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Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
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ON THE

APPLICATION OF MODERN TECHNICAL PRACTICES IN THE IRON AND STEEL INDUSTRY TO DEVELOPING COUNTRIES

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PROGRESS IN ELECTRIC PIG IRON SMELTING

by

Fredrik C. Collin

Director of Research

ELEKTROKEMISK A/S

Oslo, Norway.

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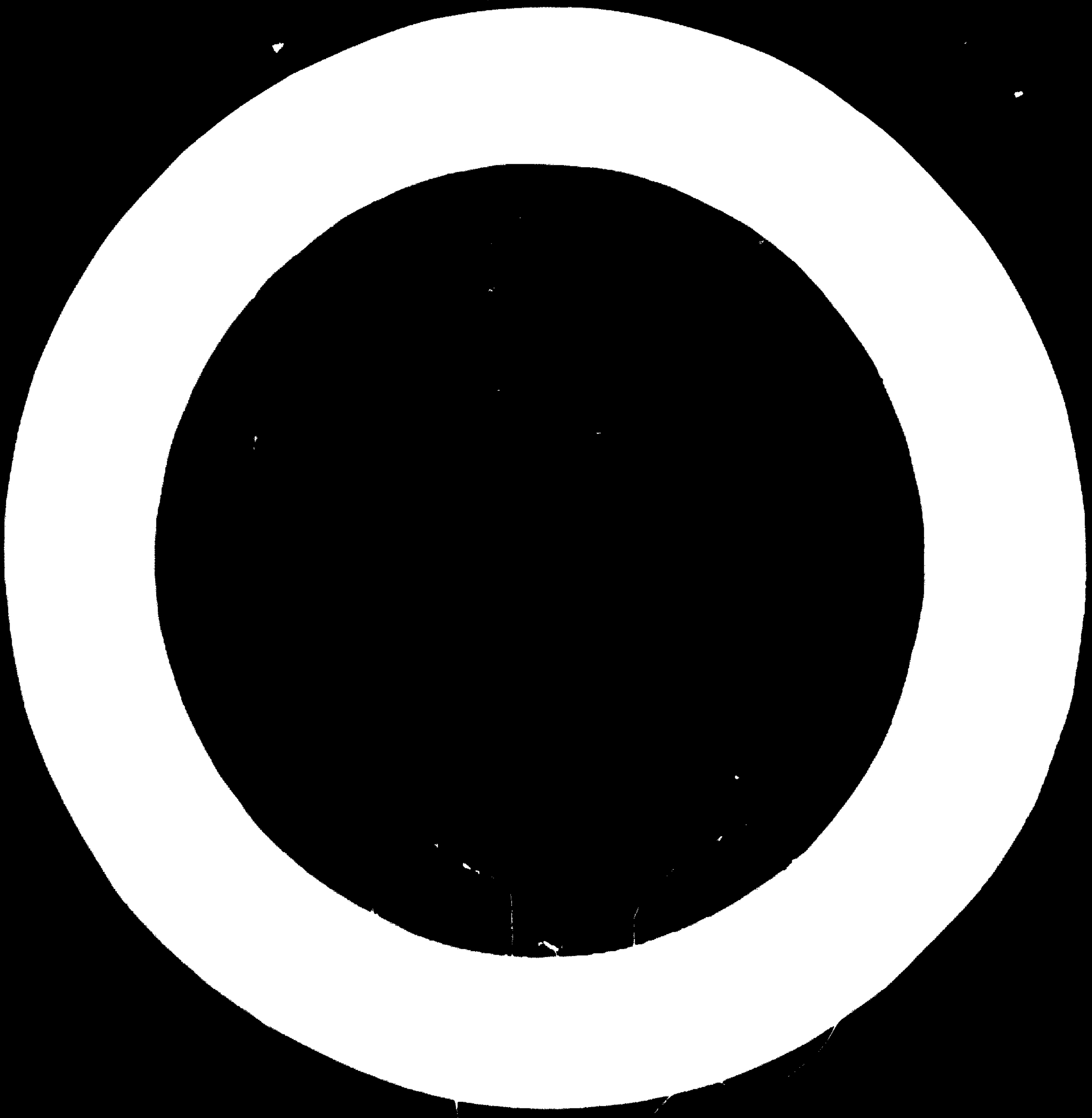

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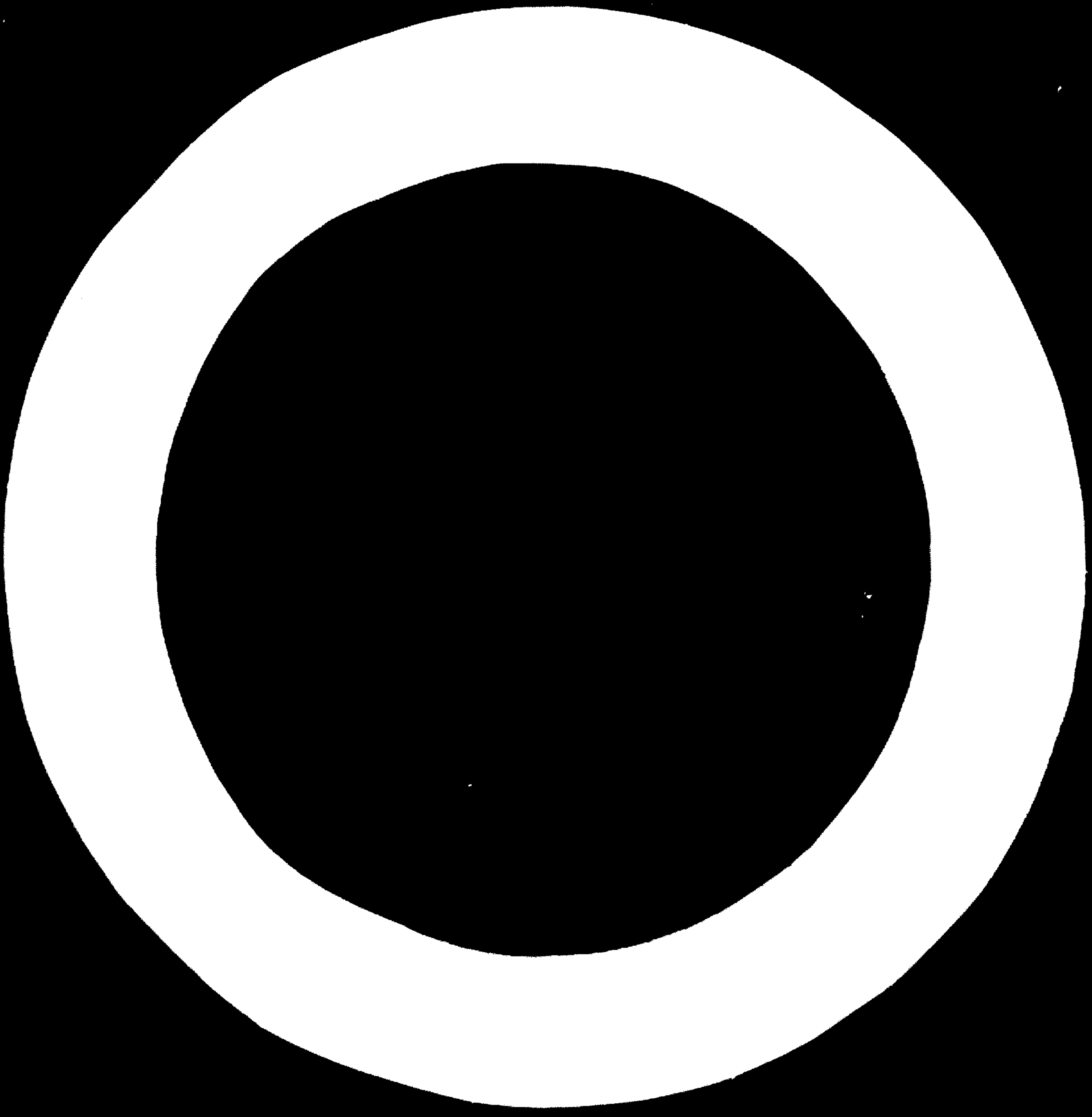

ABSTRACT

The electrical smelting process has undergone refinement and technical progress in the last few years. The original conception of electric smelting was to supply the thermal requirements of the process from electrical energy and the chemical requirements from carbon. The present trend, however, is to substitute carbon or other fuels for a portion of the thermal energy previously supplied entirely by electricity. The preheating and prereduction of the charge makes it possible to meet the demand for larger and larger reduction units since the power consumption per ton of pig iron may be drastically reduced by the thermal pretreatment.

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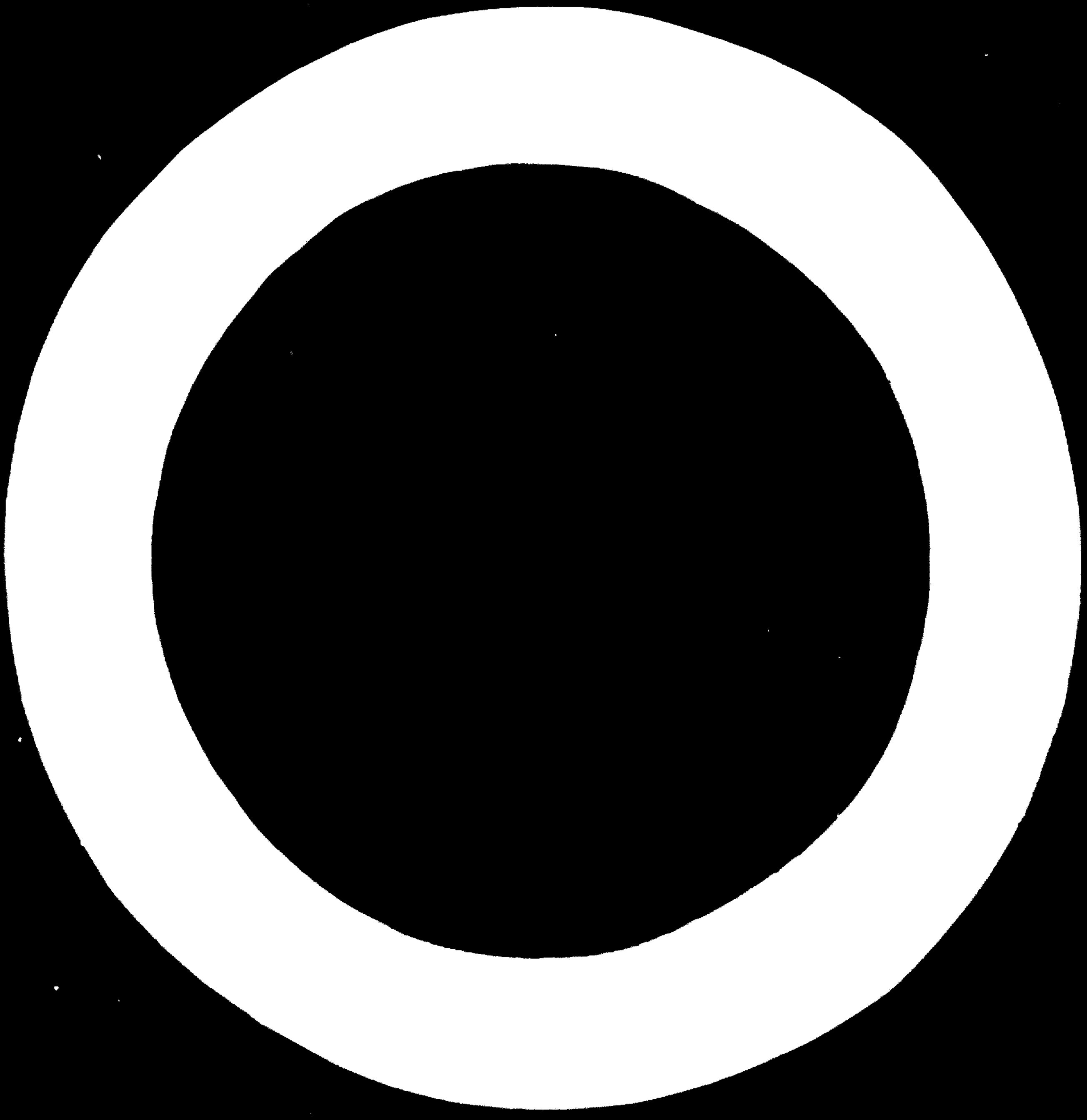


1. INTRODUCTION

The electric pig iron process is one of the very few alternatives to the conventional blast furnace process in the production of liquid pig iron. Electric pig iron production is already established in fourteen different countries and this type of smelting plants has been ordered for three other countries. In this paper the author will deal with some of the reasons for this quite wide-spread adoption of the electric reduction partly in remote and industrially somewhat less developed areas.

The electrical smelting process has undergone refinement and technical progress in the last few years. The original conception of electric smelting was to supply the thermal requirements of the process from electrical energy and the chemical requirements from carbon. The present trend, however, is to substitute carbon or other fuels for a portion of the thermal energy previously supplied entirely by electricity. The preheating and prereduction of the charge makes it possible to meet the demand for larger and larger reduction units since the power consumption per ton of pig iron may be drastically reduced by the thermal pretreatment.

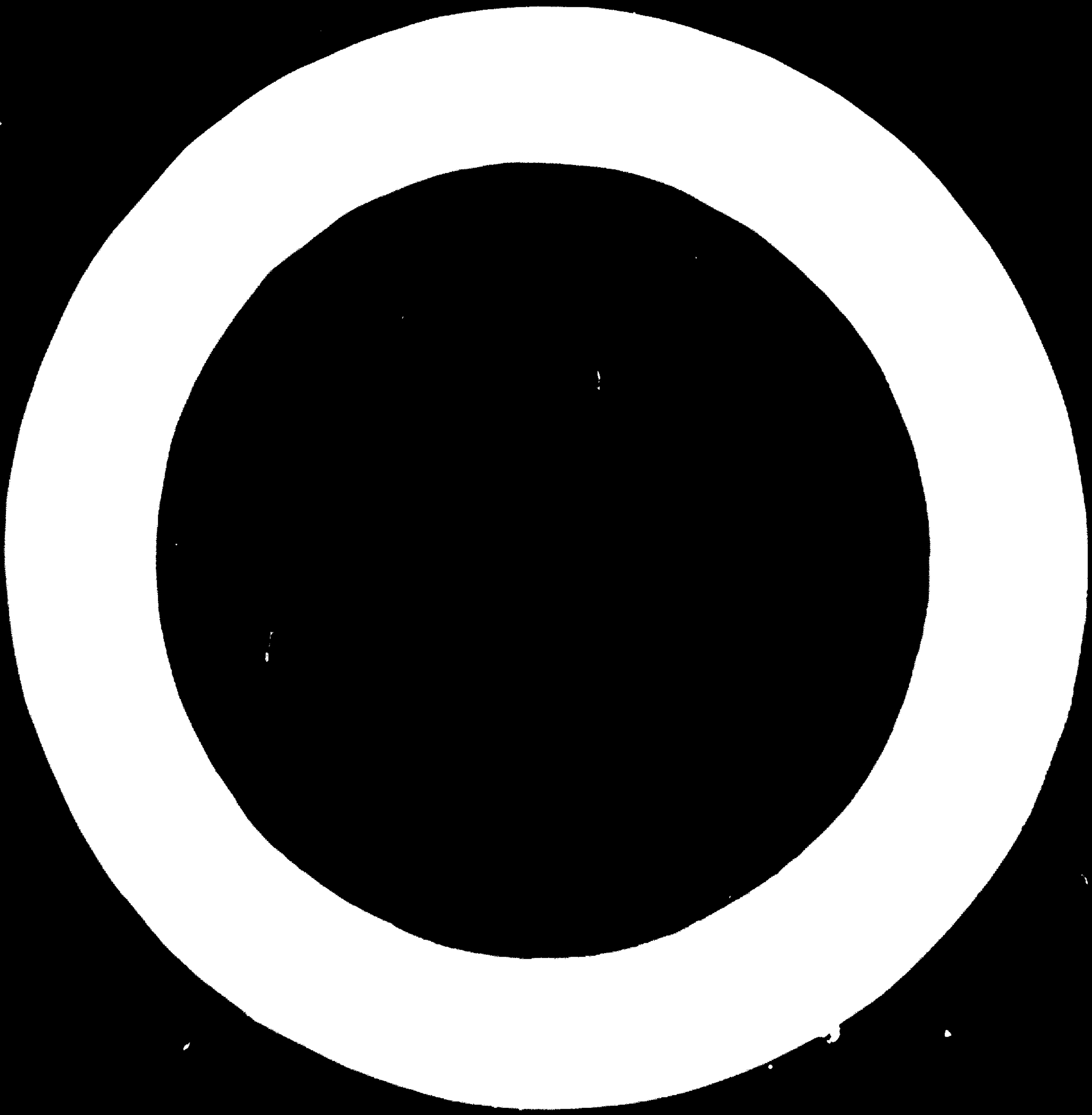
The results of pilot plant tests in preheating and prereduction and electric smelting of the hot charge will be discussed in this paper.

