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Engineering Design Of An Electron Beam (EB) Flue Gas Purification Industrial DemonstrationPlant

Basic Engineering.

Final Report.

Warsaw, January 1996

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Table of contents:

Engineering Design Of An Electron Beam (EB)
Flue Gas Purification Industrial DemonstrationPlant

Basic Engineering.

Volume 0

Executive Summary

Warsaw, January 1996

No. of Volume	List of Volumes	Author
Volume 0	**Executive Summary**	
Volume I	Process Technology	INCT
Volume II	Gas Conditioning Unit	INCT
Volume III	Ammonia storage and dosing unit	Energoprojekt-Warszawa
Volume IV	Reaction chamber	Proatom
Volume V	By-product filtration (ESP)	Energoprojekt-Warszawa
Volume VI	By-product removal from filter, its transportation and conditioning	Energoprojekt-Warszawa
Volume VII	Flue gas ducts. Emission of flue gases to atmosphere	Energoprojekt-Warszawa
Volume VIII	Measuring, monitoring and control system	SINS
Volume IX	Electrical power supply units	Energoprojekt-Warszawa
Volume X	Composite documentation	Energoprojekt-Warszawa
Volume XI	Balances	Energoprojekt-Warszawa

EXECUTIVE SUMMARY

The emission of environmental pollutants such as sulphur dioxide (SO_2) and nitrogen oxides (NO_x) into the atmosphere from heavy industrial activity, and in particular from fossil fuel burning, is arousing concern. These pollutant are the main cause for acid rain, which harms forests, farmland and lakes. A number of countries around the world have already imposed emission limits to reduce air pollution. Also the "Agenda 21" adopted at the Rio Conference in June 1992 for environmental conservation, is being followed by many countries and international organizations. Such policies have generated renewed interest in finding viable and cost-effective solutions to SO_2 and NO_x pollution control. The scientific finding and engineering developments of the past 20 years in the field of radiation technology indicate that one such needed solution is available as an alternative to conventional technologies.

The electron beam (EB) - flue gas cleaning process was developed in Japan, later in USA, Germany and Poland. The main technical advantages of the process are:

- high removal efficiencies for SO_2 and NO_x,
- production of a usable product (fertilizer),
- simple process design,
- no waste water.

Several large pilot plants were built and operated during the eighties. These projects proofed, that the EB - process was feasible and safe to operate. According to several sources the process costs were estimated in the same range or even lower than present technology if the investment costs for the electron accelerators would become significantly lower and suitable flue gas conditions were chosen.

This technology, the electron beam dry scrubbing process is proposed to be employed at the Pomorzany Electric Power Station in Poland for the simultaneous removal of SO_2 and NO_x from flue gases emitted by the Benson boilers.

The boilers were manufactured by Babcock - Wilcox Company at Oberhausen Germany in 1959/60 and were reconstructed in 1979. Each boiler has 142.5 MW_t power output. The boiler is connected with turbine and operating at combined cycle and has power output 56 MW_e and 50 MW_t. After planed reconstruction of turbines which it is intended in 1988, the output will increase to 68 MW_e and 100 MW_t. Annual operating time is 6500 h/year of equivalent to full - load operation.

Boilers fire pulverized bituminous coal that has the following characteristics:

Caloric value	22820 kJ/kg
Sulfur content	0.72 ÷ 0.8%
Ash content	21.8%
Moisture content	7.8%

The boilers are equipped with modern flue-gas dedusting systems employing four - zone electrostatic precipitators, for which efficiency of removal of fly ash is equals 99.8%. Maximum volumetric flow of flue fases from one boiler is 270 000 Nm^3/h.

Emitted stream of flue gases after treatment in the ESP contains:

SO_2	1.1 g/Nm^3
NO_x	0.6 g/Nm^3
O_2	7 - 8% vol.
CO_2	8% vol.
CO	0% vol.
N_2	to balance
fly ash	0.08 g/Nm^3
humidity	5% vol.

The temperature ranges from 145°C to 170°C.

For design purpouses the temperature of flue gas after ESP has been assumed as 145°C.

According to the Polish Ministry of Environmental Protection regulation enacted on 12.02.1990 existing plants such as the EPS Pomorzany after the year 1997 will have a permissable emission of SO_2 of 870 g/GJ of the boiler heat input and NO_x of 170 g/GJ.

The above national standards allow an hourly emission from each Benson boiler of 855 kg SO_2 and 160 kg NO_x as NO_2 equivalent.

After a detailed analysis it was decided to design and construct the electron-beam installation treating a maximum 270 000 Nm^3/h stream flow of flue gas.

The EB Pomorzany flue gas treatment installation has been designed for the station rated output reached after retrofit.

High concentration of NO_x and relatively low content of SO_2 in flue gas emitted from Benson boilers establish the specific conditions for flue gas treatment required in continuous operation. The parameters of E-B process are chosen so as to guarantee efficiency of removal of NO_x up to 80% and of up 70% SO_2 in continuous operation of the installation. For intermittent operation up to 80% removal of NO_x and 90% reduction of SO_2 are expected.

During continuous operation the electron-beam induced reaction will take place in the process vessel at a higher temperature than that which would be selected for the more typical high removal case (90% SO_2, 80% NO_x). The conceptual system arrangement of this situation is shown in Fig. 1.

The main technical parameters and composition of flue gases in the Pomorzany E-Beam installation are shown in Table 1.

A two-process-train design is proposed with each train processing max. 135 000 Nm^3/h of flue gas. This solution was selected because of existing building space limitation. The flue gas containing particulate, SO_2 and NO_x enters the existing electrostatic precipitator (ESP) at a design temperature of 145°C and fly ash is efficiently removed. The gas then passes through an evaporative spray cooler to achieve 80°C process temperature in a adiabatic cooling (with the water vapour content up to 11% volume).

After this humidification step the flue gas flows into the irradiation chamber to be accomodated in the existing building that formerly housed multi-cyclone dust collectors (two parallel compartments). This building arrangement is to be generally reconstructed.

At the inlet to irradiation chamber the gaseous ammonia reagent is added to the flue gas via nozzles mounted at the site of the duct.

The ammonia storage facility will be placed at the railroad siding serving the power plant. In each irradiation chamber flue gas is treated by beams of high energy electrons emitted by two accelerator heads each of 300 kW power rating. By-product collection is achieved in a dry ESP of special design.

After the by-product collection, it will be transported to plant storage and will be loaded and shipped to buyers.

The treated stream of flue gas will be mixed with dedusted, untreated stream The proportioning of these streams will be such as to do not harm the existing stack, by acid attack. This required minimum stack temperature is 110°C. There is no need to provide the special anticorrosion protection of the stack.

The Table 2 shows the main design parameters of the EB Pomorzany installation.

To facilitate the basic engineering design the EB Process has been divided into the following major sub-systems.

Flue Gas Cooling System

Flue gas exiting the ESP at a temperature 145°C is cooled to 80°C in a spray cooler, where atomized water is injected into flue gas stream by means dual fluid air-water nozzles. The spray cooler is operated with a dry bottom, i.e. all of the water injected into the flue gas is evaporated - Fig. 2.

Reagent Handling System

Anhydraus ammonia is delivered to the plant by truck or rail and stored in 4 tanks, total capacity 220 m^3. At ambient temperature tanks can contein 13.4 - 15 t of liquid ammonia, which is equal monthly demend. The ammonia is then vaporized using electrical heating. To ensure good distribution in the flue gas duct, ammonia is distributed using a multi-nozzle assembly configured as a grid in the flue gas duct. The ammonia is injected after the spray cooler at a flue gas temperature of approximately 80°C - Fig. 3.

SO_2 - NO_x Removal System

In the E-Beam Process vessel flue gas containing SO_2, NO_x and NH_3 is irradiated by high-energy electron beams generated by two accelerator-guns 300 kW each (800 keV x 375 mA) that are installed on the process vessel in series in respect to the gas stream flow.

A radiation dosage of 12 kGy was chosen for removals of 70% SO_2 and 80% NO_x based upon pilot plant data.

The E-Beam units are enclosed in a concrete structure to that ensure no radiation is emitted to the external surroundings.In order to minimize the volume of concrete, the entire system is partially underground to use the shielding effect of the surrounding soil - Fig. 4.

By-product Collection System

The flue gas is passed through the by-product collection system. An ESP is proposed to capture the by-product with the particulate emission of less than 20 mg/Nm^3. By-products collected in the ESP are transferred to the buffer storage. Production of 700 kg/h is anticipated. Typically, the by-product will contain 70% ammonium sulfate, 26% ammonium nitrate, 2% inert solids (fly ash) and 2% humidity.

Flue Gas System

Flue gas leaving the ESP passes through the spray cooler, E-beam vessels, and by-product ESP. All the ducts connecting this equipment are part of the flue gas system. An ID fan (550 kW, 374 400 Nm^3/h x 2600 Pa) downstream of the by-product ESP provides sufficient draft to overcome the entire pressure loss of the system.

Electrical power supply

The electrical consumers in the Pomorzany E-B Demonstration Installation will be supplied by two 6 keV cables coming from the existing transformer station. The scheme of the connection is given in Fig. 5. In the Table 3 there is presented the electric power demand.

Measuring, monitoring and constrol system (MMCS)

The scheme of the MMCS is shown on Fig. 6,7. The monitoring and control system will have a distributed structure. This means that the computers and modular measuring units of the individual technological systems, situated in the different places, will be connected together by a common serial bus.

The modular-microprocessor units, situated in cassettes (measuring units) realize under the control of the central computer, the control functions related to the following technological systems:

- inlet of the flue gas to the E-Beam installation
- humidification (dosage of water, water steam, and compressed air)
- ammonia dosage
-accelerators and a process vessel
- by-product electrostatic precipitator (ESP)
-system of the final product transfer
- ventilating system
- outlet system
- environmental monitoring system.

The microprocessor units situated in the cassettes will allow the measurement, control and stabilization of the parameters of the individual process systems.

Table 1. Technical parameters and composition of process streams at key points of the EB installation.

Stream No.	1	2	3	4	5	6	7	8
	System gas inlet	Spray cooler outlet	Reaction chamber outlet	Plant outlet	Spray water	Compressed air	NH_3	By-product
N_2	80% vol.	75% vol.	75% vol.	75% vol.				
O_2	7% vol.	6.6% vol.	6.6% vol.	6.6% vol.				
CO_2	8% vol.	7.4% vol.	7.4% vol.	7.4% vol.				
SO_2	1.1 g/Nm^3	1.03 g/Nm^3	0.31 g/Nm^3	0.31 g/Nm^3				
NO_x	0.6 g/Nm^3	0.57 g/Nm^3	0.12 g/Nm^3	0.12 g/Nm^3				
NH_3	0	0	0.03 g/Nm^3	0.03 g/Nm^3				
H_2O	5% vol.	11% vol.	11% vol.	11% vol.	max 13.5 t/h	2100 Nm^3/h	180 kg/h	700 kg/h
$(NH_4)_2SO_4$	0	0	490 kg/h	0.025 g/Nm^3				
NH_4NO_3	0	0	175 kg/h	0.01 g/Nm^3				
Pressed air	0	0	0	0				
Fly ash	0.08 g/Nm^3	0.06 g/Nm^3	2.45 g/Nm^3	0.04 g/Nm^3				
Flue gas	270 000 Nm^3/h	284 000 Nm^3/h	284 000 Nm^3/h	284 000 Nm^3/h				
Gas temp.	145°C	80°C	90°C	90°C				

Table 2. Design basis for the E-B installation at EPS Pomorzany.

	Continuous operation	Intermittent operation
FLUE GAS COOLING SYSTEM		
Inlet Temperature of Spray Cooler	145°C	145°C
Outlet Temperature of Spray Cooler	80°C	65°C
Water Flow Rate to Spray Cooler	max 13.5 t/h	max 13.5 t/h
Mode of Operation	dry bottom	dry bottom
REAGENT HANDLING SYSTEM		
Ammonia Storage	15 t	15 t
Injection Mode	gas phase	gas phase
Evaporation Media	electricity	electricity
Ammonia Flow Rate	180 kg/h	200 kg/h
SO_2 - NO_x REMOVAL SYSTEM		
SO_2 Removal	70%	90%
NO_x Removal	80%	80%
E-Beam Power Dose	12 kGy	12 kGy
E-Beam System:		
Required E-Beam Gun Output	1334 kW	1334 kW
Installed E-Beam Gun Output Capacity	1848 kW	1848 kW
Accelerator (800 kV x 375 x mA x 300 kW)		
Inlet Gas Temperature	80°C	65°C
Outlet Gas Temperature	90°C	75°C
Pressure Drop in Vessel	15 mm H_2O	15 mm H_2O
BY-PRODUCT COLLECTION AND HANDLING SYSTEM		
Collector Type	ESP	
Removal Efficiency	98.5%	98.5%
Particulate at Inlet to Flue Gas Reheat Mixer	< 20 mg/Nm^3	< 20 mg/Nm^3
Exhaust Temperature Loading at Inlet to Flue Gas Reheat Mixer	90°C	80°C
By-product Yield	700 kg/h	720 kg/h
By-product Storage Root Storage	5 months	5 months
Mode of Transport	track	track

Table 3. Electric energy consumption.

Voltage	Load	Switch. Gear	P installed kW	P simul. op. kW	cosφ -	Q kVAr	D kVA	S kVA
6 kV	Accelerators	OS	1334	1334	0.9	727	688	1688
	Main Fan	OS	550	550	0.9	266	0	611
	Total		1884	1884		993	688	2299
0.4 kV	Technological Equipment for Accel.	1S	356.4	214	0.8	160	0	268
	Light	2S	10	8	1	0	6	10
	Fans and Pumps associated with Accel.	3S	148	100	0.8	75	0	125
	Electrostatic precipitator	4S	92	92	0.9	45	63	120
	Motors assoc. with ESP (14+2+2+2+2)	4S	18.6	10	0.8	7.5	0	13
	Heaters associated with ESP	4S	100	87	0.9	65	0	109
	By-product management	4S, 6S	70	65	0.8	49	0	81
	Flue gas humidification	4S	330	220	0.8	165	0	275
	Ammonia storage and dosing unit	5S	90	90	0.8	68	0	113
	Measurement & Control	2S	25	20	1	0	8	22
	Total		1150	906		590	77	1084
Total power			3034	2790		1583	765	3298

P - active power
Q - fundamental harmonic reactive power
D - deactive power (associated with non-sinusoidal current wave forms)
S - apparent power

Investment cost

As an outcome of initial financial and economic analysis the investment cost has been estimated as per Table 4.

Table 4. Investment cost specification.

Ordinal number	Specification of objects, work and expenditures	Total cost in thousand USD	Portion %
1	2	3	4
1.	Accelerators	2 900	14,57
2.	Flue gas humidification tower	600	3,02
3.	Reaction chambers - reaction units	500	2,51
4.	Electrostatic precipitator	4 110	20,65 *
5.	Booster fan	190	0,95
6.	By-product handling system	840	4,22
7.	Ammonia storage and dosing unit	830	4,17
8.	Measuring, monitoring, and control system	1 500	7,53
9.	Refurbishment of accelerator building	1 100	5,53
10.	Radiation shield walls of accelerators and of reaction chambers	400	2,01
11.	Ventilation system for accelerator building	200	1,01
12.	Accelerator cooling system	150	0,76
13.	Sygnalling system of accelerator operation	100	0,50
14.	Lighting system of accelerators building	80	0,40
15.	Electrical power supply	710	3,56
16.	Flue gas ducts, complete with connections and support structures	1 200	6,03
17.	Process water pumping system	10	0,05
18.	Compressed air system	230	1,16
19.	Documentation, supervision	1 350	6,78
20.	Training	200	1,01
21.	Commisioning	200	1,01
22.	General civil engineering contracting; supervision on site	700	3,52
23.	Total	18 100	90,95
24.	Reserve	1 800	9,05
25.	Total	19 900	100,0

* The cost of ESP has been estimated on the basis of the quotation submitted by ABB FLAKT

Sources and time schedule of financing

The sources of financial support for capital funding of the Pomorzany Demonstration E-B Installation are presented as follow:

- 36% of investment cost: grant from IAEA,
- 30% of investment cost: own resources of investor,
- 24% of investment cost: commercial credit, intrest rate 14%, 5 years,
- 10% of investment cost: credit from National Foundation of Environment Protection (Poland), intrest rate 6%, 5 years.

Timeschedule of financing:
(in thousand USD)

Item	Specification	1996	1997	1998	Total
1	Grant from IAEA		7200		7200
2	Own resources	995	995	3980	5970
3	Commercial credit		4740		4740
4	Credit from NFoEP		995	995	1990
5	Total	995	13930	4975	19900

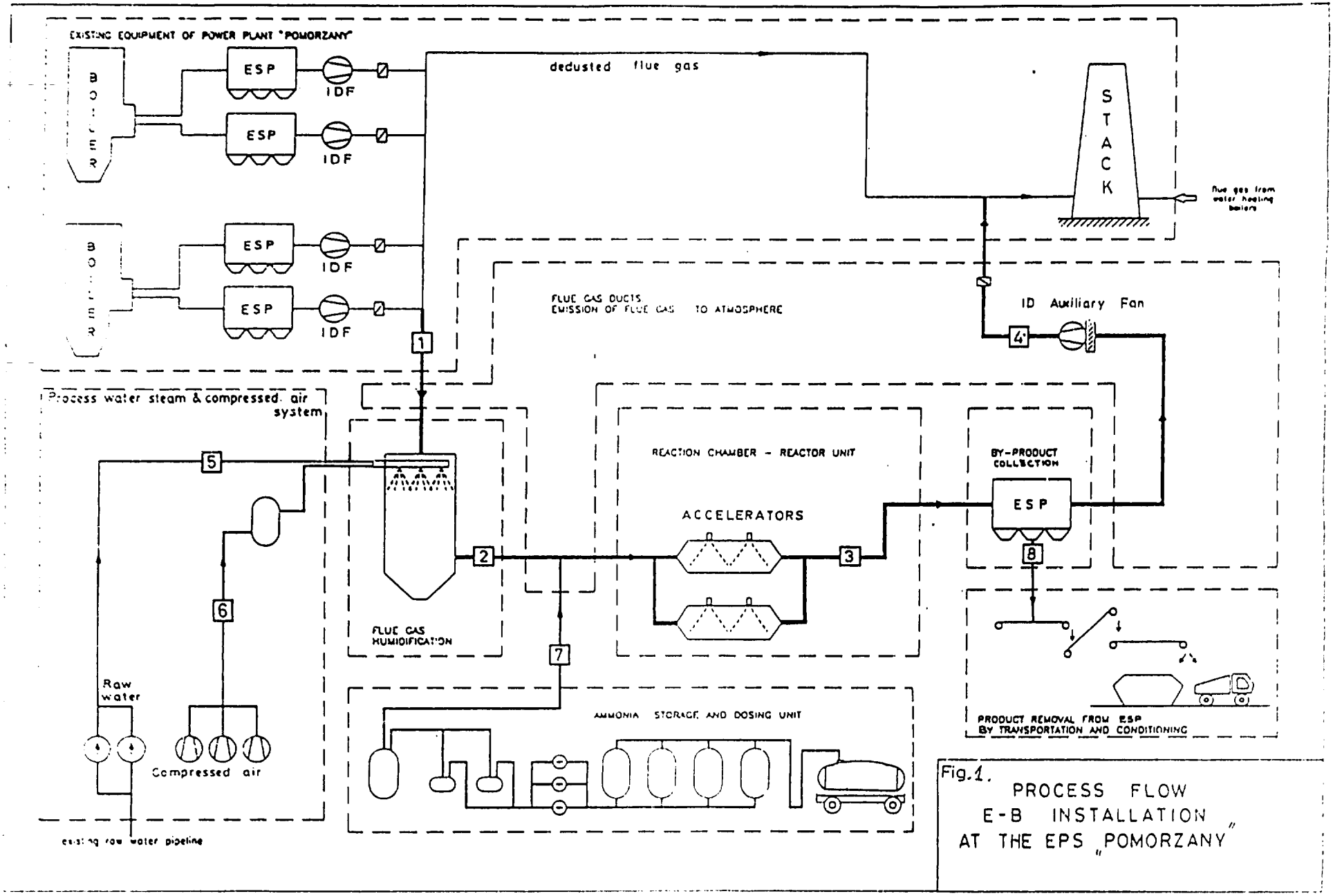


Fig.1.
PROCESS FLOW
E-B INSTALLATION
AT THE EPS „POMORZANY"

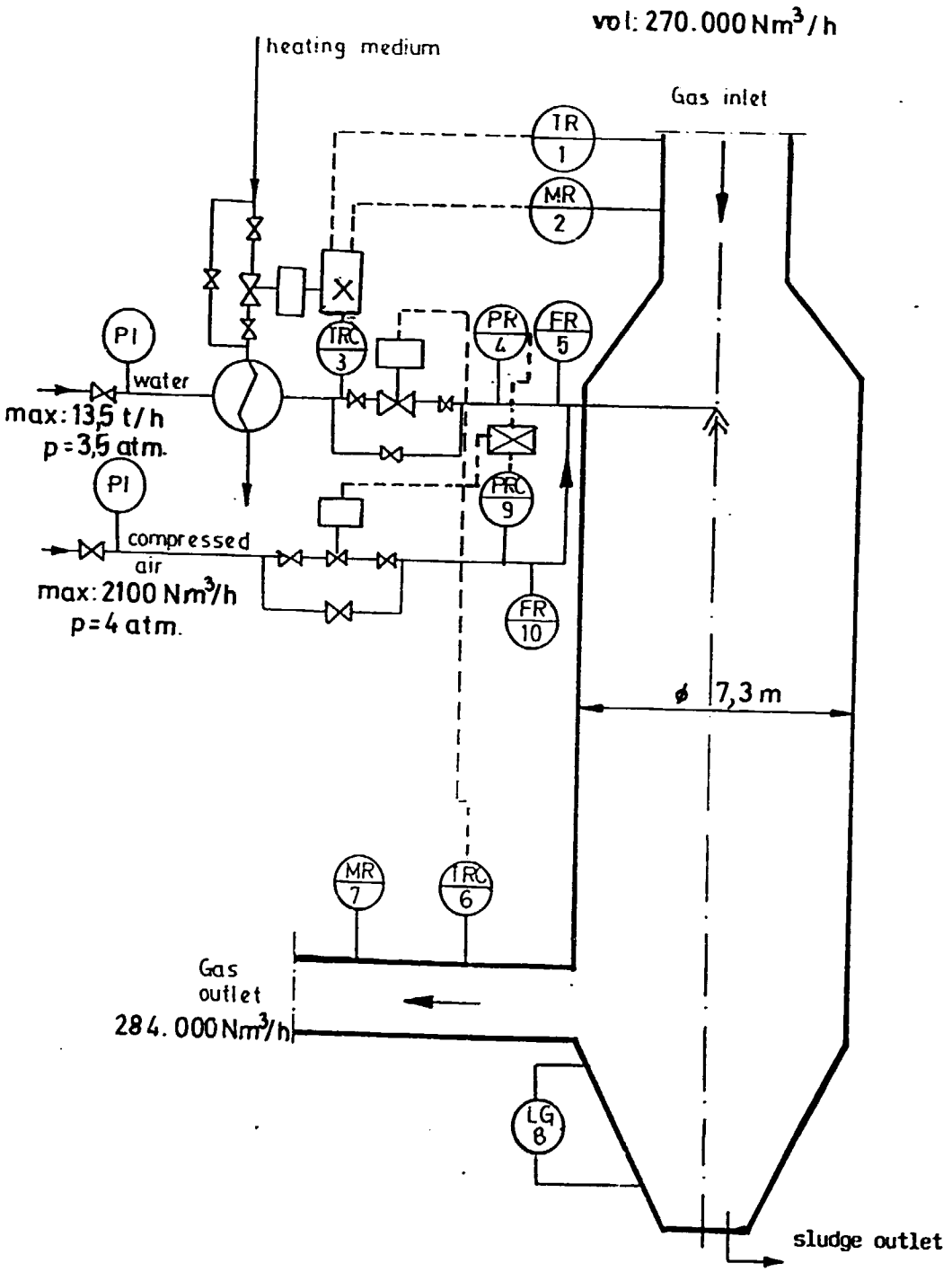
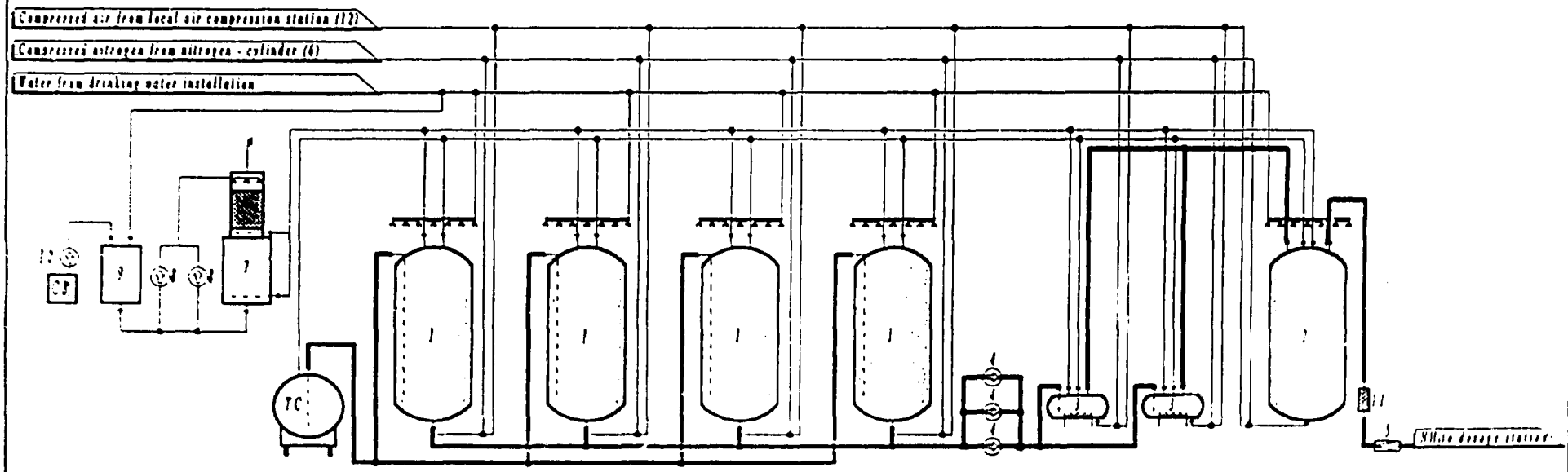


Fig. 2. Control system for humidification process of flue gas using water - air nozzles



PERMANENT INSTALLATION

1. Liquid ammonia storage tank
2. Gaseous ammonia equalising tank
3. Ammonia gasificator
4. Liquid ammonia pump
5. Gaseous ammonia decompression station
6. Compressed nitrogen cylinder
7. Absorption tower
8. Sulphuric acid solution pump
9. Preparation tank (sulphuric acid solution)
10. Reloding pump (concentrated sulphuric acid)
11. Gaseous ammonia filter
12. Air compressor

SUPLIED ACCORDING TO DEMAND

TC - Tank car (liquid ammonia)
CB - Carboy (concentrated sulphuric acid)

Fig. 3

ENERGOPROJEKT Warszawa SA Biuro Studiów i Projektów Energetycznych Warszawa ul. Krasa d/14			Nr archiwalny 1131110				Nr kart w teczce 1
Przedsięwzięcie	Symbol P - 0174	Nr rys	Branża	Tom I	Zeszyt	Część	
INDUSTRIAL DEMONSTRATION PLANT OF ELEKTRON-BEAM PROCESS FOR FLUE GAS TREATMENT OF THE ELECTRIC POWER STATION "POMORZANY" - SZCZECIN, POLAND AMMONIUM STORAGE AND DOSING UNIT FLOW DIAGRAM	Data czerwiec 1995r	Podpis/Nazwisko	Data	Format	Proc 113	Ciąg technol	
	Zastępuje rys						
	Projekt				Sprawdził		
	Wykonał						
	Kreślił						

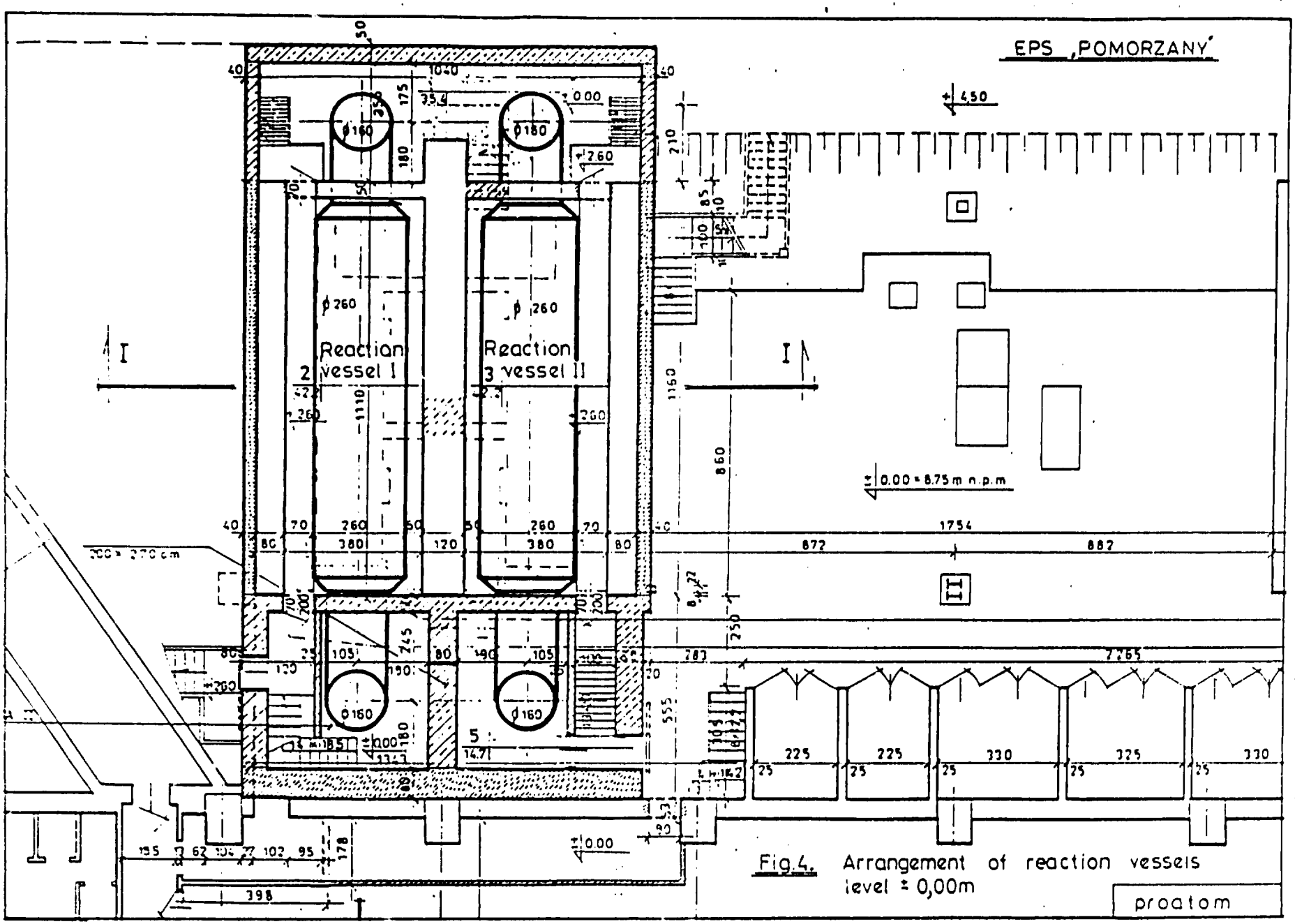


Fig.4. Arrangement of reaction vessels level ± 0,00m

proatom

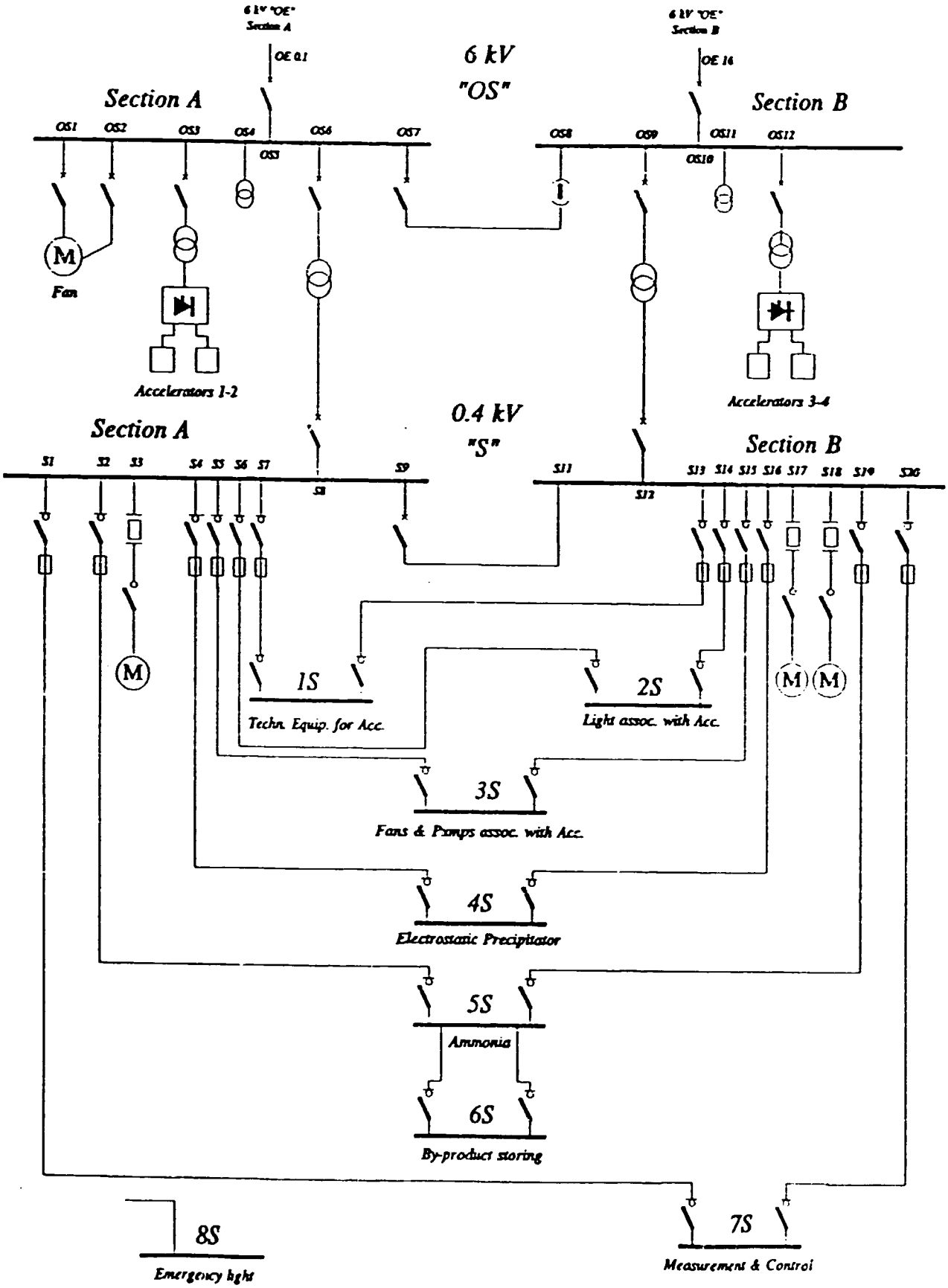


Fig. 5

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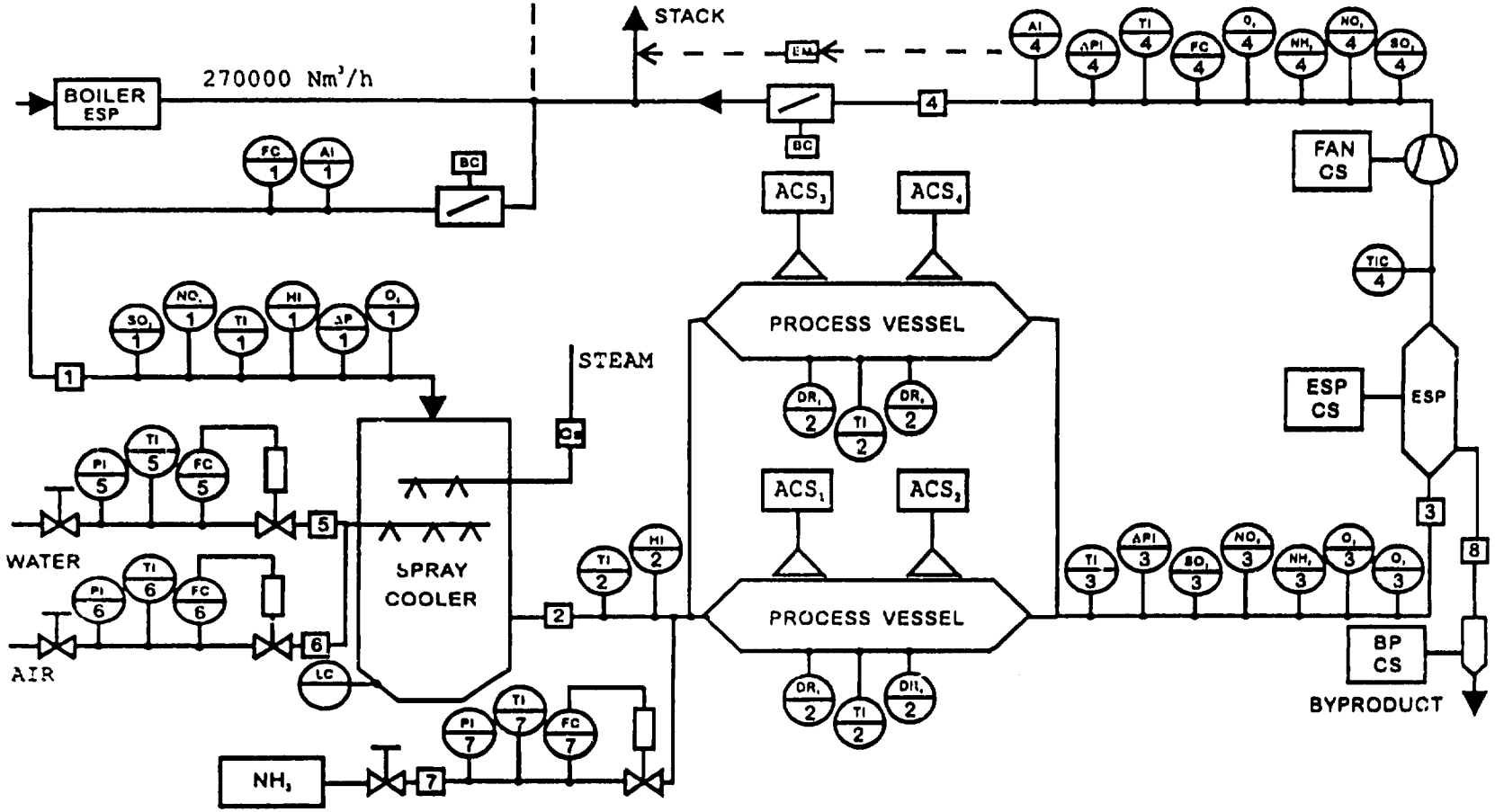
INDUSTRIAL DEMONSTRATION PLANT OF ELECTRON-BEAM PROCESS FOR FLUE GAS TREATMENT OF THE ELECTRIC POWER STATION "POMORZANY"-SZCZECIN POLAND			Data 06.95.	Podziałka	Fora	Format A4
ELECTRICAL POWER SUPPLY UNIT			Zastępuje rys. Zastąpiony przez rys. Nr			
			Projektował G.Błajszczak		Sprawdził	
			Wykonał		Kier. proc.	

Fig. 6. SCHEME OF THE MEASUREMENT POINTS



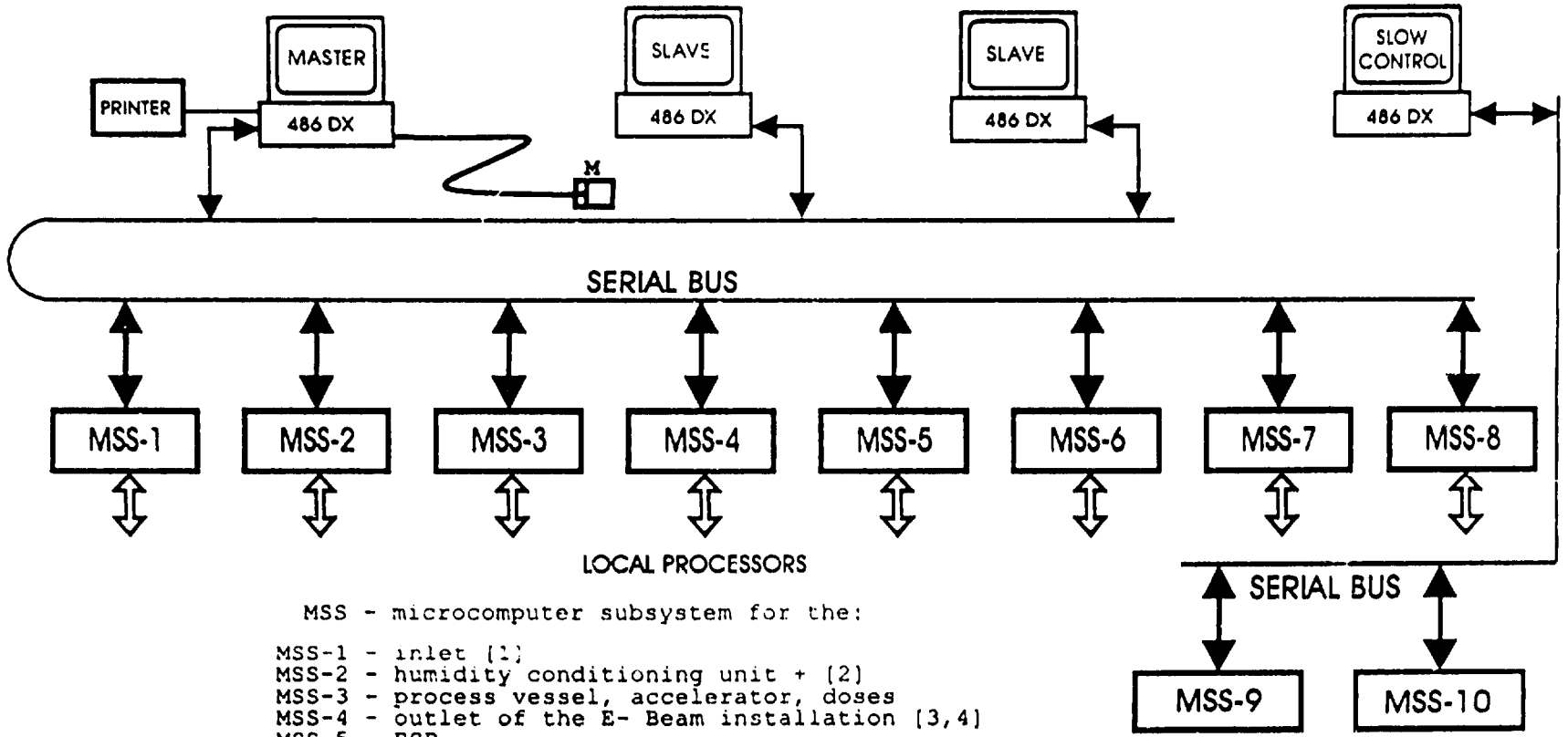
T - temperature
P,ΔP - pressure
H - humidity
L - level

F - flow
A - fly ash
D - dose

I - indicator
C - control
CS - control system
ESP - electrostatic precipitator

ACS - accelerator control system
BC - bolt controller
EM - environmental monitoring

Fig. 7. COMPUTER CONTROL SYSTEM



MSS - microcomputer subsystem for the:

MSS-1 - inlet [1]
MSS-2 - humidity conditioning unit + [2]
MSS-3 - process vessel, accelerator, doses
MSS-4 - outlet of the E- Beam installation [3,4]
MSS-5 - ESP
MSS-6 - environmental monitoring [EM]
MSS-7 - NH_3 [7]
MSS-8 - BP transfer [8]
MSS-9,10 - quality control units

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Institute of Nuclear Chemistry and Technology

Engineering Design Of An Electron Beam (EB) Flue Gas Purification Industrial DemonstrationPlant

Basic Engineering.

Volume 1

Process technology

Warsaw, January 1996

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CONTENTS

PREFACE

The emission of environmental pollutants such as sulphur dioxide (SO_2) and nitrogen oxides (NO_x) into the atmosphere from heavy industrial activity, and in particular from fossil fuel burning, is arousing concern. These pollutant are the main cause for acid rain, which harms forests, farmland and lakes. A number of countries around the world have already imposed emission limits to reduce air pollution. Also the "Agenda 21" adopted at the Rio Conference in June 1992 for environmental conservation, is being followed by many countries and international organizations. Such policies have generated renewed interest in finding viable and cost-effective solutions to SO_2 and NO_x pollution control. The scientific finding and engineering developments of the past 20 years in the field of radiation technology indicate that one such needed solution is available as an alternative to conventional technologies.

This technology, the electron beam dry scrubbing process is proposed to be employed at the Pomorzany Electric Power Station in Poland for the simultaneous removal of SO_2 and NO_x.

After preparation of Feasibility Study for Industrial Demonstration Plant of Electron-Beam Process for Flue Gas Treatment at the Electric Power Station Pomorzany, in August 1993, the next step in industrial application of E-B technology is a more deatiled specification and description of component elements of this installation i.e. Basic Engineering Study.

