	tonne (metric)	0.9078	tonne (metric)	ton (short)	1.102
pounds	grams	454	grams	pounds	0.002046
grains	grams	0.0648	grams	grains	15.42

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CONVERSION FACTORS

English Units Versus SI (and Metric) Units

To Convert From	To Get	Multiply by	To Convert From	To Get	Multiply by
pounds per million Btu	nanograms per Joule	499.2	nanograms per Joule	pounds per million Btu	0.0023
pounds per million Btu	milligrams per megajoule	499.2	milligrams per megajoule	pounds per million Btu	0.00233
cubic feet per minute	cubic meters per hour	1.699	cubic meters per hour	cubic feet per minute	0.588
gallons per minute	liters per minute	3.785	liters per minute	gallons per minute	0.264
pounds per square foot	kilograms per square meter	703.1	kilograms per square meter	pounds per square foot	0.001422
pounds per square inch	kilograms per square centimeter	0.07031	kilograms per square centimeter	pounds per square inch	14.223
pounds per square inch	atmospheres	0.0681	atmospheres	pounds per square inch	14.69
pounds per square inch	newtons per square meter	6894.8	newtons per square meter	pounds per square inch	0.00014
pounds per square inch	kilopascals	6.8948	kilopascals	pounds per square inch	0.1450
atmospheres	bars	1.0133	bars	atmospheres	0.9869
atmospheres	kilopascals	101.3	kilopascals	atmospheres	0.0098
pounds per square inch	bars	0.06895	bars	pounds per square inch	14.50
inches of water	pascals	249.08	pascals	inches of water	0.004015
millimeters of water	pascals	9.806	pascals	millimeters of water	0.102

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CONVERSION FACTORS

English Units Versus SI (and Metric) Units

To Convert From	To Get	Multiply by	To Convert From	To Get	Multiply by
Btu	kilocalorie	0.252	kilocalorie	Btu	3.968
MBtu	Gcal	0.252	Gcal	MBtu	3.968
Btu	kilowatt-hours	0.000293	kilowatt-hours	Btu	3414
Btu	Joules	1055.1	Joules	Btu	0.000948
Btu per pound	kilocalories per kilogram	0.5555	kilocalories per kilogram	Btu per pound	1.8
Btu per pound	Joules per kilogram	2326	Joules per kilogram	Btu per pound	0.00430
Btu per hour	watts	0.29307	watts	Btu per hour	3.413
Btu per sq ft-hr	kilocalories per sq meter-hr	2.711	kilocalories per sq meter-hr	Btu per sq ft-hr	0.3688
Btu per cu ft-hr	kilocalories per cu meter-hr	8.897	kilocalories per cu meter-hr	Btu per cu ft-hr	0.112
pounds per 1000 pounds (gas)	grams per cu meter	1.205	grams per cu meter (gas)	pounds per 1000 pounds	0.93
grains per cu ft (68 F)	grams per cu meter (20 C)	2.28	grams per cu meter (20 C)	grains per cu ft (68 F)	0.43

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TABLE . EXCHANGE RATES FOR SIX EUROPEAN COUNTRIES, (NATIONAL MONETARY UNIT PER U.S. DOLLAR) 1948 TO FEBRUARY, 1978(a)

	Denmark Kroner (D.Kr.)	France Francs (F.Fr.)	W. Germany Deutsch Mark (D.M.)	Netherlands Guilders (Gl.)	Sweden Kronor (S.Kr.)	Switzerland Francs (S.Fr.)
1948	4.810	2.662	3.333	2.653	3.600	4.315
1949	6.920	3.490	4.200	3.800	5.180	4.300
1950	6.920	3.499	4.200	3.800	5.180	4.289
1951	6.920	3.500	4.200	3.800	5.180	4.369
1952	6.920	3.500	4.200	3.800	5.180	4.285
1953	6.920	3.500	4.200	3.786	5.180	4.288
1954	6.914	3.500	4.200	3.794	5.180	4.285
1955	6.914	3.500	4.215	3.829	5.180	4.285
1956	6.914	3.500	4.199	3.830	5.180	4.285
1957	6.914	4.199	4.202	3.791	5.173	4.285
1958	6.906	4.906	4.178	3.775	5.173	4.308
1959	6.908	4.909	4.170	3.770	5.181	4.323
1960	6.906	4.903	4.171	3.770	5.180	4.305
1961	6.886	4.900	3.996	3.600	5.185	4.316
1962	6.902	4.900	3.998	3.600	5.186	4.319
1963	6.911	4.902	3.975	3.600	5.200	4.315
1964	6.921	4.900	3.977	3.592	5.148	4.315
1965	6.891	4.902	4.006	3.611	5.180	4.318
1966	6.916	4.952	3.977	3.614	4.180	4.327
1967	7.462	4.908	3.999	3.596	5.165	4.325
1968	7.501	4.948	4.000	3.606	5.180	4.302
1969	7.492	5.558	3.690	3.624	5.170	4.318
1970	7.489	5.520	3.648	3.597	5.170	4.316
1971	7.062	5.224	3.268	3.254	4.858	3.915
1972	6.843	5.125	3.202	3.226	4.743	3.774
1973	6.290	4.708	2.703	2.824	4.588	3.244
1974	5.650	4.444	2.410	2.507	4.081	2.540
1975	6.178	4.486	2.622	2.689	4.386	2.620
1976	5.788	4.970	2.363	2.457	4.127	2.451
1977	5.778	4.705	2.105	2.280	4.670	2.010
1978 (Feb.)	5.580	4.766	2.036	2.176	4.615	1.987

(a) Exchange Rate at end of period.

Line "ae" Market Rate/Par or Central Rate.

Source: International Financial Statistics: 1972 Supplement; April, 1978, Volume XXXI, No. 4, Published by the International Monetary Fund.

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