2. THE BLAST FURNACE PROCESS

Before discussing the electric process it is useful to have as a yard-stick for comparison the blast furnace process which has dominated the pig iron field until recently. The average capacity of the 266 blast furnaces in operation in USA was per January 1st, 1959 - 960 metric tons per day. In Western Germany 127 blast furnaces were in operation in 1961 with an average production of 550 tons per day. Approximately 1000 tons per day appears to be a typical production capacity for newer blast furnaces. There are, however, very few big blast furnaces with capacity of up to 2000 tons. The three integrated iron and steel works recently erected in India have capacities of approximately 1 million tons per year each. These works are equipped with blast furnaces designed for abt. 1000 metric tons production per day.

The performance of the blast furnace has been improved over the last years, mainly by installation of sinter plants in the large steel countries. With self-fluxing sinter the coke consumption has been reduced from abt. 1000 kgs per ton of pig iron to 600 - 800 kgs. The important reduction in the consumption of the rather expensive blast furnace coke has been accompanied by the use of abt. 200 kgs of coke breeze in the sinter plant.

Blast furnace coke - or coal of the type suitable for blast furnace coke consumption - is not available in many countries and areas. Transport or even import of coke or coal from abroad will establish higher costs and dependence of supply from overseas.



The electric pig iron furnace is not depending on the same high quality and strength of coke. Coke of small size or coal, even lignite, may be used. This is the main reason for the adoption of electric smelting in so many countries.

3. DESIGN FEATURES OF ELECTRIC FURNACES

In an electric pig iron furnace the charge is distributed to the furnace bins by transport with skip-hoist and telpher bucket. From the bins above the electric furnace the charge flows by gravity through the chutes to charge openings in the roof, and automatically keeps the electric furnace filled with charge.

All the furnaces which have been built by Elektrokemisk during the last twenty years are equipped with circular furnace pots and three Soderberg electrodes arranged in delta formation Below each electrode considerable quantities of coke float in the slag, the so-called coke bed, which constitutes an important element in the smelting process. The electrode current passes from the electrodes through the preheated part of the charge, which is conductive to electricity, and then through the coke bed and the slag.

The main reaction as well as the fusion of the charge takes place in the vicinity of the electrode tips where the liberation of electric energy is most extensive. As the height of the charge around the smelting zone is relatively low and the quantity of gas is considerably smaller than in blast furnaces, because no air is blown in, relatively little preheating and CO reduction take place in the electric furnace, except with a specially prepared, porous charge.

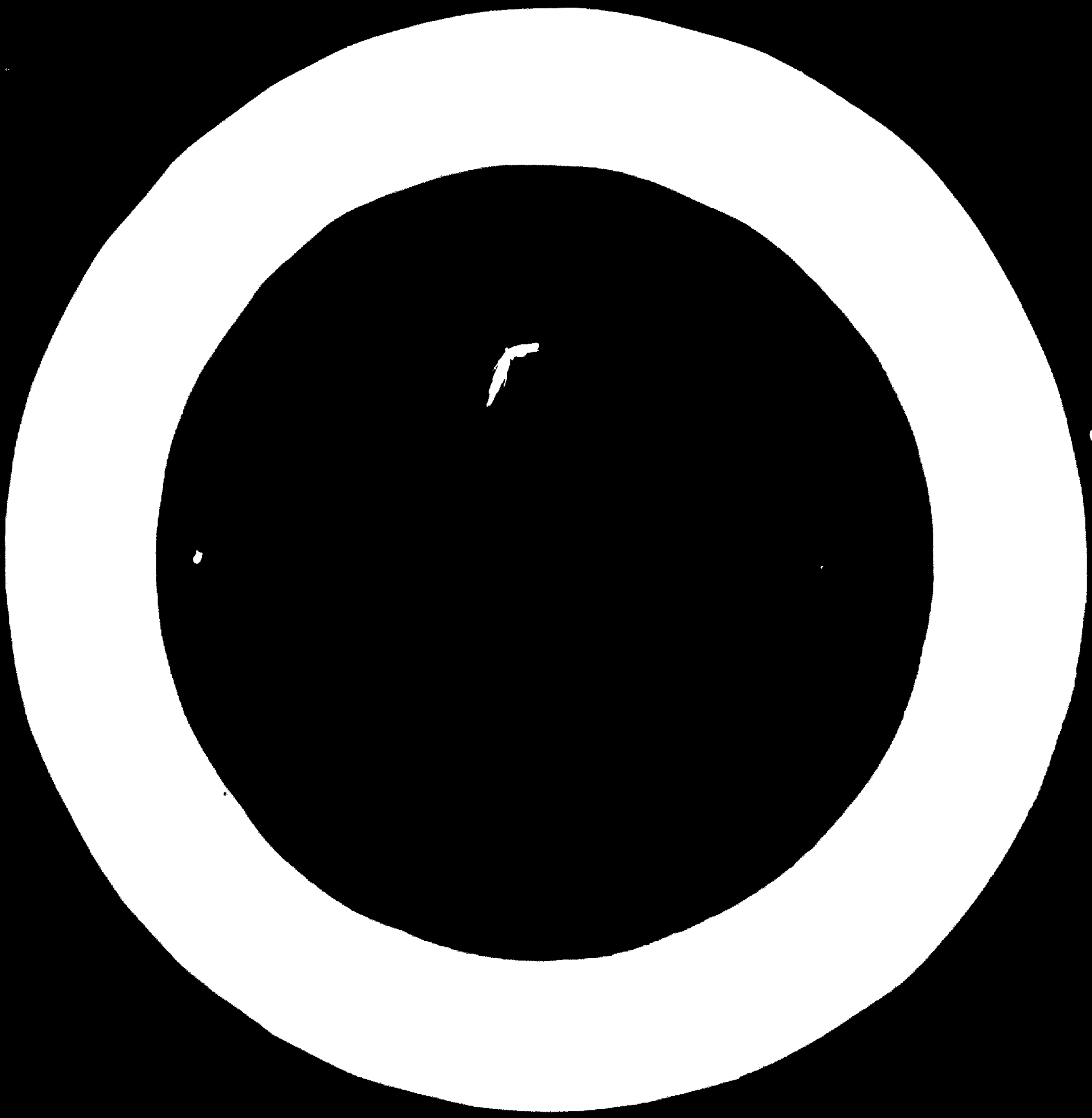
As for blast furnaces, iron and slag are tapped from a tap hole near the furnace hearth. Reaction gases are sucked off from openings in the furnace roof, scrubbed with water and distributed to gas holders and the gas distribution system.

The pioneer furnace for closed operation with collection of unburnt CO gas was the Tysland-Hole furnace operated by Christiania Spigerverk in the outskirts of Oslo. This furnace was in operation from 1923 to 1947 under inspiring leadership of Mr. Gunnar Schjelderup. Table 1 presents a list of electric furnaces of Tysland-Hole and ELKEM type in operation and presently under construction. In this table are not included furnaces for 100 to 150 MW built by other furnace manufacturers or the iron and steel producing companies themselves. Excluded are also a number of smaller furnaces built after the war by the Japanese steel works.

4. ELECTRIC PIG IRON SMELTING TO-DAY

Only a short description will be given here of the latest electric pig iron furnace installations.

Christiania Spigerverk, who pioneered in electric pig iron smelting by development of the first closed top unit, acquired a smelting plant at Bremanger in Western Norway in 1952. Here a 33 MVA electric furnace and a new sintering plant was installed in 1959. This furnace is in production on a special grade titanium and vanadium bearing pig iron.



An important and courageous step was taken by A S Norsk Jernverk just after the war, in their decision to install three electric pig iron furnaces, later supplemented with a fourth furnace unit, each with 33 MVA transformers.

This state-owned plant in Mo i Rana, just below the Polar Circle, has been in continuous operation since 1955. The yearly production is now abt. 360.000 metric tons, partly for the company's own steel works and partly for sale.

Typical data for the present operations are as follows:

Furnace load	20.000 - 25.000
Power consumption for pig iron with 1% Si	abt. 2000 kWh per metric ton
Coke consumption (85% Fixed C) - dry basis	350 - 400 kgs
Electrode paste	5 - 10 kgs
Down-time	2 - 5 %
Labour man-hours per ton	1.0 - 1.5

Presently the plant is being expanded with two 40 MW furnace units scheduled for completion towards the end of 1963. It is expected that the total annual capacity of the six furnaces will then reach 700 - 750 000 tons.

At Matanzas in Venezuela the large integrated iron and steel plant planned and built by Innocenti, Milan, was started up in 1961. Here eight 33 MVA ELKEM units have been put into operation, and one is expected to be ready for operation shortly. This state-owned enterprise is founded on the famous Cerro Bolivar "Iron Mountain", said to be the world's richest iron ore body so far discovered.

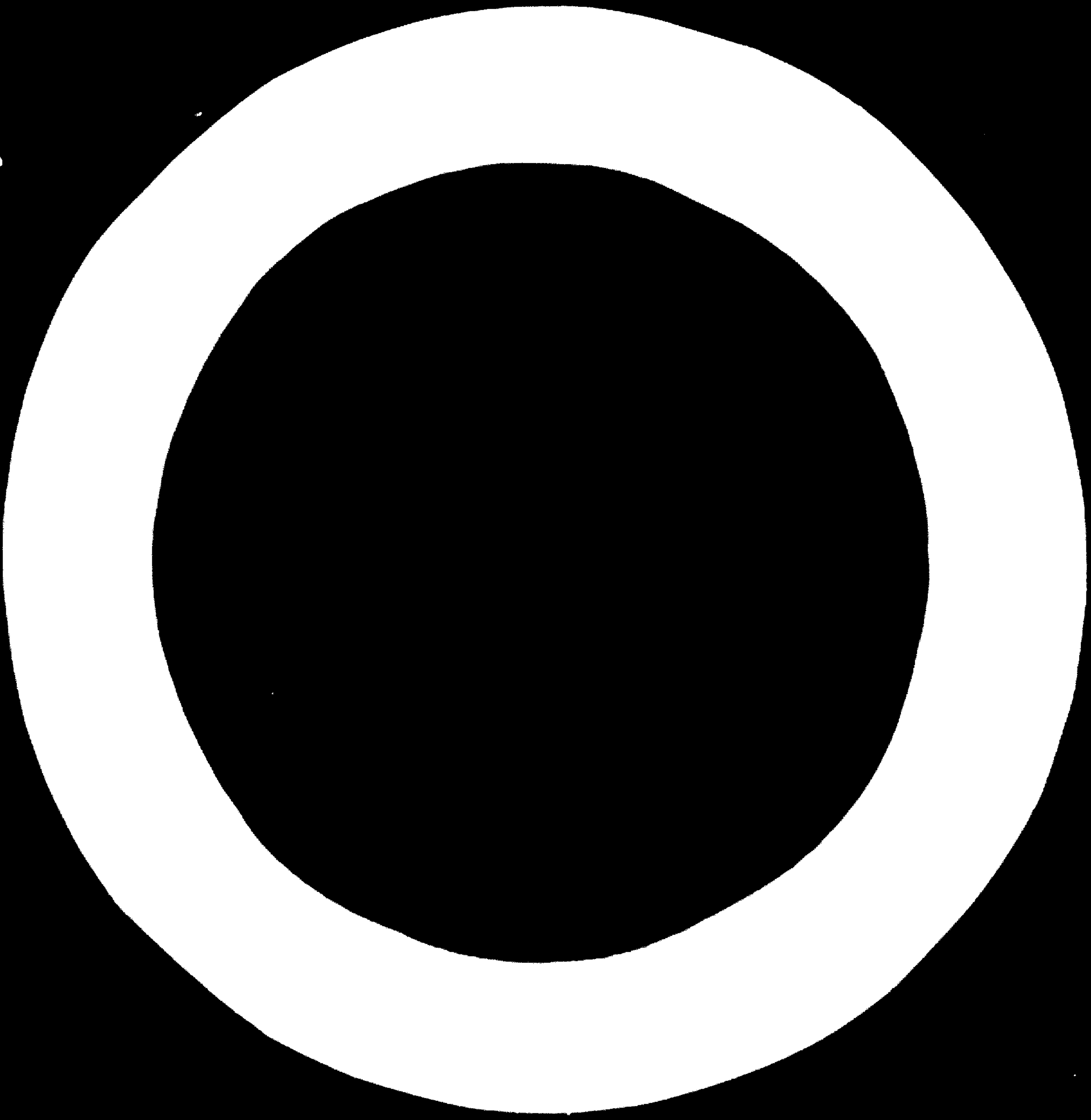
Other recent additions to the furnace family are two 18 MVA furnaces for Israel Steel Mills, and a 13,2 MVA furnace designed for the Consolidated Mining and Smelting Company of Canada Ltd., in Kimberley, British Columbia.

Early 1962 an 18 MVA ELKEM furnace for the smelting of sintered beach sand concentrate was started up by Nisso Steel Mfg. Co. Ltd., Hachinoe, Japan.

5. PREPARATION OF RAW MATERIALS

As in the blast furnace operation progress has been made in raw materials preparation for electric pig iron smelting. Also for electric furnaces smelting the lump size of the charge components and elimination of fines and dust in the charge are important for the furnace performance. Careful control of fines by screening is now standard practice with most larger electrothermic plants.

Systematic charge preparation has improved charge porosity and gas distribution. This provides a wider reaction and smelting zone in the electric furnace as well as smoother descent of the charge. Self-fluxing sinter eliminates calcination of raw limestone and dolomite by electric power. Apparently the self-fluxing sinter has increased chemical reactivity which is reflected in higher



CO_2 content in the furnace gas. Also the self-fluxing sinter is supposed to lower the formation temperature of the slag in the furnace, whereby reduced temperature in the reaction zone has been established.