This document utilizes expirience and data gained via pilot plants in Japan, USA, Germany and Poland. The experimental runs carried out in these plant confirmed high efficiency of simultaneous removal of SO_2 and NO_x from flue gases. The by-product obtained is fertilizer blending stock useful in agriculture.

Economic comparison of E-B technology with other methods of flue gas treatment has shown its advantages.

The main system components gas-process flow diagram are:

1. flue gas conditioning system
2. ammonia supply system
3. SO_2/NO_x removal system (reactor)
4. by-product recovery system (dedusting of gases, handling and storage of by-product)

Basic Engineering will be prepared as a description of apparatuses, their construction and operation each lied to experimental data from pilot plant operation.

The Basic Engineering herein will consist of the following details:

1. Process technology description
2. Flue gas conditioning
3. Ammonia supply system
4. Reactor chamber unit
5. By-product recovery system
6. Product removal from filter, its transportation and confectioning
7. Flue gas duct system and stack discharge
8. Monitoring and control systems
9. Electric power supply units
10. Appended documentation
11. Material and energy balance

1. PROCESS FUNDAMENTALS AND SURVEY OF STUDY WORK TO DATE

1.1. Physico-chemical process principles

High-energy electrons, when moving in a gas , form hundreds of ions and free radicals along their path of motion. Amount of electron energy absorbed by the various components of such gas of mixed form is proportional to their mass fraction. Hence, in the case of flue gas more than 90% of electron energy is absorbed by nitrogen, oxygen, water vapour and carbon dioxide.

Process radiolytic effectiveness is characterized by the G coefficient, defined as the number of chemical molecules formed (positive values of G) or destroyed (negative values of G) after absorption by a gas of energy equal to 100 eV.

The following equations express the process stoichiometry based on this effectiveness.

$$4.43\ N_2 \xrightarrow{100\ eV} 0.29\ N_2^* + 0.885\ N(^2D) + 0.295\ N(^2P) + 1.87\ N(^4S) + 2.27\ N_2^+ + 0.69\ N^+ + 2.96\ e^- \quad (1)$$

$$5.377\ O_2 \xrightarrow{100\ eV} 0.077\ O_2^* + 2.25\ O(^1D) + 2.8\ O(^3P) + 0.18\ O^* + 2.07\ O_2^- + 1.23\ O^+ + 3.3\ e^- \quad (2)$$

$$7.33\ H_2O \xrightarrow{100\ eV} 0.51\ H_2 + 0.46\ O(^3P) + 4.25\ OH + 4.15\ H + 1.99\ H_2O^+ + 0.01\ H_2^- + 0.57\ OH^+ + 0.67\ H^+ + 0.06\ O^- + 3.3\ e^- \quad (3)$$

$$7.54\ CO_2 \xrightarrow{100\ eV} 4.72\ CO + 5.16\ O(^3P) + 2.24\ CO_2^- + 0.51\ CO^+ + 0.07\ C^- + 0.21\ O^- + 3.03\ e^- \quad (4)$$

From the G - values given by the above equations it follows that the G - value of the process is in the range of 6 ± 2.

The acidic pollutants SO_2 and NO_x are present at low concentrations in flue gas (e.g. SO_2 up to 3000 ppm, NO_x up to 500 ppm), the energy transfer process is indirect as is illustrated by the following pathway:

gas matrix (N_2, O_2, H_2O, CO_2) → ions, excited states of molecules,radicals → products (5)

During simultaneous removal of SO_2 and NO_x from flue gas from coal combustion the values of G reach 20 in single stage irradiation.

The above given values are somewhat higher than those indicated earlier, showing that, apart from irradiation reactions, other chemical processes can take place, stimulated by appropriate physico-chemical system parameters. On the other hand, the achievable irradiation effectiveness in the system gives evidence that no chain reactions are possible since the latter would lead to G values of the order of magnitude of one thousand.

Ions formed as a result of an interaction of electrons with gas molecules react very rapidly with the predominant components of the gas matrix. This results in a redistribution of the absorbed energy so that the traces of the primary radiolytic reactions become extinet very rapidly The charge transfer reaction between positive charge ions and molecules are most relevant in this redistribution.

Besides a simple charge transfer, many reactions of positive charge ions and molecules are coupled with dissociation of the one or both reaction components, leading to the formation of neutral radicals. Thus, the reactions connected with positive charge transfer are the most relevant source of radicals in the electron beam processing for flue gas treatment [1, 2, 3].

The most reactive is the OH radical, formed at the rate of hundreds of ppm/s at the dose rate of 10 kGy/s. About 90% of OH forms as a result of the charge transfer reactions between positive ions and molecules, while only 10% are the result of direct decomposition of water vapour.

The overall rate of radicals formation is dependent on the dose rate, an increase in which results in higher process efficiency.

The formed radicals are reactive with respect to the matrix gases to a very small degree. They are, however, accessible for the desired decomposition and removal of the gaseous pollutants. The only exception is hydrogen atoms, which directly bond with oxygen producing HO_2 radicals. For a change, this radical reacts selectively at a high rate with NO yielding NO_2 and OH. The oxygen atom bonds relatively slowly with molecular oxygen forming ozone, which is used to oxidize NO and other pollutants.

The OH radical plays a key role in simultaneous removal of NO_x and SO_2 from flue gas. It is indispensable in forming sulfuric and nitric acid molecules, and in initiating their aerosol production. While OH is very reactive, four main trace components compete in bringing about its consumption:

$$NO + OH + M \rightarrow HNO_2 + M \qquad k_1 \cdot [M] = 4 \cdot 10^{-12}\ cm^3/sec \qquad (6)$$

$$NO_2 + OH + M \rightarrow NHO_3 + M \qquad k_2 \cdot [M] = 9 \cdot 10^{-12}\ cm^3/sec \qquad (7)$$

$$SO_2 + OH + M \rightarrow HSO_3 + M \qquad k_3 \cdot [M] = 7 \cdot 10^{-13}\ cm^3/sec \qquad (8)$$

$$NH_3 + OH \rightarrow NH_2 + H_2O \qquad k_4 = 3 \cdot 10^{-11}\ cm^3/sec \qquad (9)$$

The given reaction rate constants correspond to 1 bar pressure and 350 K temperature. The competition is very intensive since the differences in reaction rates are levelled off by the influence of the reagent concentration.

The most important conclusions resulting from an analysis of the above considered reactions are as follows:

- reaction (6) is only partially effective in removal of NO since as a result of heterogeneous reactions a fraction of nitrous acid decomposes into NO and NO_2,
- reaction (7) is the most important source of nitric acid and further - ammonium nitrate,
- reaction (8) induces the rapid reaction $HSO_3 + O_2 \rightarrow SO_3 + HO_2$, which causes a nucleation of the sulfuric acid mist in presence of water vapour. Such a reaction sequence resulting in substitution of a OH radical by a HO_2 radical, necessary for NO oxidation, gives evidence that presence of SO_2 in a gaseous mixture positively affects NO_x removal,
- as a result of reaction (9) OH radicals are substituted by NH_2 radicals, exhibiting chemical reduction properties with respect to NO.

While SO_2 can be removed only by its oxidation to the sulfuric acid radical, removal of NO_x is accomplished both by oxidation as well as by reduction. Nitrogen atoms and NH_2 radicals can reduce NO_x to two stable gaseous products - molecular nitrogen and nitrous oxide

$$NO + N \rightarrow N_2 + O \quad (10)$$

$$NO + NH_2 \rightarrow N_2 + H_2O \quad (11)$$

$$NO_2 + N \rightarrow N_2O + O \quad (12)$$

$$NO_2 + NH_2 \rightarrow N_2O + H_2O \quad (13)$$

In order to produce N_2O the reaction (13) is more important than the reaction (12), so the N_2O emission can be controlled by an appropriately controlled rate of ammonia injection. Balance of nitrogen usually shows a deficit amounting to up to 20% of the initial NO concentration, depending on the process conditions. The phenomenon of molecular nitrogen formation has been veritied by application of the isotopic tracer N-15 [2, 4].

The above described reaction path of NO_x removal is frequently disrupted by decomposition of the intermediate compounds. The most significant reaction of this type is

$$NO_2 + O \rightarrow NO + O_2 \quad (14)$$

This reaction results in a non-linearity of the relationships quantifying NO_x removal as a function of the irradiation dose. Formation of the intermediate product HNO_2 has been experimentally verified [5], however, the amount of its generation was less than that predicted from the model calculations [6].

Main reactions leading to SO_2 and NO_x removal from flue gases are displayed in Figs 1 and 2 [7].

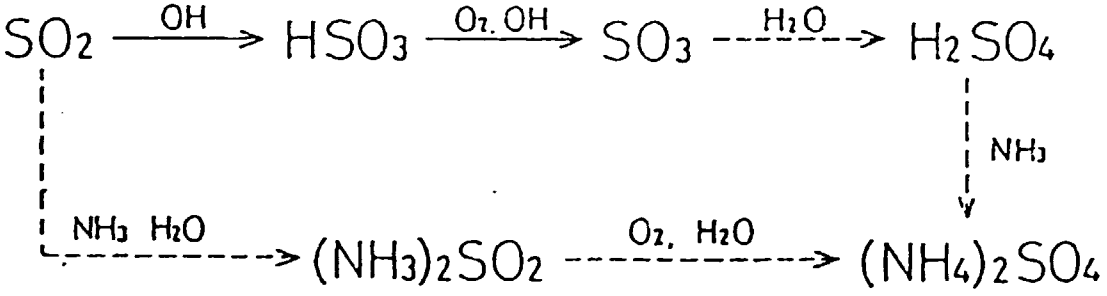

Fig. 1. Main reactions leading to SO_2 removal (—— radiochemical reactions, - - - - thermochemical reactions).

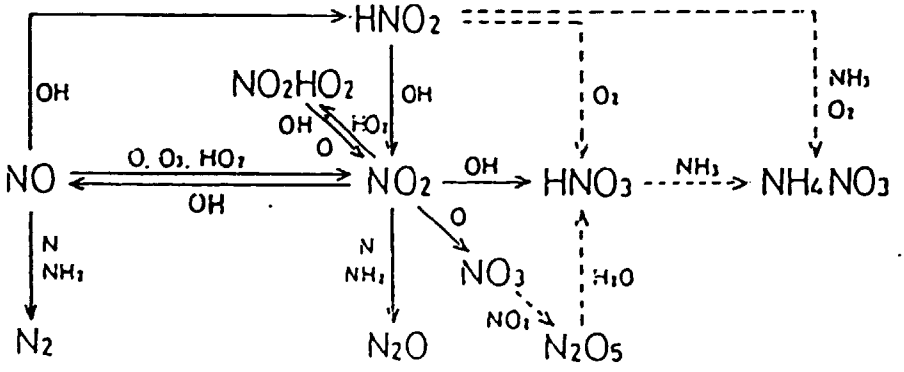

Fig. 2. Main reactions leading to NO_x removal (—— radiochemical reactions, - - - - thermochemical reactions)

These mechanisms do not account for mass transfer. The process of the reaction product removal is affected by absorption and adsorption, disolution etc. These phenomena are strongly exhibited under operating conditions closely matching optimal values of process parameters, i.e. at 60-70°C and high absolute humidity (over 10% vol. of water vapour) [8]. Oxidation reactions of SO_2 are catalyzed at the interfacial surface [9].

1.2. Effect of process parameters on SO_2 removal effectiveness

From the discussion presented in the chapter dealing with the process mechanism one can conclude that the overall SO_2 removal effectiveness is affected by two factors:
- thermal reactions and
- reactions induced by irradiation:

$$\eta\ SO_2 = \eta_1(\varphi, T) + \eta_2(D, \alpha_{NH3}, T) \qquad (15)$$

The yield of the thermal reaction is then determined by gas humidity and temperature T. Depending upon the process conditions this value may reach 20-70%.

It should be pointed out that without electron beam irradiation sulfites are also formated in the gaseous mixture (Fig. 3).

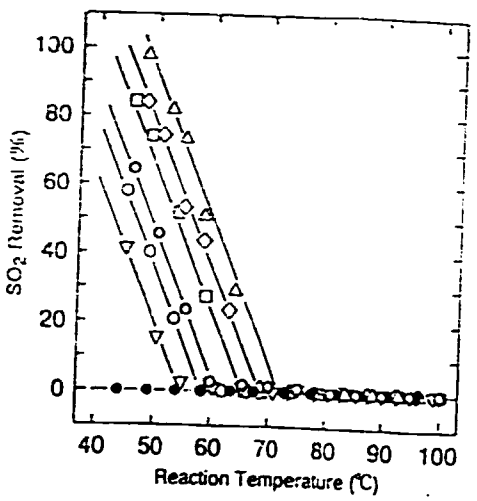

Fig. 3. Effect of thermal reaction on SO_2 removal process [JAERI].

Initial Concentration of Water:
0% (●), 3% (▽), 5% (O), 7% (⊙), 10% (□), 15% (◇), 20% (△).
Initial Concentrations:
SO_2 (600 ppm), NH_3 (1200 ppm), NO (225 ppm), O_2 (10%) and N_2 (Balance).

In the presence of irradiation their rapid oxidation takes place.
An effect of temperature on SO_2 removal is illustrated in Fig 4.

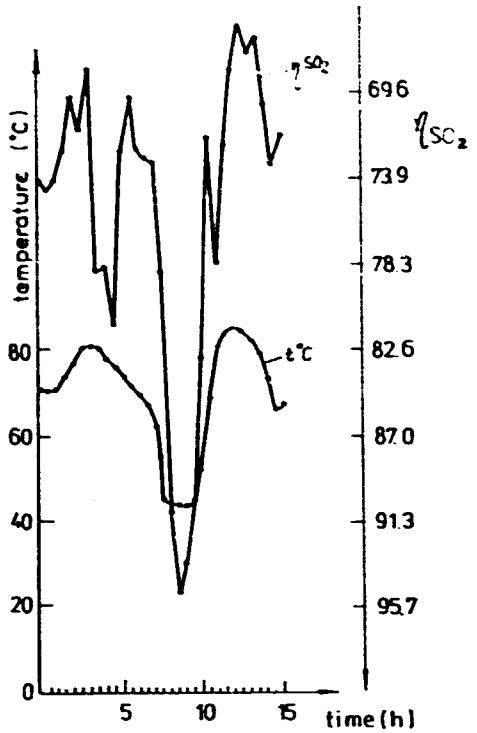

Fig. 4. Effect of temperature on the SO_2 removal process.
V = 14 250 m^3/h, SO_2 - 460 ppm, NO_x - 185 ppm, α_{NH3} = 0.62, Dose = 5.6 kGy.

At the suitable process conditions SO_2 removal effectiveness over 95% is achievable at a moderate beam power (9 kGy) as is shown in Fig. 5.

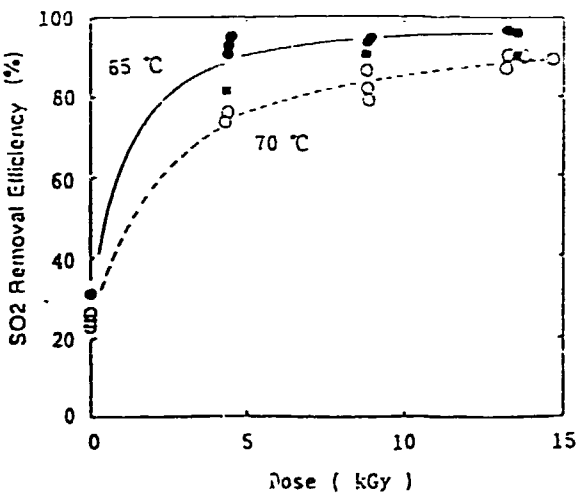

Fig. 5. Dependence of SO_2 removal efficiency at dose in temperature of e-b process equal 65°C and 70°C [JAERI].

However, it should be stresse that the ammonia stoichiometric factor will predominantly affect the SO_2 removal from the outlet gas (Fig. 6).

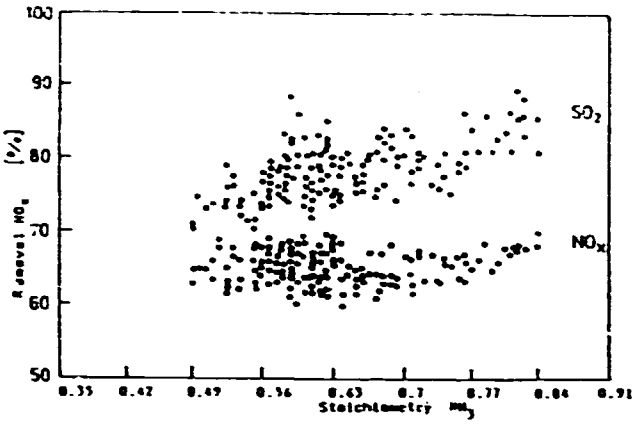

Fig. 6 Effect of ammonia stoichiometry on SO_2 and NO_x removal.
$\eta_{SO2/NOx} = F(\alpha_{NH3})$, $t_{inlet} = 70°C$, inlet SO_2 = 950 - 1050 ppm, NO_x - 135 ppm, Dose - 11.5 kGy.

Also great influence of gas humidity on the SO_2 removal effectiveness is observed (Fig. 7).

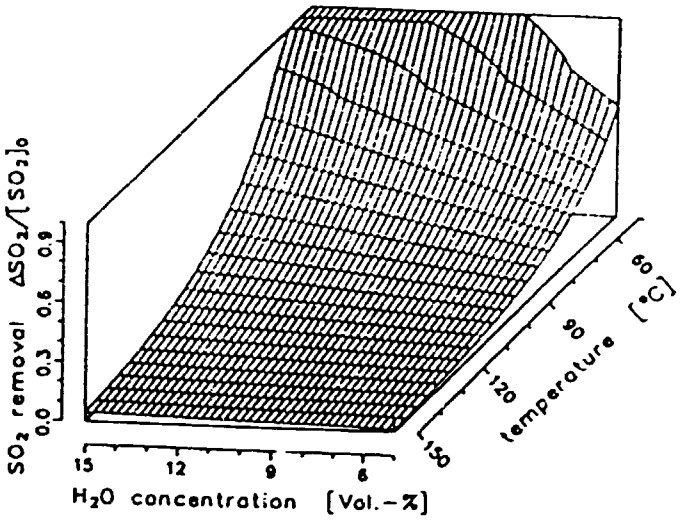

Fig. 7. Dependence of SO_2 removal effectiveness on water vapour content in the flue gas.

In practice, in order to attain the SO_2 removal effectiveness higher than 90%, it is necessary to humidify gases up to humidity corresponding to 10% vol. of water vapour

The investigations of removal SO_2 and NO_x with high humidity of flue gases achieved 10-12% vol. of water vapour content confirmed 95-98% removal efficiency of SO_2. In Figs. 8, 9, the dependency the removal efficiency of SO_2 on process parameters are shown.

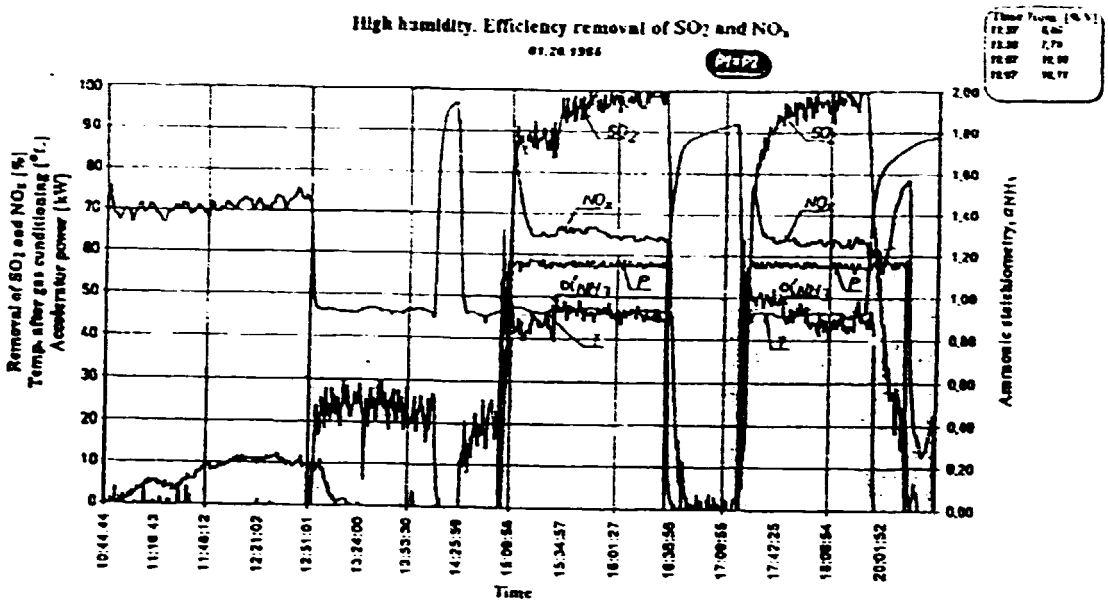

Fig. 8. Dependency of SO_2 and NO_x removal on gas humidity. Humidity up 10% vol.

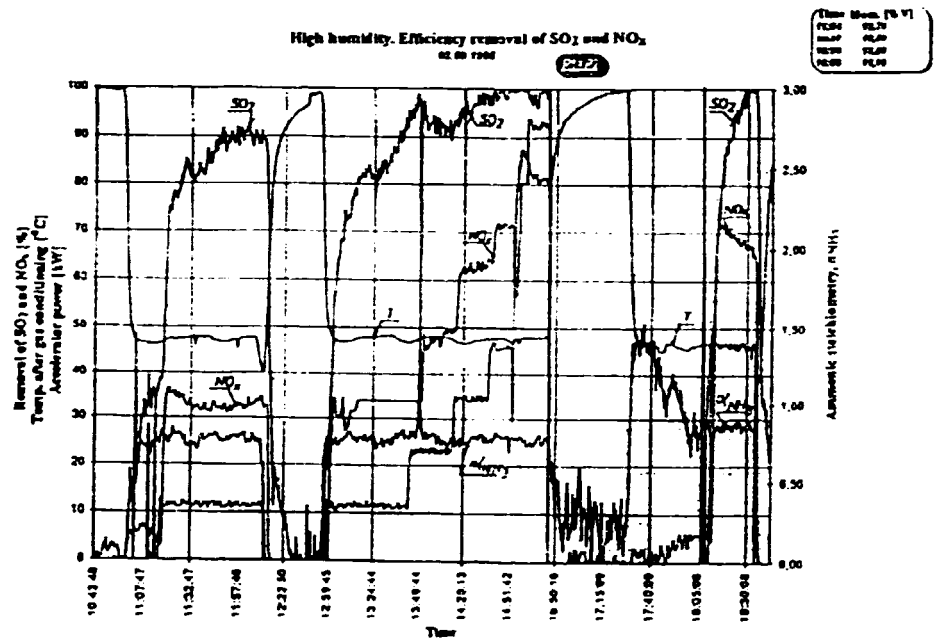

Fig. 9. Dependency of SO_2 and NO_x removal on gas humidity. Humidity above 12% vol.

1.3. Effect of process parameters on NO_x removal effectiveness

In contrast to SO_2, removal of NO_x occurs mainly as result of electron interaction and initial NO_x concentration. Such a dependence presented in Fig. 10.

An effect of temperature on NO_x removal effectiveness is slightly different than that for SO_2. In the range 60-85°C we can observe a small increase of the NO_x removal effectiveness (Fig. 11).

A value of the ammonia stoichiometric factor in the range 0.5 - 0.85 does not influence greatly on the NO_x removal effectiveness (cf. Fig. 6).

An inlet SO_2 concentration also influence the NO_x removal effectiveness. With the increasing concentration of SO_2 the NO_x removal effectiveness is higher, hence the energy demand drops. This phenomenon is illustrated in Fig. 12.

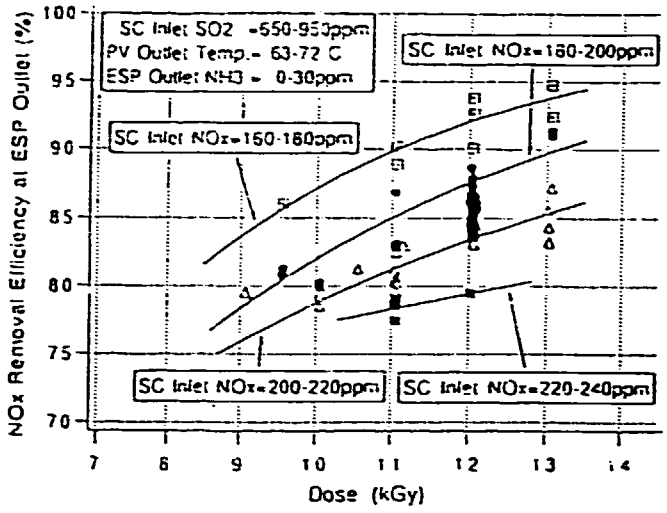

Fig. 10. Dose dependence of NO_2 removal efficiency at different NO_x concentrations [Nagoya]

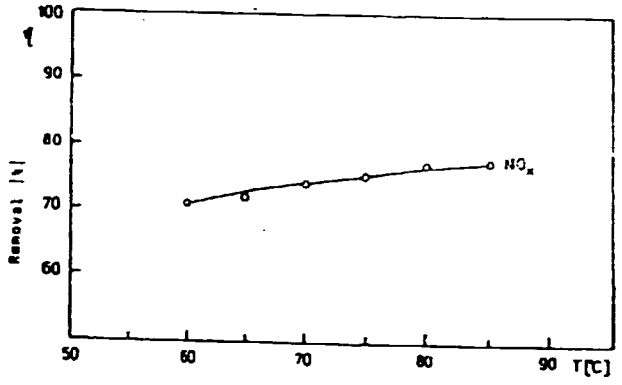

Fig. 11. Effect of e-b process temperature on the NO_x removal effectiveness.
inlet NO_x - 140 ppm, α_{NH3} - 0.6

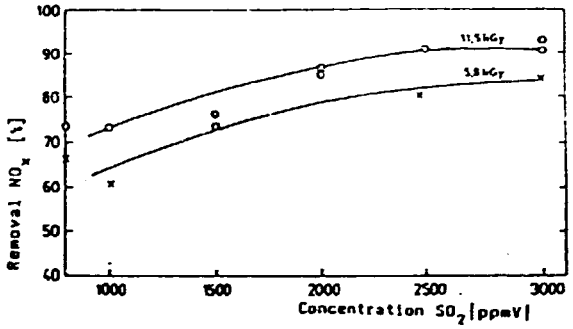

Fig. 12. Effect of the inlet SO_2 concentration on the NO_x removal effectiveness.
$\eta_{NOx} = f(C_{SO2})$, t_{inlet} = 69.5 - 71°C.
inlet NO_x - 135 ppm, α_{NH3} = 0.59 - 0.65,

1.4. Studies of formation and filtration of the solid product
Aerosol characteristics

As a result of flue gas irradiation by an electron beam, due to a number of possible reactions ammonium salts such as $(NH_4)_2SO_4$, and NH_4NO_3 will be generated.

The salts generated condense mainly as submicron aerosols. Particles of fly ash are also present in the salts which amount depends mainly on the type of combustioned coal and dust removal effectiveness in the electrostaticprecipitator limits. The amount of the generated salts depends mainly on the SO_2 and NO_x content in the flue gases and their further conversion. The results of the fractional composition of aerosols are presented in Fig. 13.

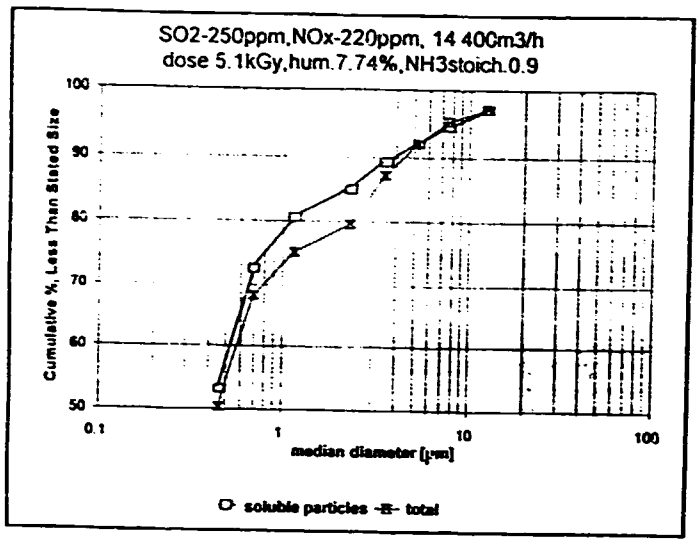

Fig. 13. Distribution of solid particles diameter of by-product.

Salts, mainly ammonium sulfate, form submicron particles (Fig. 14).

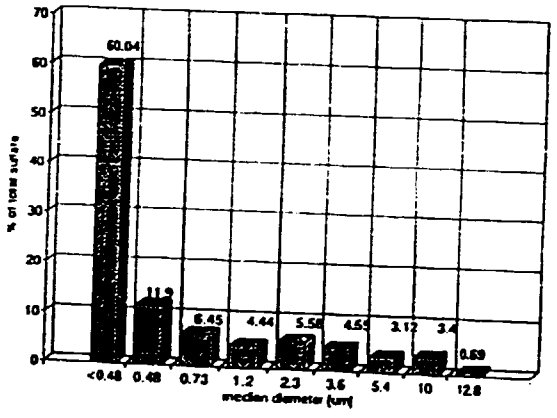

Fig. 14. Dependence of the mass of sulfates in aerosol on median diameter of particles (flow rate 10 000 m^3/h, dose 8 kGy).

1.5. Effect of new design developments on SO_2 and NO_x removal effectiveness

Application of a multiple irradiation of flue gases with an electron beam enabled to achieve high degrees of NO_x removal at about 20% lower energy demand (dose) for the reactions taking place as compared with a single stage exposition process. This dependence is presented in Fig. 14 [10].

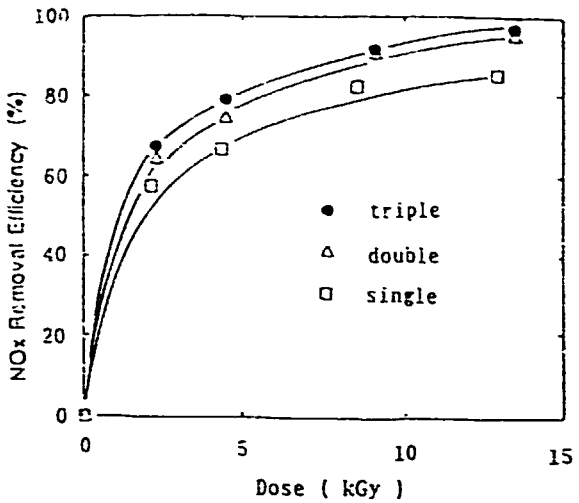

Fig. 15. Effect of multiple irradiation on the NO_x removal effectiveness [JAERI].

Deeper analysis of the multistage process of the flue gases exposition by an electron beam revealed that in the case of NO_x removal non-uniform power distribution of the accelerators at the successive stages will provide further energy savings [11].

- for two-stage gas exposition by an electron beam the optimal ratio of the dose distribution is 0.56/0.44
- for three-stage irradiation: 0.394/0.332/0.274.

The experiments have confirmed theoretical computations, and the results are shown in Fig. 16. However, the energy savings are not so significant as in the case of substitution of a single-stage irradiation by a two-stage one (Fig. 17).

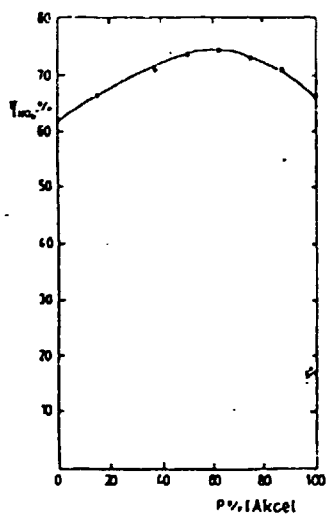

Fig. 16. Effect of the accelerator power distribution P% on the NO_x removal effectiveness.
V = 14 300 m^3/h, α_{NH3} = 0.8,
SO_2 - 395 ppm, NO_x - 176 ppm,
t_{inlet} = 70°C, dose - 5.6 kGy.

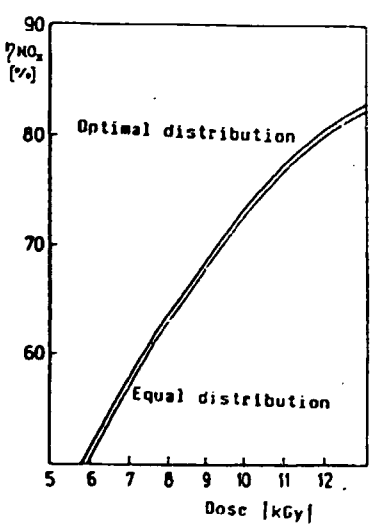

Fig. 17. Effect of the electron dose distribution at a two-stage gas irradiation on the NO_x removal effectiveness.

2. SURVEY OF RESEARCH ON ELECTRON BEAM APPLICATION FOR FLUE GAS CLEANING IN REMOVAL OF SO_2 AND NO_x

2.1. Pilot plants for cleaning of flue gas originating from coal combustion

Apart from the laboratory-scale research carried out at JAERI, Takasaki, Japan [12], INR AS, Shanghai, China [13], IPEN, Sao Paulo, Brasil [14], TU, Karlsruhe, Germany [15], some work has been carried out in small pilot plants at volumetric gas flow rates up to 1000 Nm^3/h by Ebara Co., Fujisawa, Japan [16] and KfK, Karlsruhe, Germany [17].

Scaling-up of the flue gases cleaning process is only possible after collecting relevant experimental data in a large, proof-of-concept, pilot plant with volumetric flow rate exceeding 10 000 Nm^3/h. As far as cleaning of flue gas from coal combustion is concerned, such installations have been built in the world: Indianapolis, USA [18], Badenwerk, Karlsruhe, Germany [19], Kawęczyn Poland [20] and Chubu, Nagoya, Japan [21]. A summary of the main features of these installations is presented in Table 1 [22].

Table 1. Proof-of-concept size pilot plants for cleaning flue gas from coal combustion

Institution Period	Volumetric gas flow rate Nm^3/h	Accelerator	Inlet concentration SO_2/NO_x ppm	Process temperature °C
Ebara Indianapolis 1984-1988	$8\text{-}24\cdot10^3$	800 keV 2 x 80 kW = 160 kW	1000/400	65-150
Badenwerk Karlsruhe 1985-1987	$10\text{-}20\cdot10^3$	300 keV 2 x 90 kW = 180 kW	50/500 300/500	70-100
Ebara, JAERI Chubu 1992-1994	$12\cdot10^3$	800 keV 3 x 36 kW = 108 kW	800-1000 150-300	65-75
EPS Kawęczyn, INCT Warsaw 1990-	$20\cdot10^3$	700 keV 2 x 50 kW = 100 kW	200-600 250	60-120

The installation layouts are shown in Figs. 18, 19, 20 and 21. The tests performed in these installations proved that high efficiency of removal of SO_2 and NO_x can be achieved.

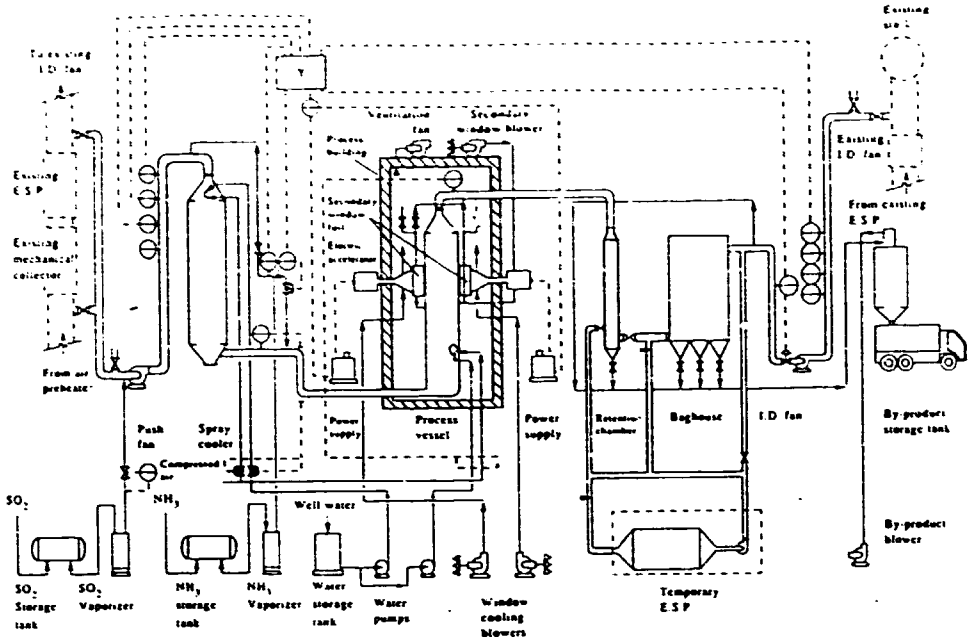

Fig.18. Pilot plant at the Indianapolis Power and Light Company.

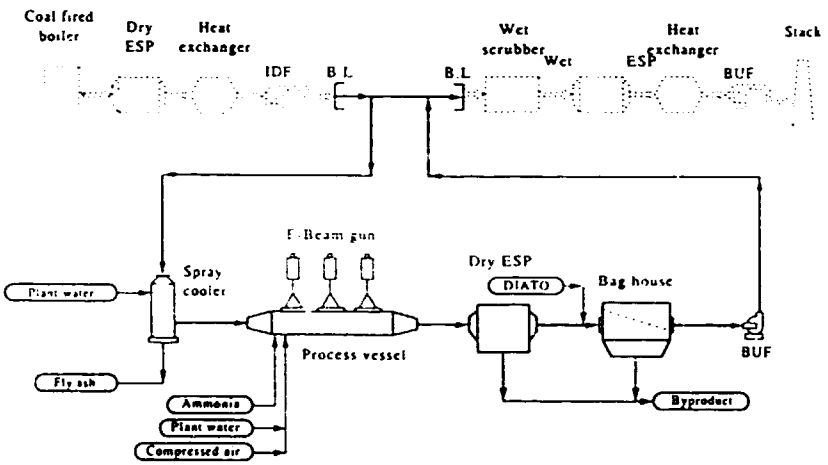

Fig.19. Installation layout at the Chubu Power Utility.

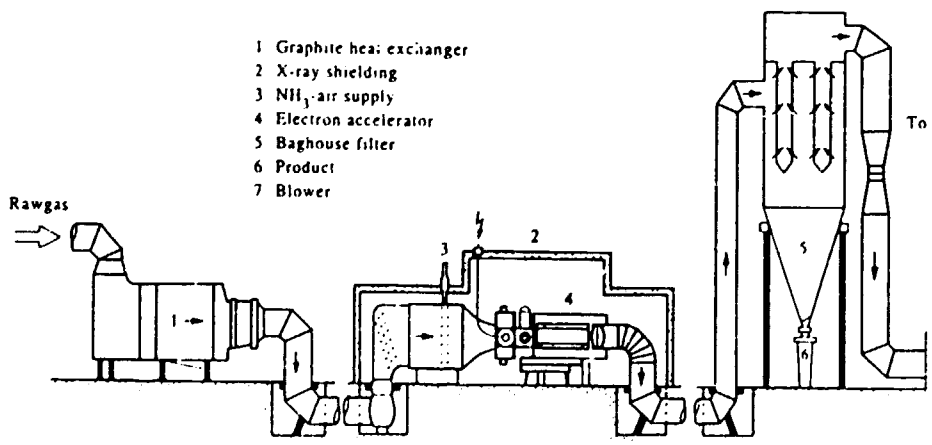

Fig.20. Pilot plant at the Badenwerk Power Utility.

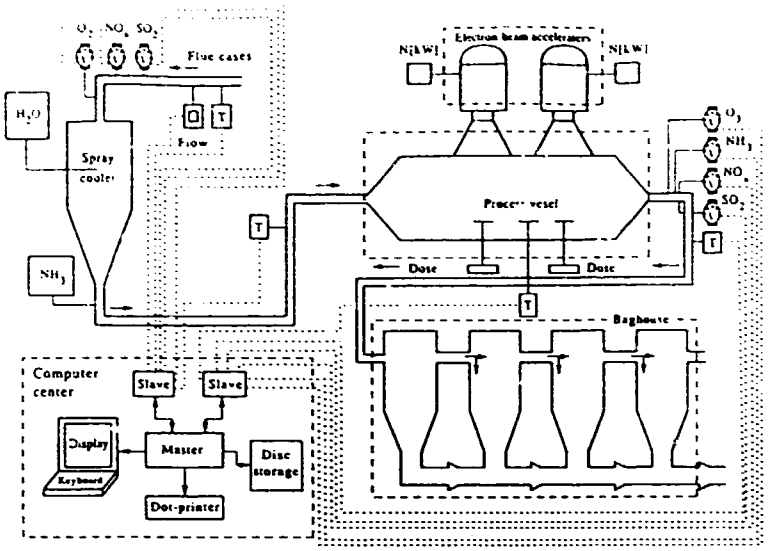

Fig. 21. Pilot plant at Electric Power Station Kawęczyn, Warsaw

Fig.22 demonstrates dependence of SO_2 removal efficiency on the irradiation dose. At a dose as high as 9 kGy over 95% SO_2 removal is attainable.

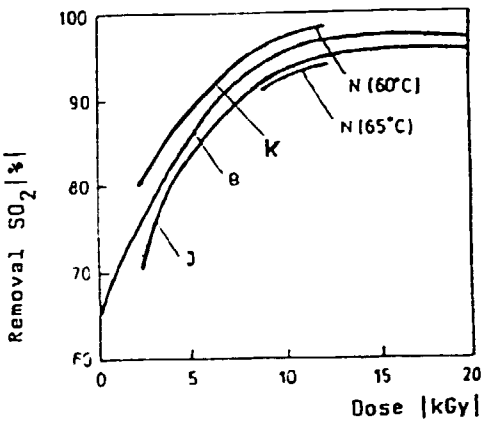

Fig. 22. Dependence of the SO_2 removal effectiveness on dose (I - Indianapolis, B - Badenwerk, N - Nagoya, K - Kawęczyn).

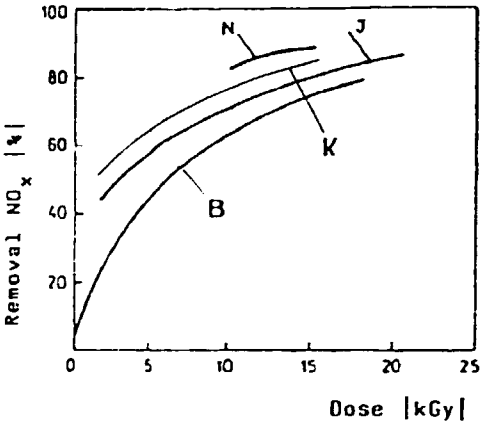

Fig. 23. Dependence of the NO_x removal effectiveness on dose (I - Indianapolis, B - Badenwerk, N - Nagoya, K - Kawęczyn).

Fig.23 shows a similar dependence for NO_x. Application of a multistage irradiation (N-Nagoya) allows to remove over 80% of NO_x at an overall dose 10 kGy. A lower removal efficiency of NO_x at the same amount of energy introduced to the gas (dose) was obtained at the Badenwerk plant. This was caused by an increased concentration of NO_x in the inlet gases. The flue gases were taken after their preliminary desulfurization. During the course of experiments at the Indianapolis and Kawęczyn pilot plants a positive effect of the higher SO_2 concentration on NO_x removal effectiveness has been observed (c f. Fig. 24).

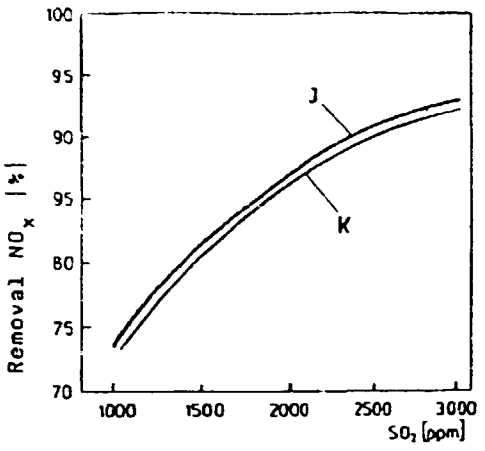

Fig. 24. Effect of the inlet SO_2 concentration on the removal (I - Indianapolis, K - Kawęczyn).

2.2. Agricultural utilization of the product

The by-product obtained in the flue gas cleaning process for SO_2 and NO_x removal using the Electron Beam process is a mixture of two ammonium salts-sulfate and nitrate. Depending upon the sulfur dioxide and nitrogen oxides concentrations in the flue gases, nitrogen content of the product ranges from 21 to 35%. In the case of a power plant firing bituminous coal with 2.5% sulfur content approximately 630 kg of product yield in achieved per mWe of electrical energy generation.
A typical product composition obtained at the Nagoya pilot plant, Japan [21], is as follows:

$(NH_4)_2SO_4$	90.2%
NH_4NO_3	7.0%
fly ash	2.0%
moisture	0.8%

where in chemical constituents are:

NH_4^+	25.4%
SO_4^{2-}	65.6%
NO_3^-	5.5%

The product has been registered under the Fertilizer Control Act in Japan as a fertilizer. Similar research was accomplished in the USA by the fertilizer manufacturer C.F. Industries, which expressed its positive opinion as far as its agricultural utilization is concerned. Also the by-product from Polish pilot plant was successfully examined by Warsaw Agriculture Academy.

A solid product obtained in the electron beam process for SO_2 and NO_x removal from flue gas value fertilizer with properties close to those of commonly used ammonium salts (ammonium sulfate, ammonium nitrate).

The heavy metals content in the tested product samples is much lower than the nominally allowed limit for agricultural use and even at only moderate effectiveness in removal of fly ash this is maintained.

Such product is applicable most importantly as a component of NPKS fertilizer supply or may be used intermixed with compost [23, 24]

During the last decade agricultural consumption of the fertilizers which contain sulfur increased by 21% (6.2 million ton). At the same time research carried out by the Sulfur Institute (USA) shows that a significant soil deficit of this element does exist in many regions of the world [25].

2.3. Process economics

Evaluation of technology applying electron beam to energetic inducing of the outlet gas components should recognize that removal of boths SO_2 and NO_x is accomplished.

One of the more commonly applied control schemes is that which couples the wet limestone method for SO_2 removal with selective catalytic reduction of nitrogen oxides.

Comparison of the investment and operation costs for such a facility against that applying electron beam is shown in Table 2.

Table 2. Comparison of SO_2 and NO_x removal costs for a boiler 35 mWe (German data [26])

Gas flow rate 120 000 Nm^3/h			
Raw Gas: SO_2 - 1650 mg/Nm^3 NO_x - 600 mg/Nm^3		Treatment Gas: SO_2 - 200 mg/Nm^3 NO_x - 200 mg/Nm^3	
Application of electron beam (dose 12 kGy)		NIRO/NOELL technology (limestone method + SCR)	
Capital costs	20.8 million DM	Capital costs	21.6 million DM
Operational costs (DM/h)			
Electric energy (1.9 mWe)	247.0	Electric energy (1.0 mWe)	130.0
H_2O (4 m^3/h)	4.4	Limestone (3300 kg/h)	45.0
NH_3 (152 kg/h)	68.4	NH_3 (20 kg/h)	9.0
Maintenance	104.0	Steam (12 000 kg/h)	32.4
		Dust removal (480 kg/h)	24.0
		Water (5.2 m^3/h)	5.72
		Maintenance	108.0
		Catalyst	120.0
	423.80 DM/h		474.12 DM/h

Continuous work of the installation	
4 000 hours work 1 695 000 DM/a 10% capital charges: 2 080 000 DM/a 3 775 000 DM/a	4 000 hours work 1 806 000 DM/a 10% capital charges: 2 160 000 DM/a 3 966 000 DM/a

In Figs. 25 and 26 a comparison of the investment costs for different methods of simultaneous removal of SO_2 and NO_x from the flue gases [27, 28].

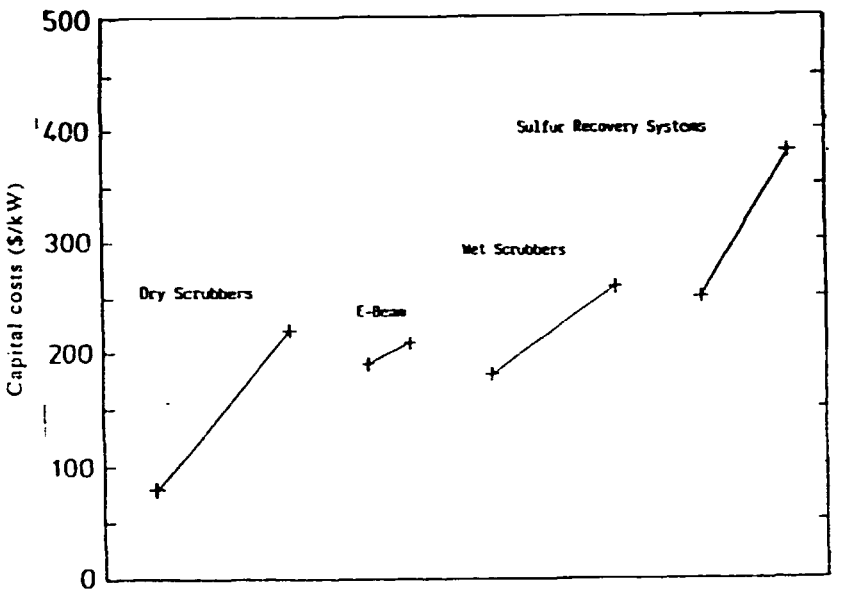

Fig. 25. Comparison of the type of system versus the capital cost in U.S.$ / kWe (based on 300 mWe and 2.6% sulfur). Publication by Prasha Publications. Coal & Synfuels Technology, Dec. 23. 1991. Source: Electric Power Research Institute (EPRI).

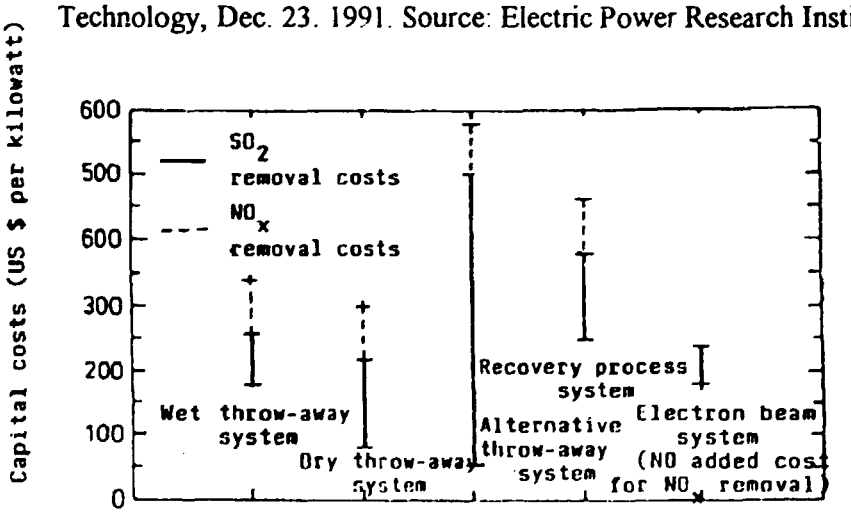

Fig. 26. Comparison of capital costs for flue gas processing (based on 300 mWe and 2.5% sulfur fuel). Source: N W. Frank, V. Markovic - IAEA Bulletin 1/1994

As follows from quoted data, the investment cost of technologies based on electron beam are on the level of 200 $/kWe of the installed electric power. Some what different comparison of the costs of a combined technology (wet limestone method and selective catalytic reduction) with the radiation technology is displayed in Figs. 27 and 28. Significant competitiveness of the electron beam technology with respect to the various cases of the combined technology is evident.

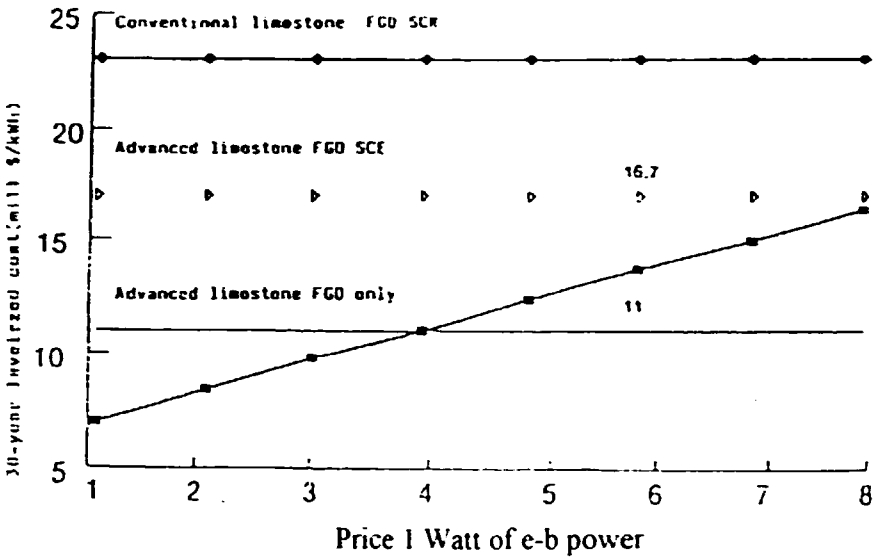

Fig. 27. Comparison of costs of technology combined with E-beam irradiation
Source: SAIC - paper presented at NATO Conference, Cambridge, 1992

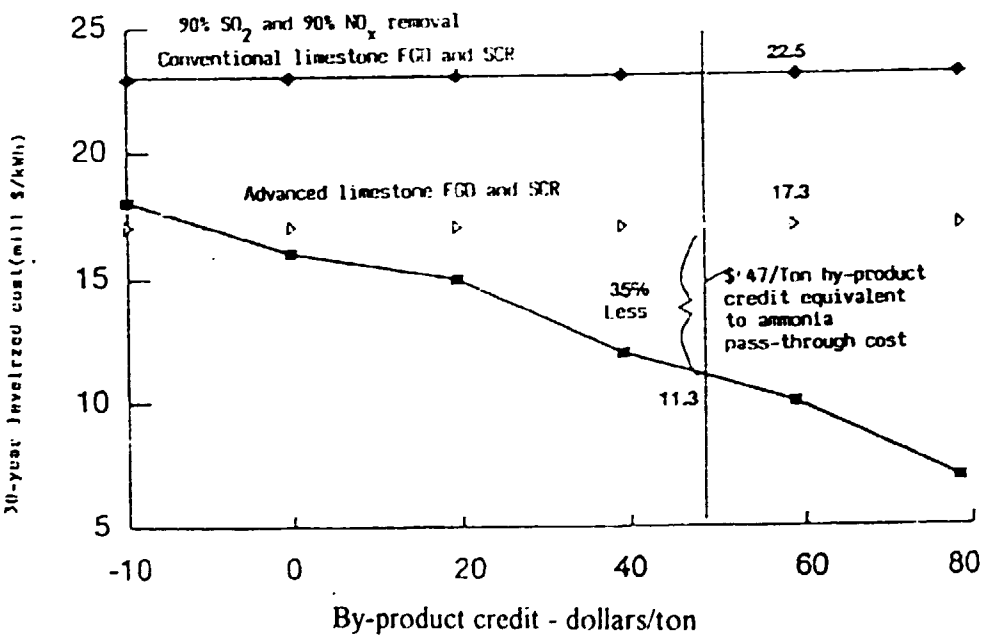

Fig. 28. Comparison of costs of technology combined with E-beam irradiation.
Source: SAIC - paper presented at NATO Conference, Cambridge, 1992.

Fig. 29 provides the running costs for the various methods in relation to one ton of removed SO_2. Costs of SO_2 and NO_x removal are particularly attractive for the electron beam technology when due account in taken of the revenues coming from by-product sale

It should be pointed out that the Electric Power Research Institute (USA) estimated that from among 70 checked technologies for simultaneous SO_2 and NO_x removal from the flue gas. application of electron beam is one of the four most promising second - generation methods recommended for simultaneous removal of SO_2 and NO_x.

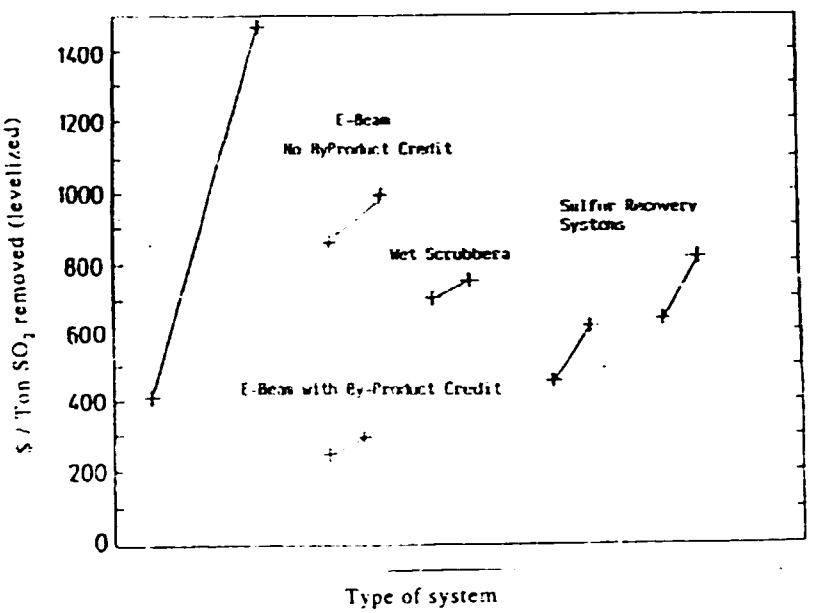

Fig. 29. Comparison of type of system versus the capital cost (based on 300 mWe and 2.6% sulfur). Publication by Prasha Publications. Coal & Synfuels Technology. Dec.23.1991. Source Electric Power Research Institute (EPRI) - acc to N.W Frank, IAEA-SM-325/168

3. BASIC DATA FOR FULL LOAD ENGINEERING DESIGN FOR EB INSTALLATION AT EPS POMORZANY

E-B technology is to be utilized for simultaneous removal of SO_2 and NO_x from flue gases emitted by the Benson boilers.

The boilers were manufactured by Babcock - Wilcox Company at Oberhausen Germany in 1959/60 and were reconstructed in 1979. Each boiler has 142.5 MW_t power output.
In the present each boiler is connected with turbine and this combined cycle has power output 56 MW_e and 50 MW_t.

After planed reconstruction of turbines which is intended in 1998, the cycle power increase to 68 MW_e and 100 MW_t. Operating time is 6500 h/year of equivalent full-load operation.

Boilers fire pulverized bituminous coal that has the following characteristics;

Caloric value	22820 kJ/kg
Sulfur content	0.72 ÷ 0.8%
Ash content	21.8%
Moisture content	7.8%

The boilers are equipped with modern flue-gas dedusting systems-four-compartment electrostatic precipitators, for which efficiency of removal of fly ash is equals 99.8%.
Maximum volumetric flow of flue gases from one boiler is 270 000 Nm^3/h.

Emitted stream of flue gases after treatment in the ESP contains:

SO_2	1.1 g/Nm^3
NO_x	0.6 g/Nm^3
O_2	7 - 8% vol.
CO_2	8% vol.
CO	0% vol.
N_2	to balance
fly ash	0.08 g/Nm^3
humidity	5% vol.

Its temperature ranges from 145°C to 170°C.
For design purpouses the temperature of flue gas after ESP has been assumed as 145°C.

According to the Polish Ministry of Environmental Protection regulation enacted on 12.02.1990 existing plants such as the EPS Pomorzany after the year 1997 will have a permissable emission of SO_2 of 870 g/GJ of the boiler heat input and NO_x of 170 g/GJ. However, these limits can be made more stringent by local government, as in the case of this site as required to adequately limit ground level pollutant concentration.

The above national standards allow an hourly emission from each Benson boiler of 855 kg SO_2 and 160 kg NO_x as NO_2 equivalent.

After a detailed analysis it was decided to design and construct the electron-beam installation treating a maximum 270 000 Nm^3/h stream flow of flue gas.

The EB Pomorzany flue gas treatment installation is being designed for retrofit conditions [29]. The E-Beam Process would be expected to be typically capable of achieving SO_2 removal of 90% or greater and NO_x removal of 80%. To achieve high SO_2 removal alone, a relatively low E-Beam dose is required as compared to that needed in achieving both high SO_2 and NO_x removal. At above low minimum E-Beam dose, the primary factors affecting SO_2 removal are flue gas temperature, its humidity and ammonia stoichiometry The nominal E-Beam dosage required

solely for 90% SO_2 removal efficiency is a minimum of 9 kGy.

The amount of removal of NO_x depends primarily on the E-Beam dosage and inlet NO_x concentration. Temperature, ammonia stoichiometry and SO_2 concentration are of secondary importance. Increase of NO_x removal requires exponentially increased irradiation dosage (see chapter 2). The pilot tests have verified that multi-stage irradiation (accelerator guns installed in an in-series sequence on the process vessel) can reduce the dosages required to achieve the same NO_x removal, typically by up to 20%.

High concentration of NO_x and relatively low concentration of SO_2 in flue gas emitted from Benson boilers at EPS Pomorzany establish the specific conditions for flue gas treatment required in continuous operation. The parameters of E-B process are chosen so as to guarantee efficiency of removal of NO_x up to 80% and of up 70% SO_2 in continuous operation of the installation. For intermittent operation up to 80% removal of NO_x and 90% reduction of SO_2 are expected.

During continuous operation the electron-beam induced reaction will take place in the process vessel at a higher temperature than that which would be selected for the more typical high removal case (90% SO_2, 80% NO_x). The conceptual system arrangement of this situation is shown in Fig. 30.

The main technical parameters and composition of flue gases in the Pomorzany E-Beam installation are shown in Table 3.

A two-process-train design is proposed with each train processing max 135 000 Nm^3/h of flue gas. This solution was selected because of existing building space limitation. The flue gas containing particulate, SO_2 and NO_x enters the existing electrostatic precipitator (ESP) at a design temperature of 145°C and fly ash is efficiently removed. The gas then passes through an evaporative spray cooler to achieve 80°C process temperature in a adiabatic cooling (with the water vapour content up to 11% volume).

After this humidification step the flue gas flows into the irradiation chamber to be sited in the existing building that formerly housed multi-cyclone dust collectors (two parallel compartments)

This building structure is to be generally reworked. At the inlet to irradiation chamber the gaseous ammonia reagent is added to the flue gas via nozzles mounted at the site of the duct

The ammonia storage facility will be placed at the railroad siding serving the power plant. In each irradiation chamber flue gas is treated by beams of high energy electrons emitted by two accelerator heads each of 300 kW power rating. By-product collection is achieved in a dry ESP of special design.

After the by-product collection, it will be transported to plant storage and will be loaded and shipped to buyers.

The treated stream of flue gas will be mixed with dedusted, untreated stream.

The proportioning of these streams will be such as to protect the existing stack, unmodified, from acid attack. This required minimum stack temperature is 110°C.

The Table 4 shows the main design parameters of the EB Pomorzany installation.

To facilitate the basic engineering design the EB Process has been divided into the following major sub-systems.

Flue Gas Cooling System

Flue gas existing the ESP at a temperature 145°C is cooled to 80°C in a spray cooler, where atomized water is injected into flue gas stream by means dual fluid air-water nozzles
The spray cooler is operated with a dry bottom, i.e. all of the water injected into the flue gas is evaporated.

Reagent Handling System

Anhydraus ammonia is delivered to the plant by truck or rail and storage in 4 tanks total capacity 220 m^3. At ambient temperature tanks can contain 13.4 - 15 t of liquid ammonia, which represents monthly demend. The ammonia is then vaporized using electrical heating. To ensure good distribution in the flue gas duct, ammonia is distributed using a multi-nozzle aasembly configured as a grid in the gas duct. The ammonia is injected after the spray cooler at a flue gas temperature of approximately 80°C.

SO_2 - NO_x Removal System

In the E-Beam Process vessel flue gas containing SO_2, NO_x and NH_3 is irradiated by high-energy electron beams generated by two accelerator-guns 300 kW each (800 keV x 375 mA) that are installed on the process vessel in series with respect to the gas stream flow. A radiation dosage of 12 kGy was chosen for removals of 70% SO_2 and 80% NO_x based upon pilot plant data.

The E-Beam units are enclosed in a concrete structure to that ensure no radiation is emitted to the external surroundings. In order to minimize the volume of concrete, the entire system is partially underground to use the shielding effect of the surrounding soil.

By-product Collection System

The flue gas is passed through the by-product collection system. An ESP is proposed to capture the by-product with the particulate emission of less than 40 mg/Nm^3. By-products collected in the ESP are transferred to silo ready to ship. Production of 700 kg/h is anticipated. Typically, the by-product will contain 70% ammonium sulfate, 26% ammonium nitrate, 2% inert solids (fly ash) and 2% humidity.

Flue Gas System

Flue gas leaving the ESP passes through the spray cooler, E-beam vessels, and by-product ESP. All the ducts connecting this equipment are part of the flue gas system. An ID fan (550 kW, 374 400 Nm^3/h x 2600 Pa) downstream of the by-product ESP provides sufficient draft to overcome the entire pressure loss of the system.

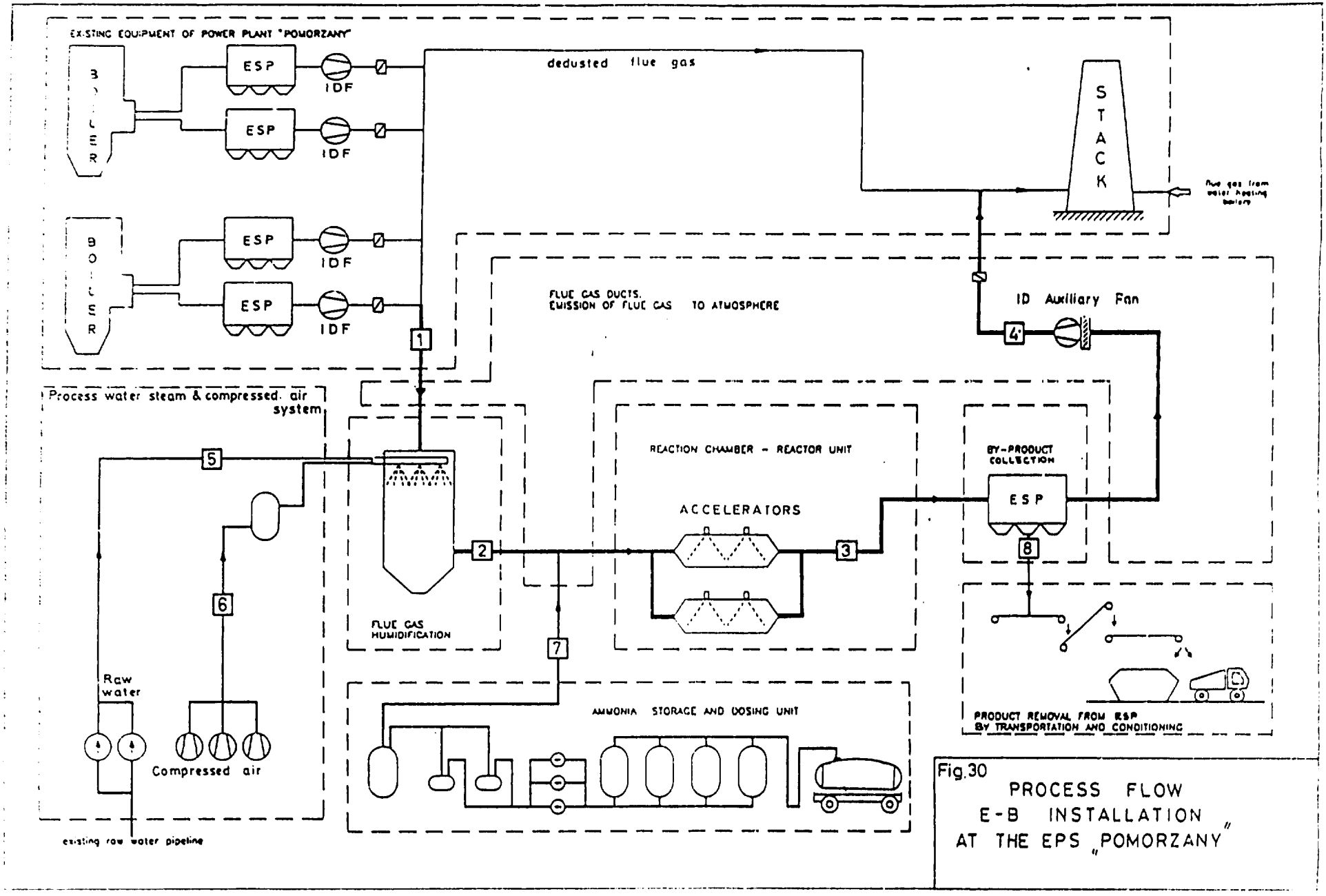

Fig.30
PROCESS FLOW
E-B INSTALLATION
AT THE EPS „POMORZANY"

Table 3. Technical parameters and composition of process streams at key points of the EB installation.

Stream No.	1	2	3	4	5	6	7	8
	System gas inlet	Spray cooler outlet	Reaction chamber outlet	Plant outlet	Spray water	Compressed air	NH_3	By-product
N_2	80% vol.	75% vol.	75% vol.	75% vol.				
O_2	7% vol.	6.6% vol.	6.6% vol.	6.6% vol.				
CO_2	8% vol.	7.4% vol.	7.4% vol.	7.4% vol.				
SO_2	1.1 g/Nm^3	1.03 g/Nm^3	0.31 g/Nm^3	0.31 g/Nm^3				
NO_x	0.6 g/Nm^3	0.57 g/Nm^3	0.12 g/Nm^3	0.12 g/Nm^3				
NH_3	0	0	0.03 g/Nm^3	0.03 g/Nm^3				
H_2O	5% vol.	11% vol.	11% vol.	11% vol.	max 13.5 t/h	2100 Nm^3/h	180 kg/h	700 kg/h
$(NH_4)_2SO_4$	0	0	490 kg/h	0.025 g/Nm^3				
NH_4NO_3	0	0	175 kg/h	0.01 g/Nm^3				
Pressed air	0	0	0	0				
Fly ash	0.08 g/Nm^3	0.06 g/Nm^3	2.45 g/Nm^3	0.04 g/Nm^3				
Flue gas	270 000 Nm^3/h	284 000 Nm^3/h	284 000 Nm^3/h	284 000 Nm^3/h				
Gas temp.	145°C	80°C	90°C	90°C				

Table 4. Design basis for the E-B installation at EPS Pomorzany.

	Continuous operation	Intermittent operation
FLUE GAS COOLING SYSTEM		
Inlet Temperature of Spray Cooler	145°C	145°C
Outlet Temperature of Spray Cooler	80°C	65°C
Water Flow Rate to Spray Cooler	max 13.5 t/h	max 13.5 t/h
Mode of Operation	dry bottom	dry bottom
REAGENT HANDLING SYSTEM		
Ammonia Storage	15 t	15 t
Injection Mode	gas phase	gas phase
Evaporation Media	electricity	electricity
Ammonia Flow Rate	180 kg/h	200 kg/h
SO_2 - NO_x REMOVAL SYSTEM		
SO_2 Removal	70%	90%
NO_x Removal	80%	80%
E-Beam Power Dose	12 kGy	12 kGy
E-Beam System:		
Required E-Beam Gun Output	1334 kW	1334 kW
Installed E-Beam Gun Output Capacity	1848 kW	1848 kW
Accelerator (800 kV x 375 x mA x 300 kW)		
Inlet Gas Temperature	80°C	65°C
Outlet Gas Temperature	90°C	75°C
Pressure Drop in Vessel	15 mm H_2O	15 mm H_2O
BY-PRODUCT COLLECTION AND HANDLING SYSTEM		
Collector Type	ESP	
Removal Efficiency	98.5%	98.5%
Particulate at Inlet to Flue Gas Reheat Mixer	< 20 mg/Nm^3	< 20 mg/Nm^3
Exhaust Temperature Loading at Inlet to Flue Gas Reheat Mixer	90°C	80°C
By-product Yield	700 kg/h	720 kg/h
By-product Storage Root Storage	5 months	5 months
Mode of Transport	track	track

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Institute of Nuclear Chemistry and Technology

Engineering Design Of An Electron Beam (EB) Flue Gas Purification Industrial DemonstrationPlant

Basic Engineering.

Volume 2

Gas Conditioning Unit

Warsaw, January 1996

No. of Volume	List of Volumes	Author
Volume 0	Executive Summary	
Volume I	Process Technology	INCT
Volume II	**Gas Conditioning Unit**	**INCT**
Volume III	Ammonia storage and dosing unit	Energoprojekt-Warszawa
Volume IV	Reaction chamber	Proatom
Volume V	By-product filtration (ESP)	Energoprojekt-Warszawa
Volume VI	By-product removal from filter, its transportation and conditioning	Energoprojekt-Warszawa
Volume VII	Flue gas ducts. Emission of flue gases to atmosphere	Energoprojekt-Warszawa
Volume VIII	Measuring, monitoring and control system	SINS
Volume IX	Electrical power supply units	Energoprojekt-Warszawa
Volume X	Composite documentation	Energoprojekt-Warszawa
Volume XI	Balances	Energoprojekt-Warszawa

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2. E. Iller	INCT

CONTENTS

GAS CONDITIONING UNIT

1. BASIC ENGINEERING DESIGN FOR POMORZANY

The design for gas conditioning by humidification relies on the continuous availability of 145°C raw flue gas temperature entering the humidification. Thus method of humidification is a choice between mechanical atomization and air - water atomization. Based on an examination of all factors including energy consumptions the specified system design is as follows.

2. THEORY AND PRACTICE

The experiments carried on in laboratory and pilot installation have confirmed that the best conditions for SO_2 removal from flue gases in the electron-beam irradiation process are: gas dry bulb temperature 65 - 70°C, with humidity 10 - 12 volume %.
The gas leaving the boiler after dedusting in ESP has temperature 110 - 150°C, (temperatures below 145°C being typically avoidable incommercial application by use of the steam coil air heater employed to prevent rotary air heater corrosion by tempering inlet air flow to the rotary heater), and humidity about 4% to 6% volume of water vapour content. It is essential that gases be cooled and humidified. This process takes place in a spray cooler.
In the Nagoya, Kawęczyn and Indianapolis Power and Light pilot plants, the spray cooler has consisted of an open, vertical, downward-gas-flow cylinder with the spray nozzles located at the top (Fig. 1). The hot flue gases flow down cocurrently with water droplets, which are completely evaporated. The spray cooler is operated with a dry bottom.
The heat and mass balance equation describe the relation between inlet and outlet parameters of flowing flue gases.
For adiabatic conditions and a complete water evaporation process the relations are as follows.

2.1. Mass balance

$$m = v(x_2 - x_1) \qquad [1]$$

where:
m - amount of injected water [kg/h]
v - flow rate of gas [kg/h], dry basis
x - humidity of gas [kg H_2O/kg of dry gas]
indices
1- inlet gas, 2 - outlet gas

2.2. Heat balance

$$I_1 + I_{H2O} = I_2 \qquad [2]$$

where: I - enthalpy
If we will take into consideration 1 kg of dry gas, reference temperature 0°C and spray water in the liquid state, the heat balance equation can be written as:

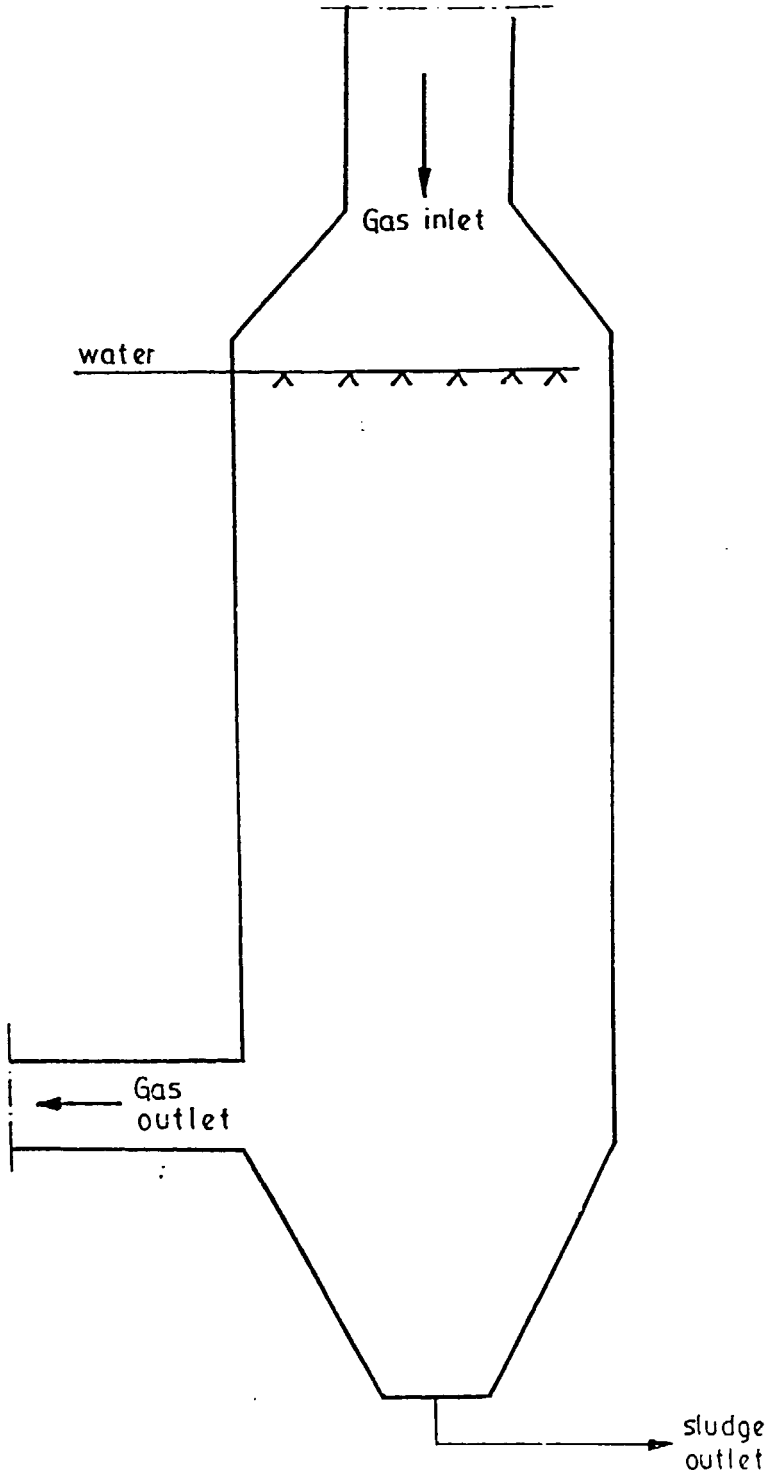


Fig. 1 SCHEME OF SPRAY COOLER

$$t_1(c_{g1} + x_1 c_{s1}) + x_1 r_0 + (x_2 - x_1) c_w t_3 = t_2(c_{g2} + x_2 c_{s2}) + x_2 r_0 \qquad [3]$$

in which
c - mean specific heat at constant pressure in range from 0°C to t [kJ/kg°C]
t - temperature [°C]
r_0 - heat of water evaporation in 0°C [kJ/kg]
indices
g - dry flue gas
s - water vapour
w - liquid water
3 - inlet water

The temperature of flue gas and its humidity after the heat and mass exchange processes is dependent on the amount of water evaporated.
This amount of water can be easily calculated from equation (1). The required temperature of water injected into the spray cooler can be evaluated from rearranged equation (3).

$$t_3 = \frac{t_2(c_{g2} - x_2 c_{s2}) - t_1(c_{g1} + x_1 c_{s1})}{(x_2 - x_1) c_w} + \frac{r_0}{c_w} \qquad [4]$$

The values of c_g, c_s, c_w for different temperatures are given in Fig. 2 and Fig. 3.
Based on the equation [4] the same calculations were performed to illustrate relationships between process parameters in the case of full water evaporation.
The results are shown in Fig. 4 - 7.
From this, it is evident that three parameters: humidity of inlet gas, temperature of inlet gas and temperature of gas after humidification have significant influence on the required temperature of spray water (t_3).
Under field conditions the temperature of flue gas after ESP is dependent on working parameters of the boiler. In case of higher temperature entering spray cooler, decreasing its temperature to a specified outlet temperature (e.g. 65-70°C) will cause a greater increase in its humidity than in the case of lower inlet gas temperature.
Humidification of low temperature inlet flue gas will require an excessively high water temperature.

3. ALTERNATIVE METHODS

Selection of the best method for flue gas humidification depends on local field conditions We can take into consideration three following possibilities:

1. two stage humidification
2. humidification with injection of water and steam
3. humidification with partial evaporation of circulating hot water

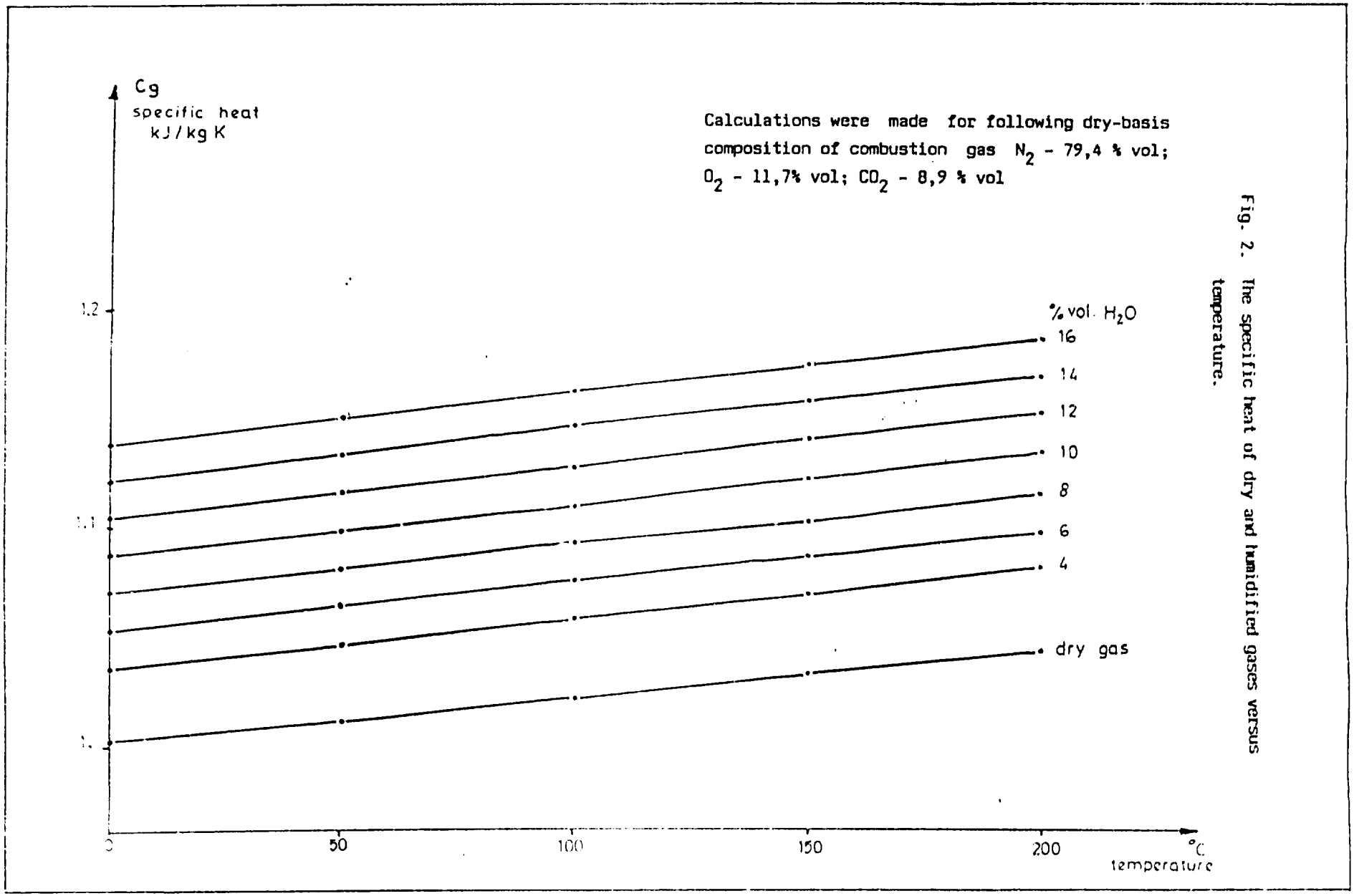


Fig. 2. The specific heat of dry and humidified gases versus temperature.