6. CHEMISTRY OF PIG IRON SMELTING

1) $3\ Fe_2O_3 + CO = 2\ Fe_3O_4 + CO_2$

2) $Fe_3O_4 + CO = 3\ FeO + CO_2$

3) $FeO + CO = Fe + CO_2$

4) $CO_2 + C = 2\ CO$

Hematite: Fe_2O_3 = Oxidation degree 100 %

Magnetite: Fe_3O_4 = " " 88.8%

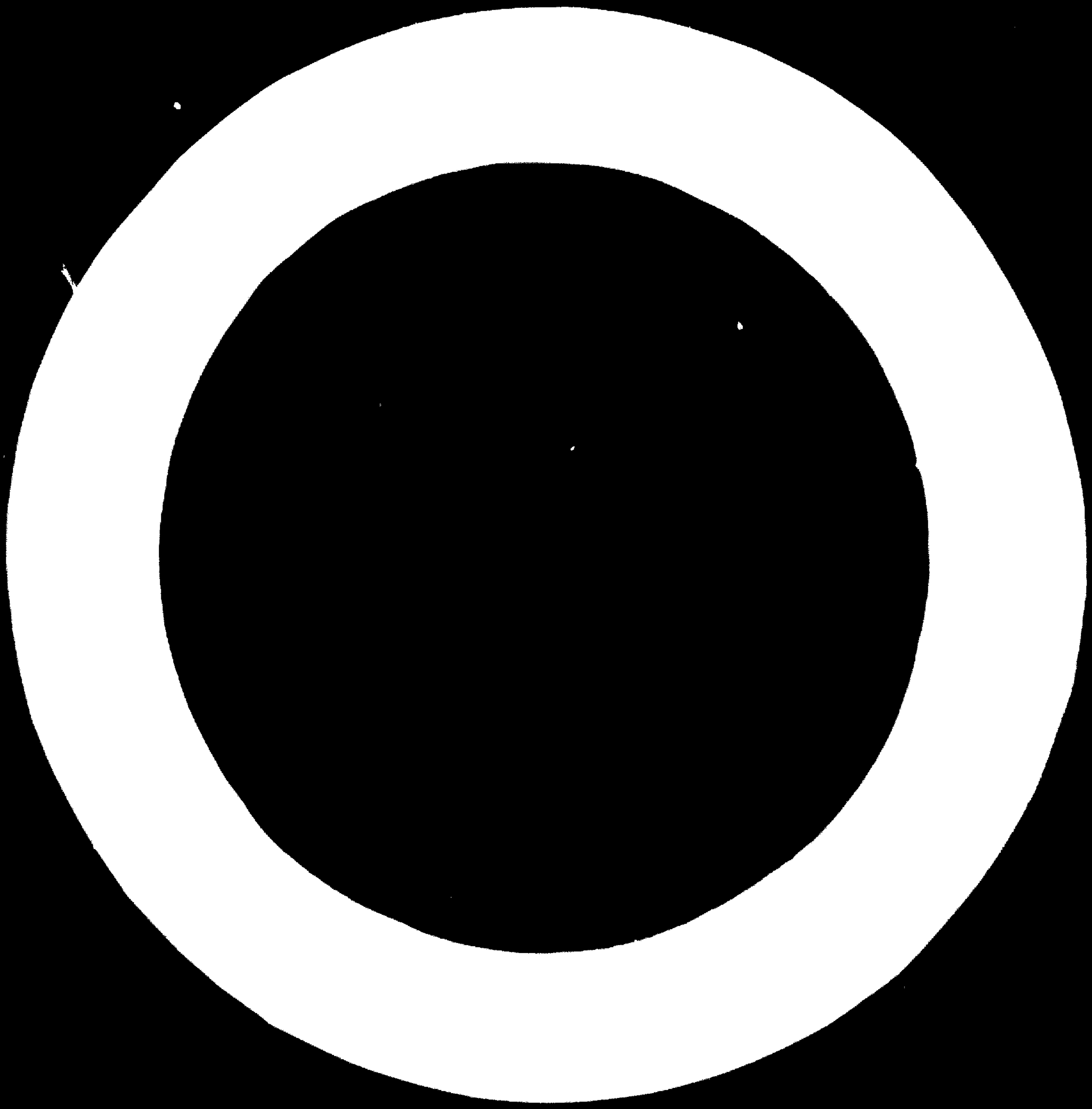
Wystite : FeO = " " 66.7%

Metallic iron: Fe = " " 0 %

Knowledge of the chemical reactions which take place during the production of pig iron ore is required in order to understand properly the prevailing technical and economical conditions. The equations 1 - 2 represent the well known step by step reduction of iron ore to metallic iron. Iron ore, in the form of red hematite, has the composition Fe_2O_3 and an oxidation degree of 100 %. In this type of ore, iron is at its highest oxidation stage. A lower oxidation stage is Fe_3O_4, which occurs as the black and dense magnetite ore with a oxidation degree of 88.8%. The formula FeO corresponds to a degree of oxidation of 66.7%. Wystite has a composition close to FeO. Finally metallic iron has a degree of oxidation of 0%.

In the reduction of hematite with solid carbon in a pig iron furnace, the ore will pass through the various oxidation stages. According to the first 3 equations the ore reduction may be considered as a primary reaction between solid iron ore and CO, with formation of CO_2. Part of this CO_2, however, will react with solid carbon resulting in regeneration of CO. In the pig iron processes the equilibrium and velocity of the reaction between carbon and CO_2 is decisive for the gas composition and carbon consumption. At 1000°C and above, the reaction 4 is completely displaced to the right in formation of CO, and the rate of reaction increases rapidly. This means that in pig iron furnaces close to 100 % CO is formed in the zones of the charge where the temperature is above 1000°C. The reduction of the iron oxide gives an increasing equilibrium concentration of CO_2 in the gas as the oxidation degree increases. This means that the equilibrium for formation of high content of CO_2 in the gas is much more favourable at the beginning of the reduction than towards the final stage. To simplify the matter the chemistry may be considered as follows:

Production of liquid pig iron from ore comprises endothermal chemical reaction and heating of the reaction products to high temperature. The energy requirement is covered, in the electric furnace, partly by utilization of the heat from carbon oxidation, and partly by electric power. To the extent that CO_2 is formed in the charge by reaction between oxygen in



the charge by reaction between oxygen in the ore and carbon in the coke, the carbon consumption is only 50 %, although the heat liberation is considerably higher. The formation of CO_2 takes place in the temperature range 800 to 950°. The retention time of the charge in this temperature range in the electric furnace is so short [illegible] smelting [illegible] charge that a special [illegible] charge [illegible] CO_2 formation or indirect [illegible]

7. PREREDUCTION

In addition to the physical charge preparations by screening and agglomeration, the electric pig iron process is ever more drastically improved by thermal and chemical pretreatment. Hereby a new process step has to be adopted - prereduction. Prereduction may be introduced in addition to sintering, or combined with agglomeration.

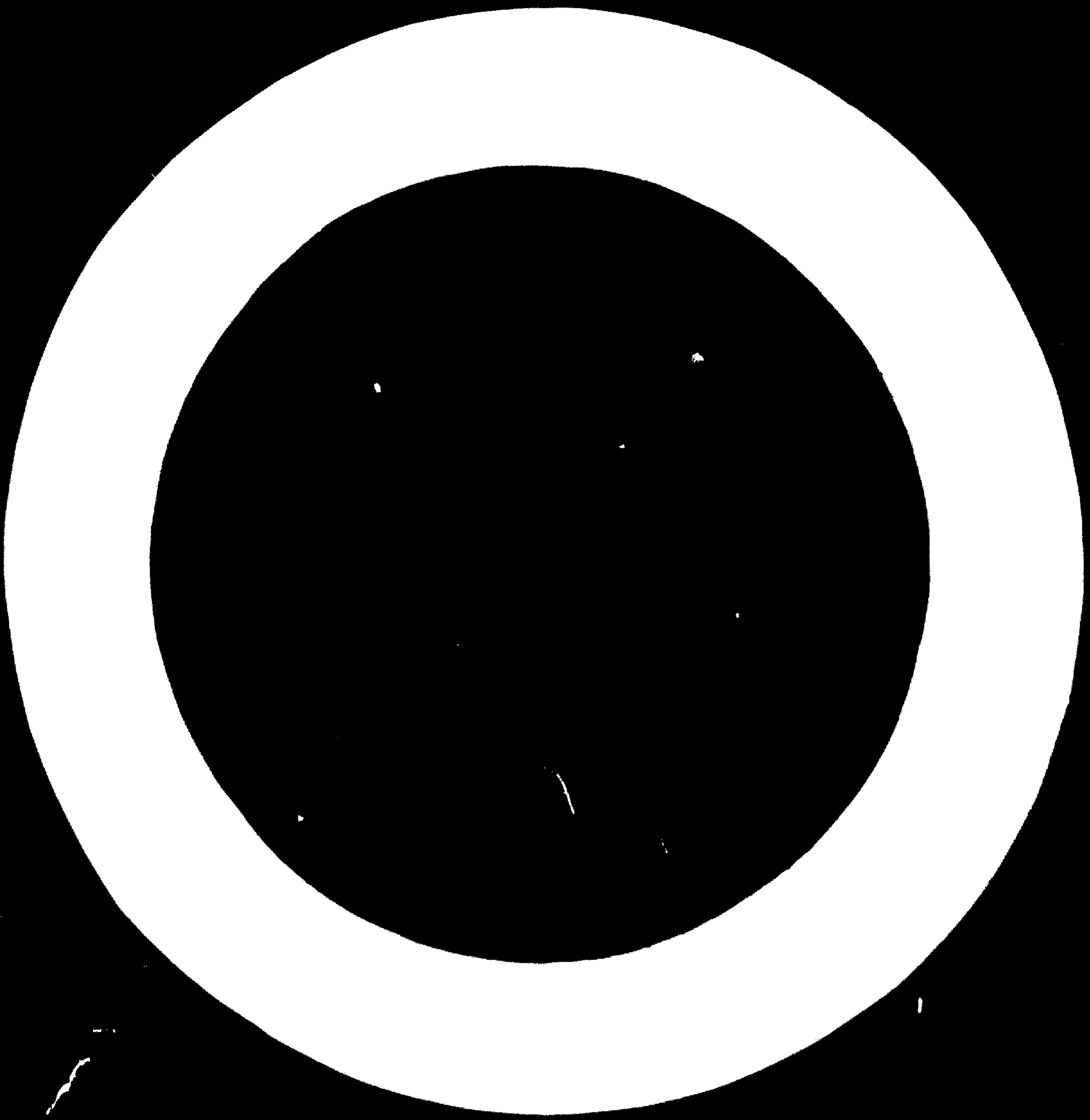
Different research institutes and private companies have attempted to develop prereduction. Independent groups in USA and Canada, and also groups in Japan, have worked intensively for improving the electric iron ore reduction. The object has been to make the process competetive with the conventional blast furnace in areas mainly supplied with thermal power. Comprehensive tests have been made with the Strategic-Udy process using a rotary kiln for preheating and prereduction followed by electric smelting with a special technique. This process is based on the late dr. Marwin Udy's inventions. The Udy process facilitates selective reduction of complex ores and allows the use of fine-grained charge. Further, the process is well suited for direct production of semi-steel with medium or low carbon content.

Independently, Elektrokemisk have undertaken research and development work on preheating and prereduction. A summary of the methods used and some results obtained will be given here.

8. SHAFT PREHEATING

A simple way to improve the performance is to preheat the complete charge in shafts installed directly above the electric furnace. In Elektrokemisk's Research Station, at their ferro-alloy smelter at Fiskaa Verk near Kristiansand in South Norway, a number of pilot plant shafts and a commercial-size prototype shaft have been built. A pilot shaft for a capacity of 500 to 1000 kgs of charge per hour is erected directly above an electric furnace. Here the complete charge is heated counter-currently in a stream of hot combustion gases. Fuel oil or CO gas from the electric furnace is burnt with a controlled quantity of air and the hot gases are passed through a bed of charge in the shaft.

A considerable number of tests has been made with different iron ore and sinter charges. Reduced power consumption and increased production are obtained not only due to the sensible heat in the charge, but also due to more indirect reduction (exothermal formation of CO_2 by gas reduction), in the electric furnace.



Ore	% Fe	Cold charge			Hot charge		
		% CO_2	kgs Fixed C per metric ton	kWh per metric ton	% CO_2	kgs Fixed C per metric ton	kWh per metric ton
Magnetite Lump Ore	56	9	295	2350	23	284	1800
Self-fluxing sinter	54	14	308	2080	41	286	1580

The main purpose of the pretreatment in shafts is to preheat the charge. The preheating is accompanied by a small amount of prereduction when using ore carbon pellets. By shaft preheating, a considerable CO_2 formation in the electric furnace occurs. This is due to the fact that the retention time of the charge in the electric furnace in the important temperature range 800 - 950° is increased. Hereby a reduced consumption of carbon as well as power is accomplished.

The combination of preheating shaft and electric furnace in some respects makes the electric smelting process adopt some of the same features as the blast furnace process.

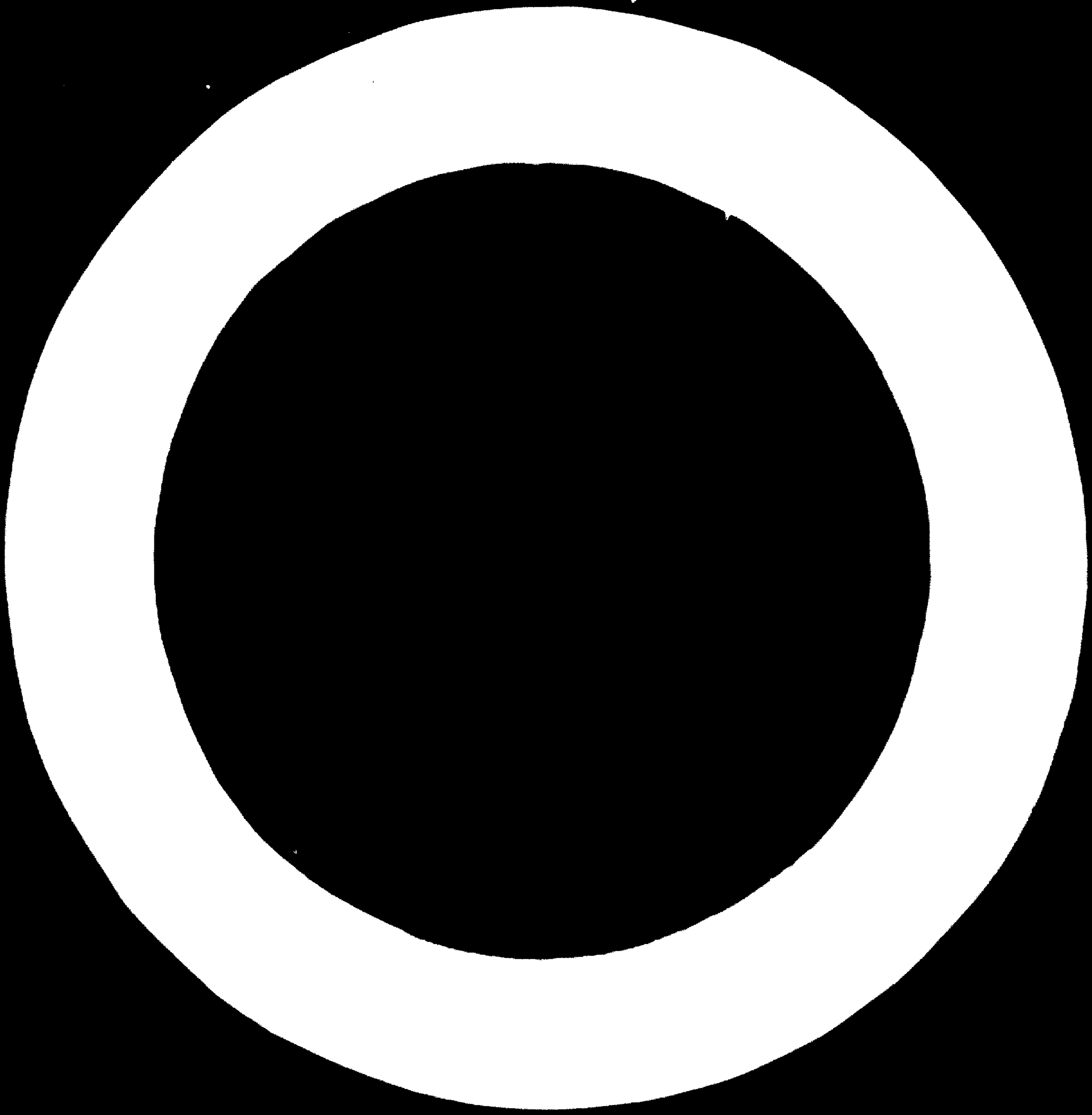
The charge is first heated to reaction temperature in a shaft, then kept in the important temperature range for indirect reduction in contact with CO at 800 - 950° and finally smelted and iron carburized. In the blast furnace the CO/CO top-gas is used for preheating the blast. In the improved electric smelting process the CO-gas covers the requirements for preheating of the charge, thereby improving the over-all heat balance.

9. ROTARY KILN

A mixture of iron ore, limestone and coke (or raw coal) is heated to about 1000°C in rotary kiln, whereby reactions between iron oxides and carbon is started, without fusion of the charge. The kiln product is transferred hot to the electric furnace in insulated containers.

The prereduction kiln is of the same type as used in other industries, for instance for burning of Portland cement clinker. These kilns are mechanically strong and have a long life. By placing thermo-couples through the kiln lining the temperature may be accurately controlled, so as to make sure that the working temperature is below the softening point of the charge. Thereby the cumbersome formation of rings is avoided. CO gas produced from reaction between iron oxides and carbon in the charge is burnt above the charge bed in the kiln by air supplied in controlled quantities through ports in the kiln shell. This supplies heat for the iron ore reduction.