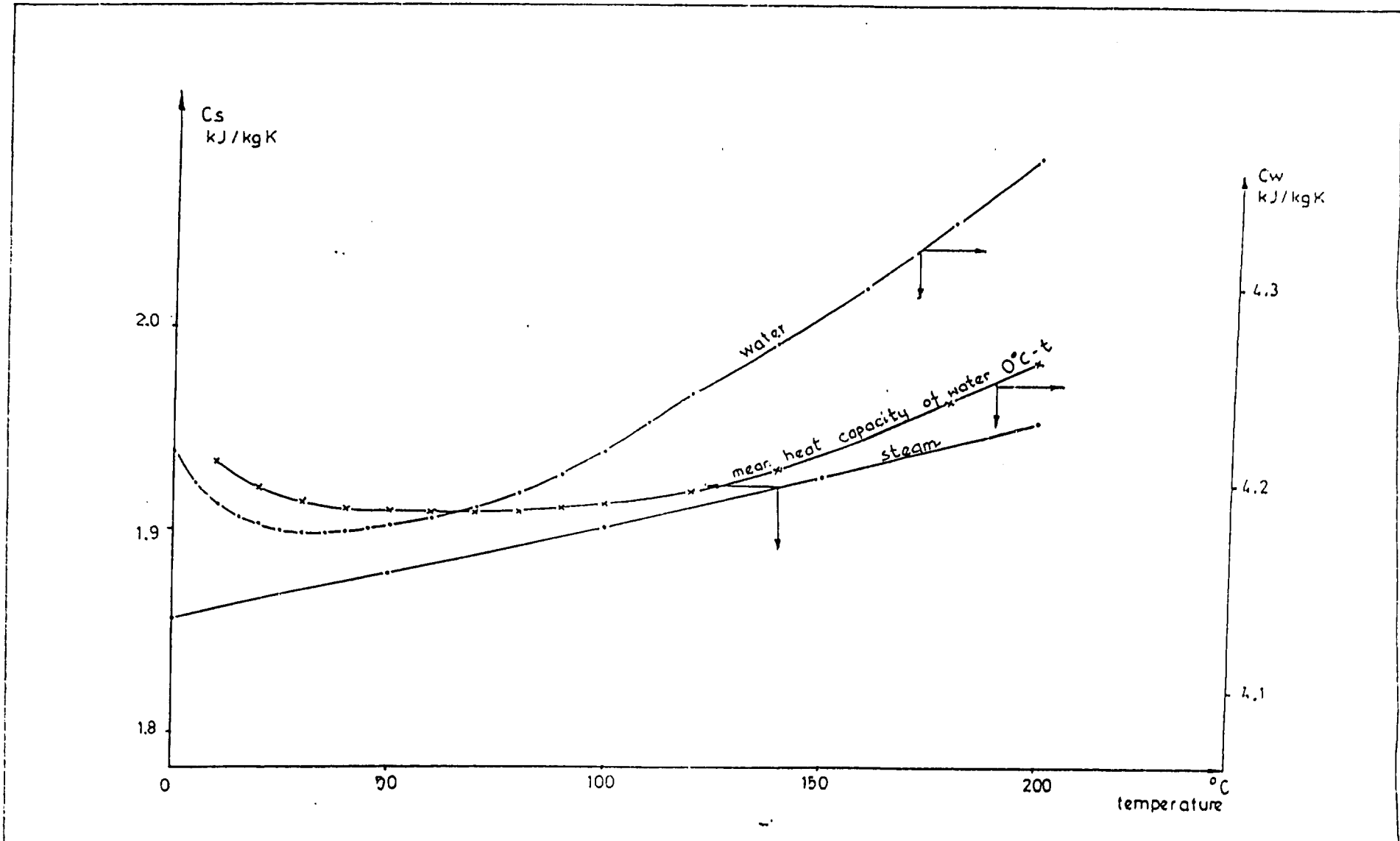


Fig. 3. The specific heat of water (C_w) and steam (C_s) versus temperature

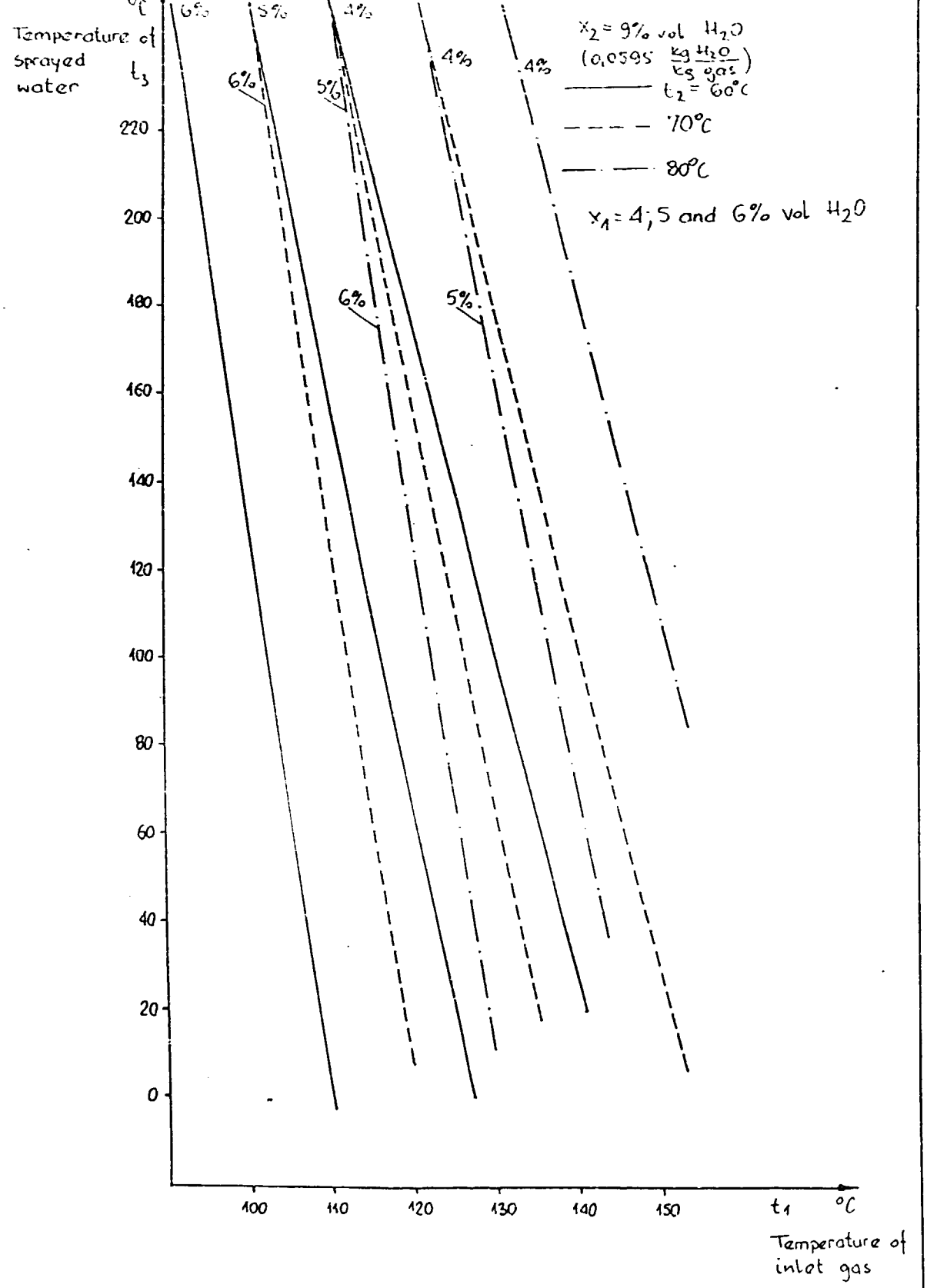


Fig. 4. Dependency of temperature of sprayed water versus t emperature of inlet flue gas (X_2 = 9%)

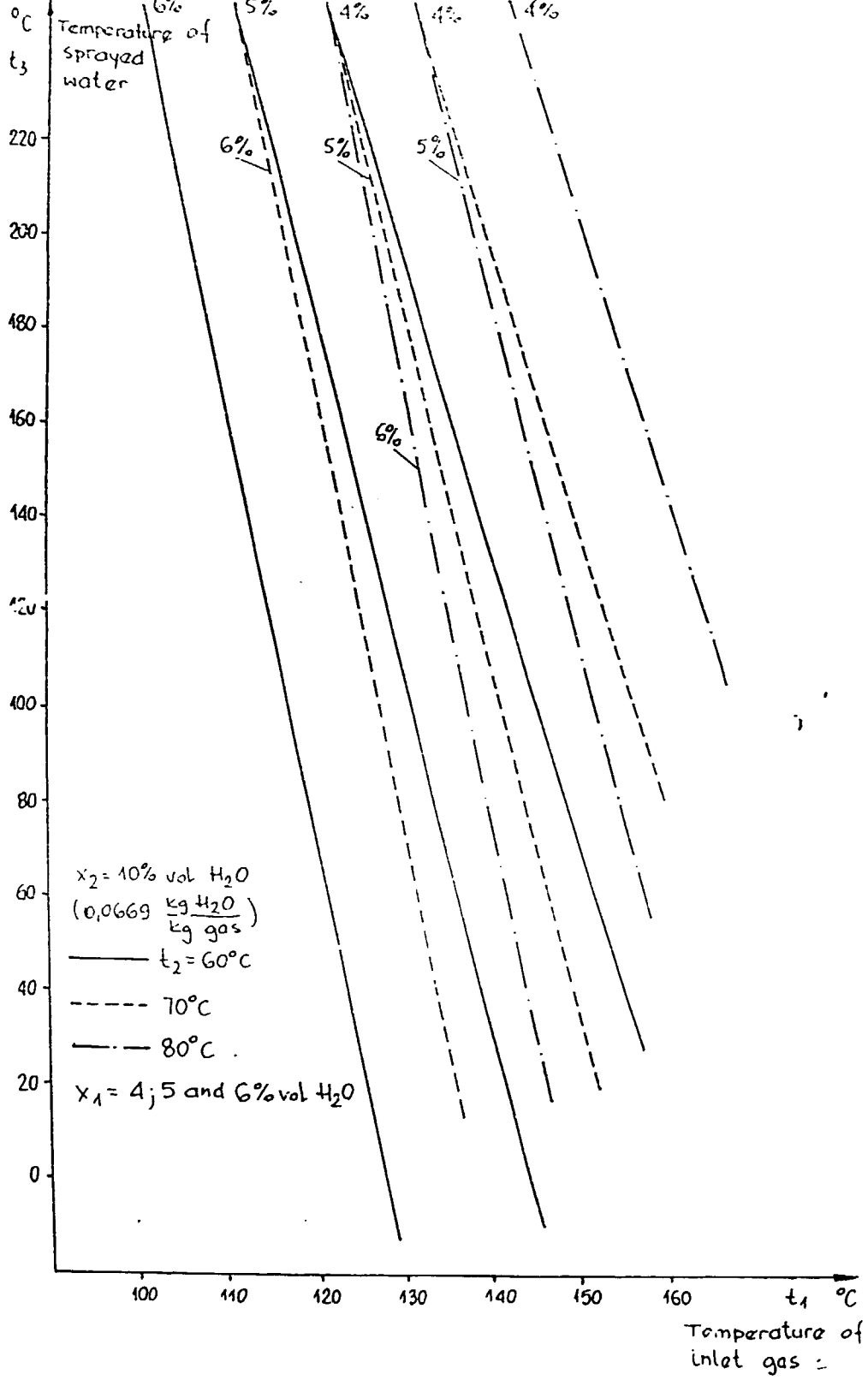


Fig. 5. Dependency of temperature of sprayed water versus temperature of inlet flue gas (X_2 = 10%)

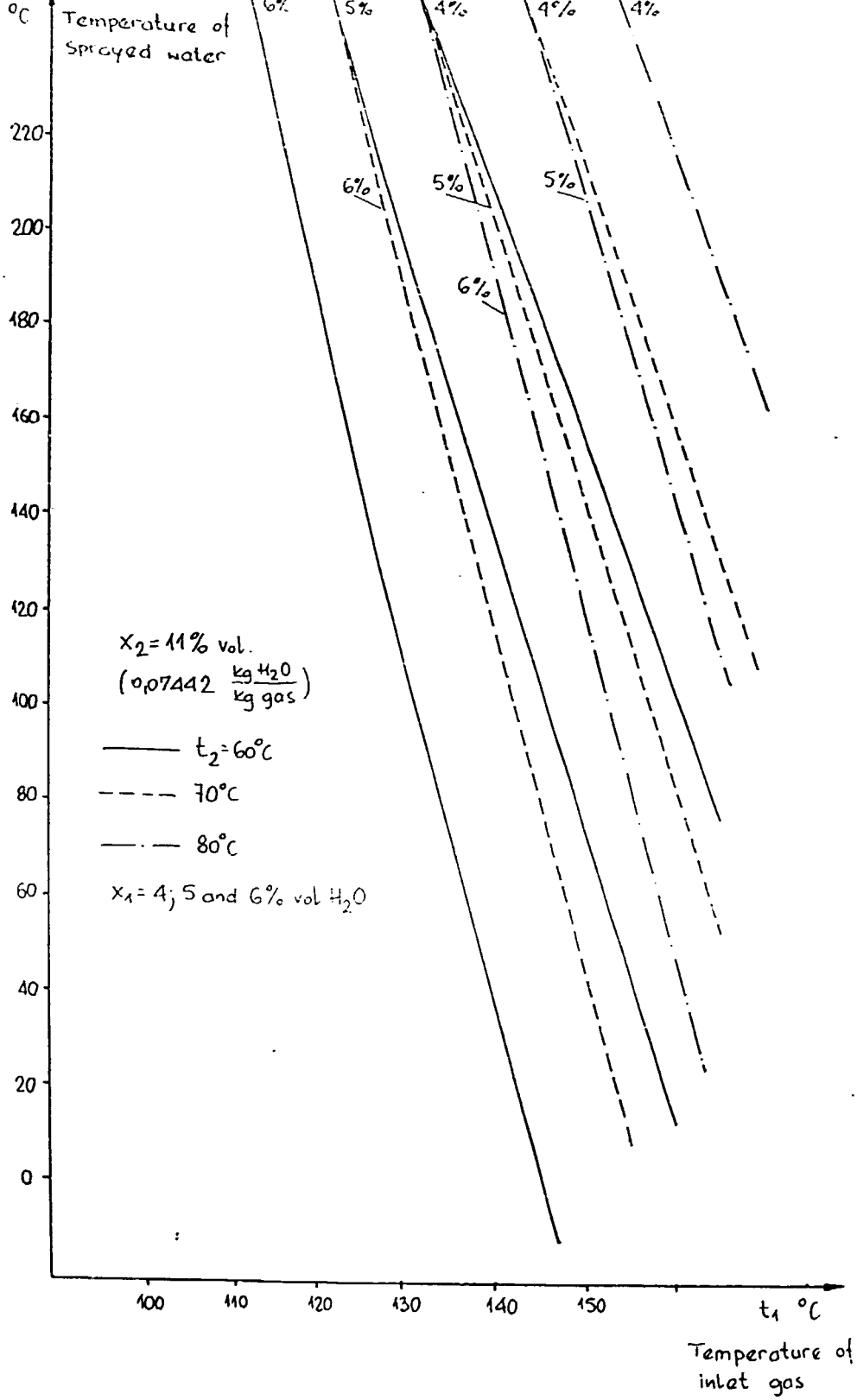


Fig. 6. Dependency of temperature of sprayed water versus temperature of inlet flue gas (X_2 = 11%)

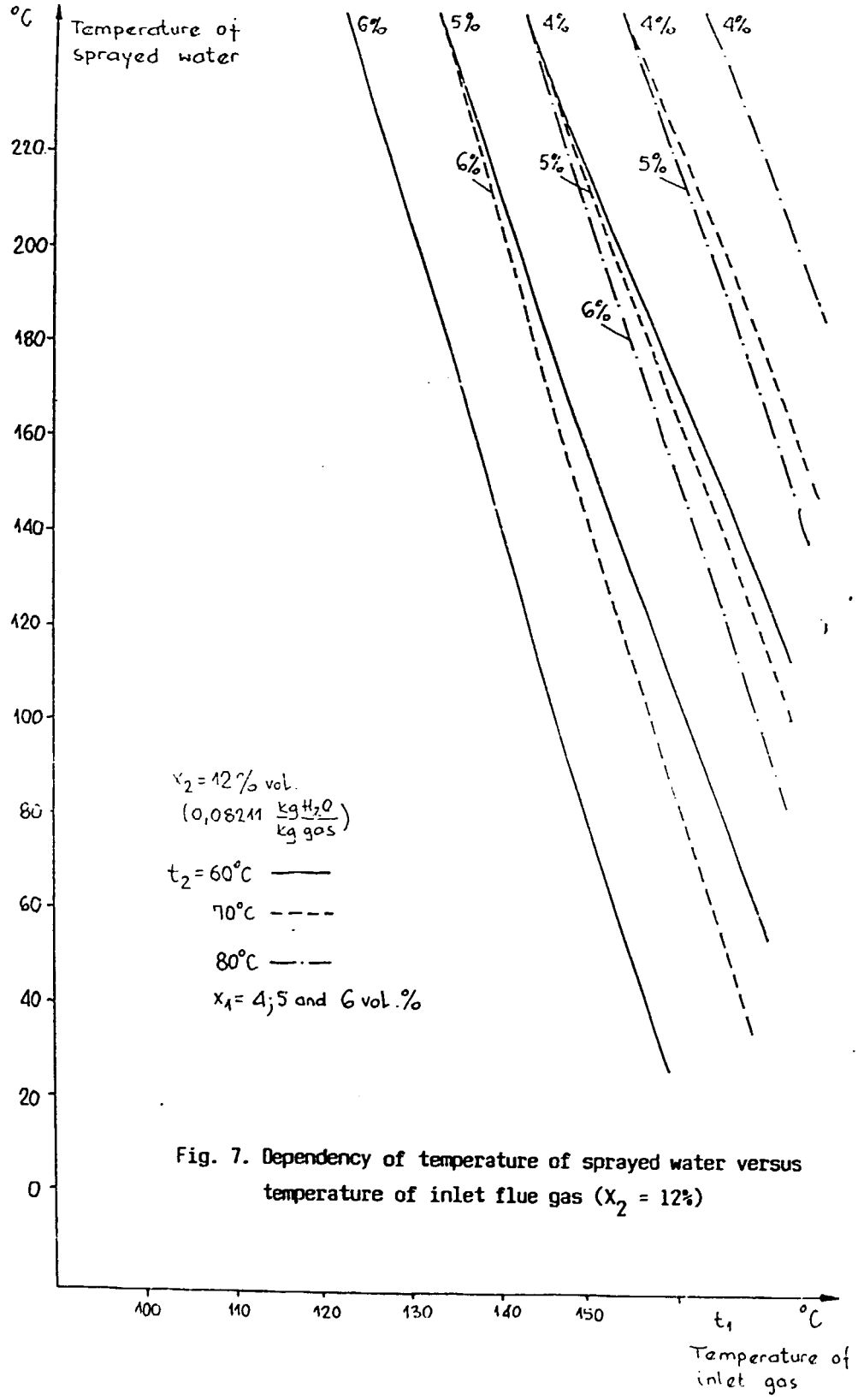


Fig. 7. Dependency of temperature of sprayed water versus temperature of inlet flue gas (X_2 = 12%)

3.1. Two stage humidification of flue gas

This system of humidification was applied in Nagoya EB Pilot Plant. Beside injection of water into the spray cooler, an additional portion of spray water is added to the reaction vessel. This design results in favorable conditions for most effective removal of SO_2 and NO_x. Removal of NO_x slightly increases with increase of e-b process temperature (Fig. 11, Vol 1). The reaction of NO_x removal is better carried out in the temperature of order 80°C. Gas humidification does not so strongly influence these reactions. The reaction in which SO_2 molecules participate is better carried out in the temperature range 50 - 65°C and strongly depends on the humidity of the mixture of flue gas with ammonia. Therefore additional injection of water between multiple irradiation zones seems to be an appropriate design for multistage treatment of flue gas. Dual-fluid (air - water) nozzles would be applied for water injection into the reaction vessel.

3.2.Injection of water and steam

In this case the equations for mass and heat balance have the following forms.

3.2.1. Mass balance

$$m_{H2O} + m_s = v(x_2 - x_1) \qquad [5]$$

where
m_{H2O} - mass of sprayed water [kg/h]
m_s - mass of injected steam [kg/h]

3.2.2. Heat balance

$$I_1 + I_{H2O} + I_s = I_2 \qquad [6]$$

where:
I_s - enthalpy of stream
Similarly as in Eq [3] this can be rewritten as follows:

$$t_1(c_{g1} + x_1c_{s1}) + x_1r_0 + x_si_s + (x_2 - x_1 - x_s)\, c_wt_3 = t_2(c_{g2} + k_2c_{s2}) + x_2r_0 \qquad [7]$$

where:
i_s - enthalphy of 1 kg steam
If we define fraction of water added in form of steam as: $a = x_s/(x_2 - x_1)$,
and after same rearrangement we obtain, based on equation [7]:

$$a = \frac{t_2(c_{g2} + x_2c_{s2}) - t_1(c_{g1} + x_1c_{s1}) + (x_2 - x_1)(r_0 - c_wt_3)}{(x_2 - x_1)(i_s - c_wt_3)} \qquad [8]$$

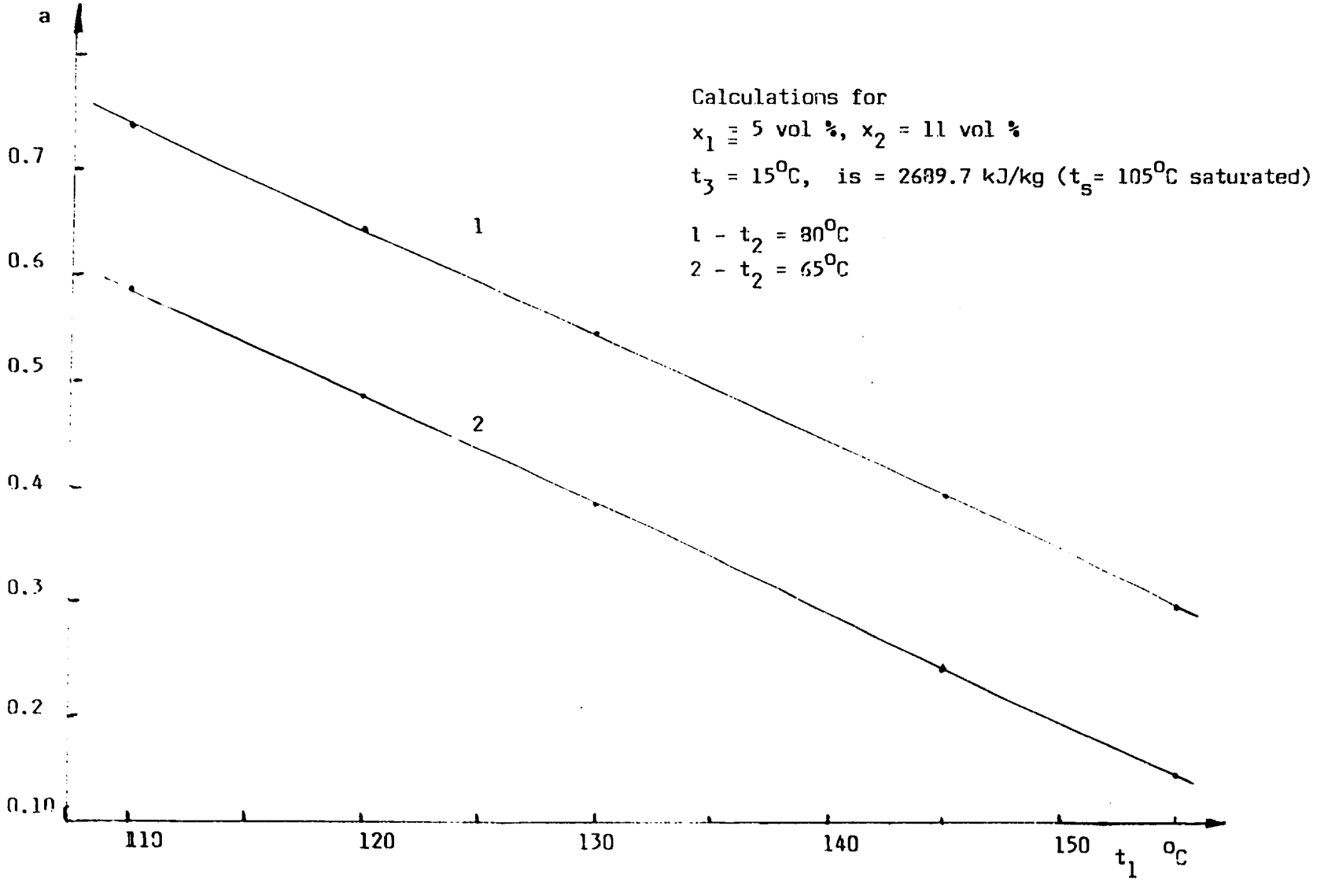


Fig. 8. Influence of inlet gas temperature on value of "a"

Dependency of fraction - a on the temperature of flue gas entering the spray coolor is presented in Fig. 8, for which calculations were made for t_3 = 15°C and steam at 105°C under pressure of 1.2 atm.

3.3. Humidification with partial evaporation of recirculating hot water

Another solution for humidification of flue gas is its conditioning by spraying a large amount of circulating hot water within a direct-contact heat exchanger.
Analysis of the process is rather complicated. In the case of cocurrently flowing streams of gas and water with the assumption that only a small fraction of the circulated water is transferred to the gas phase, we can write the heat balance equation as follows:

$$Li_{w1} + Gi_{g1} = Li_{w} + Gi_{g} \qquad [9]$$

where:
L - water flow rate
G - gas flow rate
Graphiclly the relation is presented in Fig.14.
Knowing the enthalpy (i_g) of the gas and its relative humidity-x for the beginning and end conditions of the humidification process we can determine the enthalpy of water i_{w1}, i_{w2} as well as L/G and t_{1w}, t_{2w}.
The height of spray cooler necessary to achieve this flue gas humidity may be calculated from the relation:

$$H = \frac{G}{k_g a} \int_{i_{g1}}^{i_{g2}} \frac{di_g}{i_s - i_g} \qquad [10]$$

where:
k_g - mass transfer coefficient
a - gas / liquid contact area, m^2/m^3
The values of $(i_s - i_g)$ for given i_g as it changes from i_{g1} to i_{g2} can be determined based on the curves shown in Fig. 9. (They are the equal to the magnitude of the vertical distance between the operational line and the saturation curve).
Approximate value of k_g coefficient can be calculated from dimensionless relations.

$$Sh = 2 + 0.55\ Re^{0.5}\ Sc^{0.33} \qquad [11]$$

if Re < 4 (small droplets of sprayed water)

$$Sh = 2 \qquad [12]$$

where:
$Sh = k_g d/D$
D - dynamic coefficient of diffusion of H_2O in gas
Accurate value of $k_g a$ must be determined experimentally.
This system of flue gas humidification has been tested in the E-B pilot plant at EPS Kawęczyn

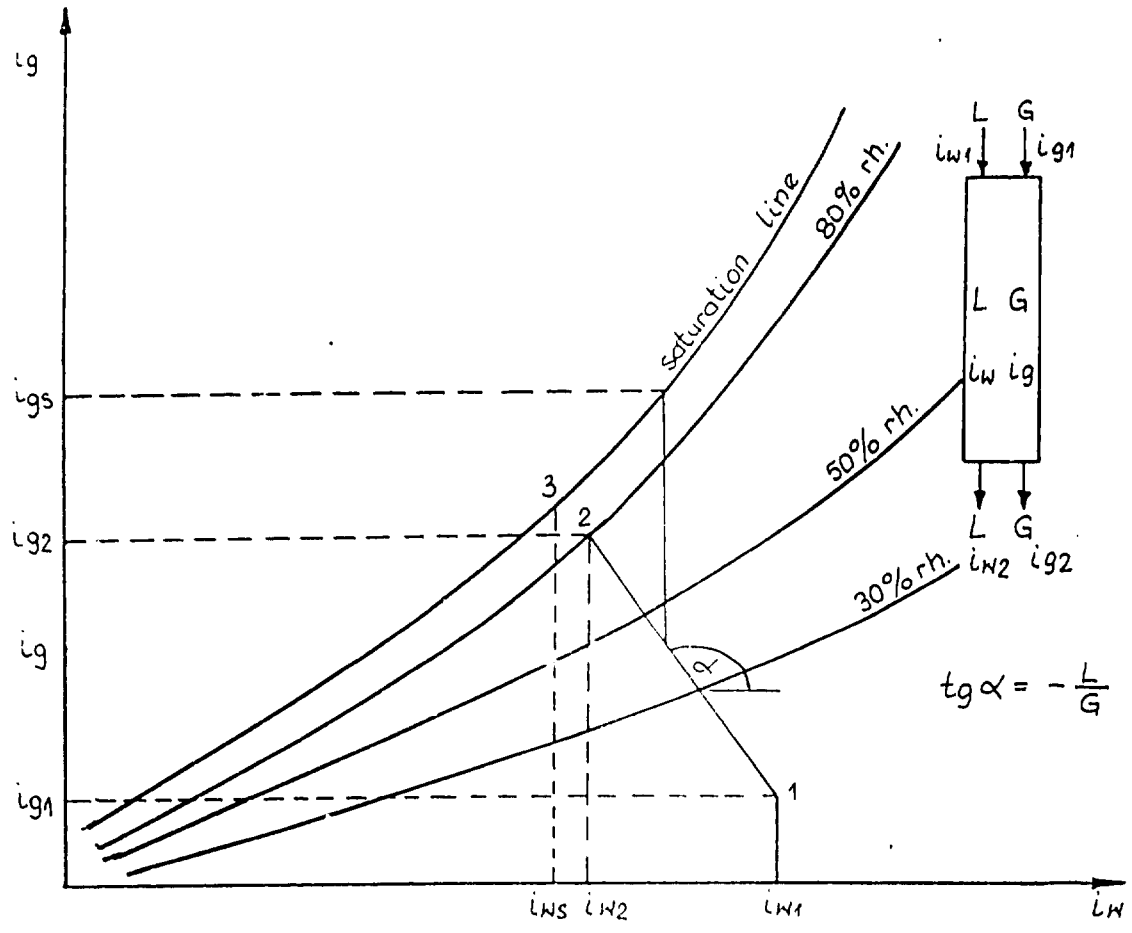


Fig. 9 RELATION $i_g = f(i_w)$

4. WATER DISTRIBUTION SYSTEM

For the spray cooler operated with "dry bottom" the water is supplied by nozzles located at the top. The droplets of water are completely evaporated during their passage through the spray cooler. If we assume that the droplets all have the same diameter, the time for evaporation can be determined from the relation:

$$t_c = \frac{\gamma_c r_A d_0^2}{8 \lambda_g \Delta t} \qquad [13]$$

where:
t_c - time [h]
γ - density of water [kg/m^3]
d_o - initial diameter of droplet [m]
- heat conductivity of gas [kJ/mhk]
Δt - mean differance of temeprature [K]
r_A - heat of water evaporization [kJ/kg]

Based on the Stokes equation, the relative velocity of water droplets in the gas phase is readily calculated; and then from simple relationship the height of cooler $H = vt_c$ can be determined Results of these evaluations are given in Fig. 10.
The shape the curves indicates that the height of the cooler mainly depends on initial diameter of droplets and that other parameters i.e. the temperature of inlet gas, gas humidity as well as temperature of injection water, do not have an important influence.
Under real condition the nozzles produce different size droplets and calculation of the spray cooler height is more complicated
Practical recommendation is to make calculation for the largest expected diameter of droplets
The diameter of droplets depends on construction of nozzles, operational parameters of the humidification process and physical properties of the sprayed medium.
Each type of nozzle possesses its own characteristics.
The curve of droplet distribution usually is experimentally determined by producer
Two types of nozzles for water injection have been applied in spray coolers at EB pilot plants:
1. Water-air nozzles
2. High pressure water nozzles
The first type nozzles were used in the Kawęczyn pilot plant, the second was applied in the Nagoya pilot plant, and Indianapolis PDU.
Application of water - air nozzles gives the possibility of reduction of spray cooler height, but the operational costs of the process increase.
Designing of the spray cooler leads to determination of its height and diameter
Real height of the spray cooling column can be calculated from the relation:

$$t_c = \frac{H}{1.2 \times v} \qquad [14]$$

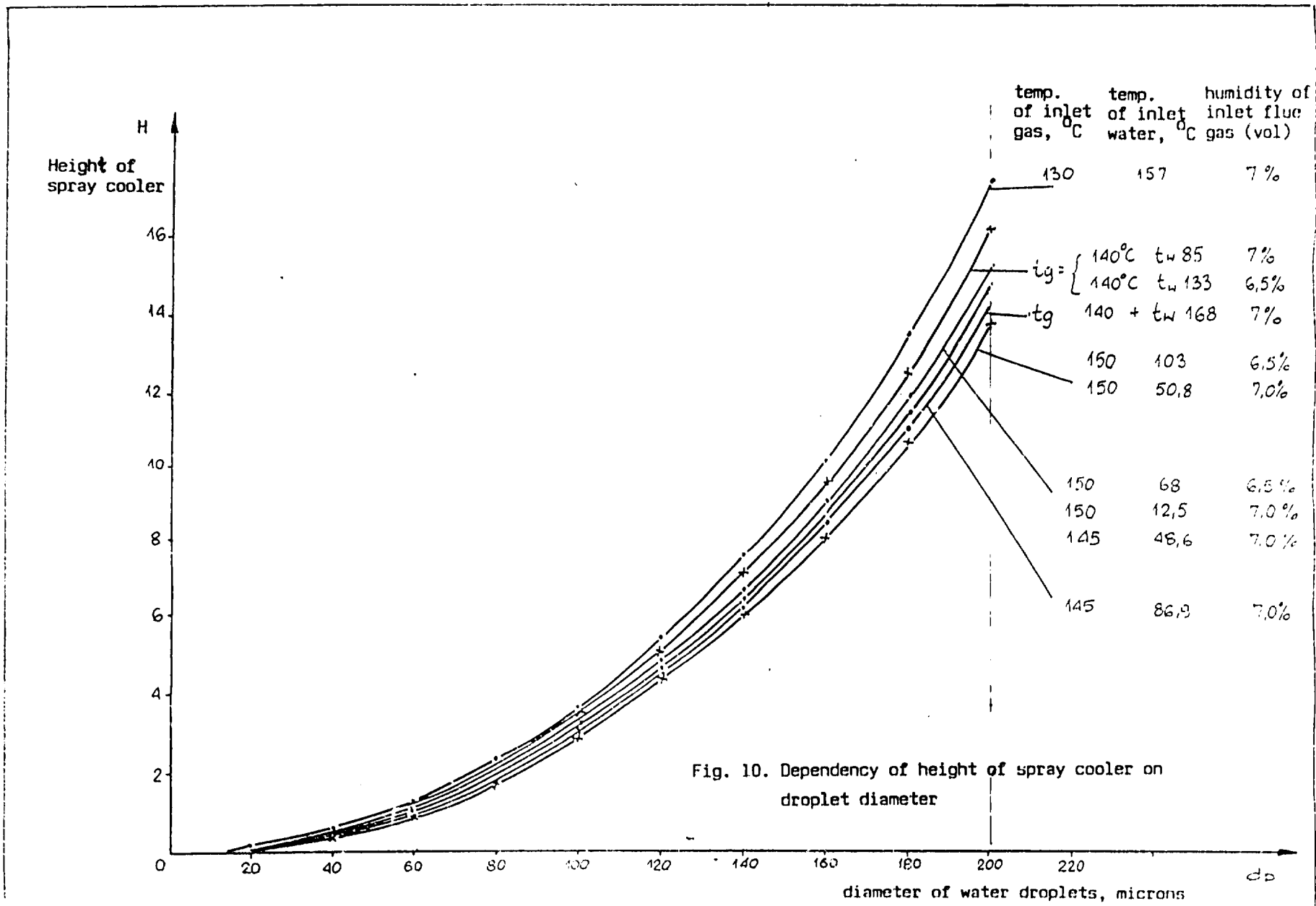


Fig. 10. Dependency of height of spray cooler on droplet diameter

in which the residence time of droplet is estimated for their maximum size (max diam).
The fluactuation of pressure and gas flow; cross-sectional non-uniformity and non-uniform distribution of droplets are included in the factor 1,2. Value of v in above relation is sum of v_g and v_d.
where:
v_g - velocity of gas
v_d - relative velocity of droplets and gas
The relative water-droplet velocity is predicted by Stokes law.

$$v_d = \frac{d^2(\varrho_w - \varrho_g)g}{18\mu_g} \qquad [15]$$

in which:
ϱ - density
g - acceleration of gravity
μ - viscosity of gas

indices:
w - water
g - gas

During evaporation of water from a droplet its diameter goes to zero. It is generally accepted that for design calculation the "d" in equation [15] is replaced by the value of the initial droplet diameter.
Diameter of spray cooler can be easy calculated assuming gas velocity in range 1.0 - 2.0 m/sec

5. CONTROL SYSTEM FOR HUMIDIFICATION PROCESS

In the case of a spray cooler operating with dry bottom we will take into consideration two systems of water injection:
- single-fluid spraying system (water injection system)
- dual-fluid spraying system (water-air injection system).

The control system for a humidification process performed by injection of pressurized water is presented in Fig. 11.
There are two main controllers TRC-3 and TRC-6.
The control system for the second method with water-air nozzles is shown in Fig. 12.
In comparison to the previous system one more control parameter is added. This is PRC-9 for control of air pressure.
The control system for humidification of flue gases by injection of water and steam is presented in Fig. 13.
The control devices for a humidification system with partial evaporation of circulated hot water is shown in Fig. 14. It can be seen that diverse control devices are required.

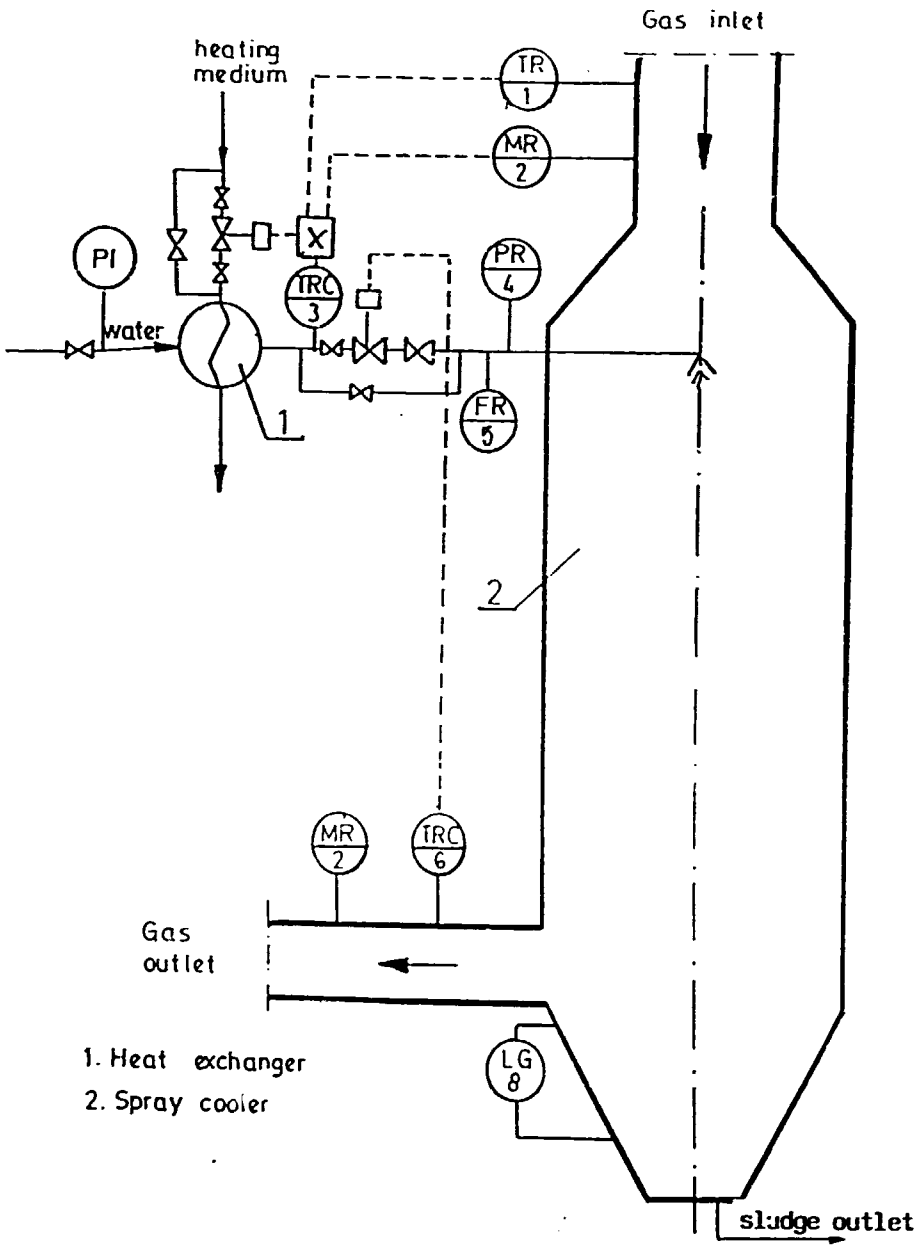


Fig. 11. Control system for humidification process realized by injection of pressurized water

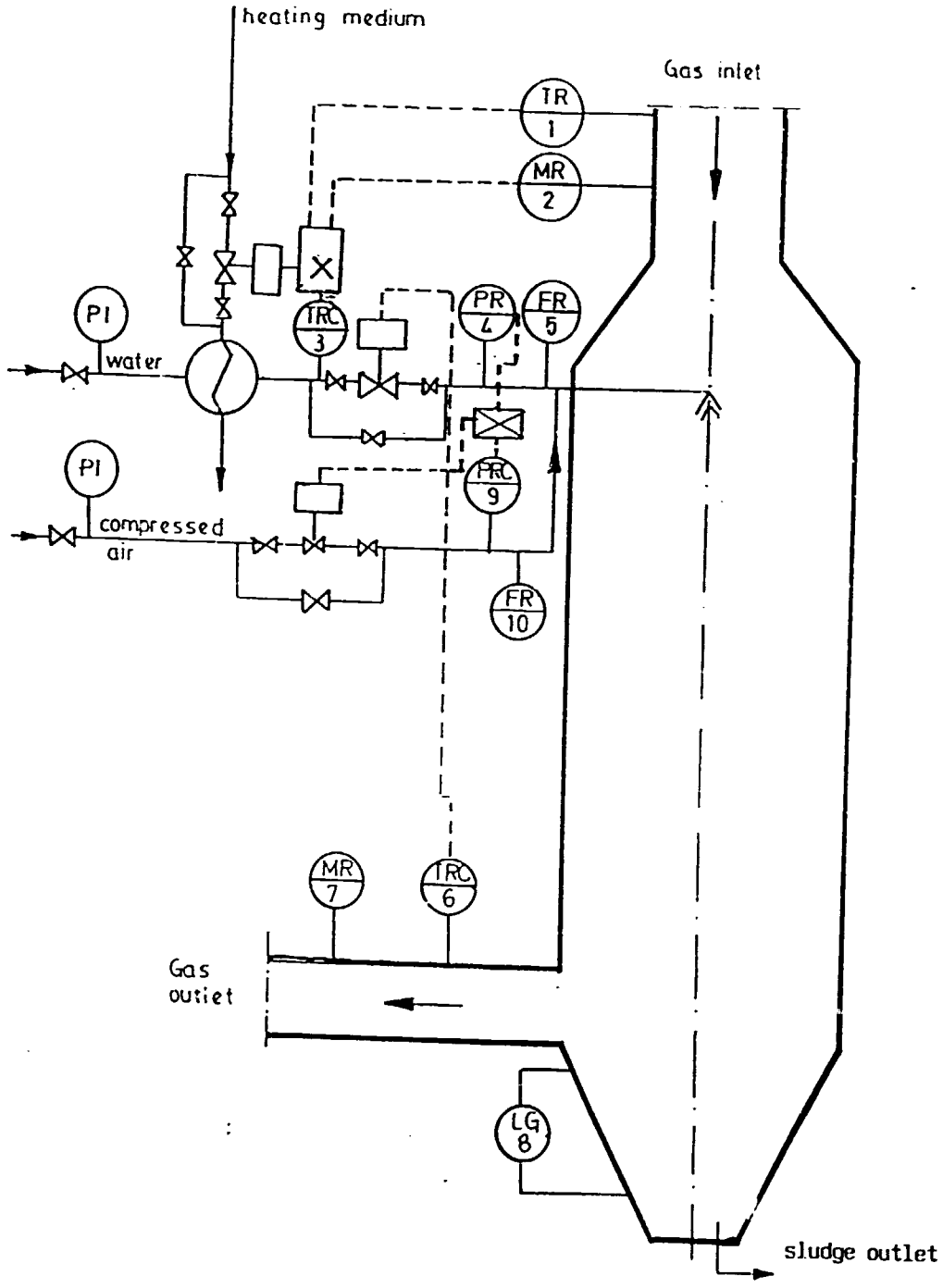


Fig. 12. Control system for humidification process of flue gas using water - air nozzles

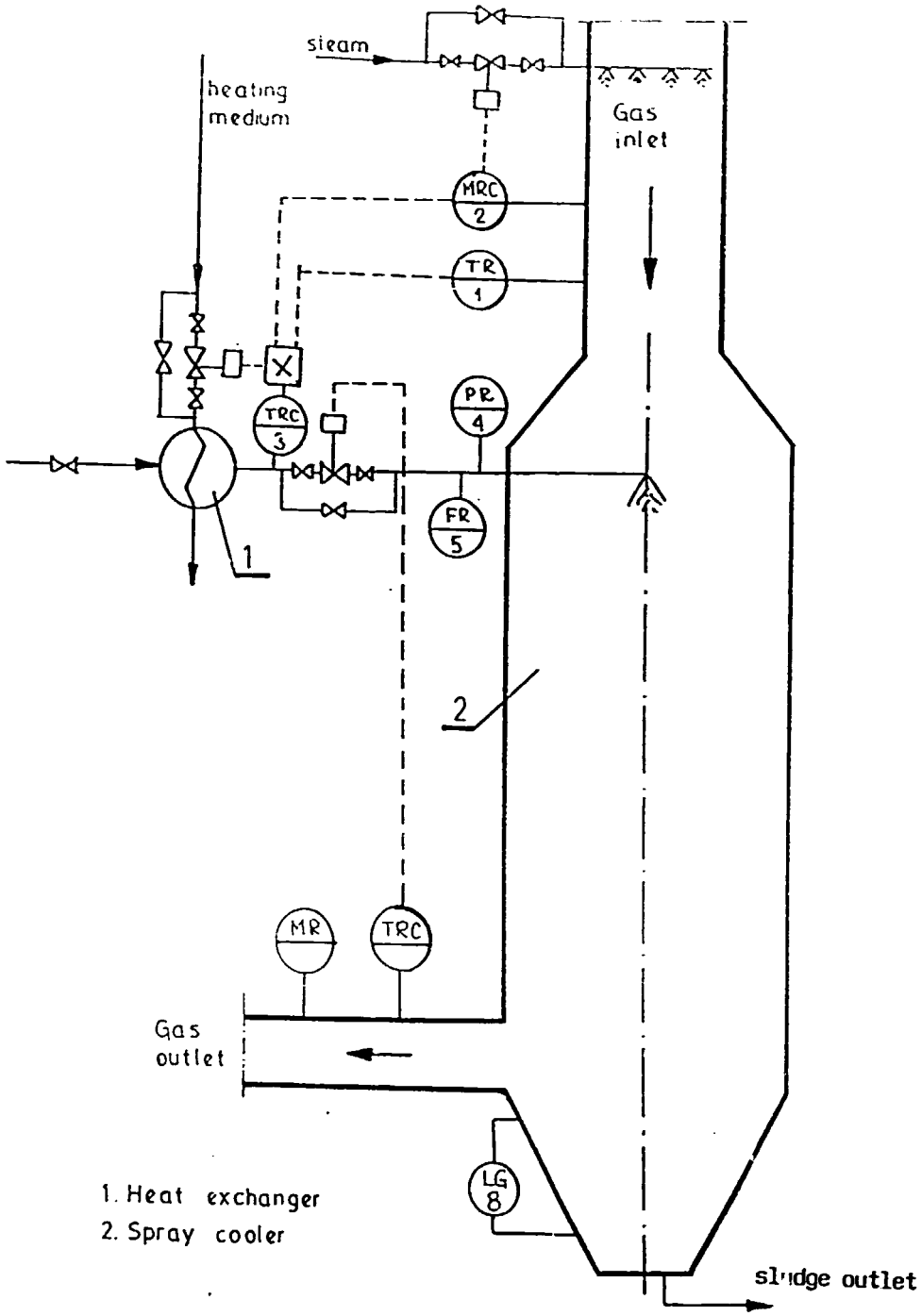


Fig. 13. Control system for humidification process of flue gas - injection of water and steam

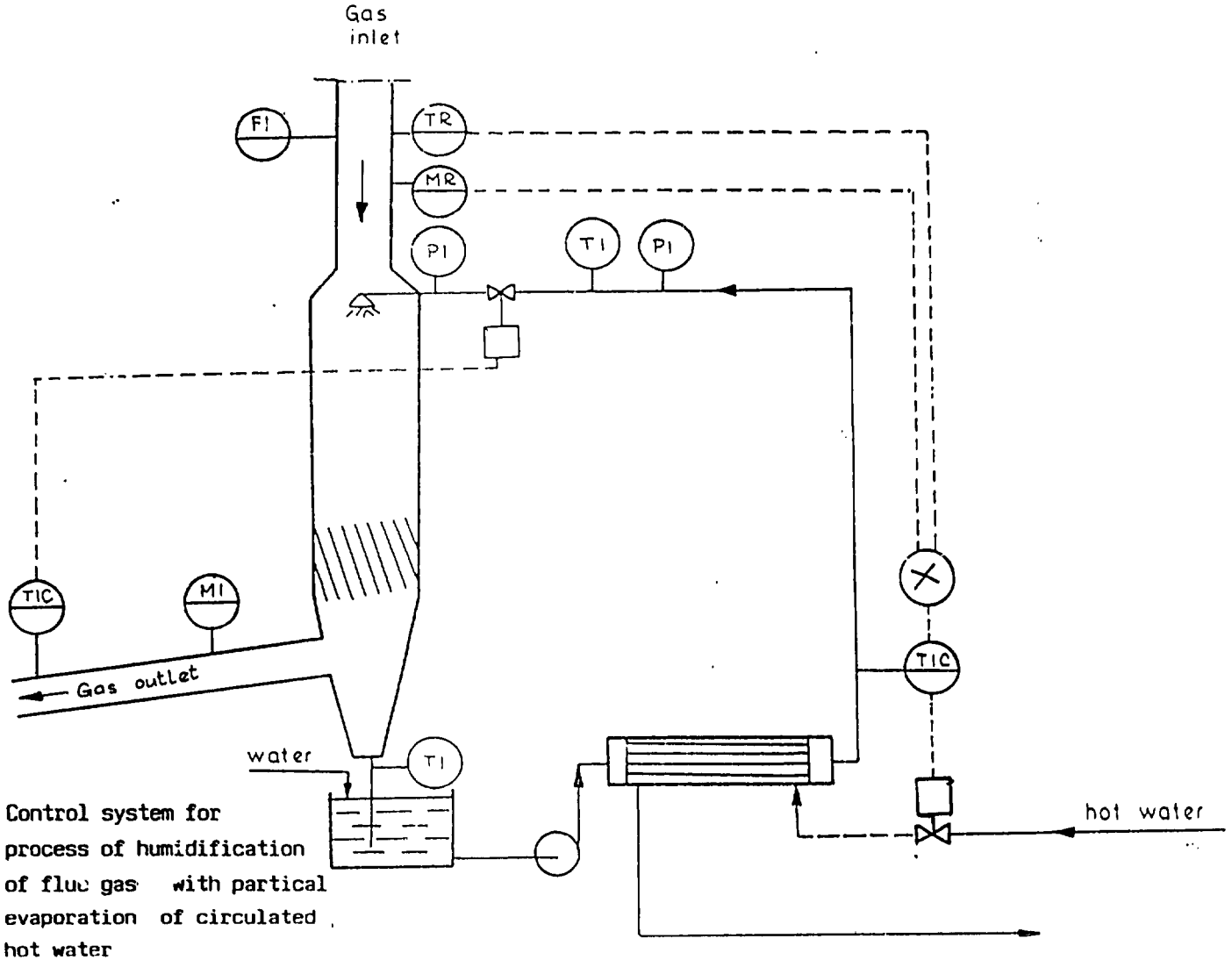


Fig. 14. Control system for process of humidification of flue gas with partical evaporation of circulated hot water

6. COOLING TOWER CALCULATIONS

6.1. Process design assumption

Amount of flue gases

Full load case 270 000Nm^3/h,
Minimum load case 150 000Nm^3/h
Humidity of flue gas
At inlet 5 vol % (wet basis), 31.7 g/kg of dry gas
At outlet 10 to 12 vol % (wet basis), 74.4g/kg of dry gas
Temperature
At inlet 145°C
At outlet 80°C Continuous operation
65°C Intermittent operation

6.2. Material balance

Amount water added to gas in the form of vapour:
Maximum - 14100 kg/h. This amount was calculated for a gas flow rate of 270000 Nm^3/h and humidities: inlet 5% and outlet 11%.
Minimum - 7836 kg/h. This amount is calculated for gas flow rate 150000 Nm^3/h and humidities: inlet 5% vol and outlet 11% vol.