Raw coal is a preferred reducing agent for kiln prereduction. By feeding raw coal through special scoop feeders directly through the kiln shell, an instantaneous carbonization of coal takes place due to the contact between the coal and the hot charge in the kiln. Hereby ring formation on the kiln lining is avoided even with strongly baking coals. This type of



coal charging sideways into the kiln liberates volatiles from the coal which burns with oxygen in the kiln and supplies additional heat of combustion for the prereduction and preheating of the charge. Many types of raw coal produce char of high chemical reactivity, advantageous for high rate of reduction in the kiln.

By combustion of all CO gas formed in the kiln and electric furnace as well as volatiles from the coal, 50 % or more of the oxygen in the ore may be removed by prereduction in the kiln. Preheating and prereduction decreases power consumption drastically with corresponding increase in the iron production. In the Fiskaa pilot plant test with high-grade ore from Algeria and Labrador and sintered magnetite pellets, power consumption figures in the range of 700 - 1300 kWh have been obtained. With low-grade silicious ore, the range 1500 - 1800 kWh is typical.

For industrial use of the combination rotary kiln/electric furnace, the kiln would have to be placed on unreasonably high foundations if the hot charge should be transferred directly to the electric furnace charge openings. The practical arrangement on a large scale, therefore, is to place the rotary kilns on normal foundations at ground level, discharge the hot prereduced material into a surge bin and transport in insulated containers to the electric furnace feed bins.

10. NEW INDUSTRIAL INSTALLATIONS

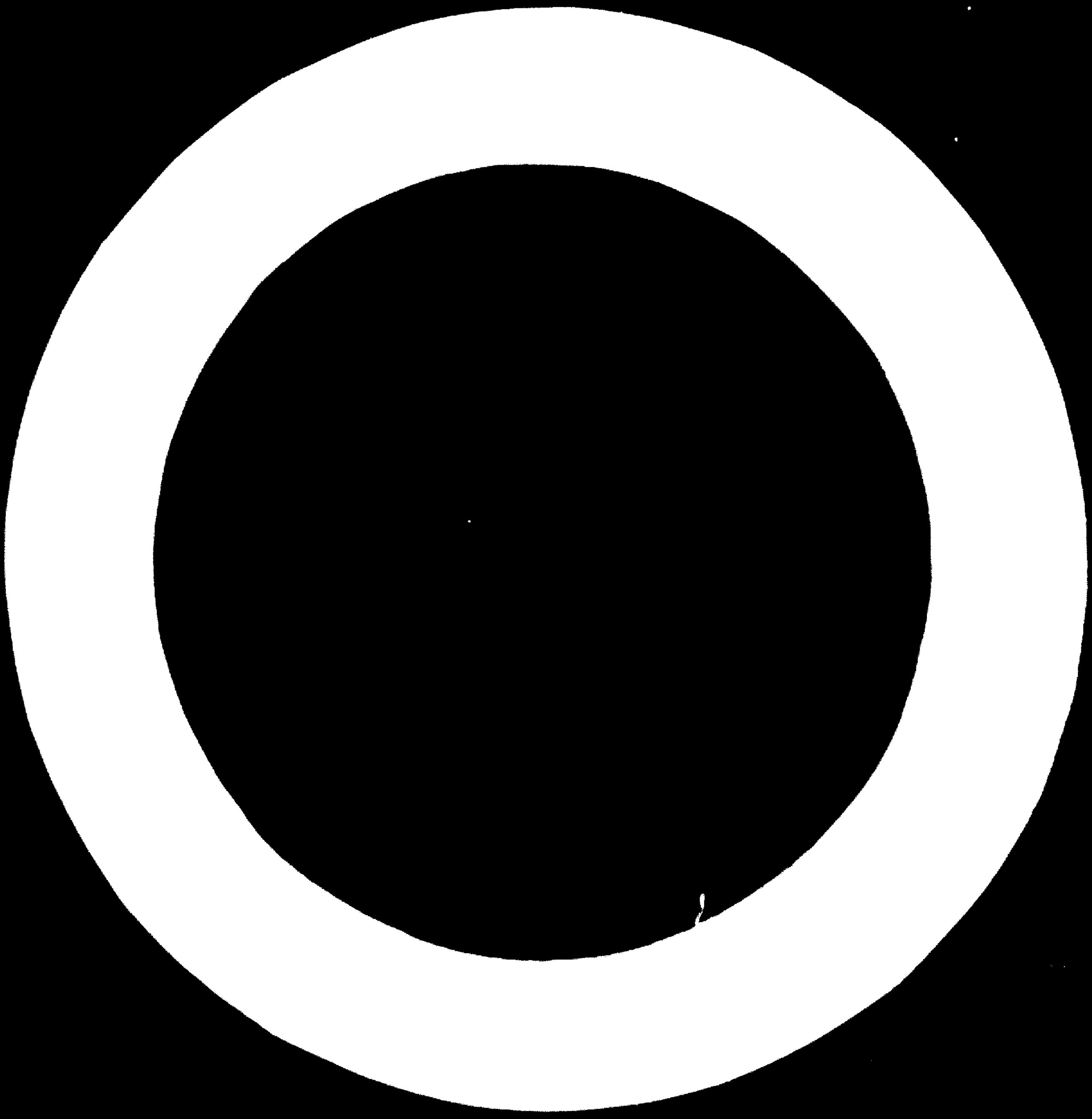
Preheating in rotary kiln with transfer of hot feed has already been in operation since 1958 in four 13, 5 MVA ferronickel furnaces belonging to S.A. Le Nickel at their New Caledonia Plant. A description of the plant and operation in New Caledonia has been published in Journal of Metals, March 1960.

The smelting technique adopted in this large plant, which now consists of 5 electric furnace units, originates from three smelting test campaigns at Elektrokemisk's Research Station.

A plant with one 4.8 MVA ferronickel furnace smelting preheated charge from a rotary kiln has been started up recently in Brazil by Morro do Nickel S.A.

In the pig iron field Rudnici I Zelezara SKOPJE in Jugoslavia is installing 3 34, 5 MVA furnaces, each with a rotary kiln. Further expansion is planned by the authorities. Here a low-grade chamosite ore, limestone and raw lignite coal will be heated in F.L. Smidth rotary kilns with scoops for feeding the lignite directly through the kiln shell. Despite the very low grade of the ore, the CO gas produced in the kilns and electric furnace and hydro-carbons and other volatiles from the lignite coal will cover the heat requirements for drying and heating of the charge in the kilns as well as partial reduction of ore and calcination of limestone.

Sinai Manganese Corporation have recently ordered a rotary kiln and 13, 2 MVA electric furnace for extraction of pig iron and ferromanganese from low-grade iron manganese ore in Egypt.



In Portugal a 13.2 MVA pig iron furnace installed five years ago for conventional pig iron smelting is now being rebuilt for shaft preheating of the charge. Presumably this plant will be in operation within the end of 1962.

In addition to these new ELKEM installations, furnace No. 9 in the Venezuelan pig iron plant is presently being rebuilt in cooperation with Stratmat Ltd. and Koppers Inc. for the use of the Strategic-Udy technique in prereduction and smelting.

II. THE ECONOMY OF ELECTRIC PIG IRON SMELTING

A complete and detailed study of the costs involved in pig iron production is a complicated matter. However, sufficiently accurate data for comparison between different processes are achieved by considering the main cost items.

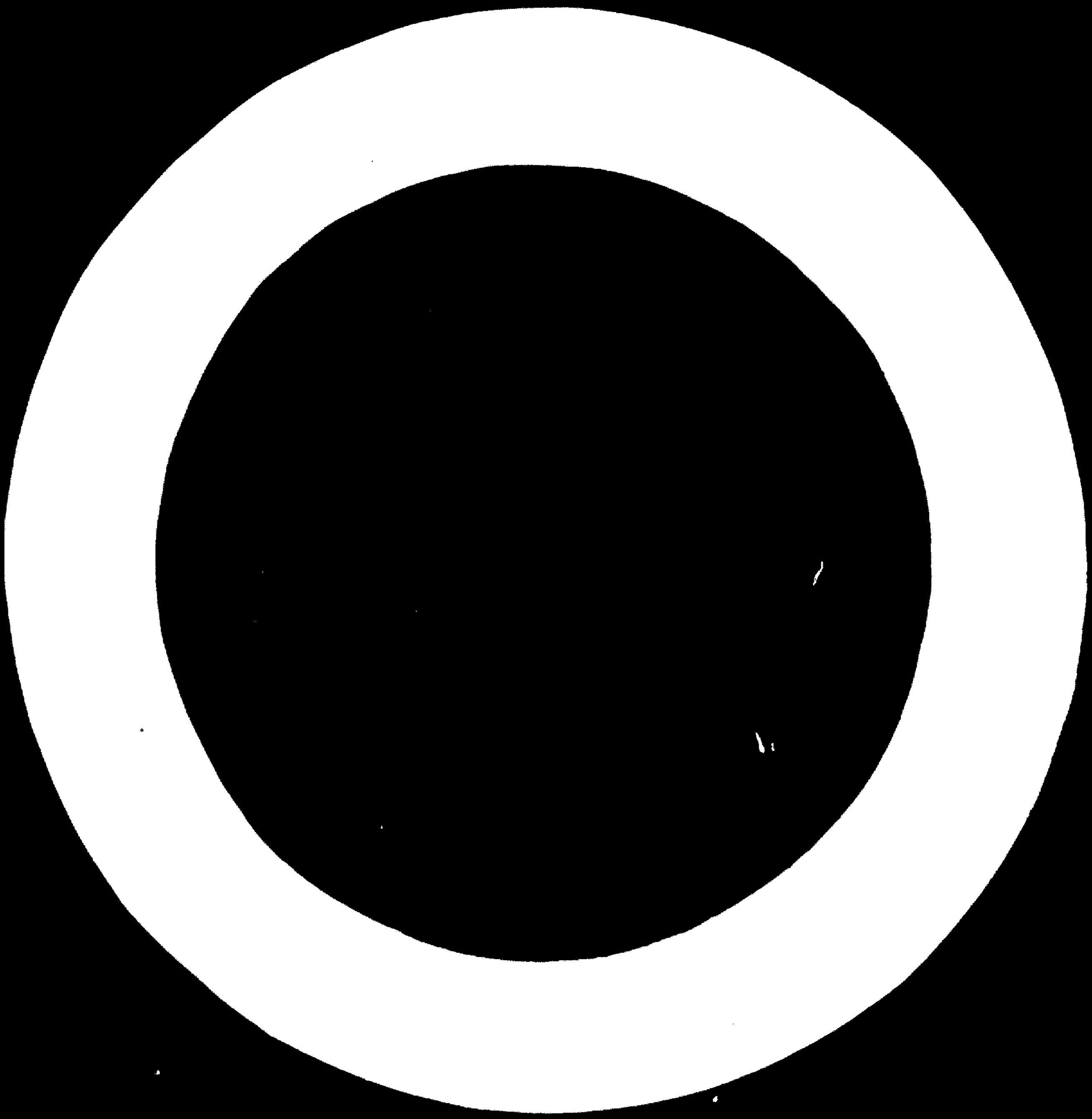
As in the blast furnace smelting the cost of the ore is very often the largest single cost item. Also for electric smelting concentration of the ore by mechanical ore dressing is preferable to smelting low-grade ore. Sintering of the fines i[illegible] cases is preferred for prereduction and smelting of fines. Gener[illegible]e, the ore cost is the same for blast furnace and electric pig [illegible] is a[illegible]sposal. [illegible] electric pig iron smelting the field of ores that are [illegible]s wider. Particularly the use of titaniferrous iron [illegible] prospects for pig iron production based on the cheap iron-sand c[illegible] in the coastal areas of many countries of the world. So far electric smelting of iron sand concentrates has only been developed in Japan. However, with reduced power consumption by prereduction the utilization of beach sand in the electric furnace industry is likely to expand considerably in the coming years.

Another important cost factor is the cost of carbon for reduction and supply of thermal energy for the process. Here the blast furnace depends on hard coke with high resistance to abrasion and lump size between 30 and 100 mm.

Traditionally in Europe electric pig iron smelting has mainly been based on gas coke and gas coke breeze. Gas coke has lower abrasion strength and higher reactivity than metallurgical coke and is actually a somewhat better reducing agent for the electric furnaces. By introduction of preheating and prereduction, raw coal even high volatile coal and lignites, may be used as reducing agents. Raw coal is carbonized by successive heating in the preheating or prereduction step. Hydrocarbons and hydrogen are developed and participate in the prereduction, and supply heat by combustion with air for the preheating and prereduction process.

There is in many areas of the world a very substantial price difference between raw coal and blast furnace coke. This makes raw coal favourable as reducing agent for pig iron production. The lower consumption of carbon and the use of raw coal cut down the carbon costs considerably for electric, as compared to blast furnace smelting.

For electric pig iron, the cost of electricity has to be considered. Before prereduction was introduced, the electric process was only economical



for areas with supply of cheap power. With prereduction of the iron ore, the power consumption can be brought down to the same order as for electric steel smelting. Electric power produced in thermal power stations comes into the picture now for electric smelting. In areas with cheap fuel in the form of coal, oil or natural gas, power can be produced at low or medium cost in modern power stations. The diagram of Fig. 9 shows the cost of thermal power as a function of the fuel price. The cost of installation is estimated to 140 US dollars per kWh and the fuel consumption 2500 kcal per kWh. The fixed charges are 2.7 US mills per kWh while the fuel expenses are propertional to the price of fuel. Considering for instance the price of large tonnage of heavy fuel oil in ports around the world as about 13 - 14 dollars, the corresponding power price is abt. 7 US mills. With this power price the electric pig iron process is competetive in many areas of the world.

12. FUTURE TRENDS

Electric pig iron smelting is a special iron ore reduction process used and under installation in 17 different countries. The electric furnaces are used not only in small iron works, but also in integrated iron and steel works of intermediate size with 300.000 - 700.000 tons annual capacity. The obvious fields for electric smelting of iron ore are areas in the world where coking coal of suitable quality for production of metallurgical quality coke is not available, while electric power such as water-power or cheap thermal power is at disposal.

By reduction of the power consumption and increase in furnace unit capacity, the pig iron process may gradually achieve a more important part of the new pig iron production capacity, perhaps mainly by expansion to countries and areas which have not so far developed steel industry. The great tolerance of the electric furnace with regard to quality of iron ores and reducing agents will justify electric smelting for new pig iron plants. Each project has to be examined very carefully with testing of the raw materials concerned to find the cheapest solution with regard to installation and operating costs.