6.3. Heat balance

Heat balances were performed for two methods of evaporation of the water into gas with minimum inlet temperature 145°C.
In this case the maximum amount of heat must be used for evaporation of water.

6.3.1. First means

Evaporation of sprayed water.
Calculations according to equation [4] give temperature of inlet water t = 229°C in case of continuous operation and 137°C for intermittent test operation. These temperature are judged to be too high, therefore this method of cooling and humidification of flue gas cannot be applied under the assumed conditions.

6.3.2. Second means

Injection of steam and water.
Assumptions
Temperature of inlet water 15°C
Pressure of inlet steam 1.2 ata.
Steam is saturated.
From Equation [8] it follows that fraction of water introduced in the forme of steam, a 0.396. In this case should be introduced 5584 kg of steam per hour and 8516 kg

of water per hour for t_2 = 80°C. For t_2 = 65°C, a = 0.24 and amounts of steam and water are 3384 kg/h and 10716 kg/h. Temperature of water and pressure of steam chosen as an average in EPS. In local conditions it is possible that these-values would be different. From economic point of view it is resonable to use water of industrial grade high temperature and steam with pressure as low as possible but higher than 1 ata.

Change of parameters of steam and water flow should be controlled by computer control system according to equation [8].

This system is economically accepted in power stations where sources of inexpensive steam exist. In another case it may be suggested to use the system of humidification with partial evaporation of circulating hot water.

Intermittent operation case: evaporation of water inlet gas temperature 145°C. This is the case when minimal amount of heat is need evaporation of water. Calculations of t_1 according to Equation [4] gives t_1 = 93.6°C. It means that it is easy to reach downstream temp. 65°C and humidity 10.9% vol.

Column diameter:

Linear gas vielocity in cooling tower is assumed, u = 2m/s

then tower diameter is 7.3m.

Water distribution system.

It is assumed-cocurrent flow of gases and water droplets from top to bottom of cooling tower. Residence time of gases provided in the cooling tower is a little higher than the time of evaporation of the largest droplets.

Spraying nozzles are full cone shape.

Two types of nozzles are proposed:

- high pressure up to 40 bar without atomizing medium
- low pressure steam-water.

Other assumptions for both options of water distribution systems is given in Fig. 15 and 16.

7. ASSUMPTION FOR COOLING TOWER CONTROL AND MEASUREMENTS

7.1. Option 1
Mechanical atomization

Water will be sprayed by high pressure single fluid nozzle.

In process following parameters will be controlled:

1. Temperature of flue gas at inlet of spray cooler
2. Amount of added steam
3. Temperature of sprayed water

Scheme of control diagram is presented in Fig. 17. Control algorith according to equation 4 and 8. If value of a from Eq. 8 is less than or equal to zero steam valve should be closed and spray water used only. Temperature of water is controlled by TRC-3 according to Eq. 4. If value of a >0 then cold water is sprayed.

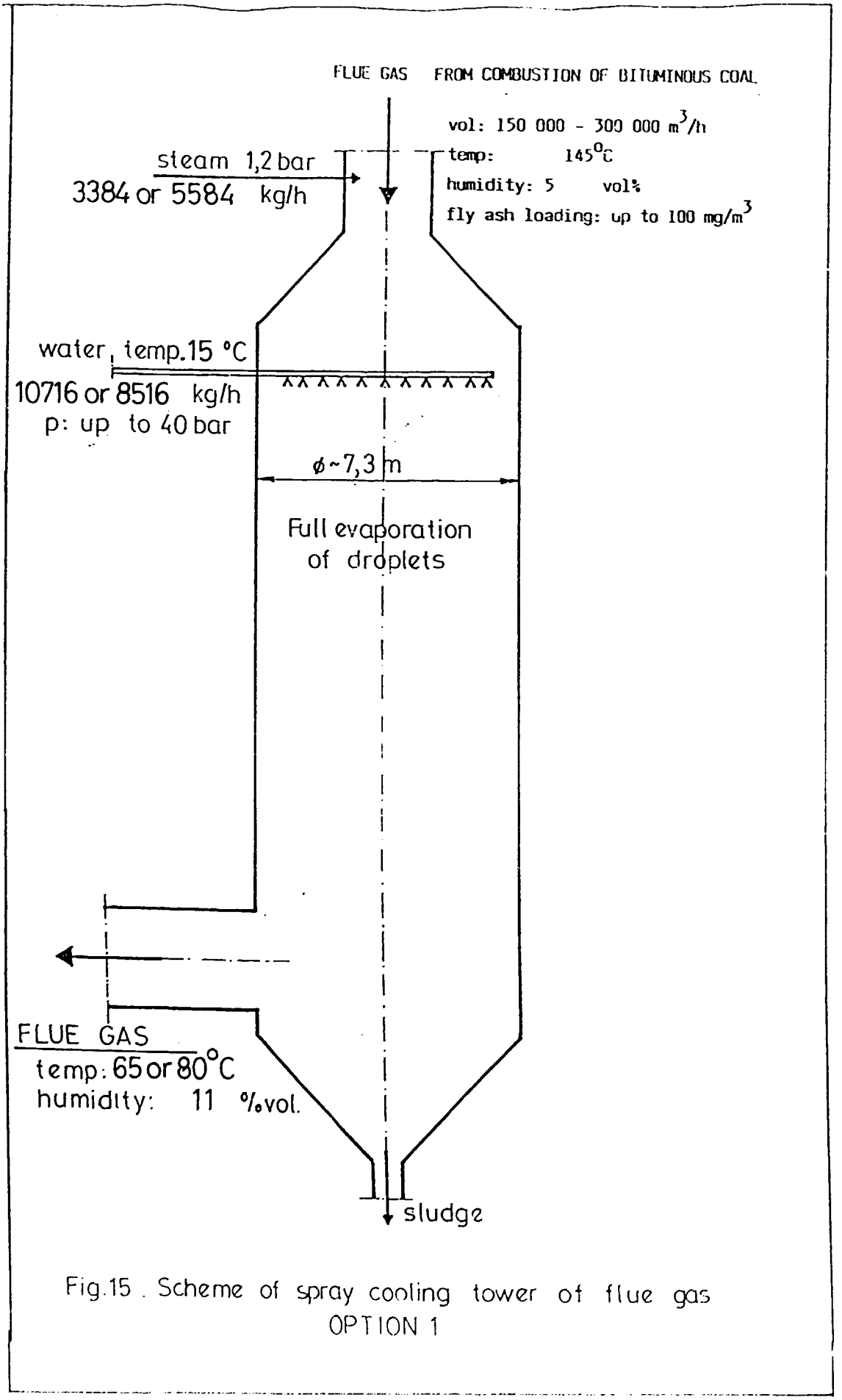


Fig.15 . Scheme of spray cooling tower of flue gas
OPTION 1

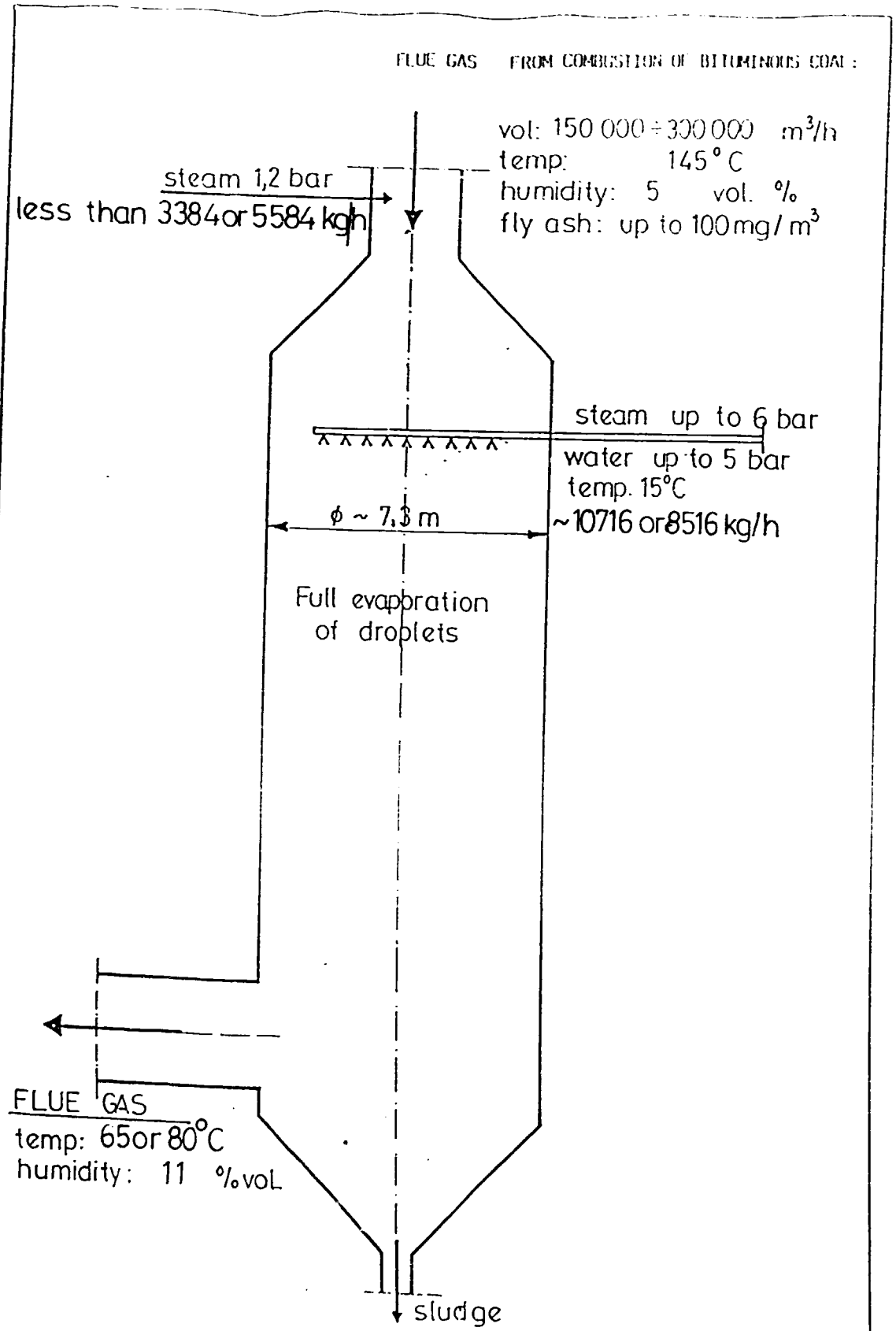
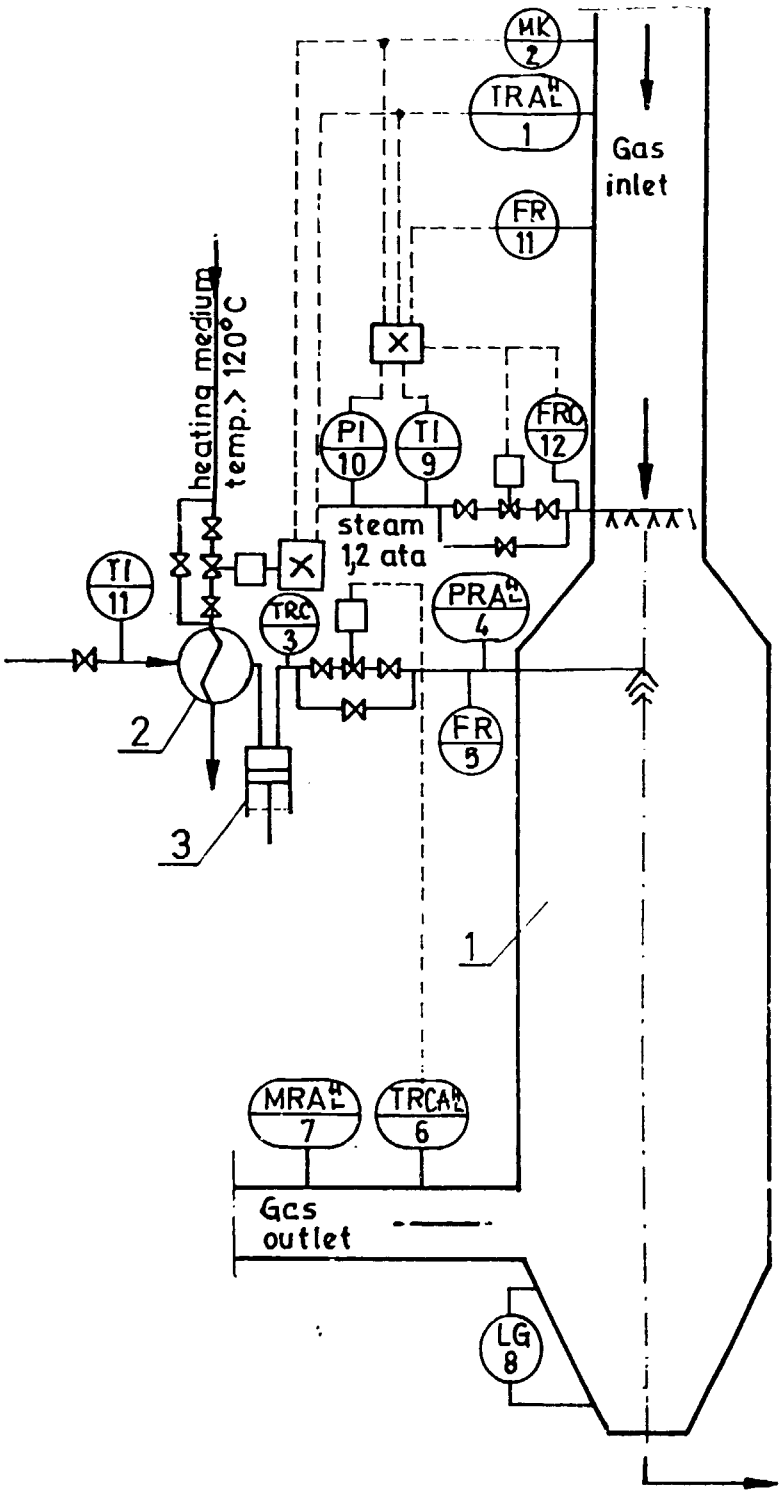


Fig.16 Scheme of spray cooling tower of flue gas
OPTION 2



1.Spray cooler
2.Heat exchanger
3.Pump

Fig.17 CONTROL SYSTEM FOR MECHANICAL ATOMIZATION OF WATER

Measured values in option 1 (Fig. 17)

Measured/ Controled point	Measured value	Range and units	Accuracy of measurement	Remarks
TRA_L^H - 1	Temperature of flue gas at inlet to spray cooler	0 - 200°C	± 1°C	Possibilities of visualization up to 3h before
MR - 2	Measurement of humidity at inlet	0 to 7vol%	± 0.1 vol%	
TRC - 3	Control of temp. of sprayed water	0 to 100°C	± 1°C	Controller PI or PID
PRA_L^H	Measurement of spray water pressure	0 to 40 atn	± 0.1 atm	
FR - 5	Measurement of amount sprayed water	0 to 15t/h	± 0.05 t/h	
$TRCA_L^H$-6	Control of temp of flue gas after spray cooler	0 to 100°C	± 1°C	Controller PI or PID
MRA_L^H-7	Measurement of humidity of flue gas after spray cooler	0 to 15%vol	± 0.1% vol	
LG-8	Indication of water and sludge level at bottom of spray cooler	0.6 m		
TI-9	Measurement of steam temperature	50 to 150°C	± 1.5%	
PI-10	Measurement of steam pressure	0 to 0.6 atn	± 2.5%	
FR-11	Measurement of flue gas flow rate	0 to $3 \cdot 10^5$ Nm^3/h	± 1.0%	Results of measurement recalculated to normal conditions
FRC-12	Control of steam flow rate	0 to 6t/h	± 1%	

7.2. Option 2
Steam - water atomization

Water is sprayed with use of steam-water nozzle.
Amount and pressure of steam follows from flow chart of nozzle

Three cases should be taken into consideration.
1. in cooling process is needed more of steam than used in nozzle.
2. amount of steam used in nozzle is bigger than needed for proper humidification of gas.
3. from equation (8) follows that steam is not necessary
In the first case amount of steam added to steam of flue gases should be less by amount of steam used in nozzle.
For calculation in equation (8) should be taken weighted mean value of is from entalphy of steam added in nozzle and directly to gas stream.
In case 2 steam should be used only in spray nozzle.
In case 3 steam in nozzle should be replaced by air (see option 3)
Measuring and control diagram is presented in Fig. 18.

7.3. Option 3
Air - water aromization (see p. 8.3)

8. DETALS

8.1. Option 1
Mechanical atomizing nozzles

In this option reduction of temperature of flue gases is recomplitet by full evaporation of sprayed water. In case the temperature and entalphy of flue gas is low to reach humidity of order 10 to 12 vol %, low pressure steam is added at the inlet of the spray cooler. In this option high pressure water nozzles model 100, size 1 produced by Schlick (Germany) are provided Table 1. Eight nozzles are in one head model 60/2 Fig. 19. Spray system consist of 5 heads. Connection tubes have protection tubes and joint with flanges Fig. 20.
Nozzles and heads are made of steel 1.4401 (S.316) and pipes of steel 1.4571 (S.316 Ti).
Advantage of this system is that it does not need air or steam for spraying of water.
Disadventages are: a) necessity to install pump and high pressure spraying system, b) spraying of less amounts of water needs lower pressure and nozzles generate bigger droplets, c) cross-section distribution of droplets is not uniform, d) diameter of holes in this nozzles is 2.0 mm, which is much smaller than for dual-fluid nozzles and therefore is more sensitive to plugging. Height of spraying part of cooling tower according to nozzle-producer suggestions should be 15 m.
Relations of flow rate and droplets size v.s. hole size and pressure are given in Fig. 21 and 22.

8.2. Option 2
Steam - water nozzles

In this option water is sprayed with use of dual-fluid, water-steam nozzles.
Dual fluid nozzles give smaller droplets and their size is almost independend of water flow rate. In

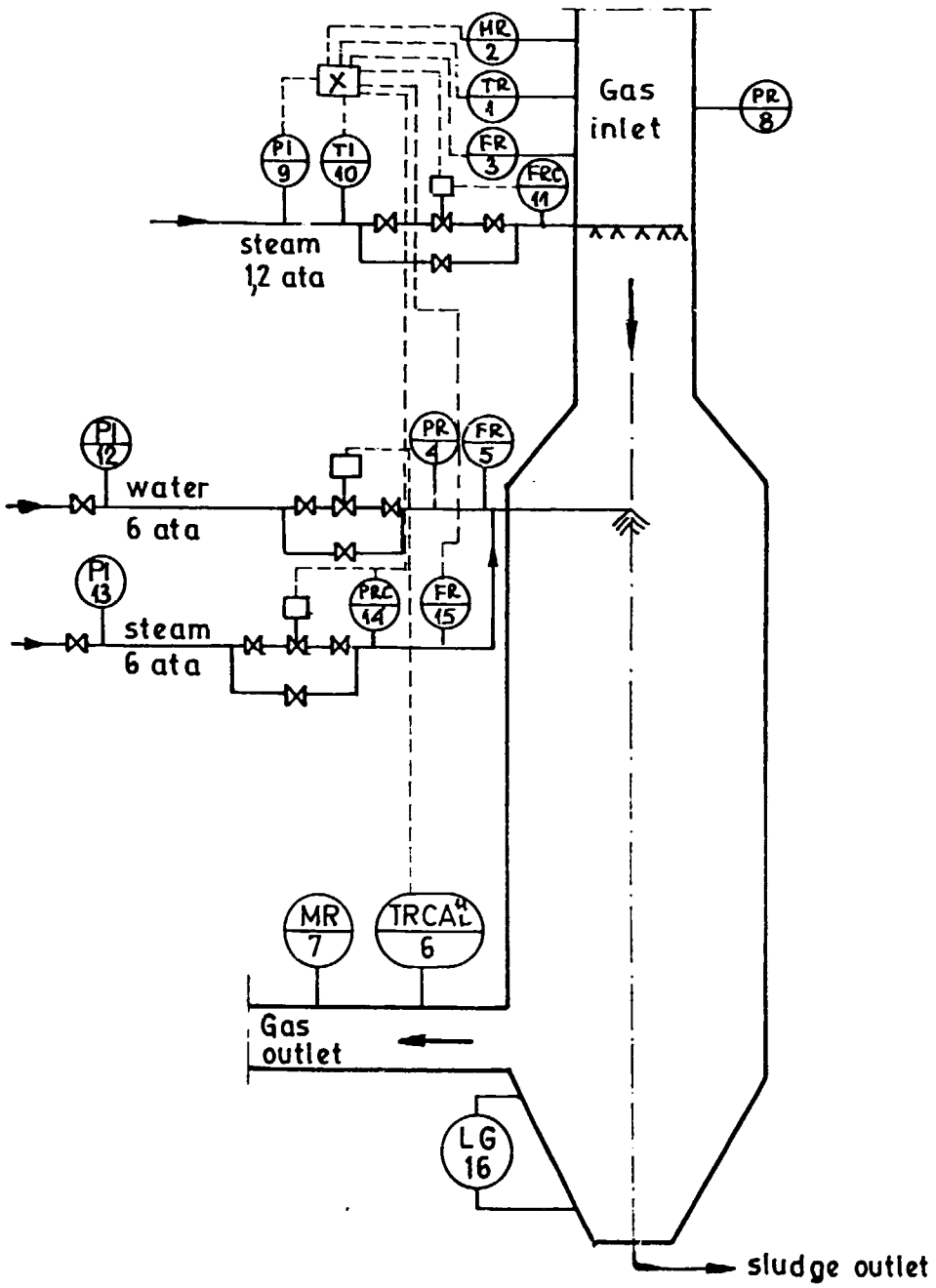


Fig. 18. CONTROL SYSTEM FOR ONE STAGE HUMIDIFICATION SYSTEM WITH TOTAL EVAPORATION AND WATER-STEAM NOZZLE

Control and measuring points for option 2 (Fig. 18)

Control or measuring point	Measured value	Range and units	Accuracy of measurement	Remarks
TR-1	Temperature of flue gas at inlet	0 to 200°C	± 1°C	Possibilities of visualisation
MR - 2	Measurement of humidity at inlet	0 to 7%vol	± 0.1%vol	
FR - 2	Measurement of amount of flue gas	0 to 3 x $10^5 Nm^3/h$	± 1%	Results of measurements recalculated to normal conditions
PR - 4	Measurement of pressure of water before nozzles	0 to 6 atm	± 1%	
FR - 5	Measurements of amount of sprayed water	0 to 15t/h	± 0.05 t/h	
$TRCA_t^{II}$-6	Control of temp. flue gas after spray cooler	0 to 100°C	± 1°C	
MR - 7	Measurement of humidity of flue gas after spray cooler	0 to 15% vol	± 0.1%vol	
PR - 8	Measurement of pressure of flue gas at inlet	under presure up to 5 kPa	± 20Pa	
PI - 9	Measurement of steam pressure	0 to 0.6 atm	± 1.5%	
TI - 10	Measurement of temperature of steam	50 to150°C	± 1%	

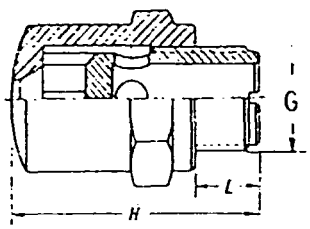
FRC - 11	Control of amount of steam added to flue gas	0 to 6 t/h	± 1%	
PI - 12	Measurement of water pressure	0 to 6 atm	± 1%	
PI - 13	Measurement of steam pressure before nozzles	0 to 6 atm	± 1%	
PRC - 14	Control of pressure of steam before nozzles	0 to 6 atm	± 1%	
FR - 15	Measurement of amount of steam	0 to 3.0 t/h	± 1%	

Dimensions:

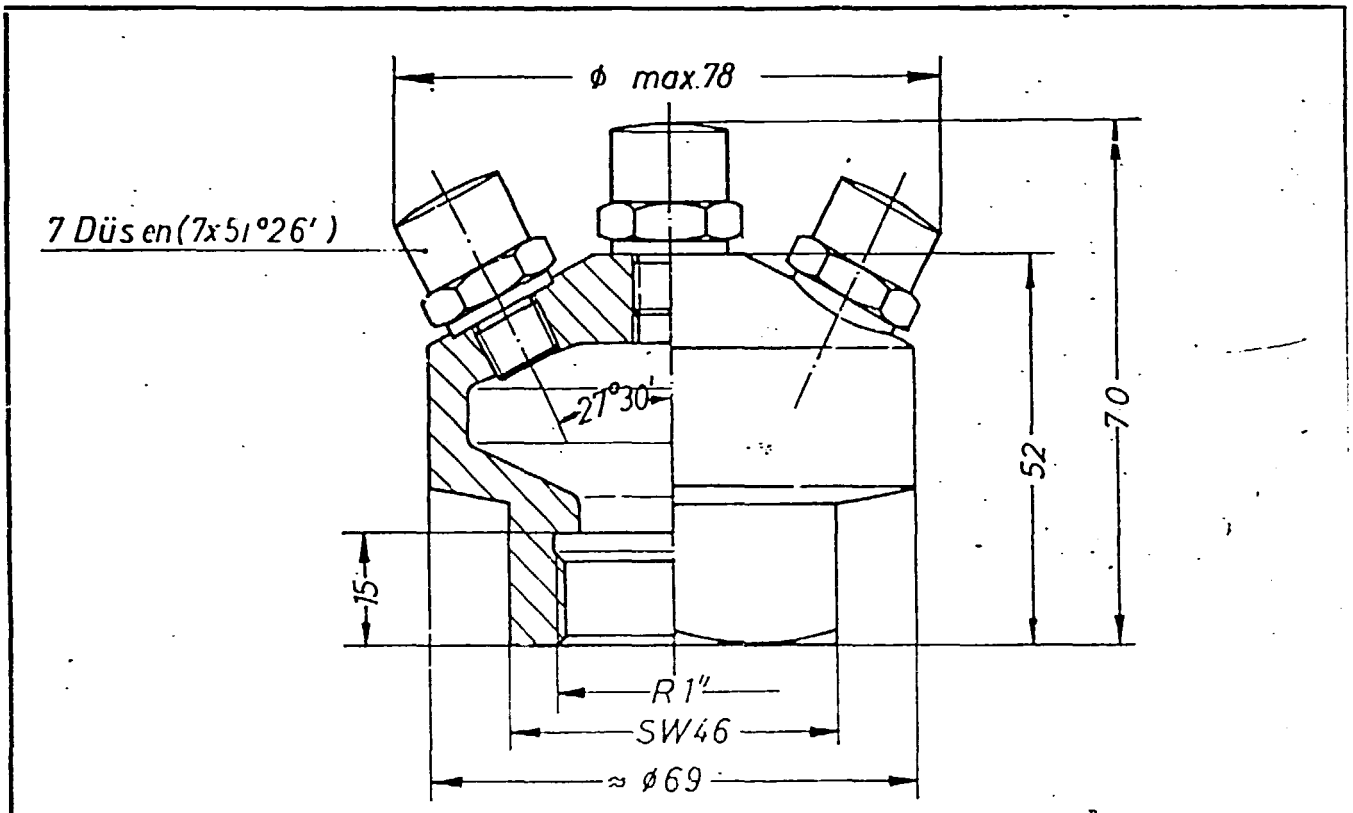
model 100 – standard design

TABLE 1

size		1	2	3	4	5	6	7	8	9	10
connection,	G DIN 259	R⅛"	R¼"	R⅜"	R½"	R¾"	R1"	R1¼"	R1½"	R2"	R3"
length of thread	L in mm	8	9	11	14	16	19	20	21	24	30
total height	H in mm	26	32	40	50	60	80	90	100	110	160
width of wrench	SW in mm	17	20	24	27	36	46	55	65	80	120
weight brass	approx. kgs	0,03	0,05	0,08	0,12	0,28	0,70	0,88	1,4	2,4	6,0



ill 1102



Teil	Stück	Benennung	Rohabmessung	Gewicht

M		Tag	Name
1:1	Gez.	5.3.73	Knoblich
	Gepr.		

Gustav Schlick KG
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Düsenkopf Modell 60/2
mit 8 Düsen Modell 100/1

G1. 275

Ersatz für
Ersetzt durch

Fig. 19

Schlick
S2.2326
Einsteckrohr mit Schutzrohr und Düsenkopf Modell 60/2 für 8 Düsen Modell 100/1
M 1:1
Schutzrohr 88,9x3,2
1.000
88,9
100
Flansch C DN100 PN16 DIN 2527
Flansch C DN25x33 PN16 DIN 2633
Spülluft
R¼
Kondensatablauf
ø5
5

Fig. 20

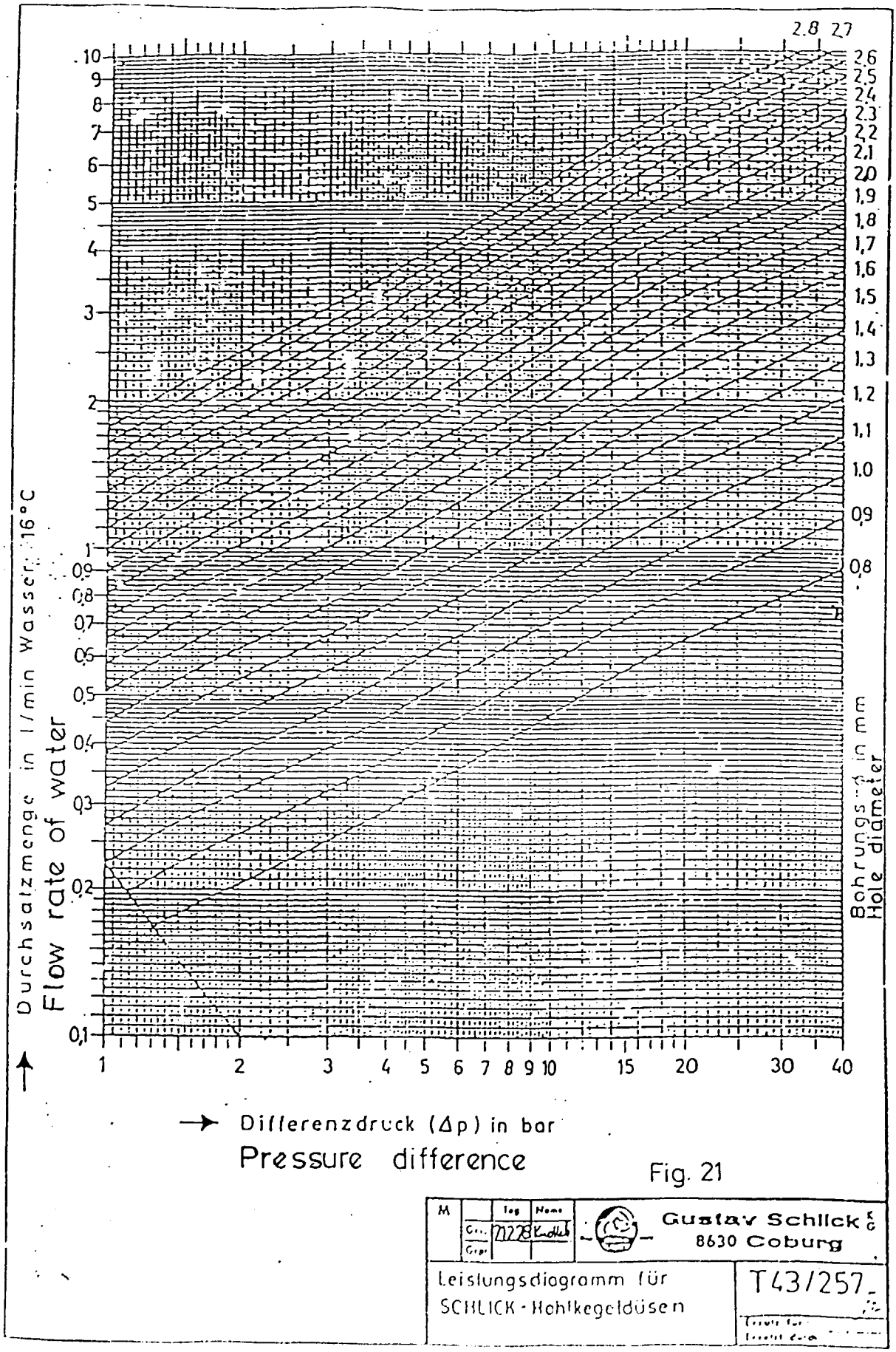


Fig. 21

M		Tag	Name
	Gez.	7228	Endlich
	Gepr.		

Gustav Schlick & Co
8630 Coburg

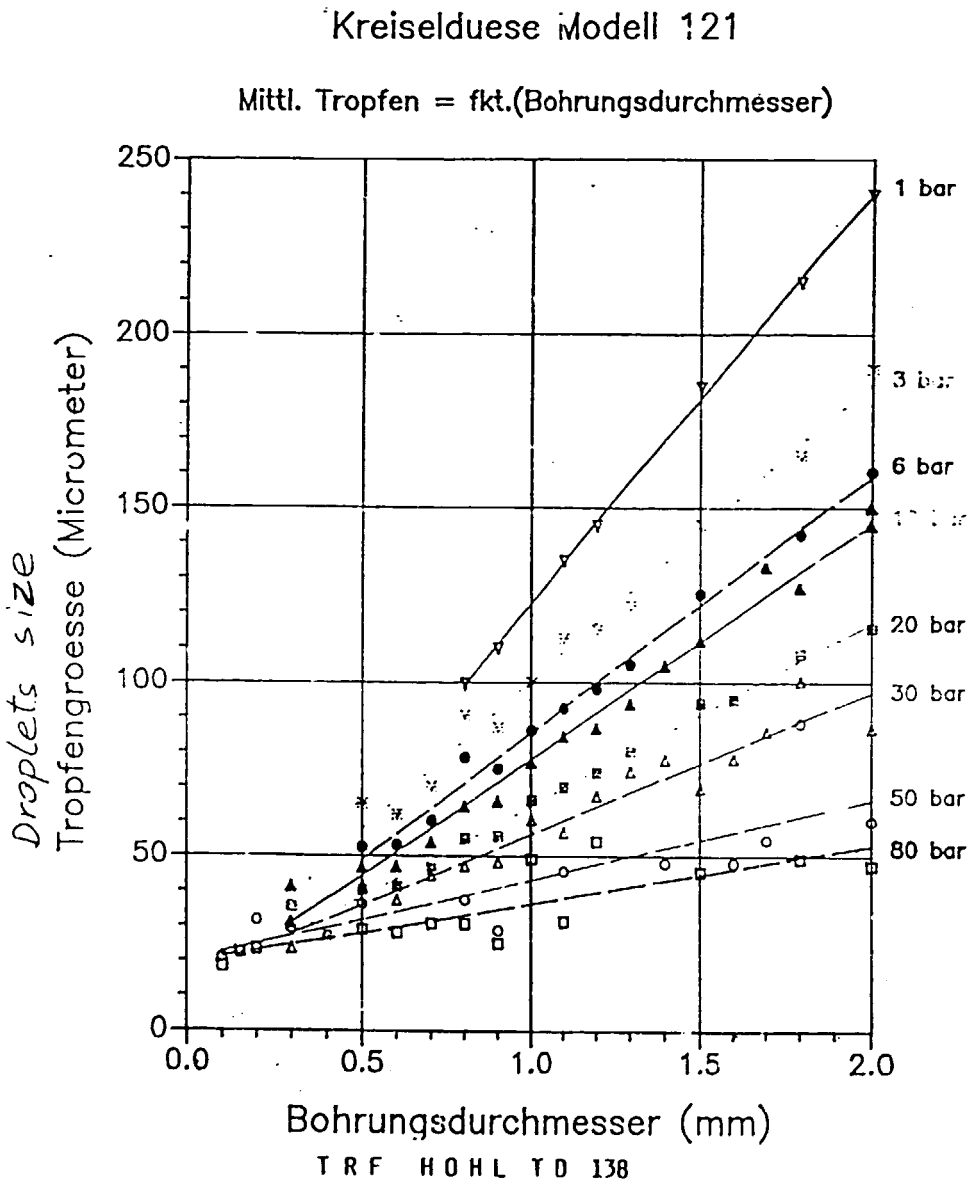
Leistungsdiagramm für
SCHLICK-Hohlkegeldüsen

T43/257

Gustav Schlick GmbH & Co.
Coburg

Schlick Düsen Filter Apparatebau

Gustav Schlick GmbH + Co., Postfach 2843, D-8630 Coburg, Telefon (09561) 1245, Telex 663233, Telefax 09561/28258



Hole diameter

Fig. 22

case when steam should be added to flue gas it is reasonably use as part or all of the amount of steam use in nozzles for spraying of water. The pressure of that steam should be higher, of order up to 6 atm. In this option are provided nozzles Model 0/50-57 (Fig. 23). Schlick production (Germany). Three nozzles are installed in one lance - Fig. 24. All elements are made of stainless/steel 1.4571/1.4401 (S 316 or 316 Ti).
Amount of sprayed water of one nozzle as a function of pressure is given in Fig. 25. Similar chart for steam consumption is given in Fig. 26. In the case where the amount of steam to be used in nozzles than that needed for humidification of gases the amount of steam may be reduced by reduction its pressure. Nevertheless pressure of the steam should be 0.2 to 0.4 atm higher than pressure of water.
Producer of nozzles sugests the height of evaporation zone in the spray cooler should be 15 m. Nozzles system is able to spray up to 13.5 t/h of water (9 nozzle). Steam consumption if its pressure is 6 atm is 2700 kg/h. It is maximum value and may be reduced by a control unit. Bore diameter of nozzle is 8 mm.

8.3. Option 3
Air - water nozzles

In this option are used dual fluid air-water nozzles. Such nozzles should be applied if inlet temperature of gas is high and evaporate an amount of water subficient to achieve a absolute humidity in coordinate an outlet temperature of 80°C.
In this option are provided nozzles type 170.881 produced by Lehler GmbH (Germany). For spraying of 13.5 t/h of water 15 nozzles should be used. Nozzles will work with maximum pressure of water 3.5 atm and pressure of air 4 atm. Maximum consumption of air is 2100 Nm^3/h.
In case of a lesses amount of spray water, amount of air may be reduced by lowering its pressure. In such case should be fulfilled 2 conditions:
1. pressure of air ahould be at least 0.5 bar greater than pressure of water.
2. ratio of air flow rate (in Nm^3/h) to water flow rate (in l/min) should be greater than 10.
Relations between throughput of air and water and their pressure for one nozzle are given in Fig. 27.
Dimensions of nozzle are given in Table 2.
Nozzles are made of stainless steel 1.4571 (S 316 Ti). The smallest hole diameter for water is 7.6 mm and for air 2.8 mm.
This option has been selected for application in e-b installation at EPS Pomorzany - Szczecin.

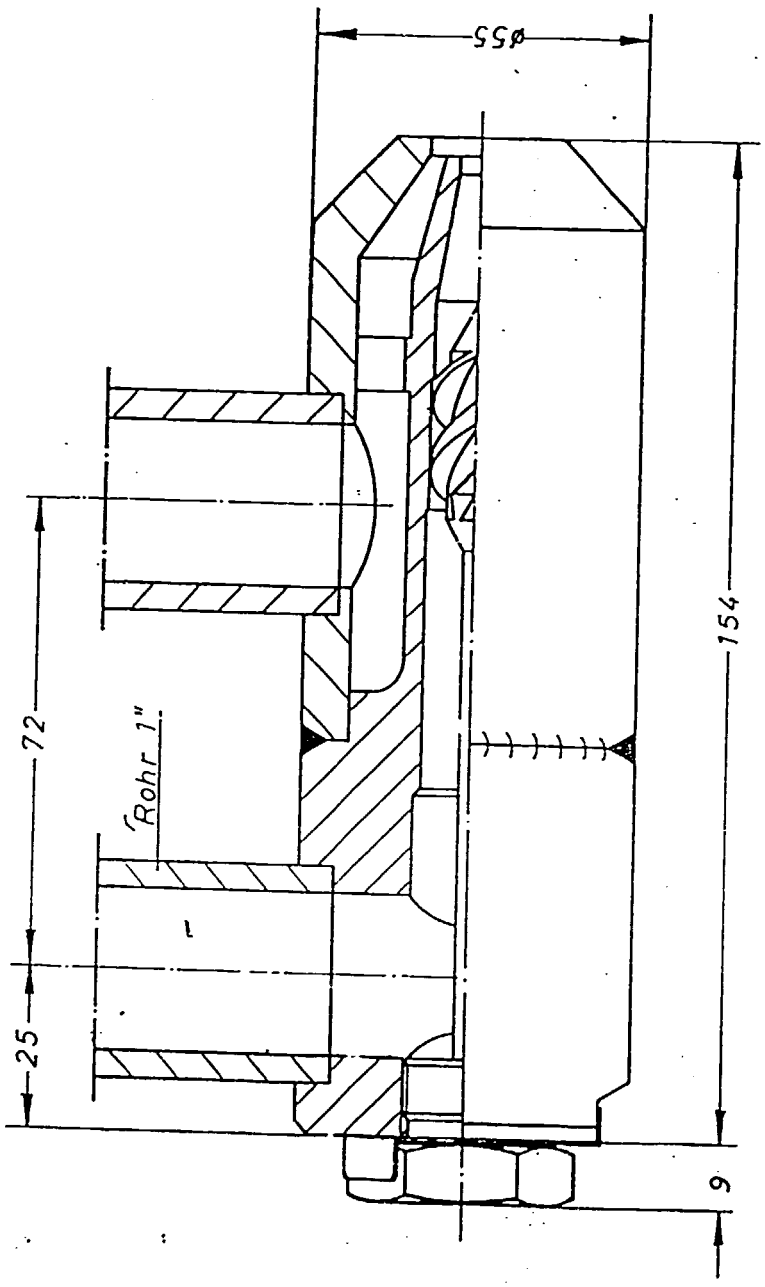


Fig. 23

SCHLICK-binary aggregat model 0/50-S7

Teil	Stück	Benennung	Bohrmessung

M		Tag	Name
1:1	Ges.	1.8.77	
	Gepr.		

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8630 Coburg

SCHLICK-Zweistoffaggregat Modell 0/50 – S 7

D5.304

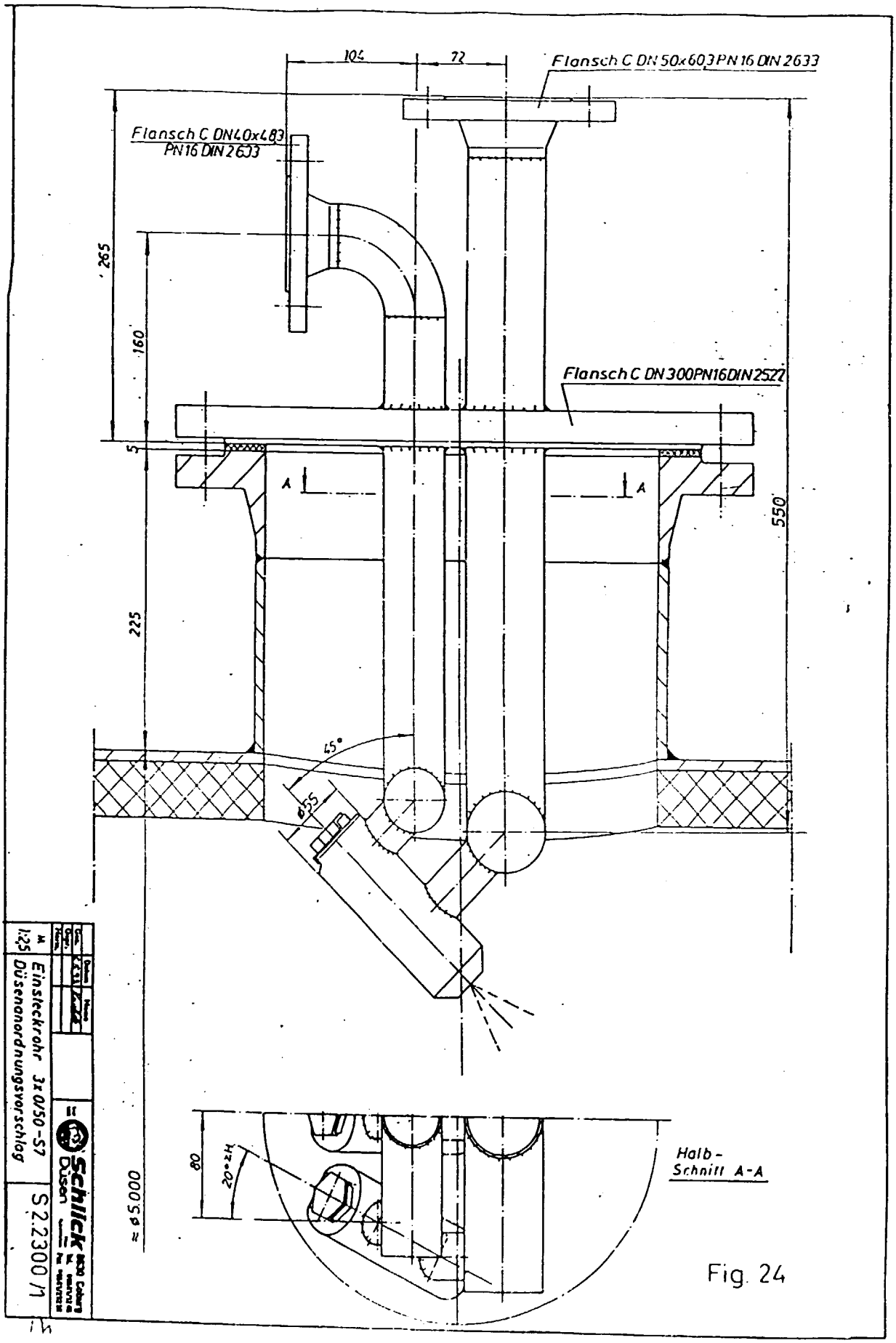

104
72
Flansch C DN 50x60,3 PN 16 DIN 2633
Flansch C DN 40x48,3 PN 16 DIN 2633
582
160
Flansch C DN 300 PN 16 DIN 2527
5
A
A
550
225
45°
ø55
≈ ø 5.000
80
20°±4
Halb-
Schnitt A-A
M 1:25
Einsteckrohr 3x 0/50 -S7
Düsenanordnungsvorschlag
S 2.2300 /1
Schlick
Düsen

Fig. 24

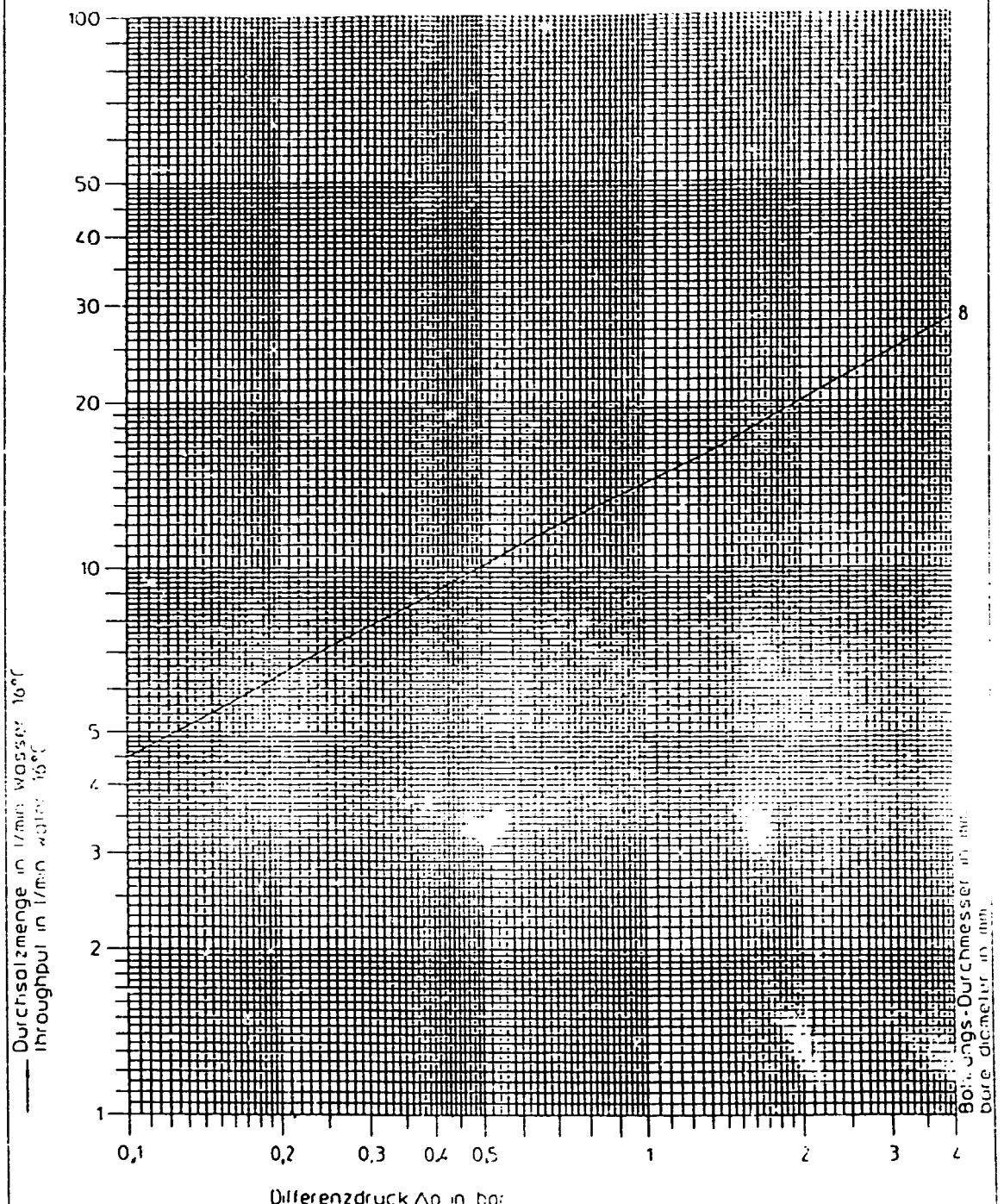


Fig. 25

	Datum	Name
Bearb	13.04.1995	Zeltzmann
Gepr		
Norm		

Schlick

Leistungsdiagramm
Modell 0/50-S7
mit Dreinutendrall
diagram model 0/50 S7
with 3-slot-spinner

0 | 50 S7 4 100 W N 0

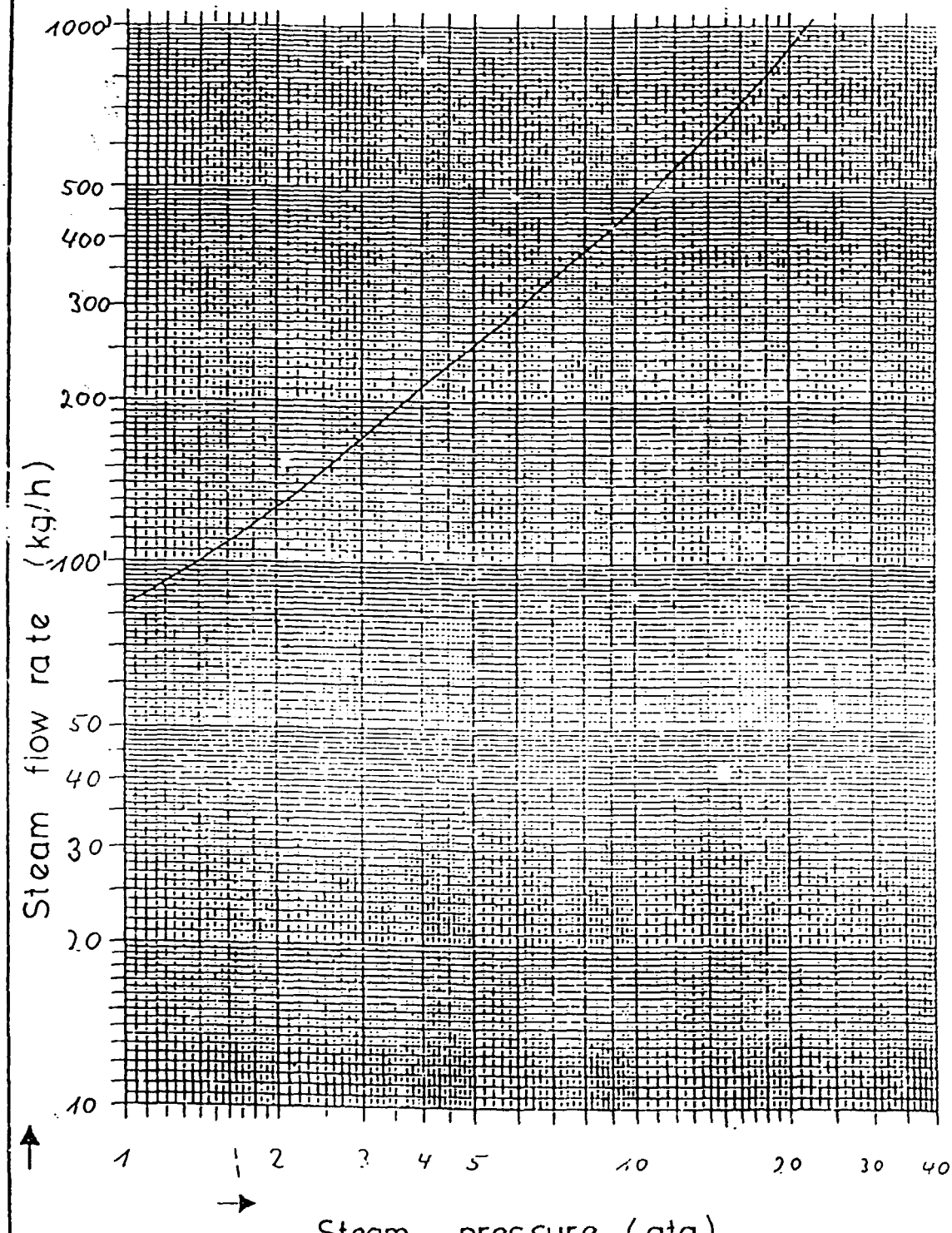


Fig 26

a - air
b - water

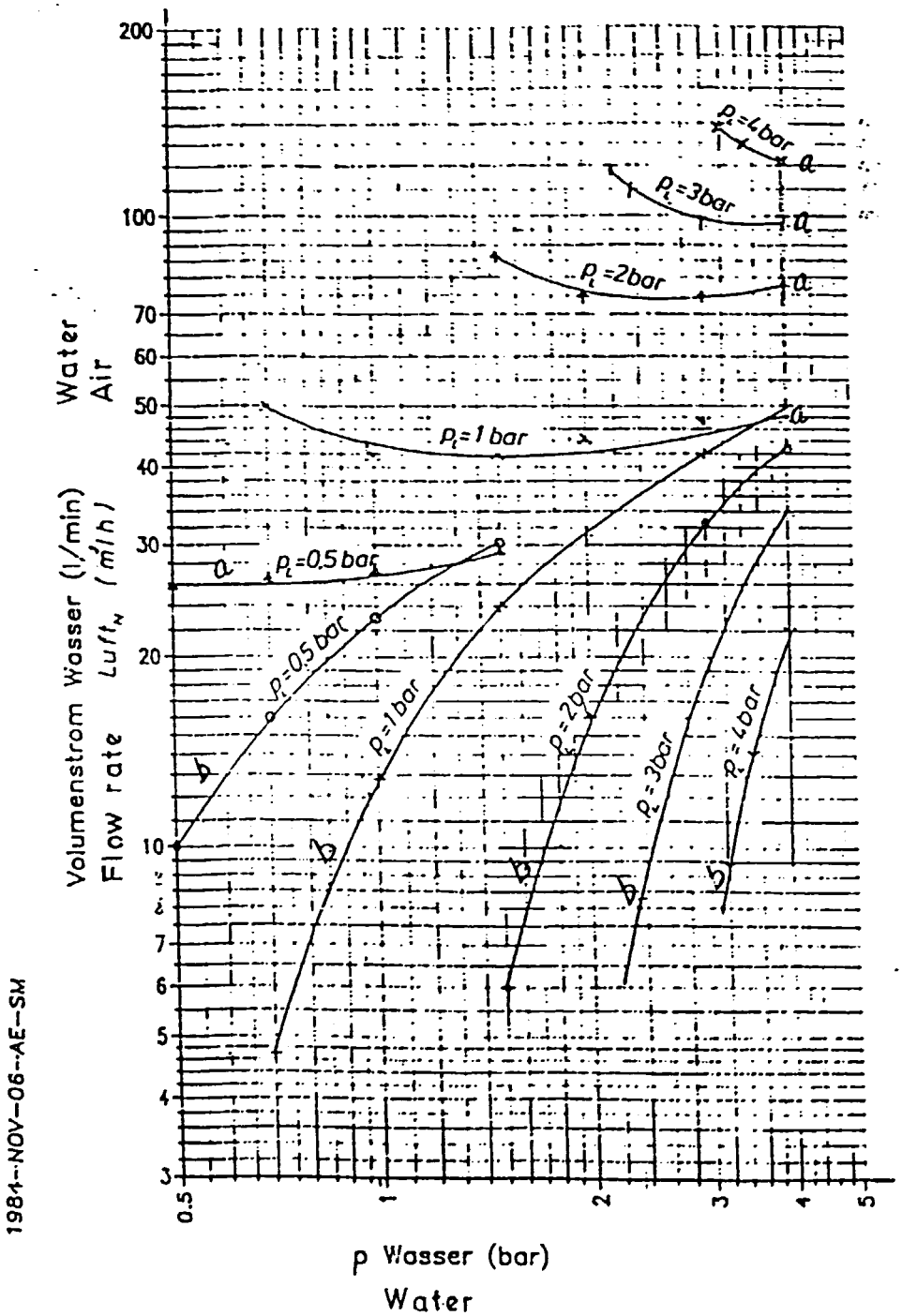
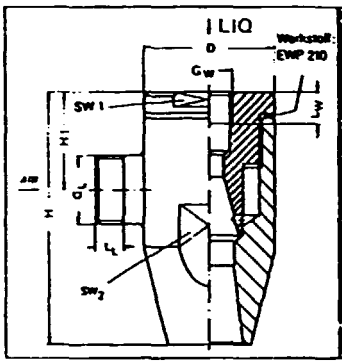


Fig. 27

TABLE 2



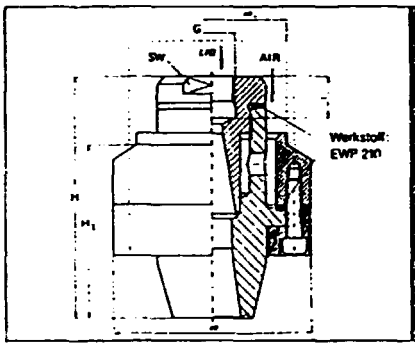
LIQ	Abmessungen/dimensions [mm]									Gewicht Mat. 1.4571 [g]
	H	H_1	D	SW_1	SW_2	G_W ISO 228	G_L ISO 228	L_W	L_L	
170.641	48	28	25	22	22	G 1/8	G 3/8 A	7.5	10	140
170.721	48	28	25	22	22	G 1/8	G 3/8 A	7.5	10	140
170.801	81	29.5	38	32	32	G 3/8	G 1/2 A	14	13	540
170.881	81	29.5	38	32	32	G 3/8	G 1/2 A	14	13	565
170.961	112	42	52	46	46	G 1/2	G 3/4 A	18	15	1275

Sonderausführungen:
mit koaxialem Anschluß

Special designs:
with coaxial connection

Constructions spéciales:
avec raccord coaxial

Construcciones especiales:
con racores coaxiales



LIQ	Abmessungen/dimensions [mm]						
	H	H_1	D	D_1	SW	G ISO 228	L
170.641.17.20	47.5	34	56	36.0	22	G 1/8	7.5
170.721.17.20	47.5	34	56	36.0	22	G 1/8	7.5
170.801.17.20	80.5	58	70	53.1	32	G 3/8	14.0
170.881.17.20	80.5	58	70	53.1	32	G 3/8	14.0
170.961.17.20	112.0	91	92	68.8	46	G 1/2	18.0

Andere Sonderausführungen auf Anfrage.

Other special designs upon request.

Autres constructions spéciales sur demande.

Otras construcciones especial sobre demanda.

This volume has been prepared by:

Consulting Engineers - Power Engineering Study and Design Company. „Energoprojekt - Warszawa SA"

Engineering Design Of An Electron Beam (EB) Flue Gas Purification Industrial DemonstrationPlant

Basic Engineering.

Volume 3

Ammonia storage and dosing unit.

Warsaw. January 1996

No. of Volume	List of Volumes	Author
Volume 0	Executive Summary	
Volume I	Process Technology	INCT
Volume II	Gas Conditioning Unit	INCT
Volume III	Ammonia storage and dosing unit	Energoprojekt-Warszawa
Volume IV	Reaction chamber	Proatom
Volume V	By-product filtration (ESP)	Energoprojekt-Warszawa
Volume VI	By-product removal from filter, its transportation and conditioning	Energoprojekt-Warszawa
Volume VII	Flue gas ducts. Emission of flue gases to atmosphere	Energoprojekt-Warszawa
Volume VIII	Measuring, monitoring and control system	SINS
Volume IX	Electrical power supply units	Energoprojekt-Warszawa
Volume X	Composite documentation	Energoprojekt-Warszawa
Volume XI	Balances	Energoprojekt-Warszawa

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Volume 3

Ammonia storage and dosing unit

Contents

- Drawings:

1. Schematic diagram of ammonia management	1 131 110
2. Layout of buildings and installations of ammonia store	1 131 111
3. Layout of the area of ammonia storage and dosing unit	958 673

1. Introduction

This volume gives the presentation of ammonia management system for Electron Beam Flue Gas Purification.

2. System function. Design criteria

The ammonia management system shall cover the following functions:

- liquid ammonia unloading from (railway) tank cars to storage tanks,
- storing of liquid ammonia,
- automatic liquid ammonia transportation to preheater gasificator,
- retention and decompression of gaseous ammonia,
- transportation (transfer) of gaseous ammonia to dosing points.

3. Ammonia (NH_3) characteristic

3.1. General characteristic of NH_3

- liquid under pressure,
- colourless,
- pungent odour,
- density
  - gas at 0° C temperature - 0.771 g/dm^3
  - liquid at 0° C temperature - 610 g/dm^3.
- explosion danger at ammonia concentration of 15-28% vol. in the air,
- self ignition point at 630 °C,
- very caustic and toxic, very soluble in water, gas lighter from the air (0.597 in relation to the air), inflammable, creating with the air, chloride, bromide and iodine tincture explosive mixture.

3.2. Quality characteristic of NH_3

- NH_3 contents	99.85 % by weight
- Fe contents	max 5 mg/dm^3
- dry matter contents	0.15 % by weight

4. System description

4.1. Ammonia stores (NH_3)

4.1.1. Liquid ammonia store

The store consists of four steel vertical cylindrical tanks 100 m^3 total capacity, 55 m^3 useful capacity each one. Tank max. working pressure amounts 1.6 MPa.

Total useful capacity of the store is equal approximately 220 m^3. It means that at ambient temperature tanks can contain 134000-150000 kg of liquid ammonia, what meets completely monthly demand for SO_2 and NO_x reduction.

Liquid ammonia store is provided with full equipment required by respective regulations, namely:

- tanks will be based inside concrete basin with walls 0.3 m high, equipped with drainage system collecting waste water in a drainage pit within the basin,
- draining of leakage water and rain water from the basin to rain water sewage system or neutralizator, stop valves on take-off pipes situated at the distance of 50 m outside the basin,
- tanks are protected against excessive temperature increase by applying of automatically activated warter curtains,
- alarm of too high level in the storage tank (all tanks are protected from gaseous ammonia pressure increase; the service platform is predicted for operating of valves situated at the tank heads),
- ammonia store possesses auxiliary compressed air and nitrogen installations,
- ammonia store is separated from other Power Plant objects by the fence.

4.1.2. Gaseous ammonia store

The gaseous ammonia store consists of steel vertical cylindrical tank 100 m^3 total capacity, identical as for liquid ammonia tanks. Tank working pressure amounts 1.6 MPa.

After gasification process in preheater gaseous ammonia (for SO_2 and NO_x reduction reaction) gaseous ammonia is stored in the tank.

Another task of this buffer-storage tank is reducing of ammonia pressure difference between gasification and distribution section of the system.

Gaseous ammonia is kept in buffer tank under maximal pressure of 1.6 MPa. Before delivery to dosing installation ammonia is decompressed to the pressure of 0.3-0.5 Mpa.

The buffer storage tank of gaseous ammonia is situated in common with liquid ammonia tanks at the same concrete basin and has the same safety devices as the remining storage tanks.

4.2. Auxiliary installations for ammonia store

Storage and gasification of ammonia requires a lot of special protective measures of which the main task is to ensure efficient and safe operating of the whole plant.

4.2 1. Reloading installation of liquid ammonia

Liquid ammonia will be delivered to the Power Plant by tank cars. Reloading from cisterns to store tanks will be carried out by displacement of fluid with the aid of gaseous ammonia delivered to the cistern from gasificator.

Reloading installation of ammonia consists of the following elements:

- unloading point provided as two fittings of gaseous ammonia under pressure, adjusted to cistern construction requirements and two fittings of liquid ammonia (simultaneous unloading of two cisterns situated in the protective basin will be possible),
- transfer pipelines of liquid and gaseous ammonia.

4.2.2. Ammonia gasification installation

Liquid ammonia is gasified, stored, corrected to required parameters (pressure decrease) and delivered to dosing points of SO_2 and NO_x reduction installation. Gasificators serve also as a source of gaseous ammonia for liquid ammonia replacement from cistern cars to store tanks.

Ammonia gasification installation consists of:

- three liquid ammonia pumps delivering ammonia to gasificator,
- two gasificators with a heating unit used to evaporate liquid ammonia. Max. working pressure amounts 1.6 MPa,
- transfer pipelines of liquid and gaseous ammonia, cut-off fittings and fittings protecting from pressure increase.

Ammonia gasification installation works at fully automatic system.

4.2.3. Decompression installation of gaseous ammonia

Gaseous ammonia delivered to dosing point should have constant pressure and temperature. Decompressing installation is to ensure constant ammonia pressure.
It consists of:

- two independent decompressing systems of gaseous ammonia; gaseous ammonia has to be decompressed from the max. pressure 1.6 MPa (in buffer-storage tank) to the value of 0.3-0.5 MPa,
- electric preheaters stabilising gas temperature at the latter part of delivery pipeline.

4.2.4. Decompression installation of gaseous nitrogen

Each emptying of ammonia filled tank requires special protection against explosive mixtures creation and against leakage of ammonia into the atmosphere. In order to prevent from these dangers nitrogen is used to displace ammonia into neutralising installation. Nitrogen is fed from the cylinder after previous reducing of pressure. Decompressing installation of gaseous nitrogen is supplied as a whole by Welding Equipment Factory "Perun" in Warsaw. There is predicted to install an installation with one reducing system, collecting pipeline and fittings to 20 cylinders. Distribution pipelines of nitrogen located within reach of ammonia system have to be made of steel.

4.2.5. Sprinkling installation (water curtains)

Storage tanks of liquid ammonia are exposed to sun radiation. In the summer time it will cause excessive pressure increase and as a consequence it will create danger of tanks, pipelines and valves damage. In order to protect tank surface from excessive overheating by sun radiation cooling water curtains will be applied. The system consisting of pipes in the form of perforated rings will start automatically depending on set values of pressure and temperature switches.

4.2.6. Compressed air installation

Compressed air will be used for nitrogen removal from tanks in the period of tank shut down, routine repair and periodical survey. Installation consists of delivery pipeline equipped with stop valves, control valves protecting against pressure increase above admissible value and reducing pressure to required value.

4.2.7. Ammonia neutralising installation

Leakage of liquid and gaseous ammonia from storage installation has to be neutralise due to toxic and explosive properties of the product. Ammonia bleeding from safety valves, ammonia from decompression of gaseous space, gases carried away during run-purge of tanks and pipelines are directed to neutralizator i.e. to bubbling system in the tank under the absorption tower with Raschig rings.

Neutralising tank is filled with 10-20 % sulphuric acid solution which is pumped onto the surface of the tower. System is put into operation automatically after creation of pressure difference caused by gas flow in the delivery pipeline on the way to barbotage.

Consumption of acid solution has to be systematically controlled and in case of necessity replaced by new solution. Installation consists of:

- reloading pump of concentrated sulphuric acid,
- preparation tank of 10-20 % sulphuric acid solution,
- neutralizing solution tank under spray irrigation tower with Raschig rings,
- spray irrigation tower,
- two recirculating pumps of neutralising solution.

Under standard conditions (i.e. at time of control gas flow to the tower) one pump turns on, then liquid flow amounts 20 m^3/h. In other conditions two pumps turn on automatically.

Also air drawn out from emergency ventilating hood of technological rooms will be directed to spray irrigation tower.

4.2.8. Electric installation of ammonia pipelines preheating

There is a danger of ammonia outdropping due to delivery of ammonia for long distances (in the period of low atmospheric temperatures). From above mentioned reasons preheating of ammonia in specified points of pipeline is predicted. These points will be determined after definite pipeline location.

4.2.9. Installations of drinking water, sewage system and fire protection water

Ammonia storage installation is supplied with drinking water to meet the following demands:

- water supply of water curtains (tank surface cooling),
- process water (preparation of neutralising solution),
- potable water for staff needs,
- water for tank pressure tests.

All these water streams together with rain water and post-neutralizing solutions should be discharged into sewage system. The whole object creating ammonia store has to be protected by fire protection installation. Spacing of fire hydrants in accordance with respective ammonia management regulations.

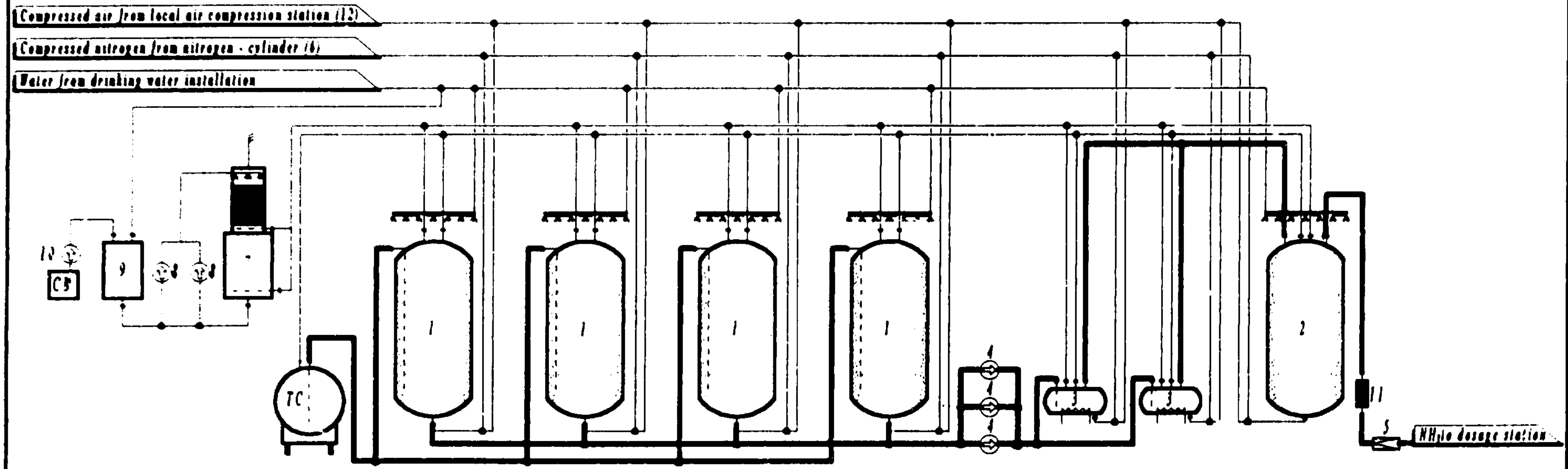
5. Conclusions and recommendations

Ammonia store was located according to suggestion of Investor. This proposal is very inconvenient from length of liquid ammonia suction pipe point of view. It is recommended to analyse accepted localisation in detail once more. Ammonia store should be located nearer the railway track.

6. Specification of equipment and materials

Item	Specification of equipment and its characteristic	Supplier Symbol	Unit	Quantity of units	Weight /Price of equipment Unit [kg]/ATS	Total [kg]/ATS
1	2	3	4	5	6	7
1	Storage tank of liquid ammonia (NH_3) D400 H7500, working pressure 3 MPa		unit	4	22000	88000
2	Equalising tank of gaseous ammonia (NH_3) D400 H7500, working pressure 3MPa			1	22000	22000
3	Gasificator of liquid ammonia (NH_3) D1200 L1500 with electric preheater or steam coil			2	2500	5000
4	Liquid ammonia pump (NH_3), type of 4NH2 Q=3 m^3/h H=20 m H_2O			3	44	132
5	Decompression gaseous ammonia station - stop valve DN32 - control valve - pressure reducing valve			 6 2 2		
6	20-points decompression station of nitrogen with supports and fittings to gas cylinder	Welding Equipment Factory "Perun" in Warsaw		1	200	200
7	Absorption tower with Raschig rings and neutralising solution tank - tower D1400 H3000 - tank D2400 H3750			 1 1	 2500 4650	 2500 4650
8	10-20% sulphuric acid solution pump (H_2SO_4), type of 50 KCZ 30 Q=30 m^3/h H=13 m H_2O			2	169	338
9	Preparation tank of sulphuric acid solution (H_2SO_4) D2000 H3000 (with protective coating)			1	1800	1800
10	Reloading pump of concentrated sulphuric acid, type of LUT2 MI4 Q=210 l/min H_{max}= 19 m			1	6	6
11	Gaseous ammonia filter Q= 300 Nm^3/h p=1.6 MPa			1		
12	Ball stop valve with electric drive DN32 (ammonia)	ST123 SGR BW EBRO		7	/8642	/60500
13	Ball stop valve with electric drive DN40 (ammonia)	ST123 SGR BW EBRO		15	/8792	/131900

1	2	3	4	5	6	7
14	Ball stop valve with electric drive DN50 (ammonia)	ST113 SGR BW EBRO		13	/14258	/185400
15	Ball stop valve with electric drive DN80 (ammonia)	ST113 SGR BW EBRO	unit	4	/17416	/69700
16	Safety valve DN32			8	19	152
17	Ball stop valve with electric drive PVC (H_2SO_4) DN40	11 PVC-U GF		6	5.6	33.3
18	Ball stop valve PVC (H_2SO_4) DN50	346 PVC-U GF		2	0.82	1.7
19	Ball stop valve (ammonia, nitrogen, compressed air) DN32			7	3.5	24.5
20	Ball stop valve (ammonia, nitrogen, compressed air) DN50			3	6.0	18
21	Ball stop valve DN80 (ammonia)			2	22	44
22	Ball stop valve DN100 (ammonia)			4	30	120
23	Pressure reducing valve DN50 (ammonia)			3	according I and C	
24	Check valve DN50 (ammonia)			3	9.9	30
25	Check valve DN80 (ammonia)			1	18.1	18.1
26	Control valve DN80 (ammonia)			3	20	60
27	Ball stop valve with electric drive DN50 (water)			5	26	130
28	Ball stop valve DN50 (water)			1	6	6
29	Steal pipe DN32		m	150	2.75	420
30	Steal pipe DN40		m	200	3.26	660
31	Steal pipe DN50		m	350	4.25	1490
32	Steal pipe DN80		m	350	8.38	2950
33	Steal pipe DN100		m	600	10.3	6180
34	PVC pipe DN40	PVC B 40x1.8 GAMRAT	m	40	0.422	17



PERMANENT INSTALLATION

1. Liquid ammonia storage tank
2. Gaseous ammonia equalizing tank
3. Ammonia gasificator
4. Liquid ammonia pump
5. Gaseous ammonia decompression station
6. Compressed nitrogen cylinder
7. Absorption tower
8. Sulphuric acid solution pump
9. Preparation tank (sulphuric acid solution)
10. Reloding pump (concentrated sulphuric acid)
11. Gaseous ammonia filter
12. Air compressor

SUPLIED ACCORDING TO DEMAND

TC - Tank car (liquid ammonia)
CB - Carboy (concentrated sulphuric acid)

Archiwum

ENERGOPROJEKT Warszawa SA Biuro Studiów i Projektów Energetycznych Warszawa ul. Krucza 6/14		Nr archiwalny 1131110		Nr porz. w tomie 1
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INDUSTRIAL DEMONSTRATION PLANT OF ELEKTRON-BEAM PROCESS FOR FLUE GAS TREATMENT OF THE ELECTRIC POWER STATION "POMORZANY" - SZCZECIN, POLAND	Data czerwiec 1995r	Podziałka	Faza / Format	Proc H2 / Czas przech.
AMMONIUM STORAGE AND DOSING UNIT FLOW DIAGRAM	Zastępuje rys.			
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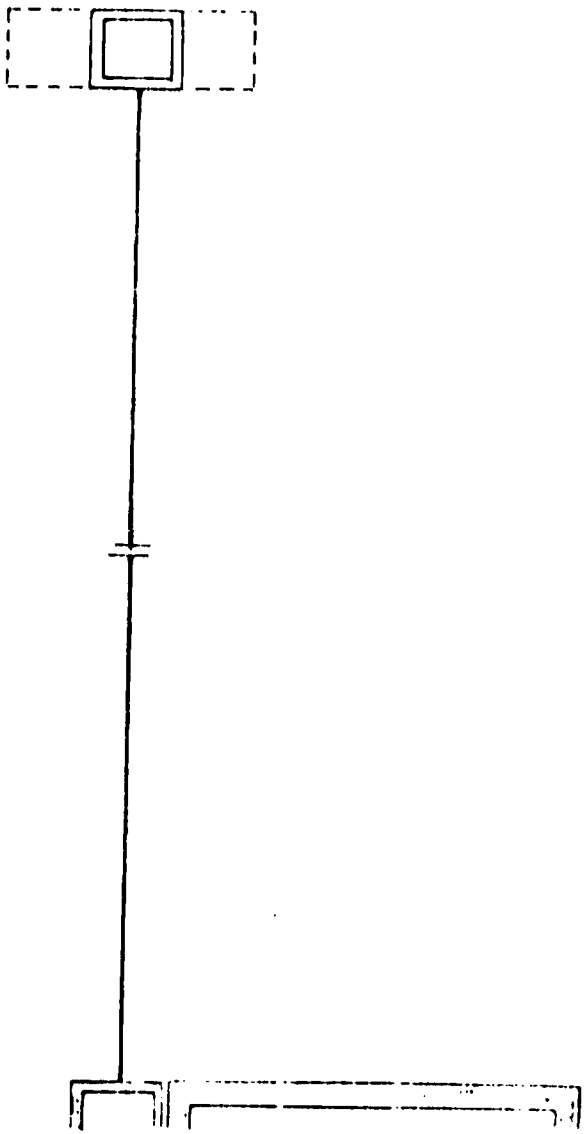
	Wykonał: mgr inż. [illegible]		Kier. prac.	
	Kreślił: PDM & PR1		Gł. proj.	

Railway track

Unloading station of liquid ammonia



Sol. 1

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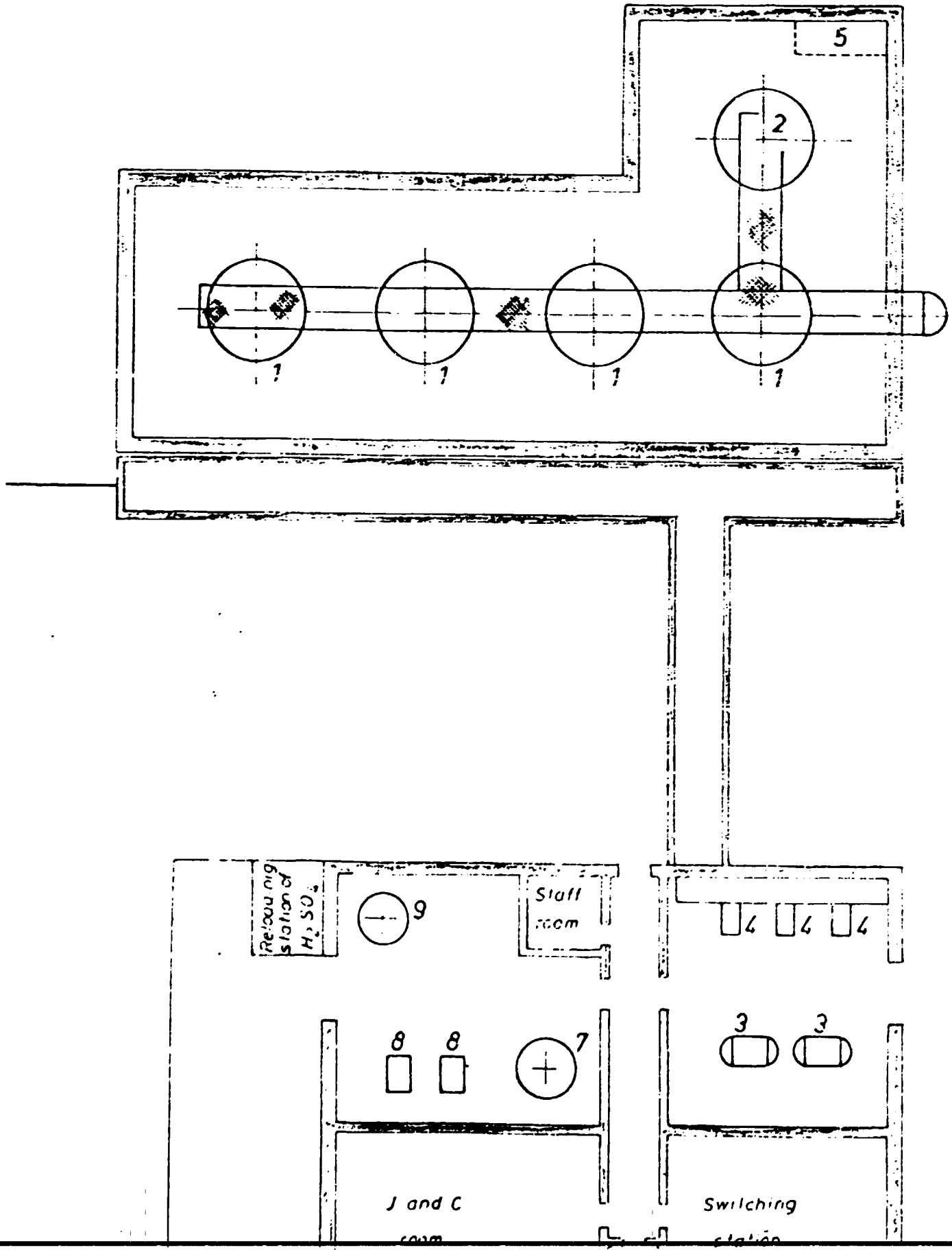

5
2
1
1
1
1
Relaying station of H₂SO₄
9
Staff room
4
4
4
8
8
7
3
3
J and C room
Switching station

Sec 3

Specification :

1 Storage tank of liquid ammonia D 4000 H 7500

2 Equalizing tank of gaseovs ammonia D4000 H7500

3 Gasification pressure tank with heating unit D1200 L1500

4 Liquid ammonia pump type of 4NH2 Q= 3 m^3/h H=20 m H_2O

5 Decompression station of gaseovs nitrogen

6 Decompression station of nitrogen

7 Absorption tower of outlet ammonia D1400 H 30[illegible] D2400 H7500

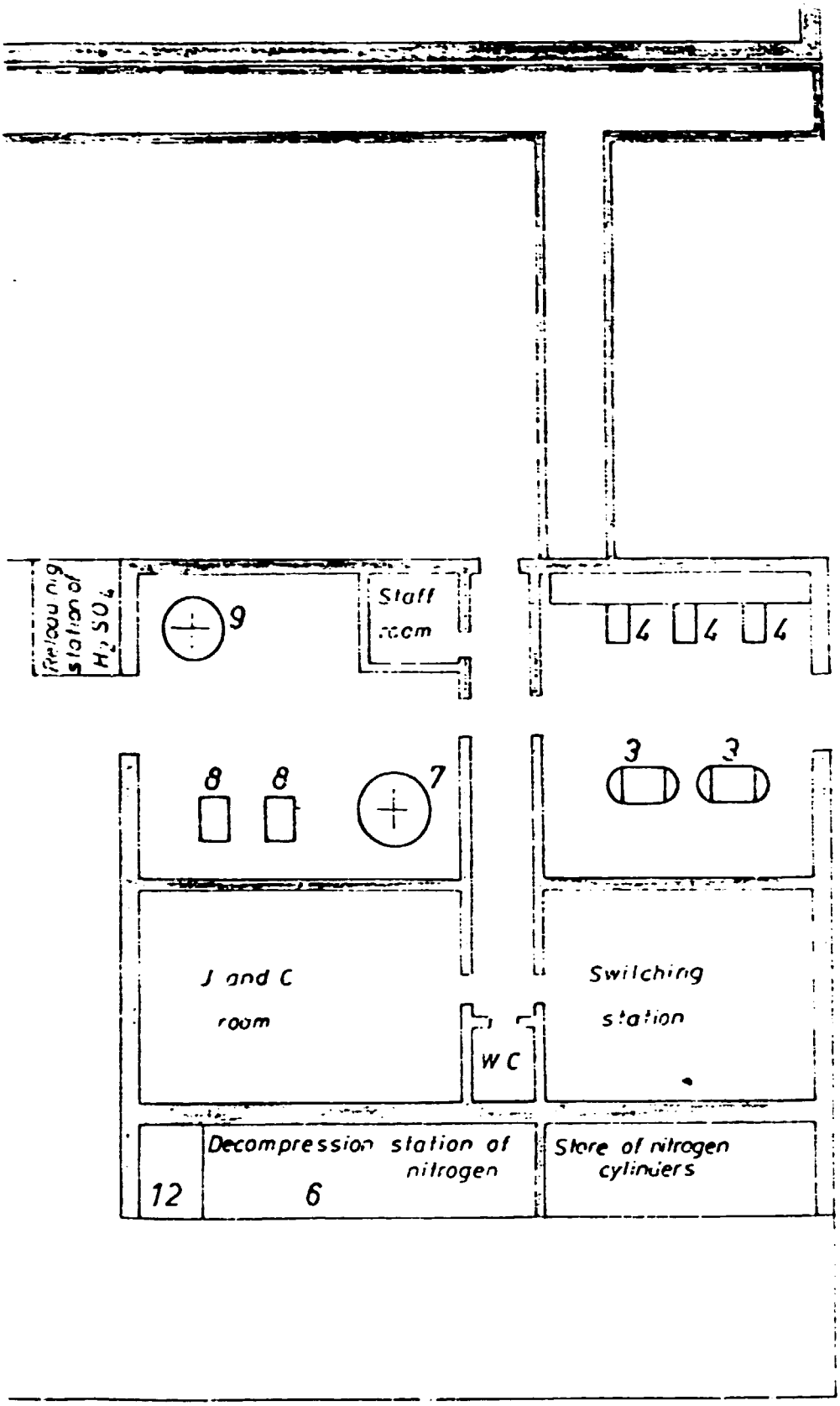
8 Pump of sulphuric acid solution type of 50KCZ 30 Q = 30 m^3/h H = 13 m H

9 Tank of 10 20 % sulphuric acid solution D 2000 H 3000

12 Low pressure air compression station

Unloading station of
ammonia

Fig 4



3 Gasific

4 Liquid

5 Decom

6 Decom

7 Absor

8 Pump

9 Tank

12 Low p

.ENEP
Bu
E. Pomorzany
Industrial de
electron - Bec
gas treatmer
station, Pomor
Ammoniu
and dosing

See 5

2 Equalizing tank of gaseovs ammonia D 4000 H 7500

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9 Tank of 10 20 % sulphuric acid solution D 2000 H 3000

12 Low pressure air compression station

Sz 6

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Nr part. w tomie 2

E: Pomorzany P.0176

Industrial demonstration plant of electron - Beam process for flue gas treatment of the electric power station „Pomorzany" Szczecin, Poland

Ammonium storage and dosing unit layout

Data 95 06

Format A2

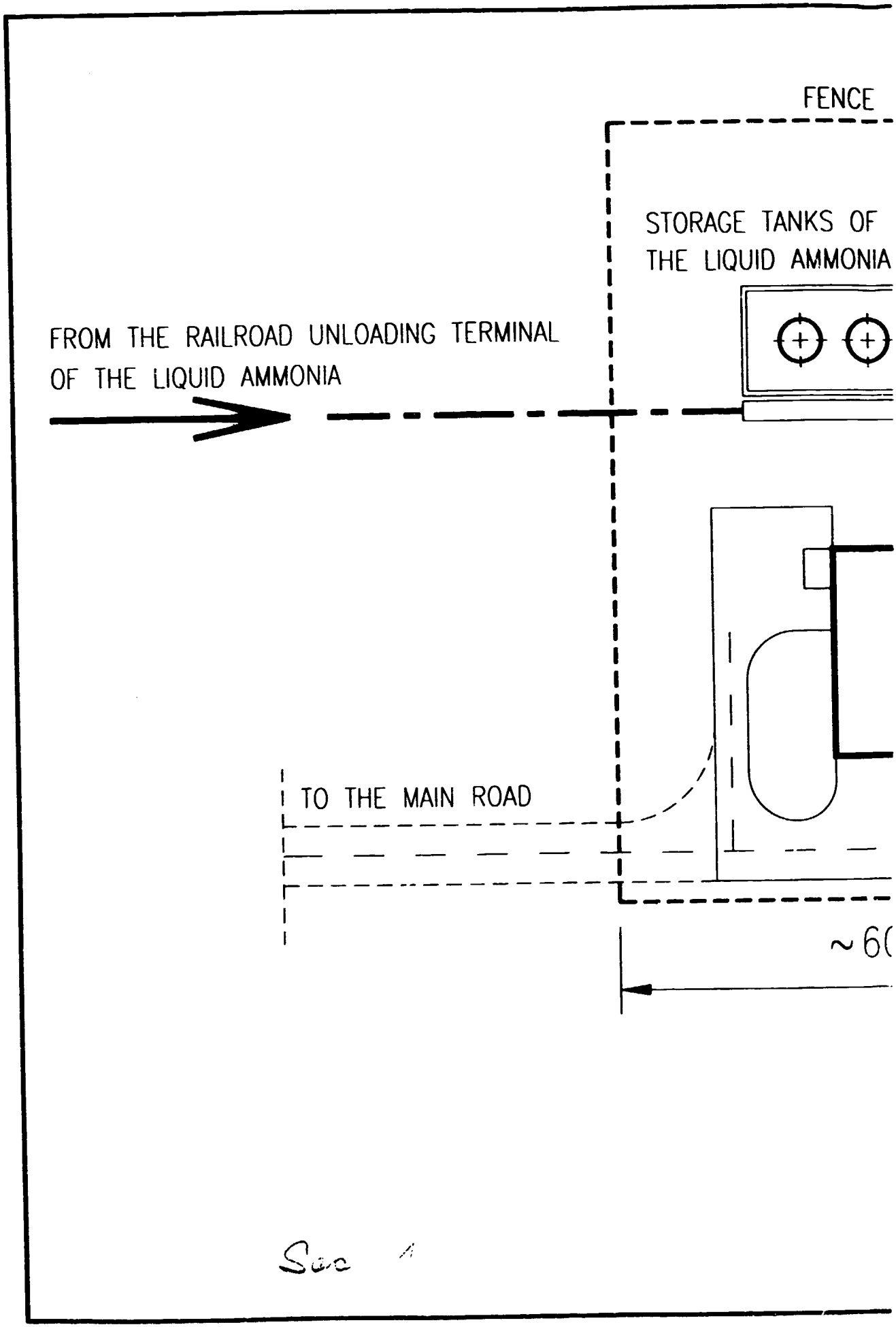
Proc. H2

Projekt mgr inż.