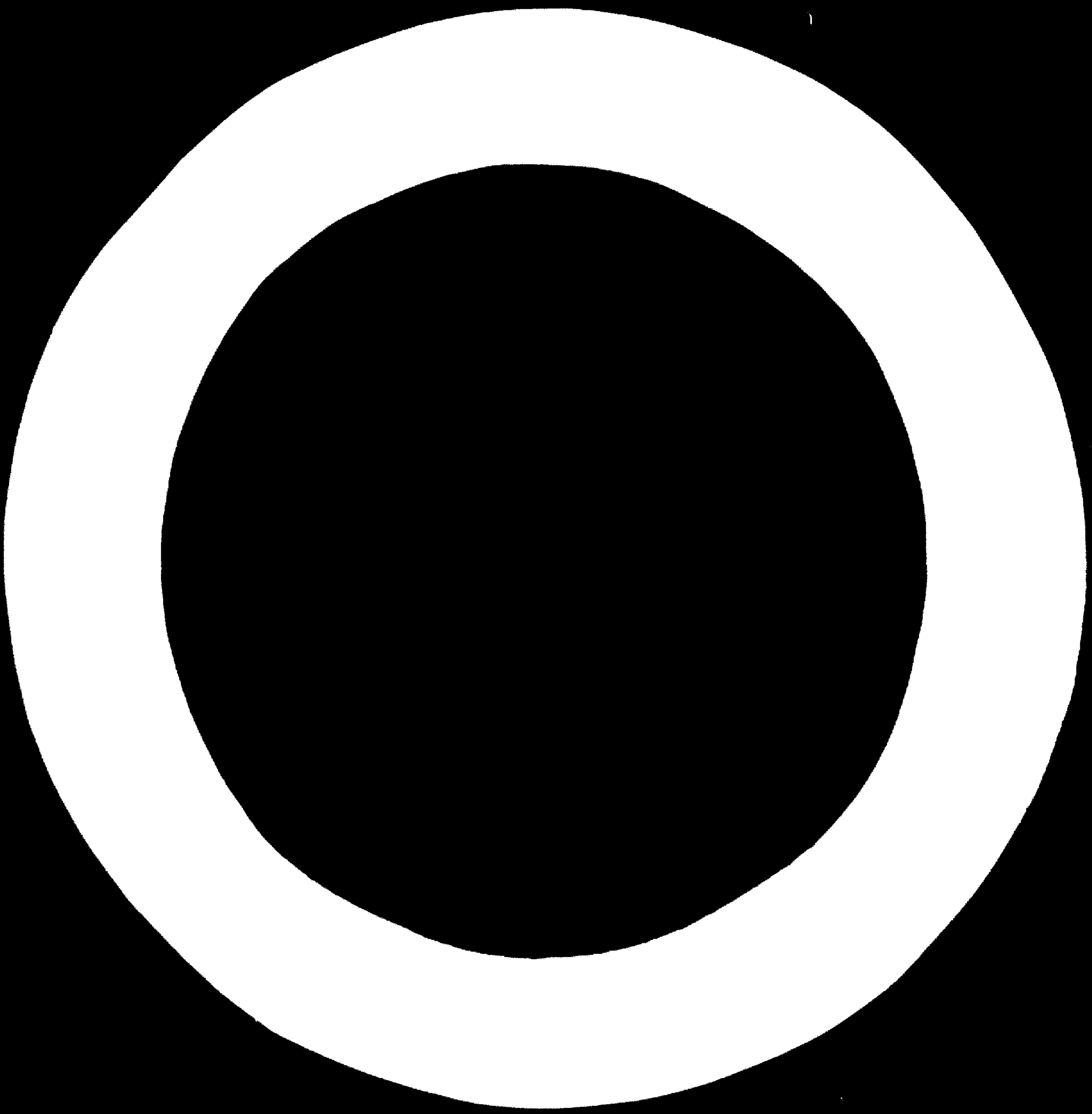


Table 1.

	Number of furnaces in operation	MW	Number of furnaces under construction	MW	Total number of furnaces	Total MW
Canada	1	10.0	1	20.0	2	30.0
Egypt			1	10.0	1	10.0
Finland	1	10.0			1	10.0
India	2	20.0			2	20.0
Israel	1	13.5	1	13.5	2	27.0
Italy	13	101.5			13	101.5
Japan	2	18.5			2	18.5
Norway	5	110.0	2	80.0	7	190.0
Peru	2	20.0			2	20.0
Philippines			2	28.0	2	28.0
Portugal	1	10.0			1	10.0
Spain			1	6.5	1	6.5
Sweden	6	50.0			6	50.0
Switzerland	1	8.5			1	8.5
Venezuela	9	198.0			9	198.0
Yugoslavia	3	30.0	3	78.0	6	108.0
	47	600.0	11	236.0	58.	836.0

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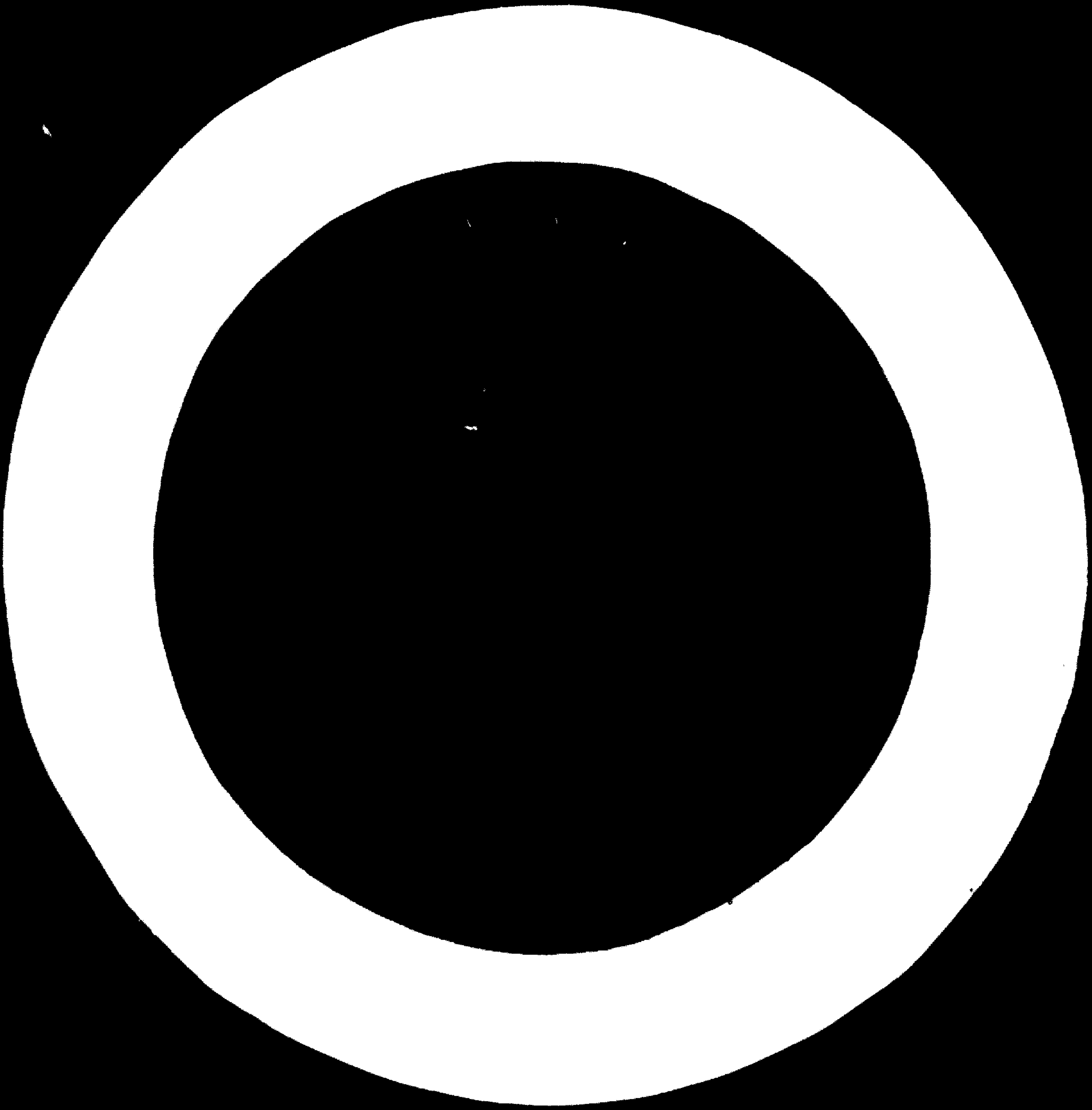


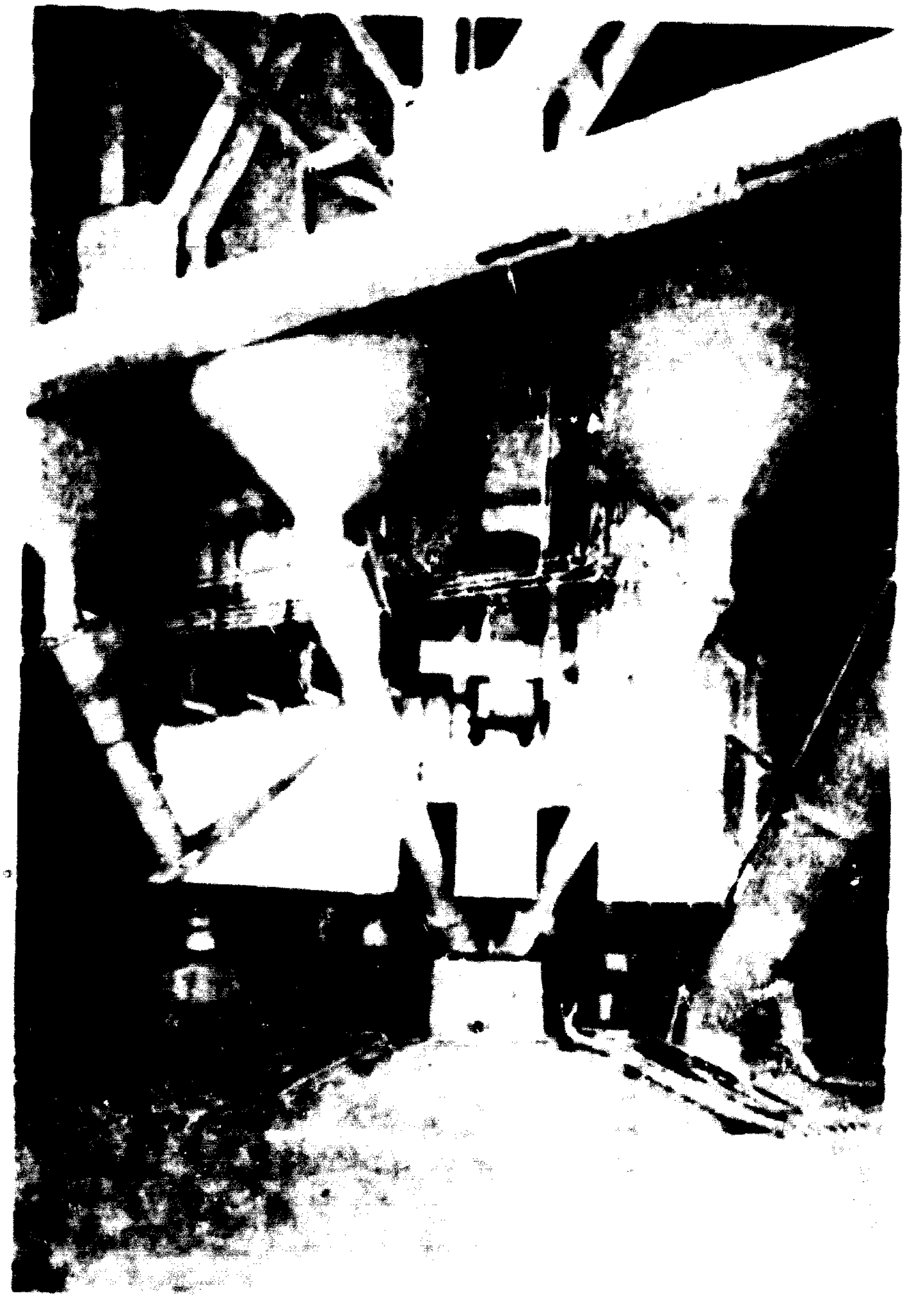
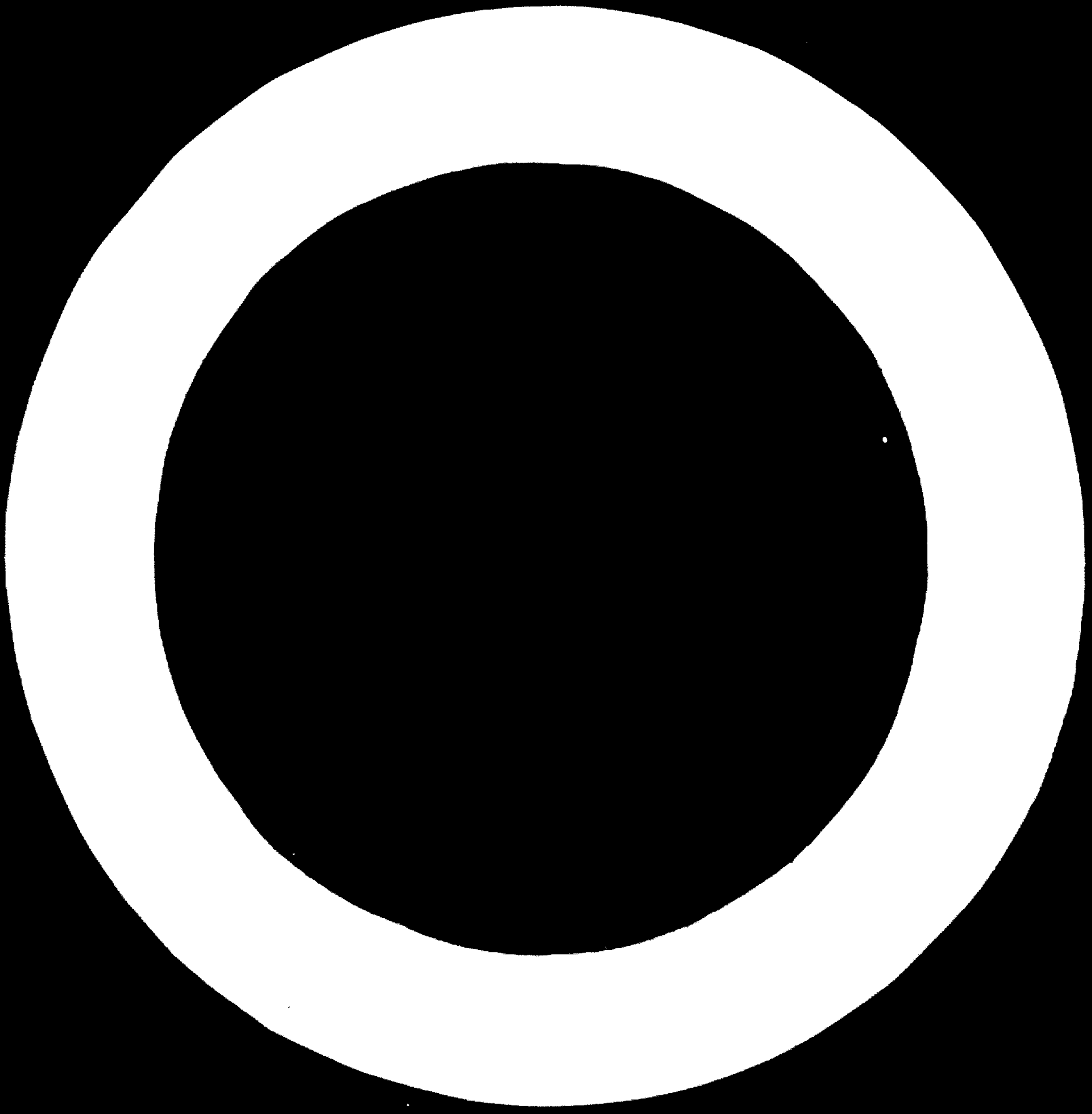


Fig. 1. From Bremanger Smelteverk, Svelgen, Norway.



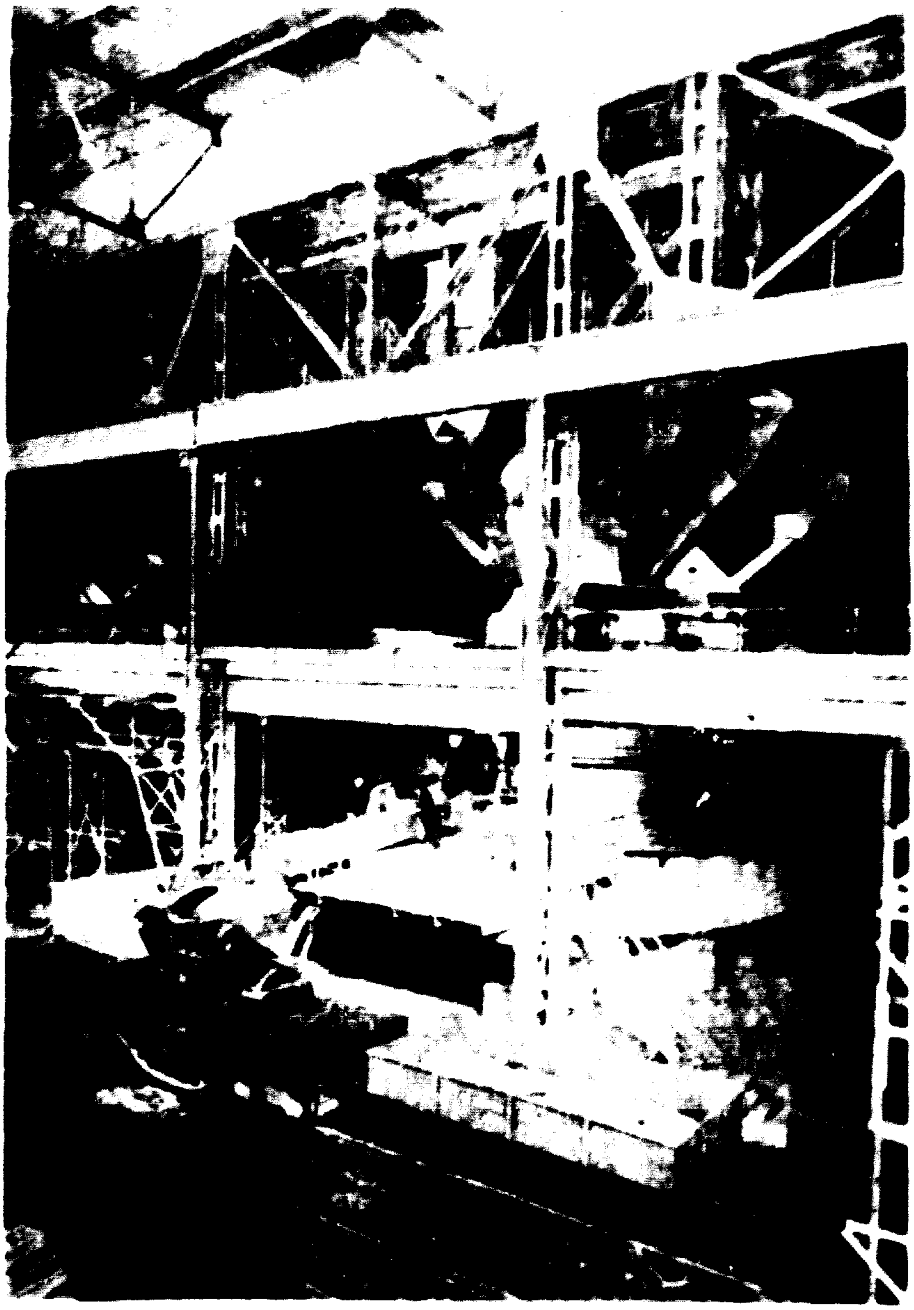
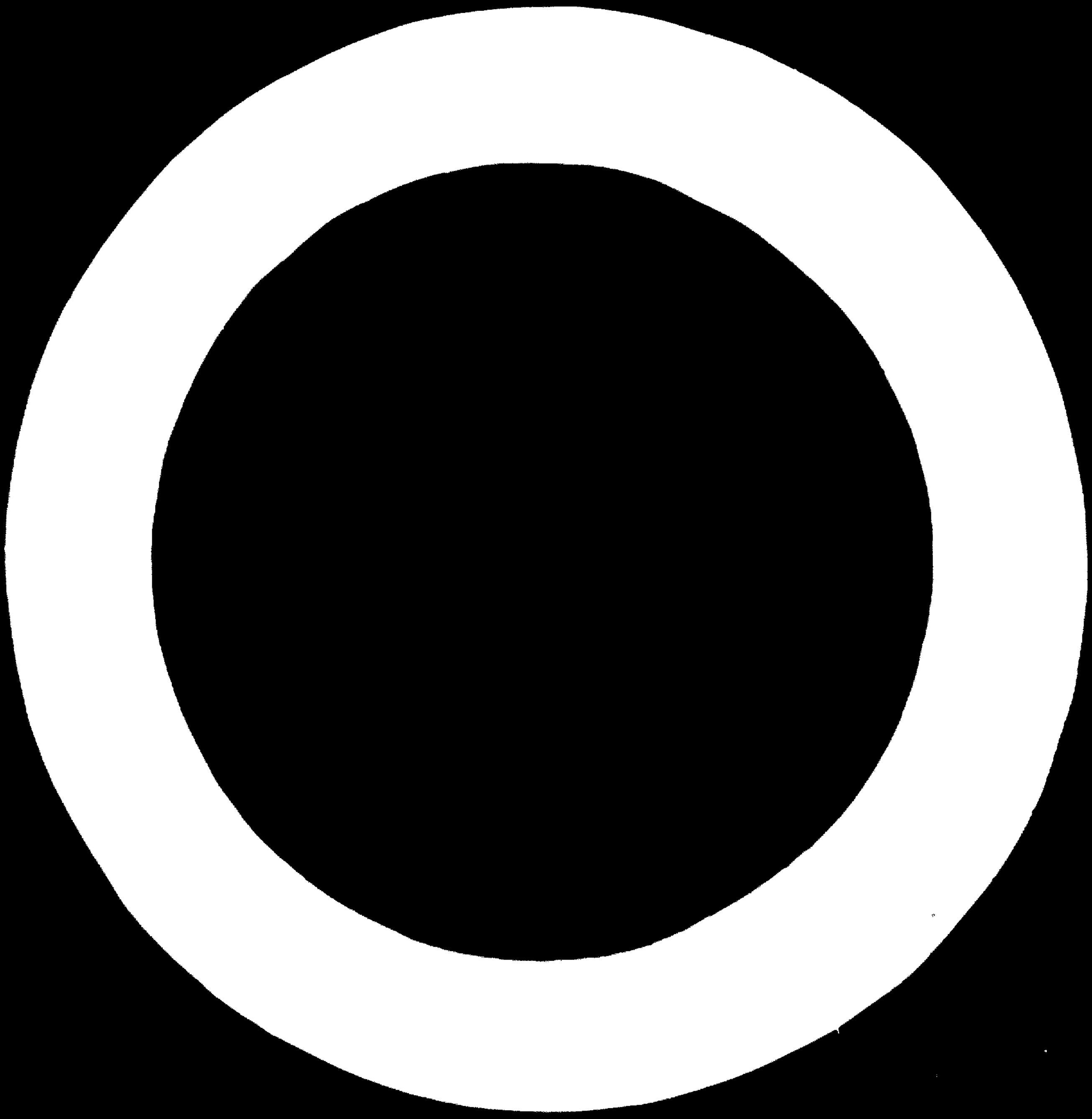


Fig.2. From [illegible]



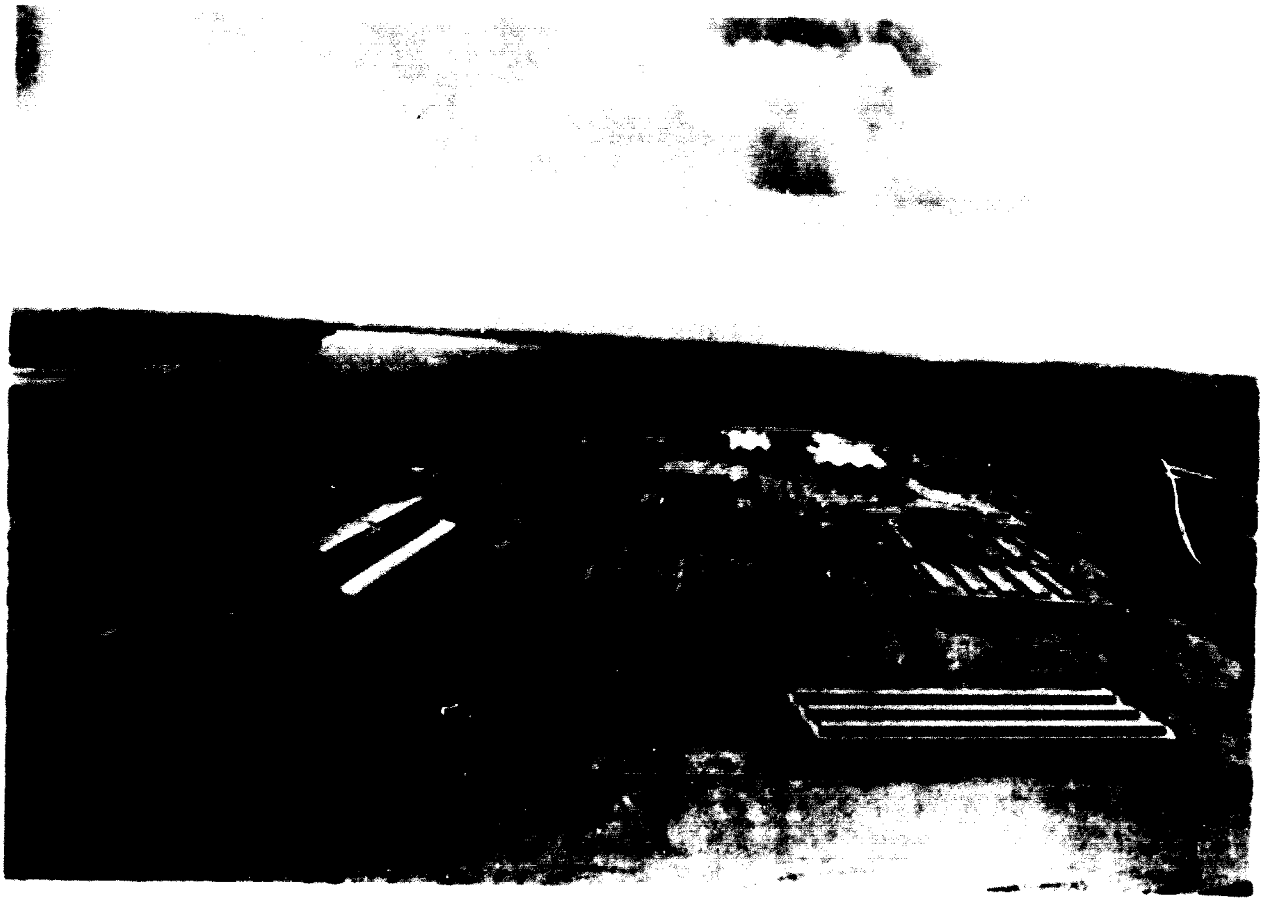


Fig. 3. From Corporacion Venezolana de Guayana, Matanzas.

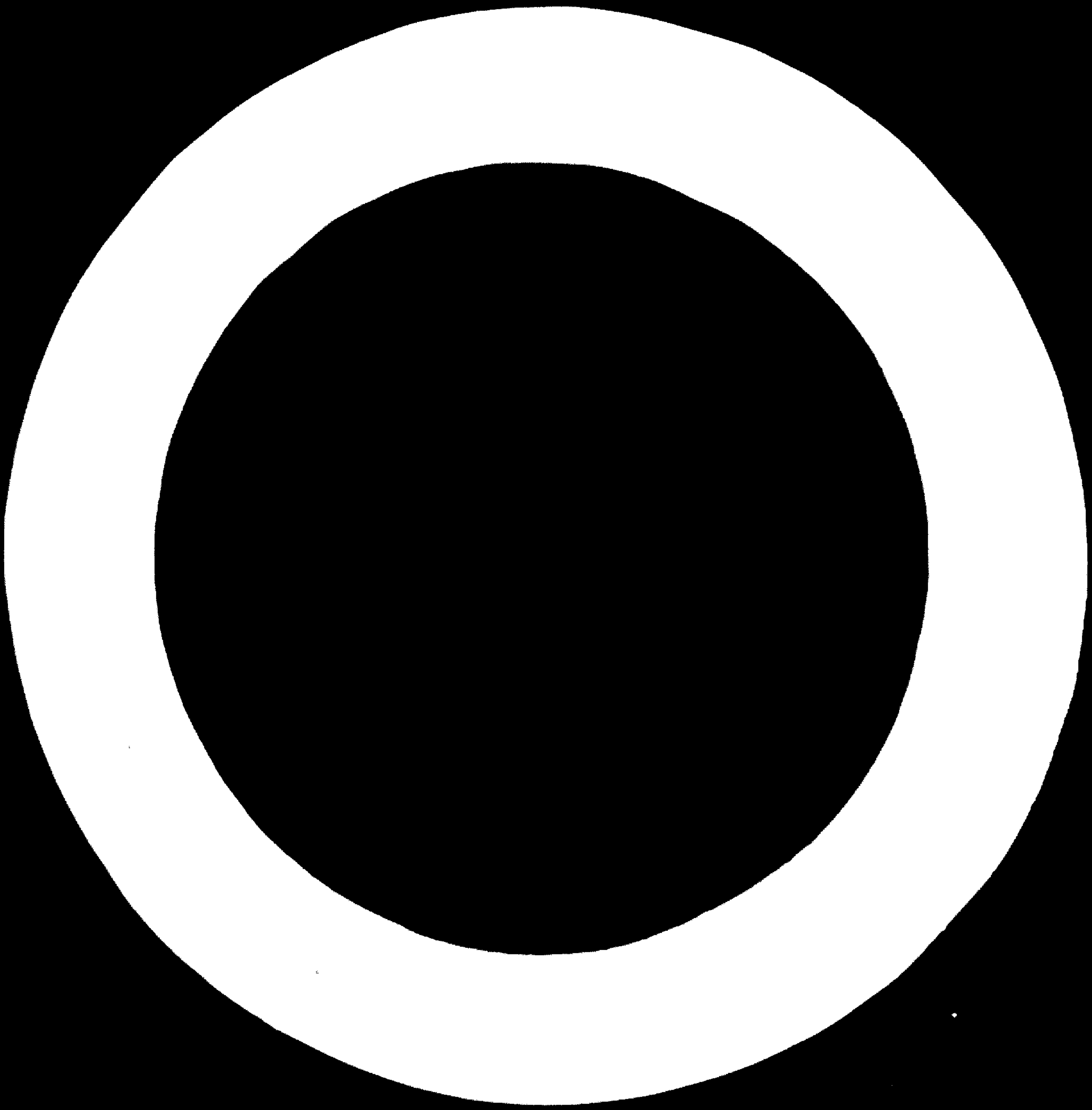
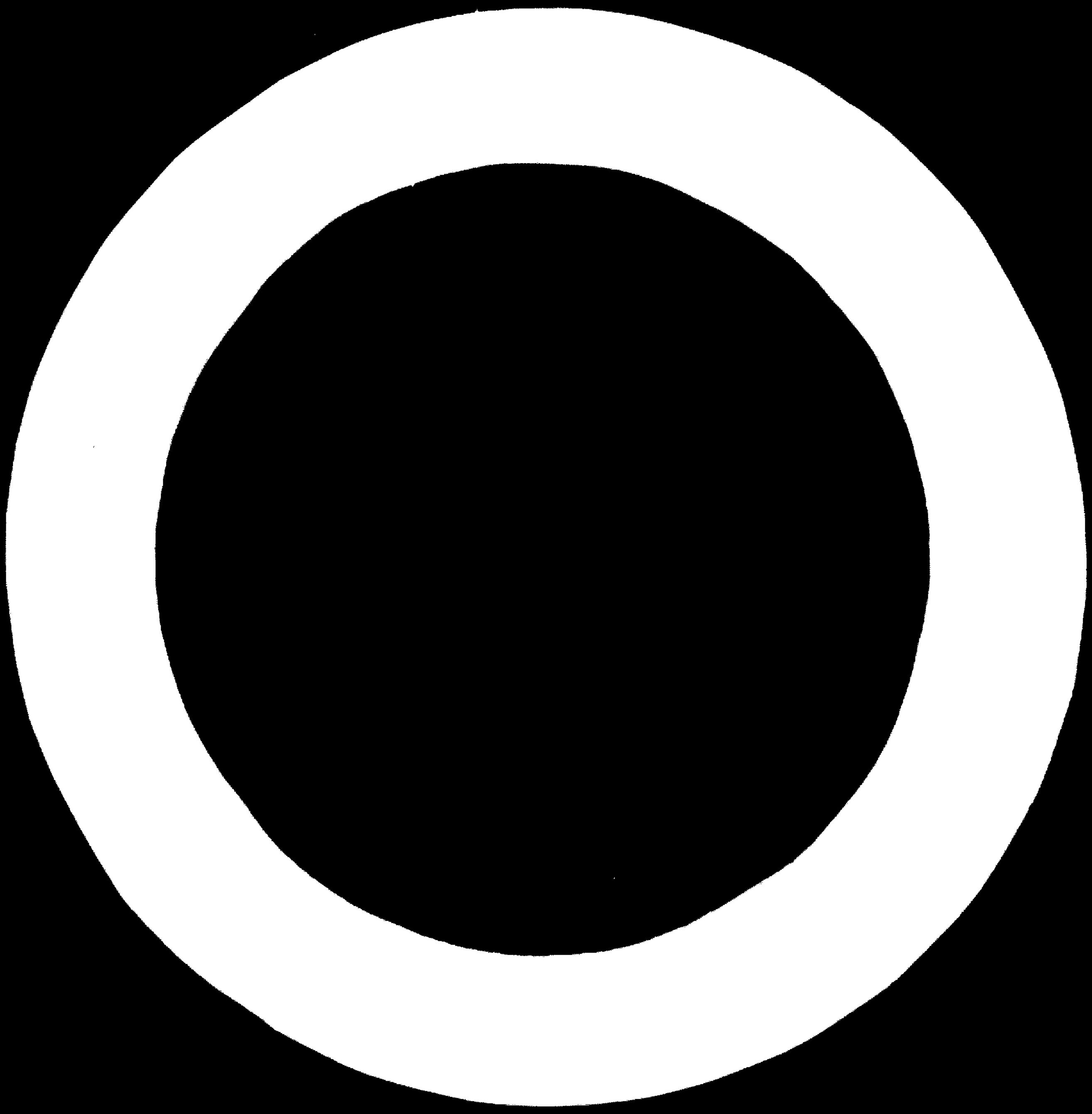


Fig. 4. Pilot Preheating Shaft, Elektrokemisk A/S, Fiskaa Verk, Norway.