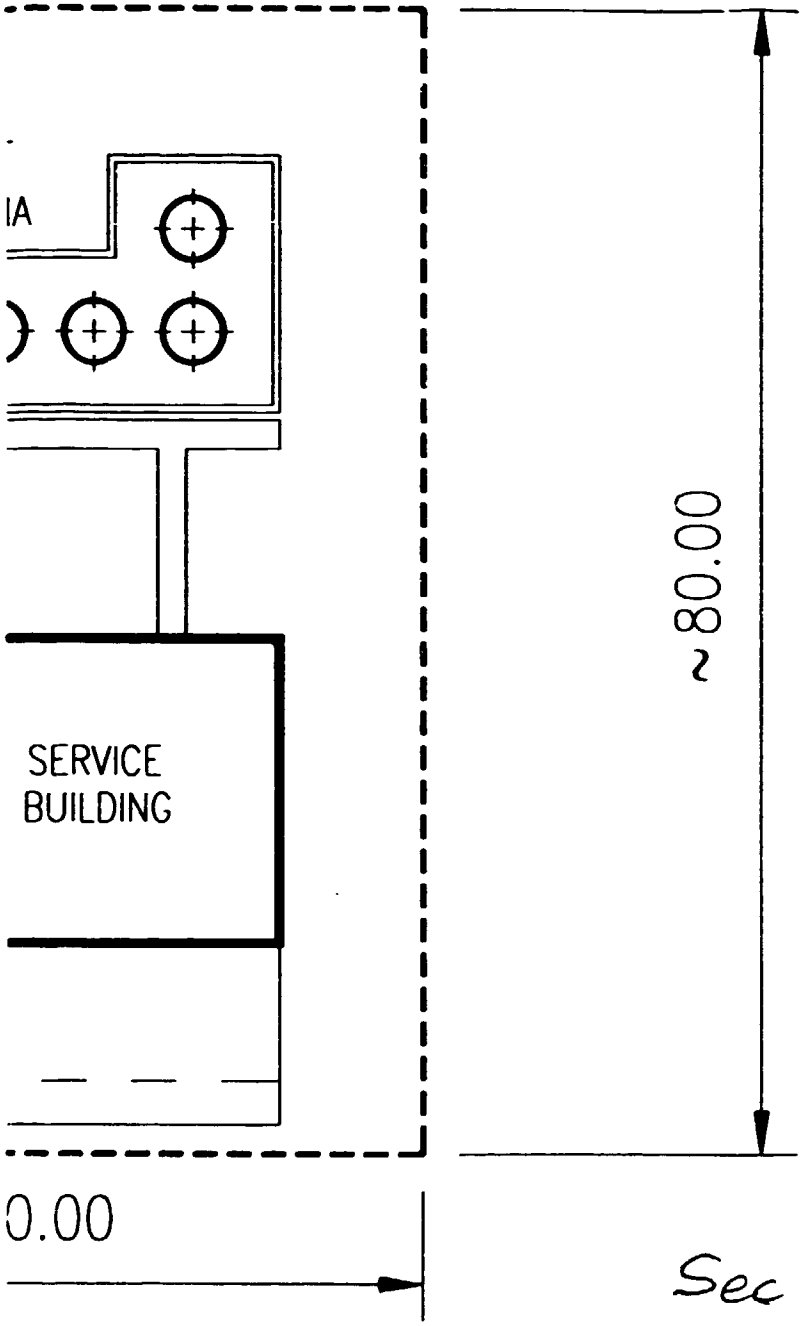
Rysował L. Chmielewska

Sprawdził mgr inż. Z. Gorałczyk

Kierował Zimowska


FENCE
STORAGE TANKS OF
THE LIQUID AMMONIA
FROM THE RAILROAD UNLOADING TERMINAL
OF THE LIQUID AMMONIA
TO THE MAIN ROAD
~60

Sec 4



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INDUSTRIAL DEMONSTRATION PLANT OF ELECTRON-BEAM PROCESS FOR FLUE GAS TREATMENT OF THE ELECTRIC POWER STATION "POMORZANY" -SZCZECIN, POLAND

LAYOUT OF THE AREA OF AMMONIA STORAGE AND DOSING UNIT

Data	Podziałka	Faza	Format	Proc.	Czas przech.
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Zastępuje rys. Nr
Zastąpiony przez rys.

Projekt.	mgr inż. Zb. Waraksiński	Sprawdził	mgr inż. J. Drobczyk	
Wykonał		Kier. proc.	mgr inż. R. Kołakowski	
Kreślił		Gł.proj.		

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Institute of Nuclear Chemistry and Technology

Engineering Design Of An Electron Beam (EB) Flue Gas Purification Industrial DemonstrationPlant

Basic Engineering.

Volume 4

Reaction Chamber

Warsaw, January 1996

No. of Volume	List of Volumes	Author
Volume 0	Executive Summary	
Volume I	Process Technology	INCT
Volume II	Gas Conditioning Unit	INCT
Volume III	Ammonia storage and dosing unit	Energoprojekt-Warszawa
Volume IV	**Reaction chamber**	**Proatom**
Volume V	By-product filtration (ESP)	Energoprojekt-Warszawa
Volume VI	By-product removal from filter, its transportation and conditioning	Energoprojekt-Warszawa
Volume VII	Flue gas ducts. Emission of flue gases to atmosphere	Energoprojekt-Warszawa
Volume VIII	Measuring, monitoring and control system	SINS
Volume IX	Electrical power supply units	Energoprojekt-Warszawa
Volume X	Composite documentation	Energoprojekt-Warszawa
Volume XI	Balances	Energoprojekt-Warszawa

Authors of this volume:

1. Michał Romanowski	Proatom
2. Zbigniew Zimek	INCT

CONTENTS

BASIC ENGINEERING
Reaction chamber

1. Description of the process kinetics.

1.1. Dependence of the ionizing radiation dose on the specified outlet gas chemical composition and charactristics of flue gas traversing system:
- density,
- velocity,
- flow rate.

1.2. Determination of the required level of irradiation dose when gas is treated by:
- single - stage irradiation,
- two - stage irradiation,
- multi - stage irradiation.

2. Selection of accelerators.

2.1. Documentation of applicable assumptions in accelerator selection:
- determination of accelerator power,
- technical parameters of the accelerator unit, including: size, power and weight of feeders, means of cooling - SF_6 or oil,
- constructional design of the accelerator configuration (coupling feeder-head, length of horn, length and width of window, means of beam introduction, size and weight of the units),
- maintenance requirements time duration, frequency of foil replacement, regulation and control of accelerator),
- method of assembling and fitting units,
- accelerator maintenance (personnel requirements).

2.2. Technical characteristics of selected accelerators (availability for purchase and application).

3. Technical documentation for BE (basic engineering) of the reaction chamber to support detailed engineering design.

3.1. Selection of the chamber configuration and establishment of its size (diameter and length) as a function of gas density and the electron beam range.

3.2. Materials of construction (carbon steel, alloy steel with anti corrosive coating, and stainless steel).

3.3. Window construction:
- manner of window installation in the reaction chamber accounting for rate of titanium foil and ease of the window replacements,
- means of window protection from the influence of flue gas particulates (air flashing under the window),
- means of window cleaning from the chamber side.

3.4. Selected method of cleaning the chamber walls of deposits (scrapers, water nozzles, water introduction).

3.5. Water feed to the reaction chamber to increase gas humidity (selection of a nozzle location).

3.6. Determination of thermal expansion compensation in the chamber and piping.

3.7. Composite drawings (BE) of the reaction chamber with principal dimensions and critical provisions in technical project design.

4. Basic engineering of the reactor building.

4.1. Selection of ozone removal method:
- exhaust from the unit (ventilation),
- removal by recirculation to the reaction chamber or gas line.

4.2. Ventilation of the reactor building.

4.3. Installation of SF_6 isolating gas.

4.4. Accelerator cooling system.

4.5. Selection of generators.

4.6. Ventilation of high voltage generator rooms.

4.7. Ventilation of accelerator rooms.

4.8. Protection against ionizing irradiation including:
- location of permanent biological shields,
- location of mobile biological shields,
- thickness of the shield walls and type of materials utilized.

4.9. Layout of the reaction chamber unit wit cooperating installations (parameters and utilities requirements show shown).

4.10. Composite drawings (BE) of the reaction chamber unit including arrangement of accelerators, generators and accompanying equipment, to permit detailed engineering design.

4.11. Specification of principal non typical and commercialy available units.

4.12. Choice of construction materials.

4.13. Protection against corrosion.

4.14. Estimation of media sources.

4.15. Assumptions for branch designs:

- for structural and construction part, indicating magnitude and nature of loads,
- for electrical part (listing of installed power supply),
- terminal of the external feeding installations,
- for the monitoring, control and measuring projects, including:

a) dose control and optimization,
b) continuous observation of the gas irradiation system (TV cameras),
c) gas analysis,
d) measurements of the process parameters,
e) installation of measuring and control systems to ensure safety (control of ozone concentration level etc.).

5. Costs calculation for supply of the reaction chamber system.

1. DESCRIPTION OF THE PROCESS KINETICS.

1.1. Dependence of the ionizing radiation dose on the outlet gas chemical composition and characteristics of flue gas traversing the system: gas density, gas velocity, gas flow rate specified.

Oxidizing radicals OH, HO and O are produced in the process energy of transfer from the electron beam to the molecules of the flowing gas. The main components of the flue gas such as N_2, O_2, H_2O, and CO_2 are almost totally responsible for the energy absorption in this multi component gas system. The energy absorption by each component is proportional to its partial pressure switch also means that SO_2 and NO_x relatively low in concentration have little impact on primary processes. The SO_2 and NO_x removal process efficiency (G value, energy cost of the removal process) depends on a number of competing reactions in which the primary radicals decay.

The principal parameters of radiation technology are related to required dose level, connected to radiation process efficiency (G value, required dose level for a specified removal efficiency), energy requirements and radiation utilization efficiency of radiation, which depends on irradiated material density and electron beam spatial characteristics.

This relation are is well defined by the following equation:

$$W = \frac{3600}{D} \cdot F_e \cdot P_{eb} [kg/h] \qquad [1.1]$$

where: W - throughput of the installation; W = m x F, [kg/h],
m - gas - phase mass density, [kg/m],
F - flow rate, D = 3600 x s x v, [m /h],
s - reaction vessel crosssectional dimension, [m],
v - gas phase linear speed, [m/s]
D - required dose, [kGy],
F_e - electron beam utilization factor,
P_{eb} - electron beam power; $P_{eb} = I_{eb} \times E = P \times F_a$, [kW],
I_{eb} - electron beam current, [mA],
E - electron energy, [MeV],
P - electrical power of the radiation facility, [kW],
F_a - electrical efficiency of the accelerator.

It can be easily seen from above that throughput of the removal process depends directly on beam power level and, for fixed electron energy range, depends proportionally on electron beam current level. The relation between electron energy level and dose is more complex. Fig. 1.1 represents the universal curve relating dose distribution vs electron energy. The maximum penetration range can be determined for a specified mass density of the irradiated object and an electron energy.

Electrons interact with matter in several ways, the chief of which are inelastic and elastic collisions along with the emission of electromagnetic radiation (important at higher electron energy levels).

At lower energies (below several MeV) electrons lose their energy by inelastic collisions with electrons of the interfering material resulting in ionization and excitation in the irradiated material. The equation describing the rate of energy loss of an electron as a result of ionization and excitation, first derived by Bethe and completed (modified) by Bloch, is given by:

$$\frac{dE}{dx} = \frac{4\pi N e^4 Z}{m_0 v^2}\left[\ln\frac{m_0 v^2 E}{2I^2(1-\beta^2)} - \ln 2.2\sqrt{(1-\beta^2)} - 1 + \beta^2 + 1 - \beta^2 + \frac{1}{8}\left(1-\sqrt{(1-\beta^2)}\right)^2\right] \qquad (1.2)$$

where:

E is electron energy [MeV]
x is the distance within travelled by the electron the material [m]
N is the number of atoms per cm^3
e is the charge on the electron (for mixture z_{eff})
Z is the atomic number of the interfering material
m_0 ia the rest mass of the electron; 0.511 MeV
v is the velocity of the electron [cm/s]
I is the mean excitation potential for the atoms of the stopping material [eV]
and β v c where c is velocity of light; 1c = 2.99 · 10^8 m/s

The quantity dE/dx, i.e. rate of loss of energy with distance, is usually known as the stopping power. It can be expressed in MeV · cm^2/g or in MeV/cm. The main conclusion to be drawn from Bethe's equation about stopping power of electrons is: The product is equal to the number of electrons per cm^3, i.e. stopping power is directly proportional to the electron density and will therefore be much lower in gases than in solids or liquids. Electrons because of their small mass are readily deflected by the Coulombic field of a nucleus. Although there is no energy loss in electric collisions of this kind, such collisions are important in that they result in a non-linear passage of the electron through the irradiated medium. When the percent of transmitted electrons is plotted as a function of absorber thickness, a rapidly decreasing value is displayed with a "tail" that merges with a background value.

The absolute maximum range, R_0, is determined by the intersection of the tail of the transmission curve with the background. The extrapolation range, or practical range R_p, is determined by the extrapolation of the linear portion of the transmission curve to the intersection with the background.

The electron range can be calculated by (numerical) integration of the collision energy loss.

On the other hand an empirical relation may be used:

$$R_0/E,Z,\theta/ = a\left(\sqrt{1+25E^2} - 0.9865\right) \qquad (1.3)$$

where

$$a \quad \frac{0.161\cos(\theta/2)}{Z^{0.2}}$$

for 0.03 · E · 3 MeV
and 0° ≤ θ_0 ≤60°
R in g/cm^2.

The above formula takes into account effects of Z and also the incidency angle, θ. The angle θ depends on scanning and on electron scattering in curved window foils.

The temperature of the gas phase and its pressure have significant influence on dose distribution due to differing specific mass density for at each temperature level. The basic parameters of the air and flue gas are given in Table 1.1.

The dose distribution for certain process parameters and multilayer irradiated object can be evaluated by computer code. Examples of results that were obtained using computer simulations (Tabata, 1989) are presented on Fig. 1.2 and 1.3. Unfortunately different results were obtained based on calculations tied to different literature data (Table 1.2).

Table 1.1
Physical parameters of air and flue gases.

Parameter	Air	Flue gases	Remarks
Gas composition	N_2 - 75.45 % O_2 - 23.2 % Ar - 1.28 %	N_2 - 76 % CO_2 - 13 % H_2O - 11 - 12 %	
Density [kg/m^3]	1.293 kg/m^3 1.205 1.0 0.946	1.295 kg/m^3 0.950	0°C , 760 Tr 20°C 80°C 100°C , 760 Tr
Stopping power [MeV·g/cm^2]	1.798 1.739 1.703	1.8328 1.7719 1.7340	500 keV 600 keV 700 keV
Electron density	$3.03 \cdot 10^{23}$	$3.1 \cdot 10^{23}$	
Z_d	7.64 7.35	7.5 7.2	

Mean value of the dose collected by stream of flue gas can be calculated from the formula:

$$D = E \cdot I \cdot F_c \cdot \frac{2.148}{V} \cdot \rho \cdot \frac{T_0}{T_x} \cdot \frac{P}{P_0}$$

where
E - electron energy [keV]
I - beam current [A]

F_c - electron beam utilization factor
V - flue gas flow rate [Nm^3/h]
ρ - flue gas density [kg/Nm^3]
T_x - flue gas temperature, [°K]
T_n - 273.16 [°K]
P - flue gas pressure ($P_{atm} - \Delta P$)
$\Delta P - P_{in} - P_{out}$
P_0 - 760 mm Hg or 1013.2472 hPa
$T_x - (T_{in} + T_{out})/2$ [°K]

The dose deposited in the flue gas depends on electron beam parameters and reaction vessel dimensions. When a double window configuration is applied, additional losses are observed.

The electron beam passing through accelerator window, layer of air, and reactor chamber window loses energy. The loss of energy can be evaluated basing on:

1) the loss of energy during transmission of electron, through the accelerator window - usually titanium foil,
2) the loss of energy in air - layer between accelerator and reaction vessel windows,
3) the loss of energy during transmission of electrons through reaction vessel,
4) absorbed energy in the heated flue gas, imported to the walls of the process vessel

There are several kinds of EB energy losses, as follows:

- backscattering of some electrons, reflected from titanium foils,
- ionization losses in Ti (significant part), with simultaneous electron energy degradation,
- radiation losses in Ti (insignificant fraction),
- partial absorption of some electrons in Ti.

In the measurement and utilization of fast electrons, accurate knowledge of backscattering is frequently required. One of the quantities characterizing this phenomenon is the backscattering coefficient defined as the ratio of the number of backscattered electrons to the number of incident electrons. The backscattering is to a considerable degree due to the electric field of the nucleus (of the atom of irradiated material, i.e. Ti in our case). Hence it is not surprising to see that it increases with Z (atomic number).

On the other hand, the backscattering coefficients increase with increasing target thickness until saturation is reached at a thickness of approximately half the practical range of the incident electrons. It also depends on incident electron energy y.

The spatial distribution of the electron beam dose from the accelerator inside the process vessel can be measured using the thin ACT or PVC foil dosimeters that were chosen after critical selection of published dosimetric methods. The basic parameters of such dosimeters are given in Table 1.3.

Table 1.3.
The intercomparison of main characteristics of PVC and CTA film dosimeters

weight and composition	CTA cellulose triacetate 85% $(C_{12}H_{16}O_8)_n$ triphenyl phosphate 15%	PVC polyvinyl chloride $(C_2H_3Cl)_n$ of approx. 98%
nominal thickness	0.125 mm ±5%	0.26 mm
width of tape	8 mm	8 mm
specific weight	1.32 g/cm^3	1.4 g/cm^3
electron density	3.18 x 10^{23} e$^-$/g	3.15 x 10^{23} e$^-$/g
effective atomic number (Z)	6.7	11.37
effective Z/A (A - atomic weight)	0.526	0.5
mass stopping power (1 MeV electron)	1.75 to 1.8 MeV/g/cm^2	1.64 MeV/g/cm^2
linearity range	200 kGy 10 to kGy	5 to 50 kGy
wavelength (λ)	279.5 nm	394 nm
precision	8 - 10 %	6 - 10 %
manufacturer	FUJI Co., LTD. Tokyo	Kunstoffwerke Staufen

Dose distribution was measured In Kawęczyn Pilot Plant using foil dosimeters. The basic data regarding electron accelerator are given in Table 1.4.

Table 1.4

Main radiation data characterizing the ELV-3A high power low energy electron resonance accelerators

- energy of electrons	500-700 keV
- instability of electron energy	±5%
- average electron beam current	100 mA
- instability of electron beam current	±5%
- average electron beam power (max)	50 kW
- homogenity of linear density of scanned beam measure at the distance of 50 mm from output	±10%
- output window dimensions	75 x 1500 mm
- thickness of titanium window foil	50 μm
- max electron beam scanning angle	±30°
- cooling water flow rate	1.5 m^3/h
- cooling air flow rate	200 m^3/h

The process vessel has dimensions: 1.6 m in diameter with a length of 7.5 m. The process vessel is made of stainless steel 1H18N9T, and thermally insulated using the rock wooi. It is equipped with two secondary windows made of titanium foil (also of 50 μm thickness). Dimensions of the window (its active part) are 1500 x 75 mm.

Dose spatial distribution inside the process vessel was measured by both PVC and CTA film dosimeters cut in the form of long tapes (stripes) of about 115 cm. The dosimetric film stripes were placed in a special by designed square frame of external dimensions approximately 113 x 113 cm in seven levels 20 cm apart.

For radial dose distribution measurement the frame positioning was perpendicular to the geometrical axis of the process vessel in the middle of double titanium window of the ELV-3A accelerator EB system for injection into flue gas stream.

Longitudinal dose distribution determination needed consecutive shifting of the frame along the main geometrical axis of the process vessel in steps of 35 cm. Four shifts were adequate for measurement of the inside spatial dose distribution zone (contour). The frame construction ensures that the mutual self-screening of dosimetric film stripes is avoided. The configuration of dosimetric foil during dose distribution measurements is shown on Fig. 1.4.

The measurement were performed at 500, 600 and 700 keV of electron energy and 1 mA EB current to keep the 500 mA integral value constant (it is controlled by computer). Radiation induced absorbance of PVC and CTA stripes was spectrophotometrically sampled with a 3 cm step along each stripe. At the lowest energy (i.e. 500 keV) the reading level from the seven film stripe of the matrix closest to bottom was indistinguishable from the unirradiated film absorbance. Obtained measurement results for electron energy 0.6 MeV are presented in Fig. 1.5.

The dose distribution along the main axis of reaction vessel is shown on Fig. 1.6.

The experimental results of depth dose distribution for different electron energies are presented on Fig. 1.7. The evaluation of electron beam losses vs electron energy for Kawęczyn Pilot Plant experimental conditions is illustrated on Fig. 1.8.

1.2. Determination of the required level of irradiation dose when gas is treated by:- single-stage irradiation, two - stage irradiation, multi - stage irradiation.

The dose rate delivered to the flue gas is one of the major parameters of the irradiation process. It has direct relation to the NO_x and SO_2 removal efficiency and required electron beam power to be provided in the process installation (number and size of the accelerators). The results are influenced by variation in electron energy and different configurations of the reaction vessel. This means that economics of the process strongly depends on the effectiveness of the beam power transmission to the flue gas.

To get highest efficiency in performance of the flue gas irradiation process the dose distribution should be optimized.

This can be done in different ways:

- irradiation from the same side in at least two steps with gas mixing means.
- irradiation from opposite sides.

The electron energy and spatial dose distribution are the key parameters for evaluation of different irradiation configurations. Electron accelerators with energy 300 keV can be applied with the thickness of individual gas channels is below 0,9 m for one side and 1,8 m for two side irradiation. Comparable values for 800 keV are 2,9 and 5,8 m respectively.

To optimize the electron energy or width of the irradiation vessel the window and wall losses should be taken into account. Fig. 1.8 shows the optimum electron energy level for a certain reaction vessel configuration.

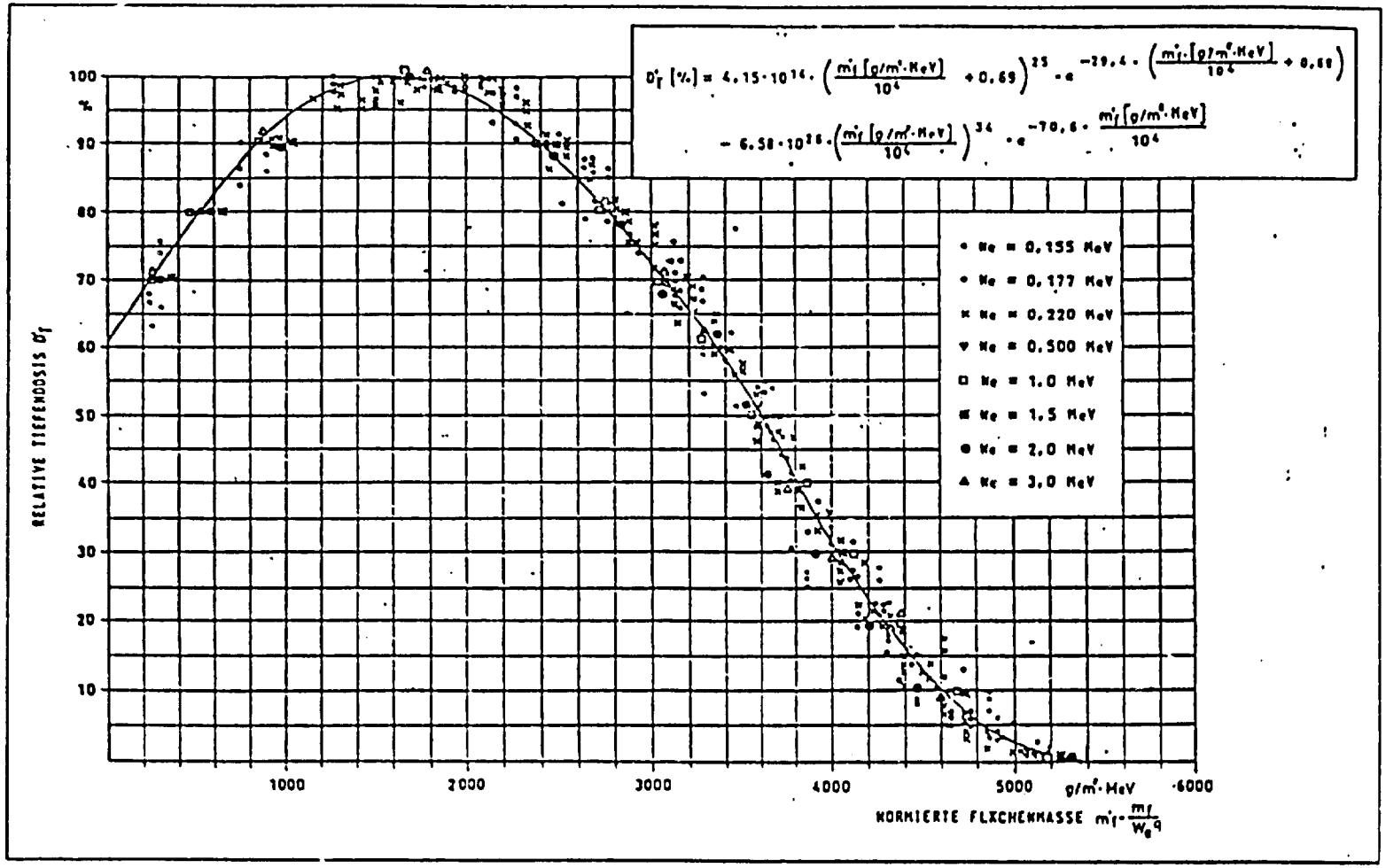


Fig. 1.1 Universal curve of dose distribution us electron energy

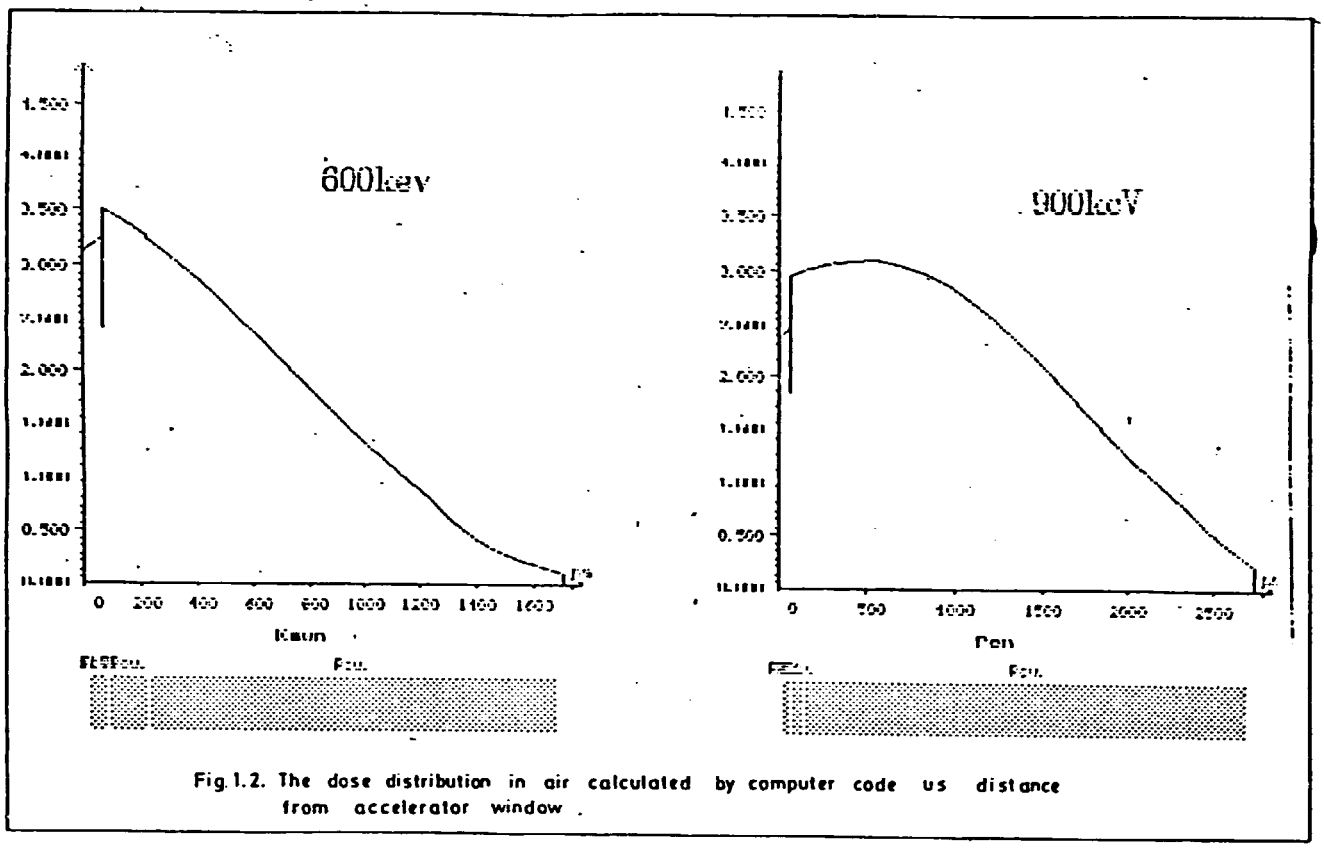


Fig. 1.2. The dose distribution in air calculated by computer code us distance from accelerator window .

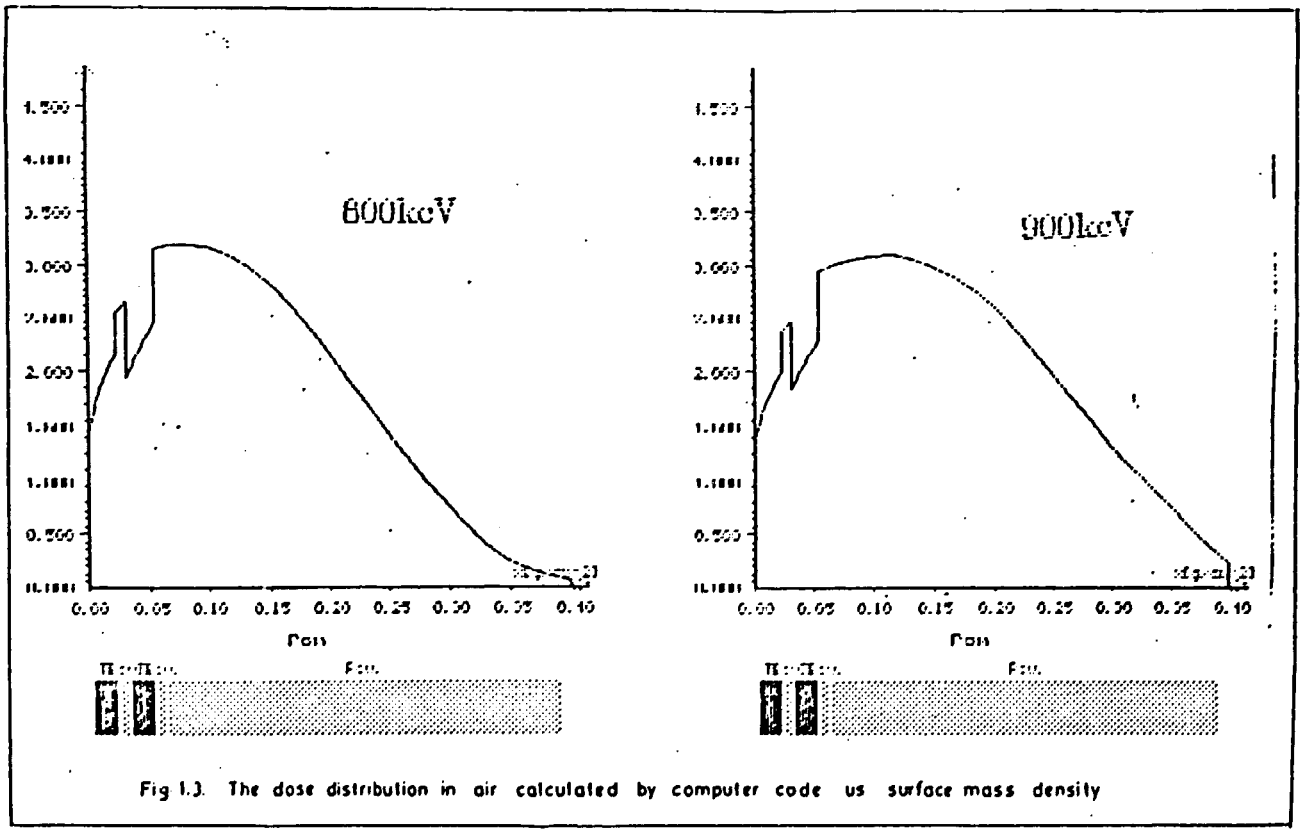


Fig 1.3. The dose distribution in air calculated by computer code us surface mass density

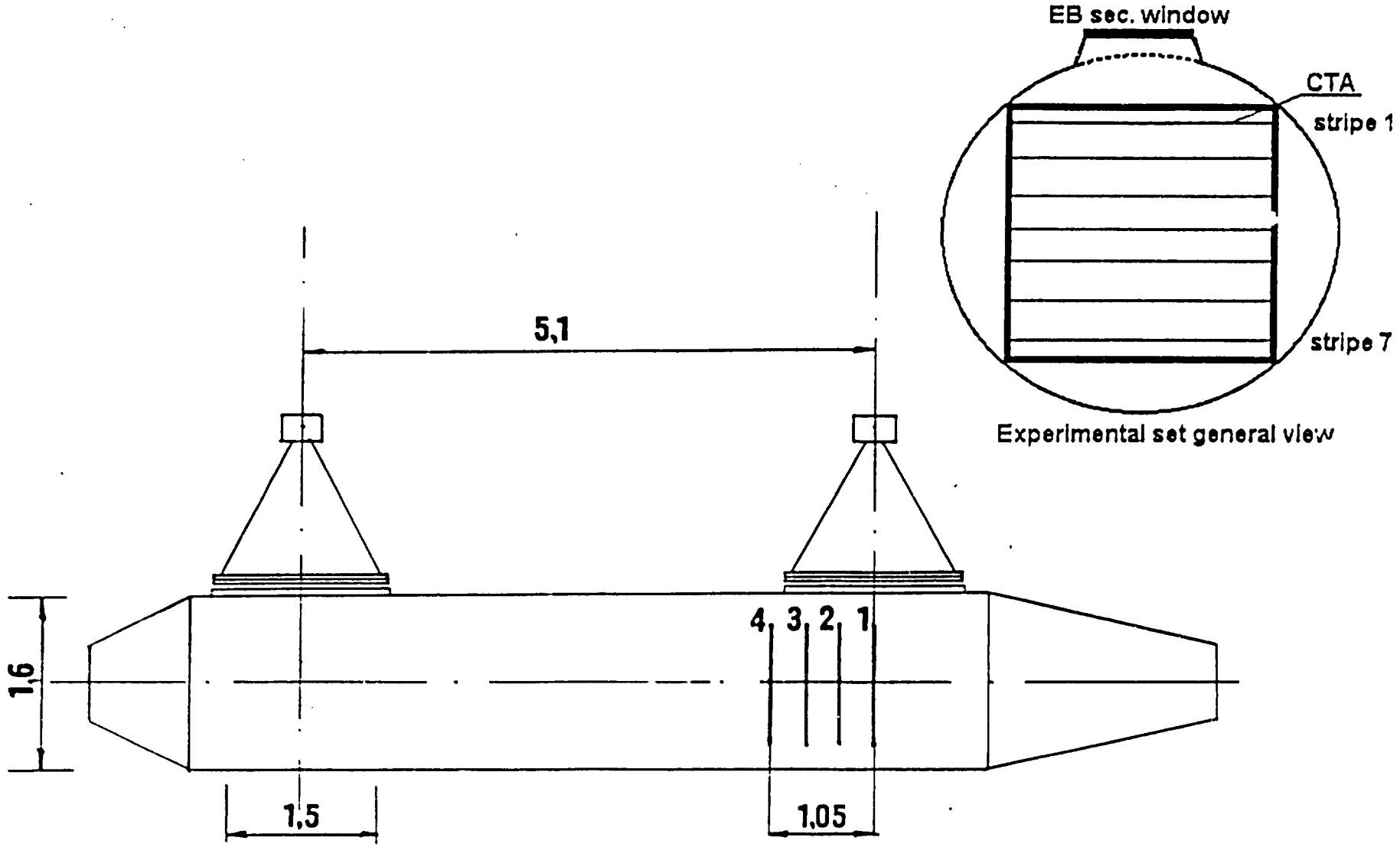


Fig. 1.4. The configuration of dosimetric foil during dose distribution measurements

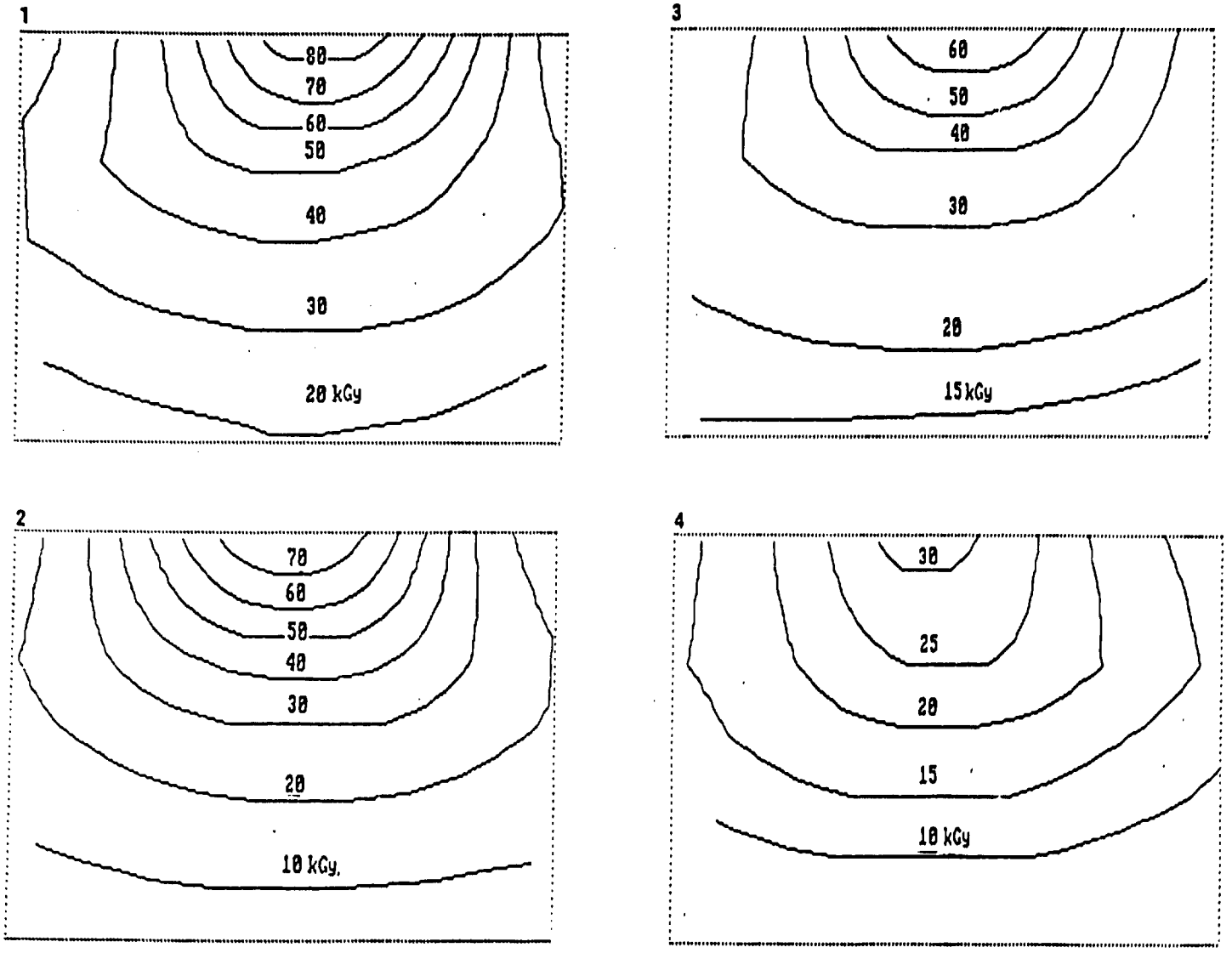
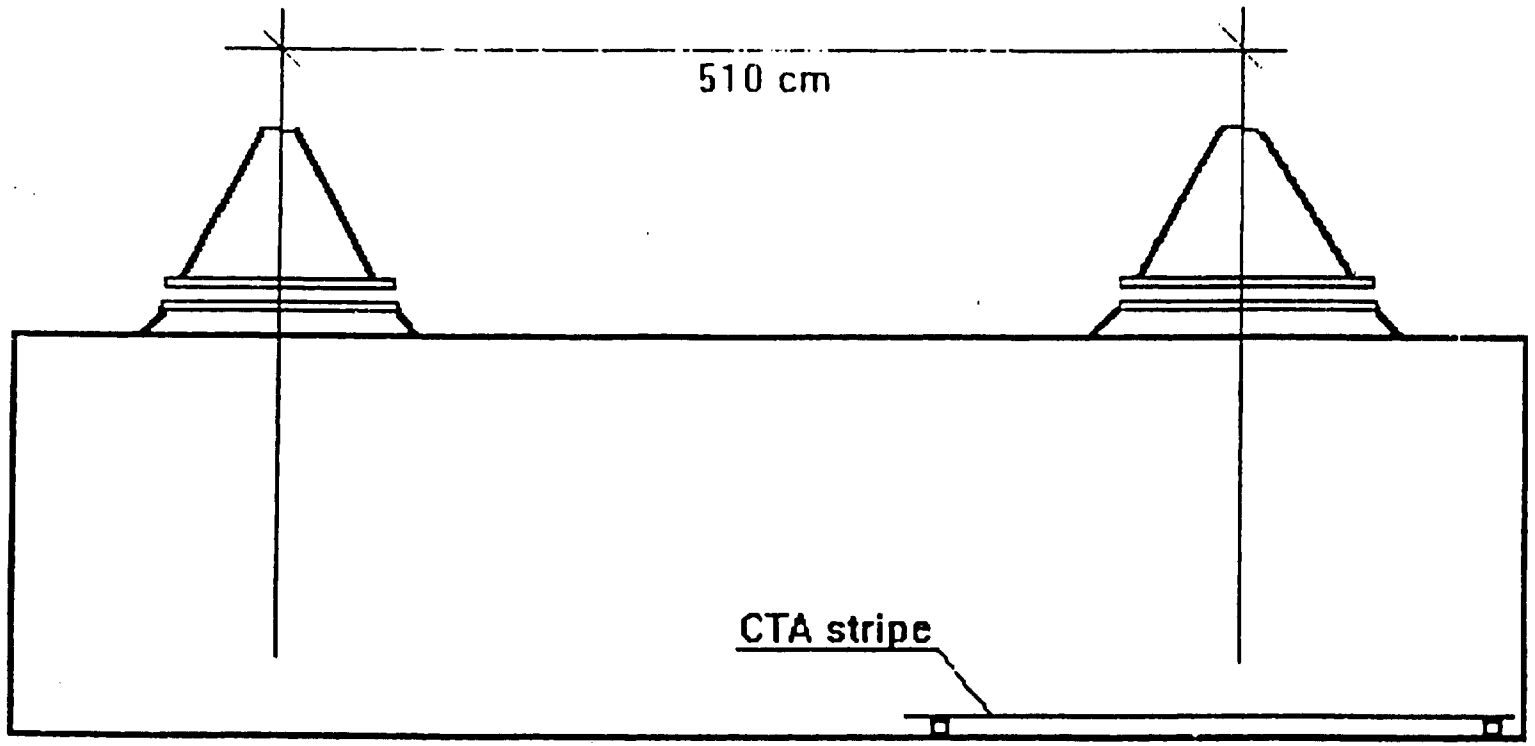