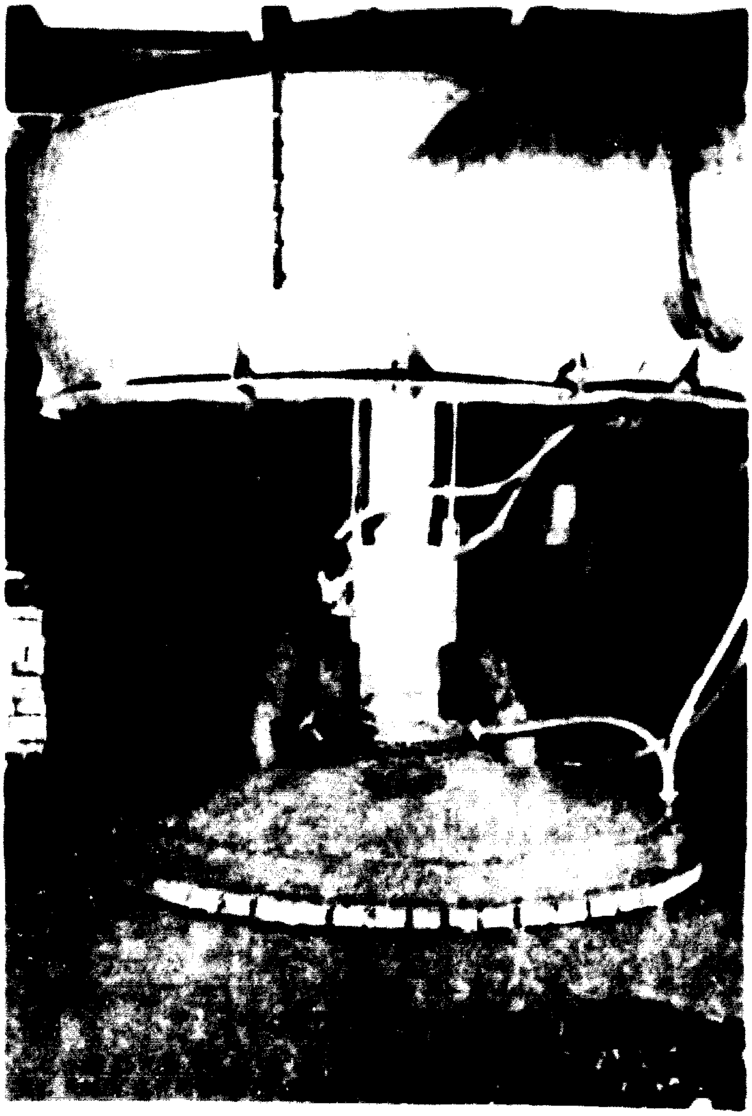
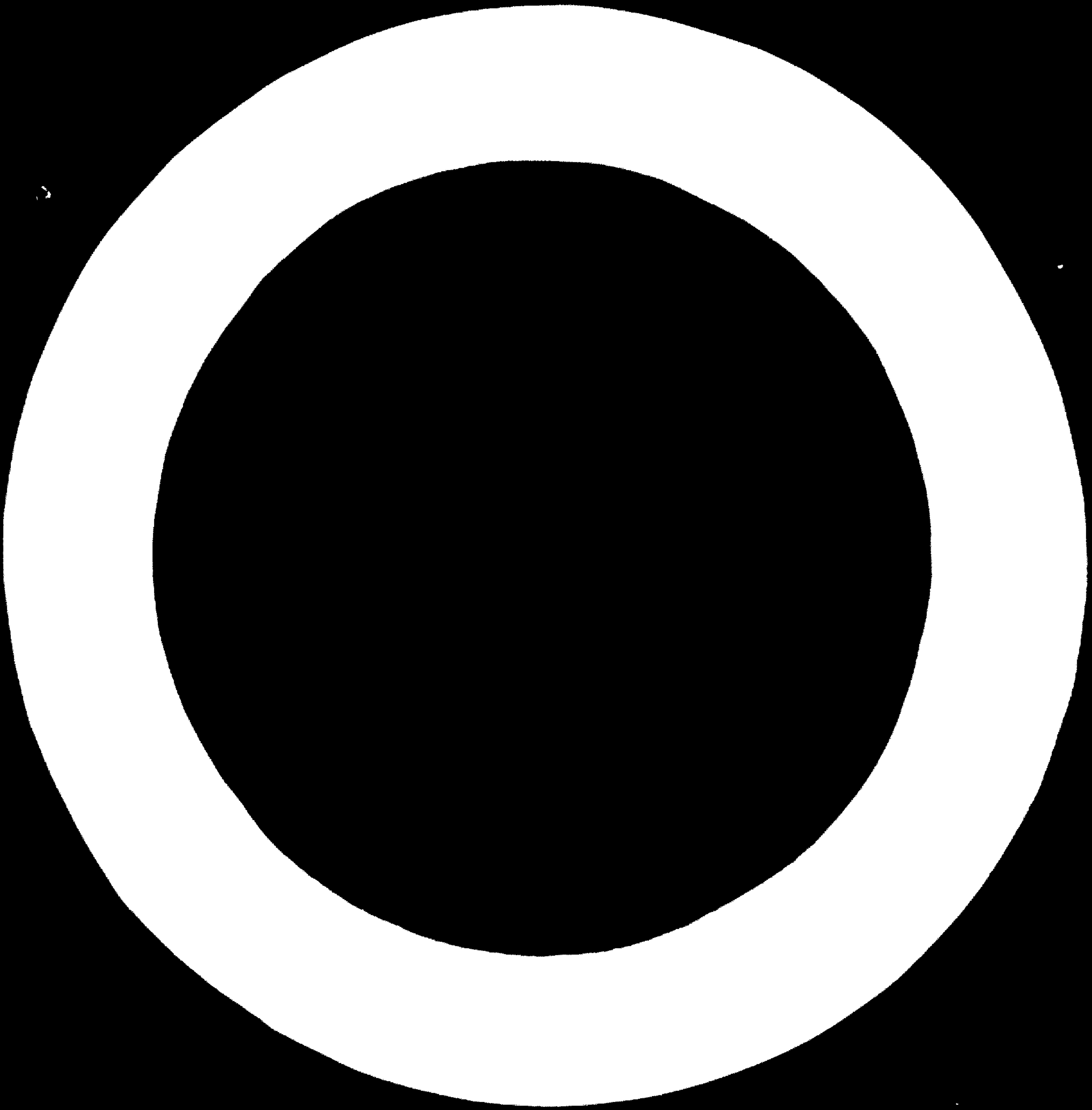


Fig. 5. Pilot Furnace for Shaft-preheated Charge.



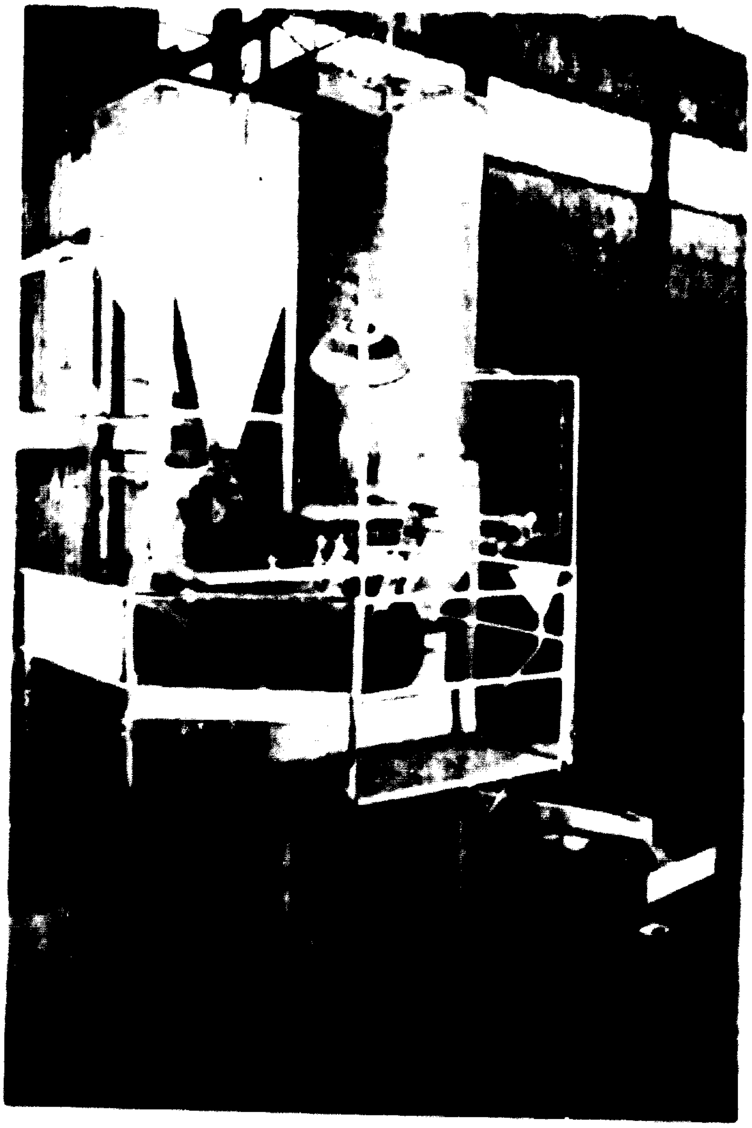


Fig. 6. Pelletizing Plant at Fiskaa Verk

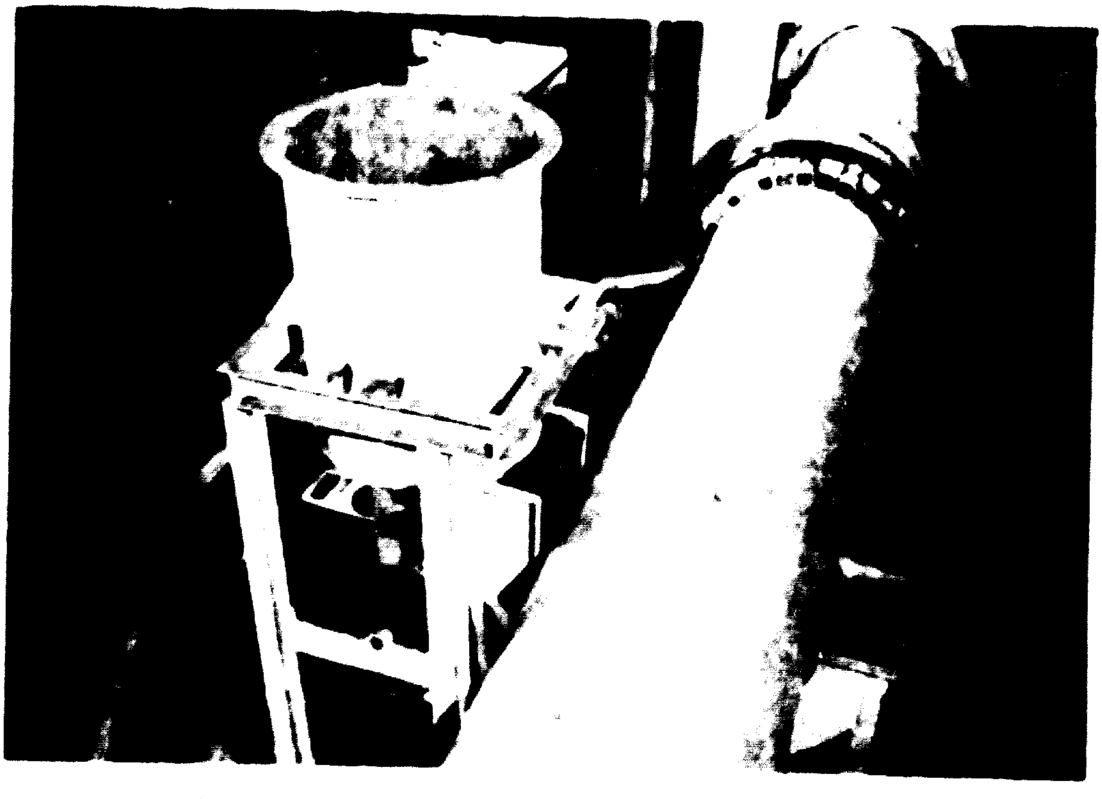
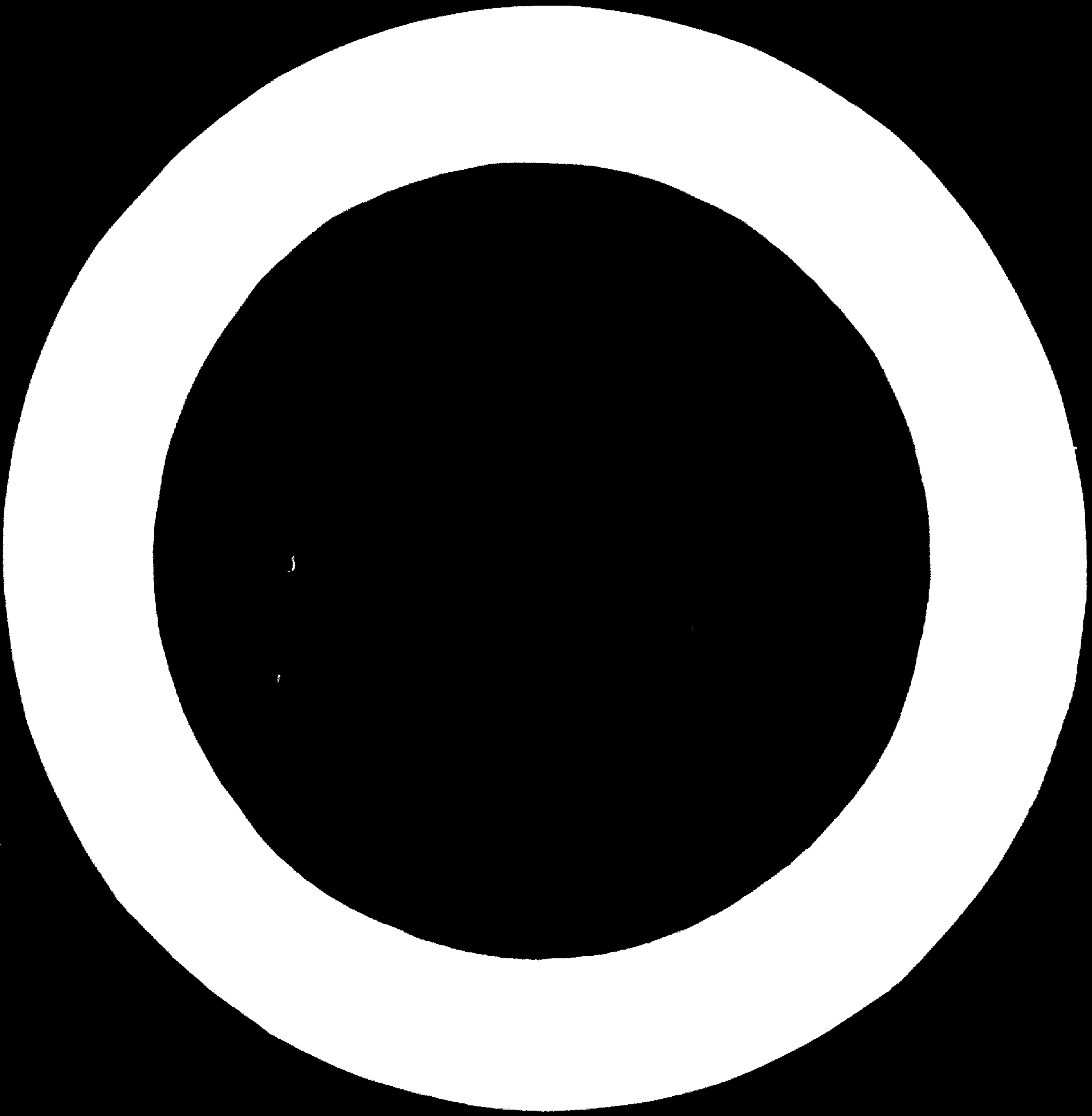


Fig. 7. Pilot Rotary Kiln, Fiskaa Verk



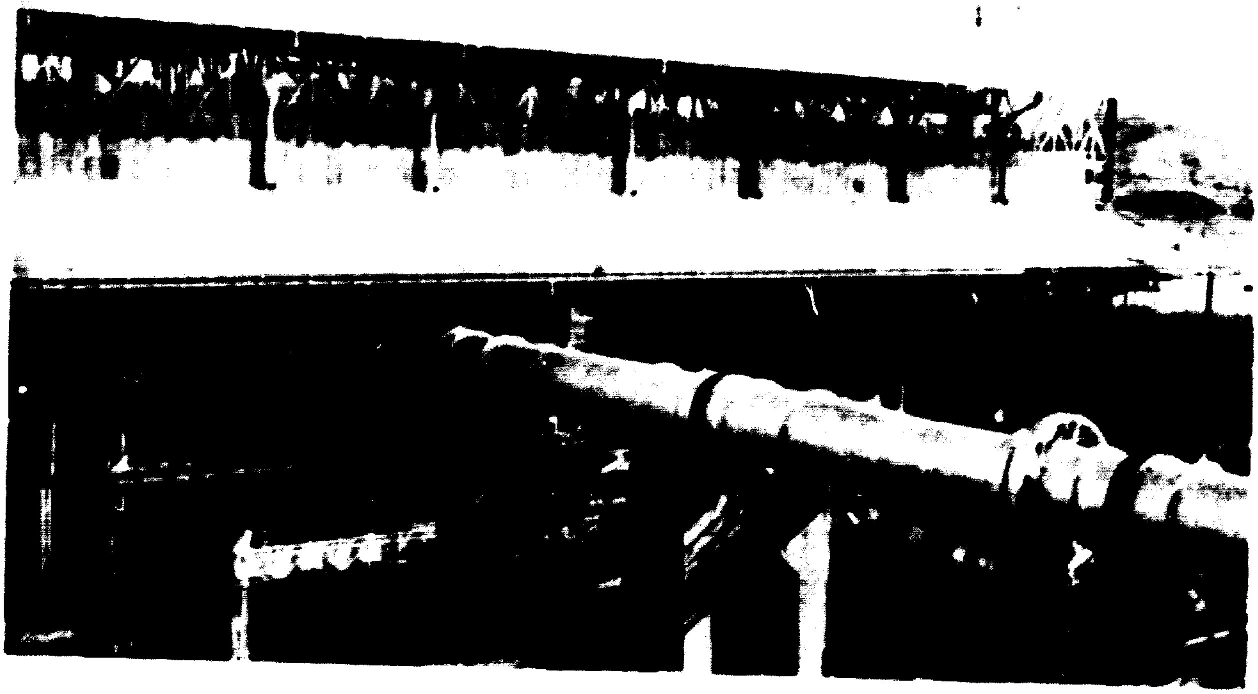
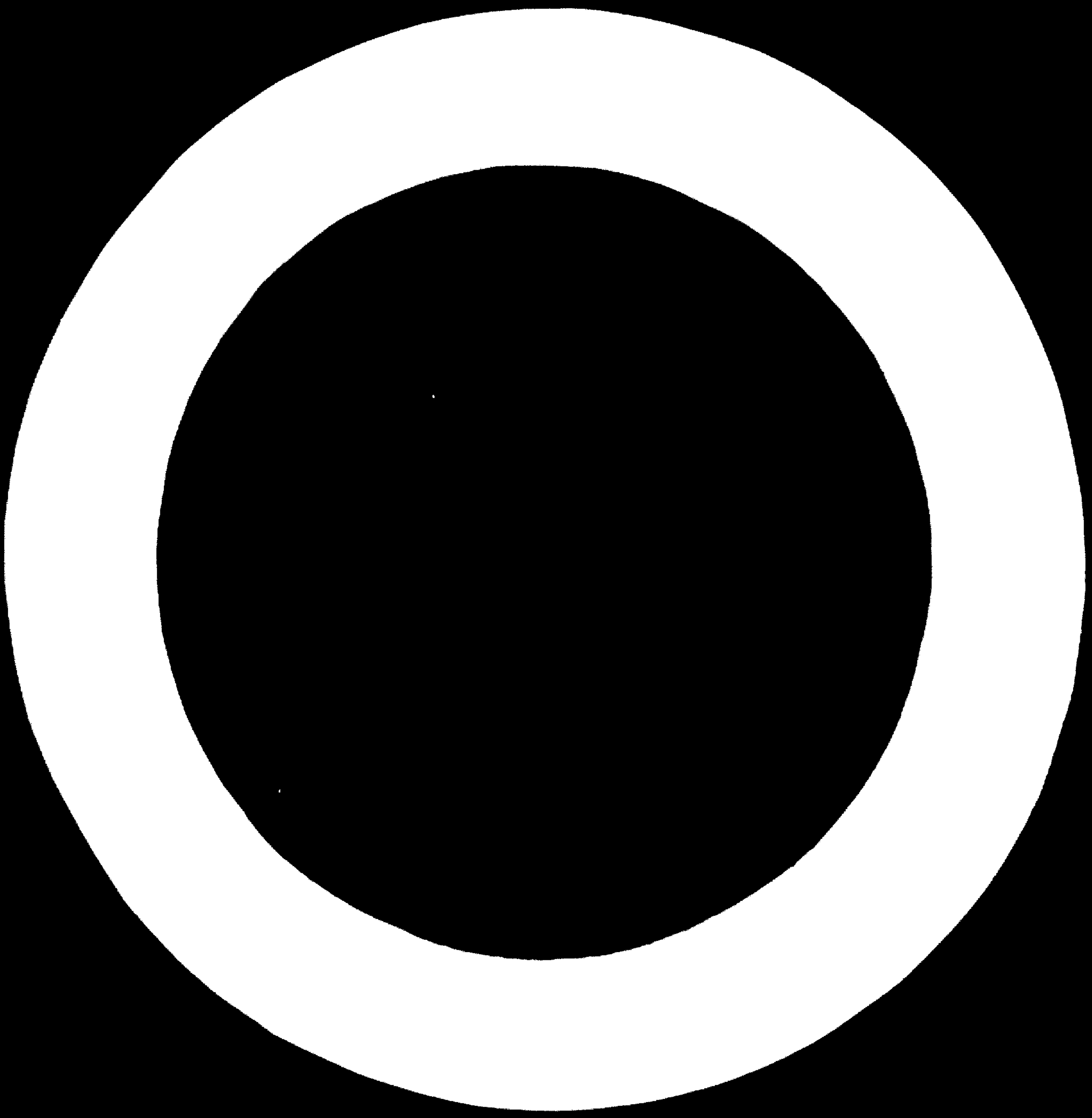


Fig. 8. From Ferronickel Plant in New Caledonia.



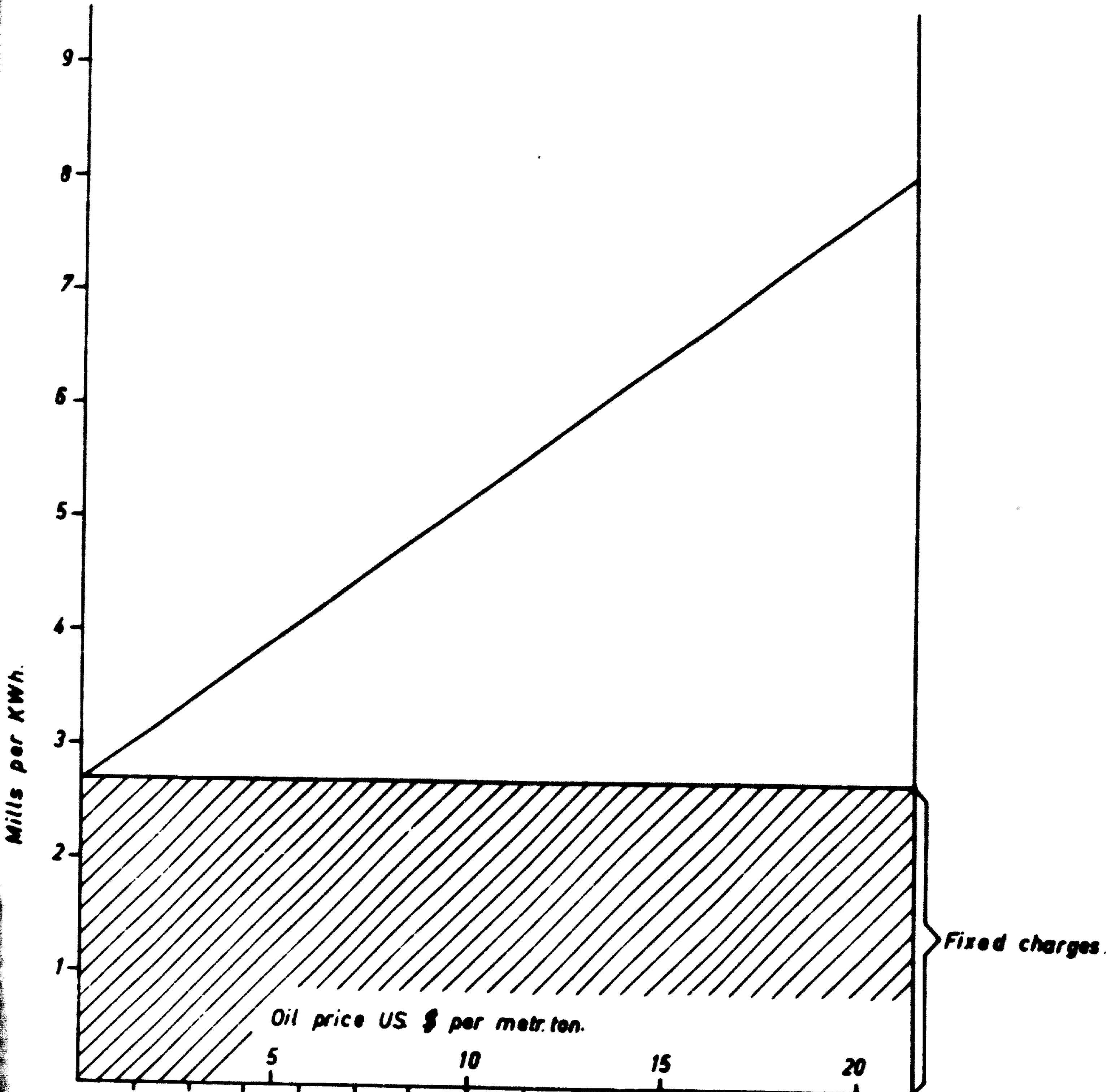
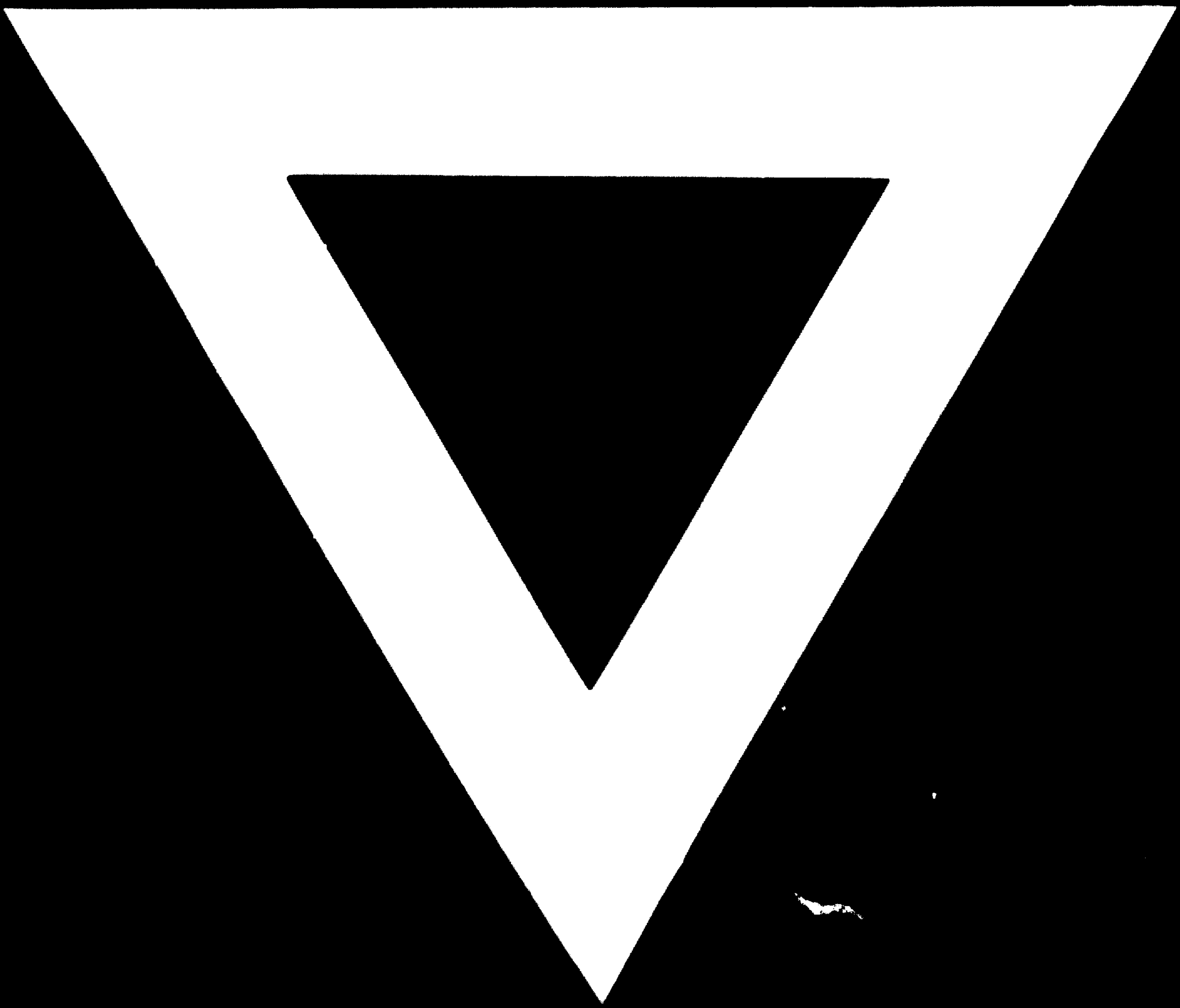

Mills per KWh.
9
8
7
6
5
4
3
2
1
Fixed charges.
Oil price US $ per metr. ton.
5
10
15
20
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
Coal price US $ per metr. ton.

FIGURE 9



8. 8. 74