Fig. 15. Spectral dose distribution for different location of metal frame (position 1 to 4; Fig. 1.4.) and electron energy 600 keV



EB energy 700keV
EB curr. 1mA
curr. vs time integr. 2000 mAs

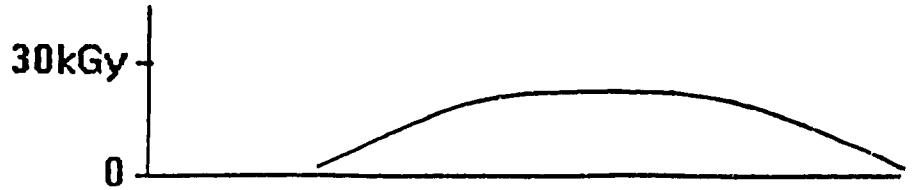


Fig. 1.6. Experiment for determination of dose distribution along the main axis of reaction chamber

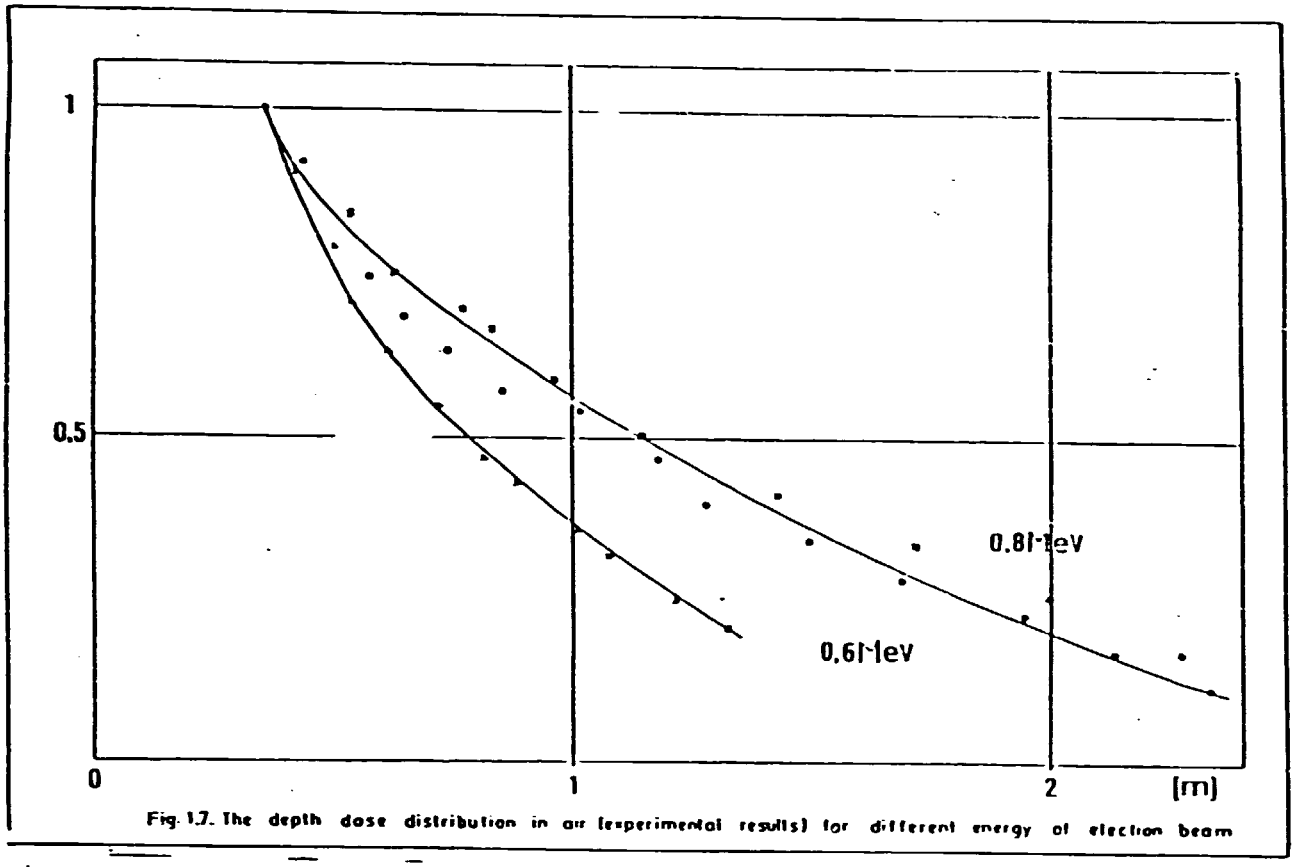


Fig. 1.7. The depth dose distribution in air (experimental results) for different energy of electron beam

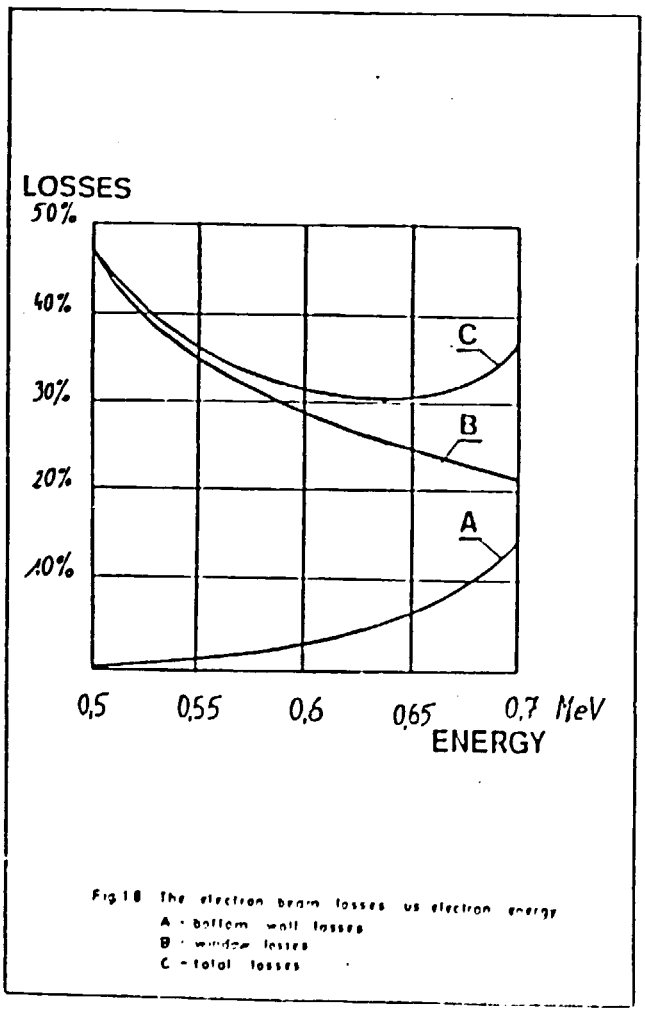


Fig. 1.8 The electron beam losses vs electron energy
A - bottom wall losses
B - window losses
C - total losses

2. SELECTION OF ACCELERATORS.

2.1 Documentation of applicable assumption in accelerator selection.

Technical parameters and application of accelerators to remove SO_2 and NO_X from flue gas are dependent on elements which can be put together in following groups:

a) factors arising from process technology,
b) factors arising from site specific conditions,
c) factors arising from means of operation and maintenance of accelerators.

Factors dependent on process parameters are:
- accelerator's beam power,
- accelerator's beam energy.

These two basic technical parameters are derived from technological assumptions for installation to remove SO_2 and NO_X from the flue gas. Technological assumptions for installation determine:
- volumetric flow rate of the cleaned gas,
- reduction ratio of SO_2 and NO_X
- chemical composition of the flue gas.

Factors dependent on the site specific conditions are:
- accelerator's configuration (vertical or horizontal),
- method of leading out the beam,
- length of beam's scan,
- parameters of cooperating systems (generators, pumps, tube dimensions, electrical supply systems)
- method of connecting accelerator's units
- weight of units
- cooling method (oil or SF_6)

If installation is at an existing power station (heating or power station) above listed factors may be critical for choice of accelerator because they are basic to application of the accelerator unit. They do not have basic sigificance for application in the newly designed power station.

Factors tied to the influence of the method of operation and maintenance of accelerators are:
- method of accelerator control,
- method of accelerator regulation,
- systems durability,
- durability of the foil of the accelerator window,
- warranty of failure-free operation,
- method of assembly and disassembly of accelerator,
- ease of maintenance,
- ease of service.

Listed factors are important for accelerator operation and may be crucial in the minds of installation operators as well as technical and service personnel.

2.2. Technical characteristics of selected accelerators (availability for purchase and application).

2.2.1. Assumptions for potential accelerators deliverers.

Choice of accelerator in application of SO_2 and NO_x removal technology will be dependent on below listed technical parameters. Firms competing for supply of the accelerator should include in offers:

a) for basic parameters relating to the beam:

- accelerator power,
- beam energy,
- configuration of the unit,
- method of leading out the beam,
- beam's current,
- length of scan,
- accelerator's efficiency,
- material and thickness of foil for the accelerator window.

b) for cooperating systems:

- type of power supply units,
- transformers,
- supply units,
- vacuum pumps,
- control panels.

c) for design arrangements:

- overall dimensions of units (length, width, height),

d) for utility requirements:

- power supply per unit,
- total installed power,
- amount of cooling water,
- type and amount of water consumed (raw, distilled, demineralized),
- temperature of water,
- type of cooling system (open, closed).

e) for supply isolation system:

- isolating agent (SF_6 - oil),
- method of isolation and de-isolation in the emergency situation,
- if oil isolation is applied - technical parameters and chemical composition of oil, (operation and ignition temperature, evaporation ratio, protection).

f) for assembly and operation:

- requirements for installation,
- requirements for assembly,
- requirements for adjustment and positioning,
- failure-free operation.

g) for accelerator maintenance:

- method of control and adjustment of the beam,
- frequency of window replacement,
- required qualification of staff following from device construction.
- reliability

h) the cost of investment

- cost of the accelerator
- spare parts cost (cost of exploitation)
- warranty and conditions of delivery

Technical data for diverse accelerators is shown in Table 1.

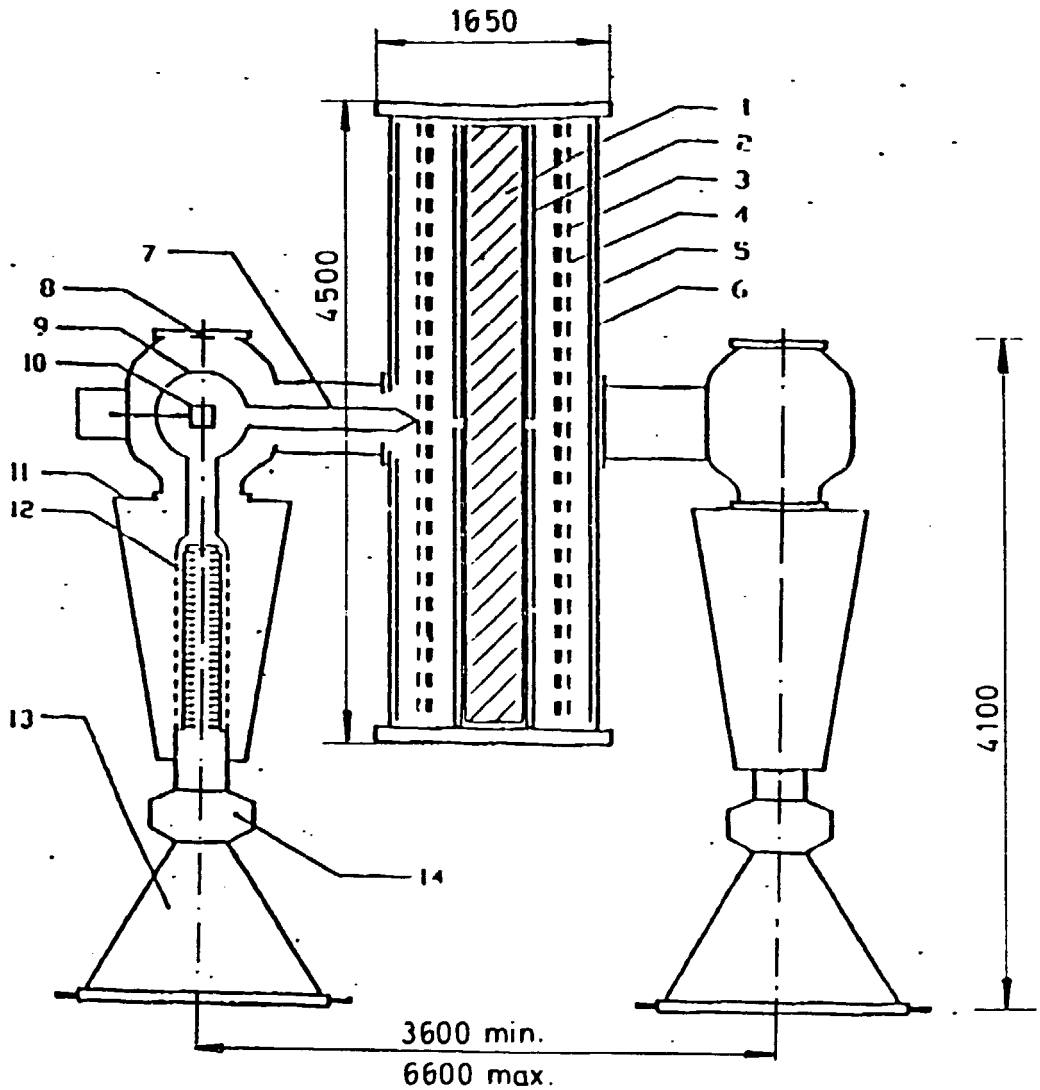
Technical characteristics of accelerators selected for EB technology are presented in fig. 2.1, 2.2., 2.3., 2.4., 2.5.

Comparison of characteristic parameters of accelerators is shown in fig. 2.6.

For the EPS Pomorzany siting of accelerators is presented - fig. 2.7., 2.8., 2.9. and 2.10.

TABLE 1. COMPARISON OF ACCELERATOR TECHNICAL PARAMETERS

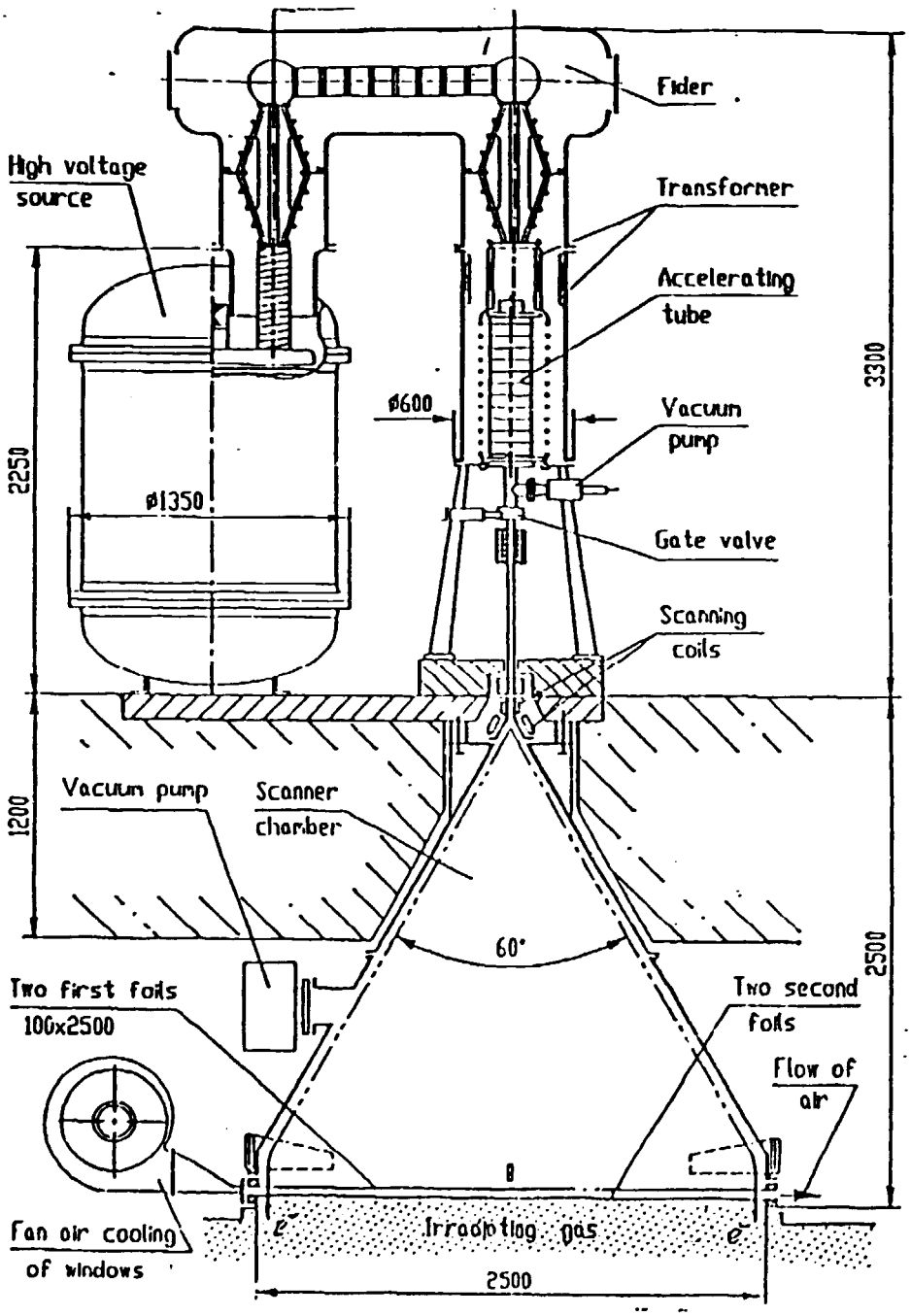
No	Parameter	Unit	RUSSIA			JAPAN	
			ELV	ISE-300	AURORA	NISSIN	NISSIN
1	2	3	4	5	6	7	8
1	Accelerating voltage	kV	1000	1000	1000	1000	800
2	Accelerating voltage instability	%	~±5	±5	<±5	±2	±2
3	Number of accelerating heads		8	4	4	4	4
4	Position of accelerating heads		vert	vert.	vert.	vert.	vert.
5	Number of power supply systems		4	4	2	2	2
6	Maximum beam power	kW	8x150	4x300	4x300	4x300	4x300
7	Maximum beam current	mA	8x150	4x300	4x300	4x300	4x375
8	Electron beam instability	%	<±5	±5	<±3	±2	±2
9	Length of scan	mm	1600	2500	2000	1800	2250
10	Maximum scan angle	°	60	60	46	60	60
11	Surface dose uniformity	%	<±10	±10	<±10	±5	±5
12	AC power supply	kW	3x6.0	3x6.0	3x6.0	3x6.0	3x6.0
13	Accelerator efficiency	%	>80%	>82%	>80%	>90%	>90%
14	Window material		Ti	Ti	Al	Ti	Ti
15	Power supply isolation		SF_6	SF	SF_6	oil	oil
16	Cooling system		air	air	water	air	air
17	Time of equivalent full load	h/year	6500	6500	6500	6500	6500



ELV, BINP - Russia

Fig. 2.1. Main dimensions of accelerator

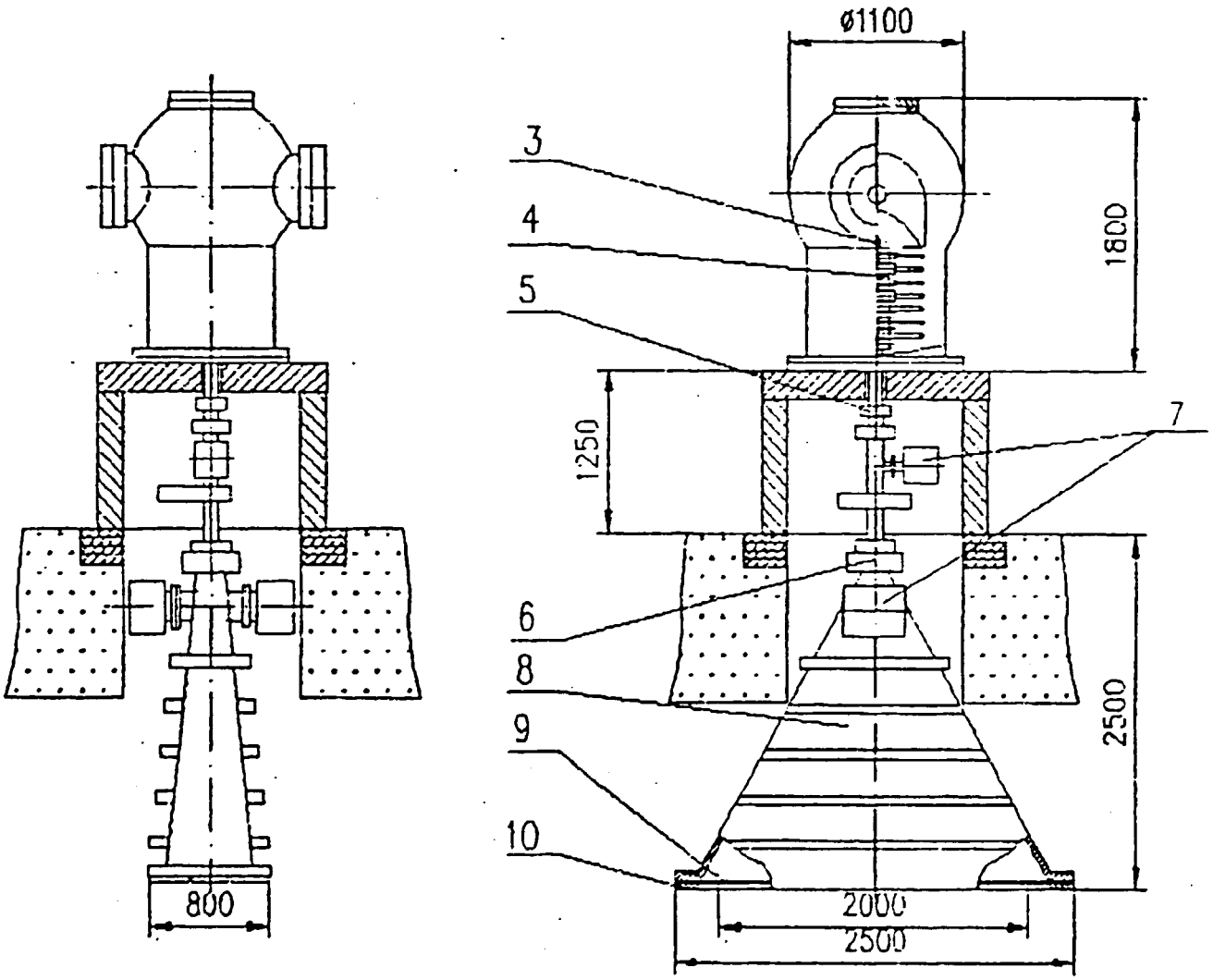
proatom



ISE -300, BINP -RUSSIA

Fig. 2.2. Scheme of accelerator

proatom



AURORA , EFREMOV,SRIE - Russia

Fig. 2.3. Main dimensions of accelerator

proatom

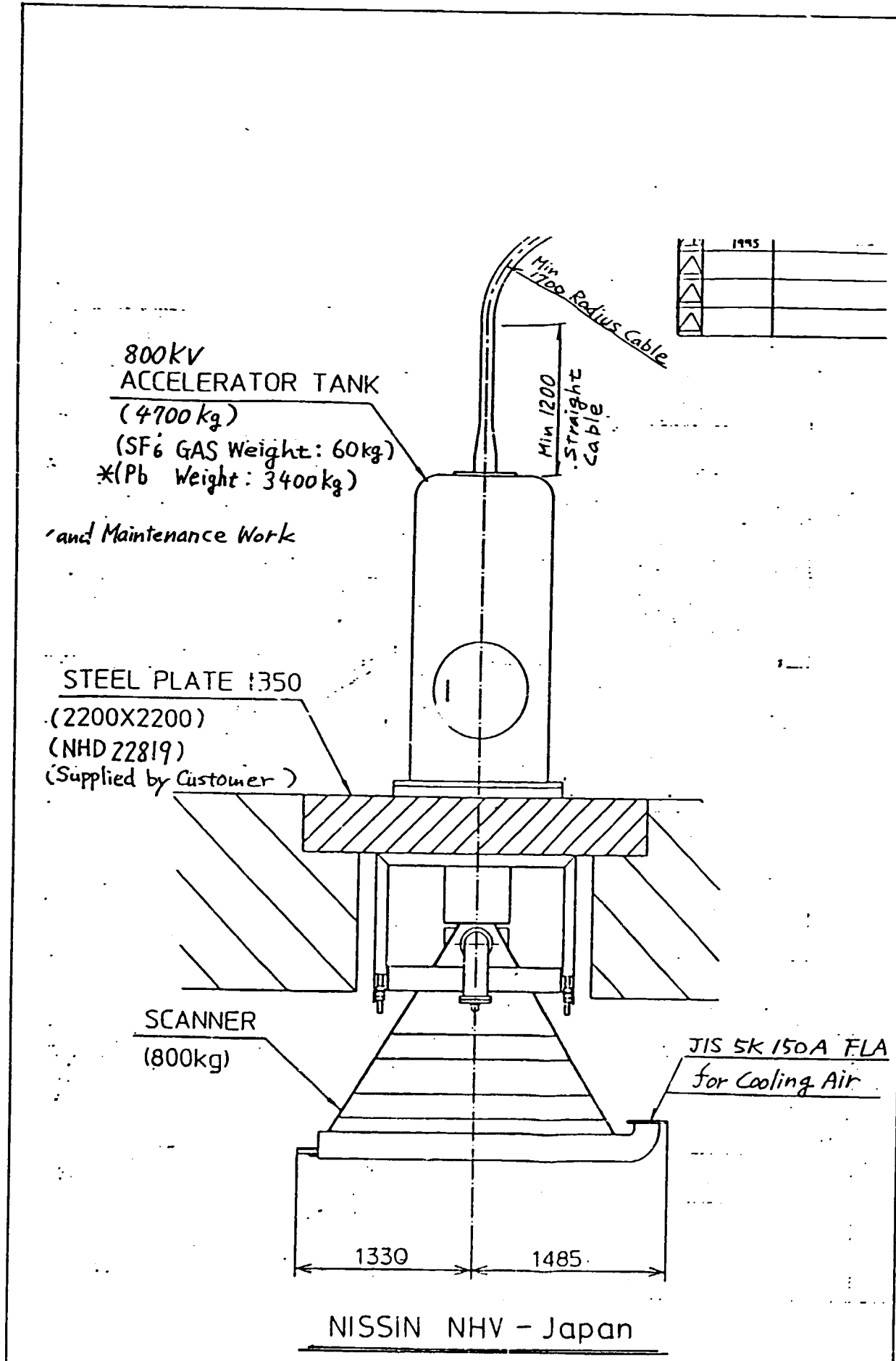
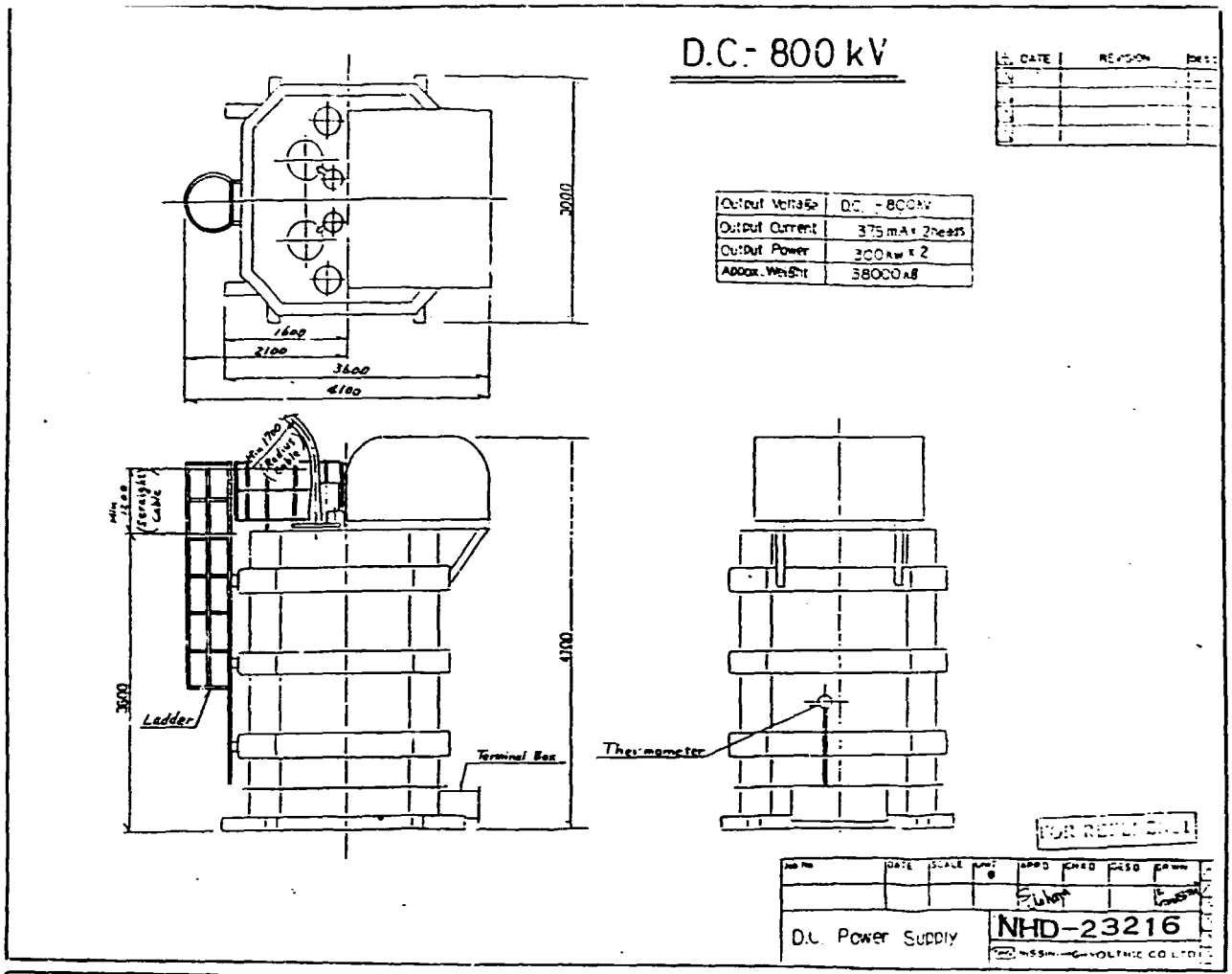


Fig. 2.4. Scheme of accelerator

proatom



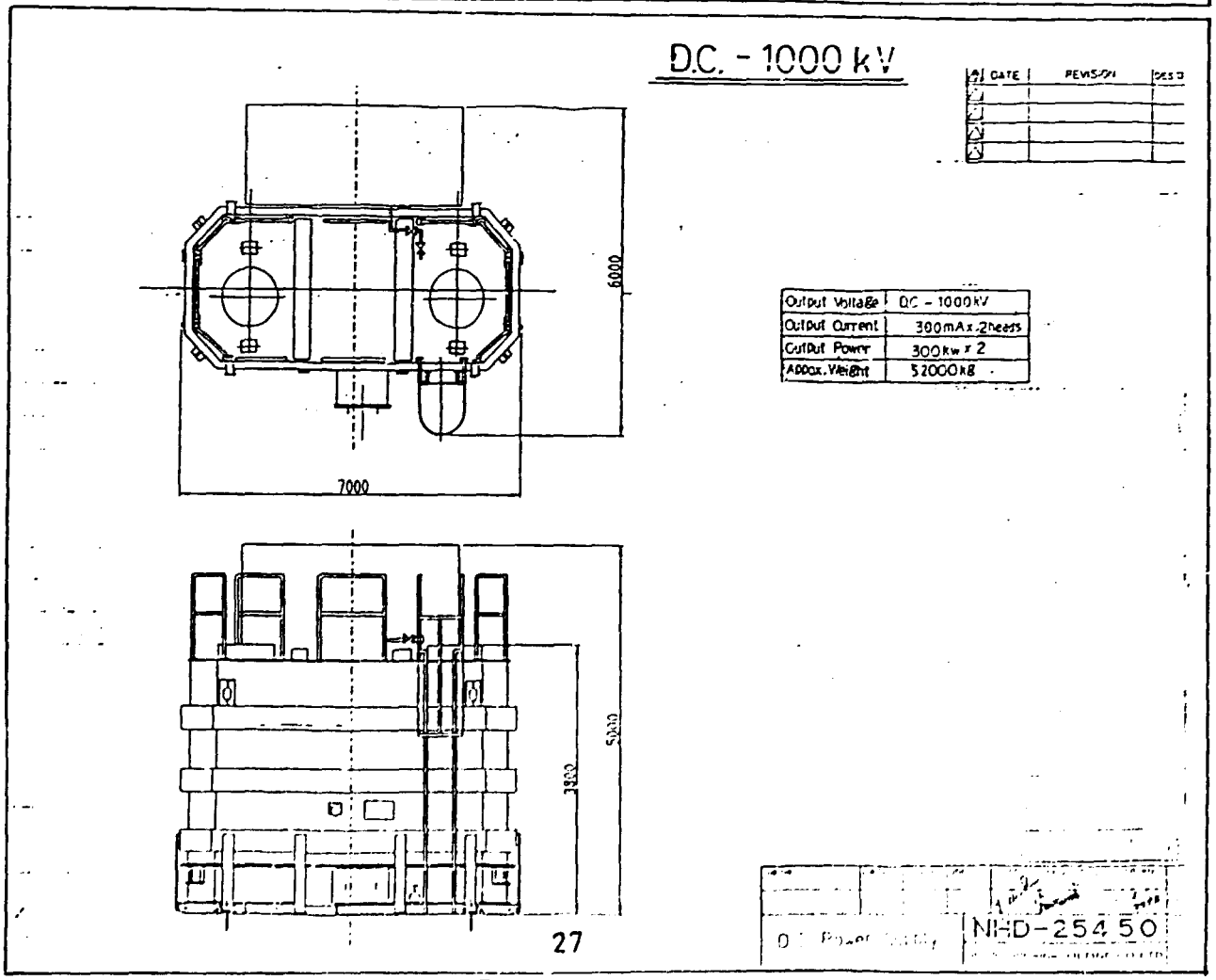
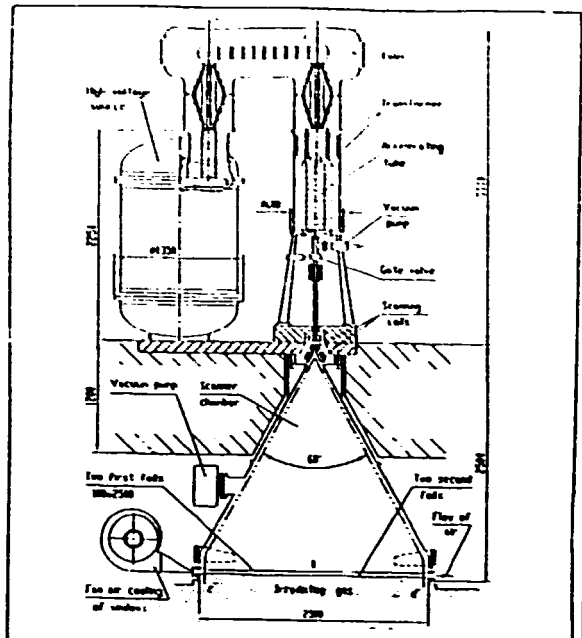
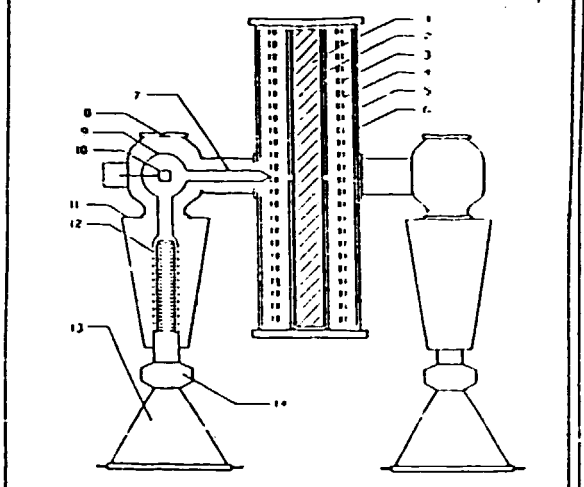


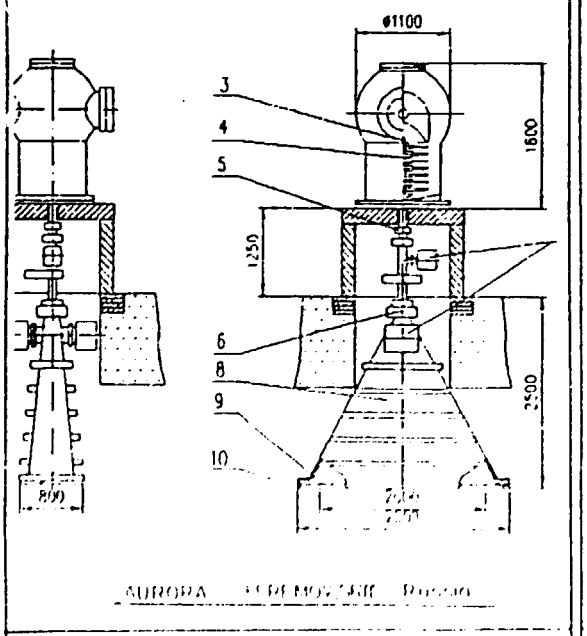
Fig. 2.5. Power supply



ISE -300, BINP -RUSSIA

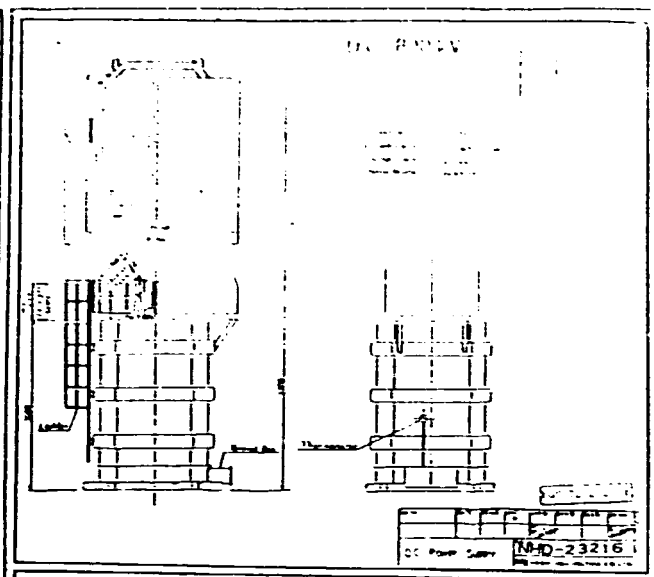


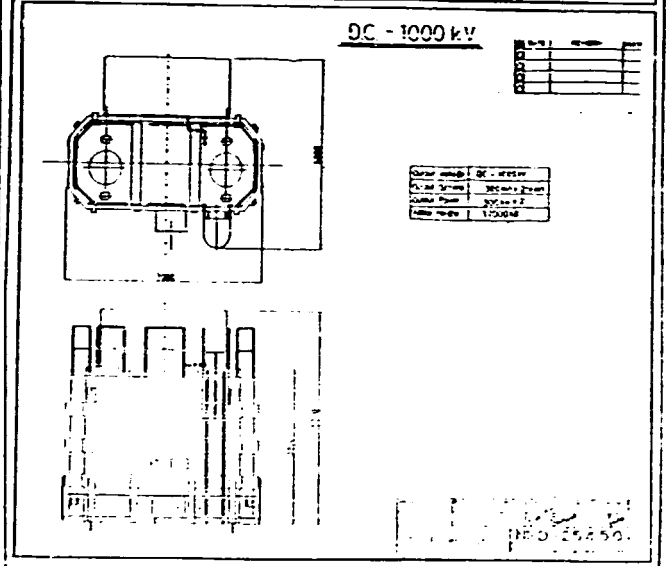
ELV, BINP - Russia

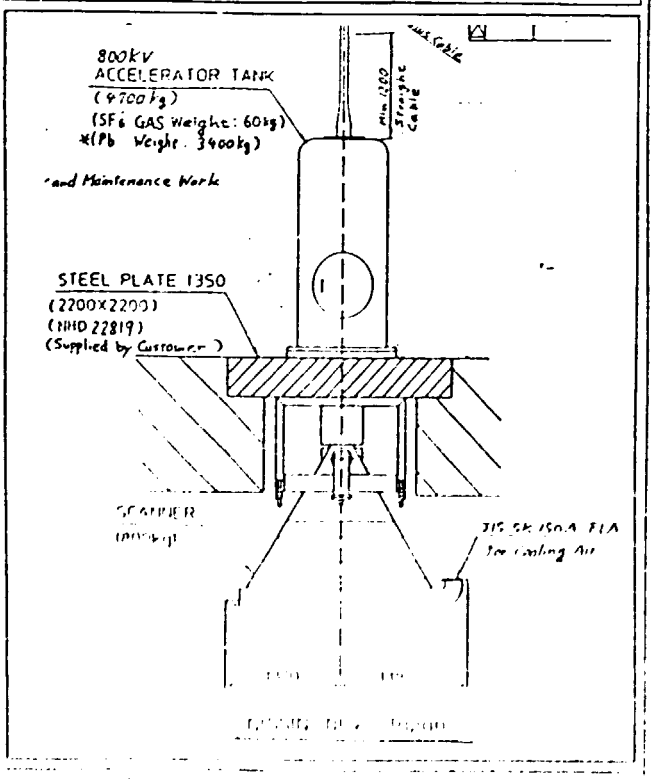


AURORA

RUSSIA - accelerators







JAPAN - accelerators

Fig. 2.6. Comparison of accelerators

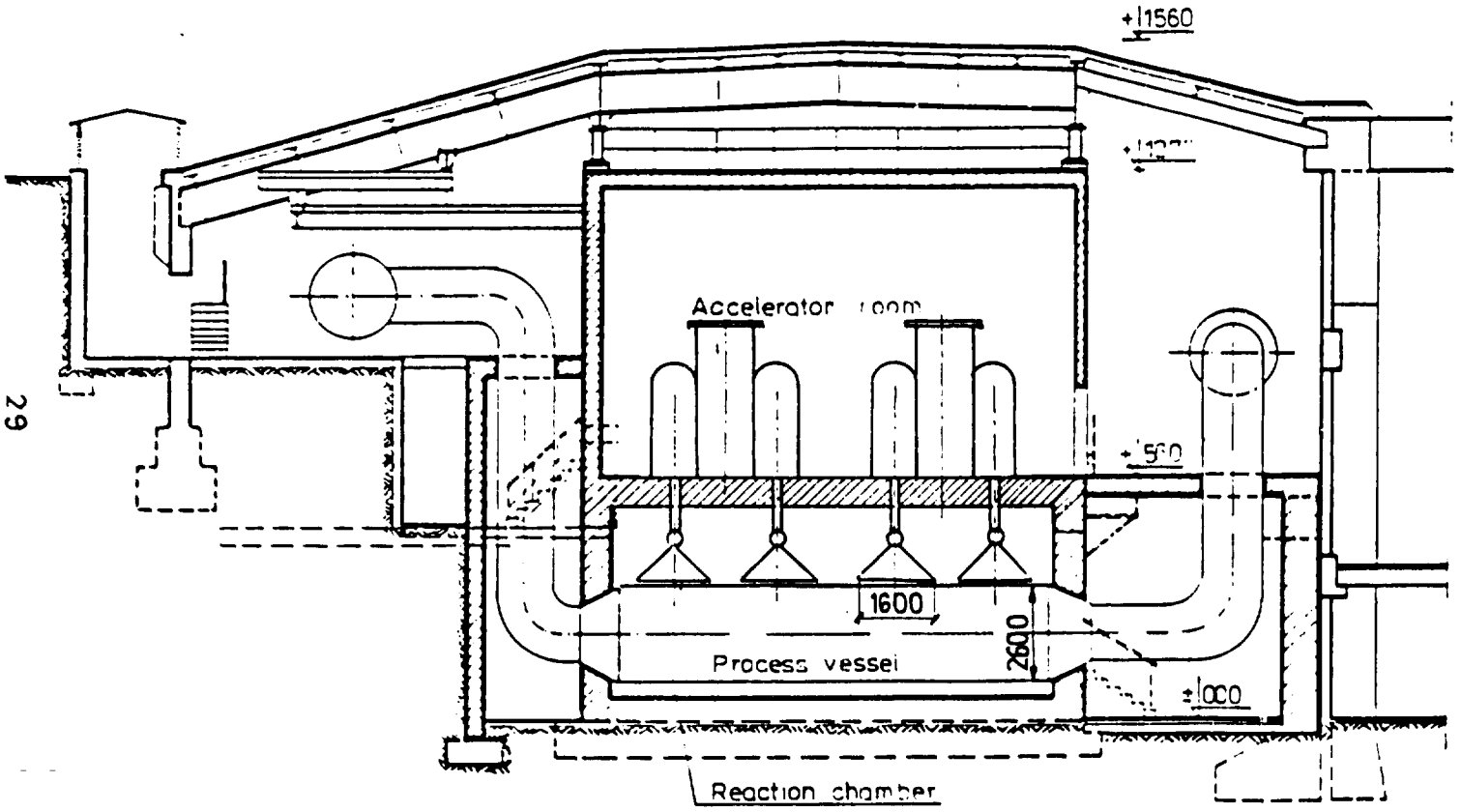


FIG. 2.7. ACCELERATOR ELV, BINP - RUSSIA

„ POMORZANY" POWER STATION

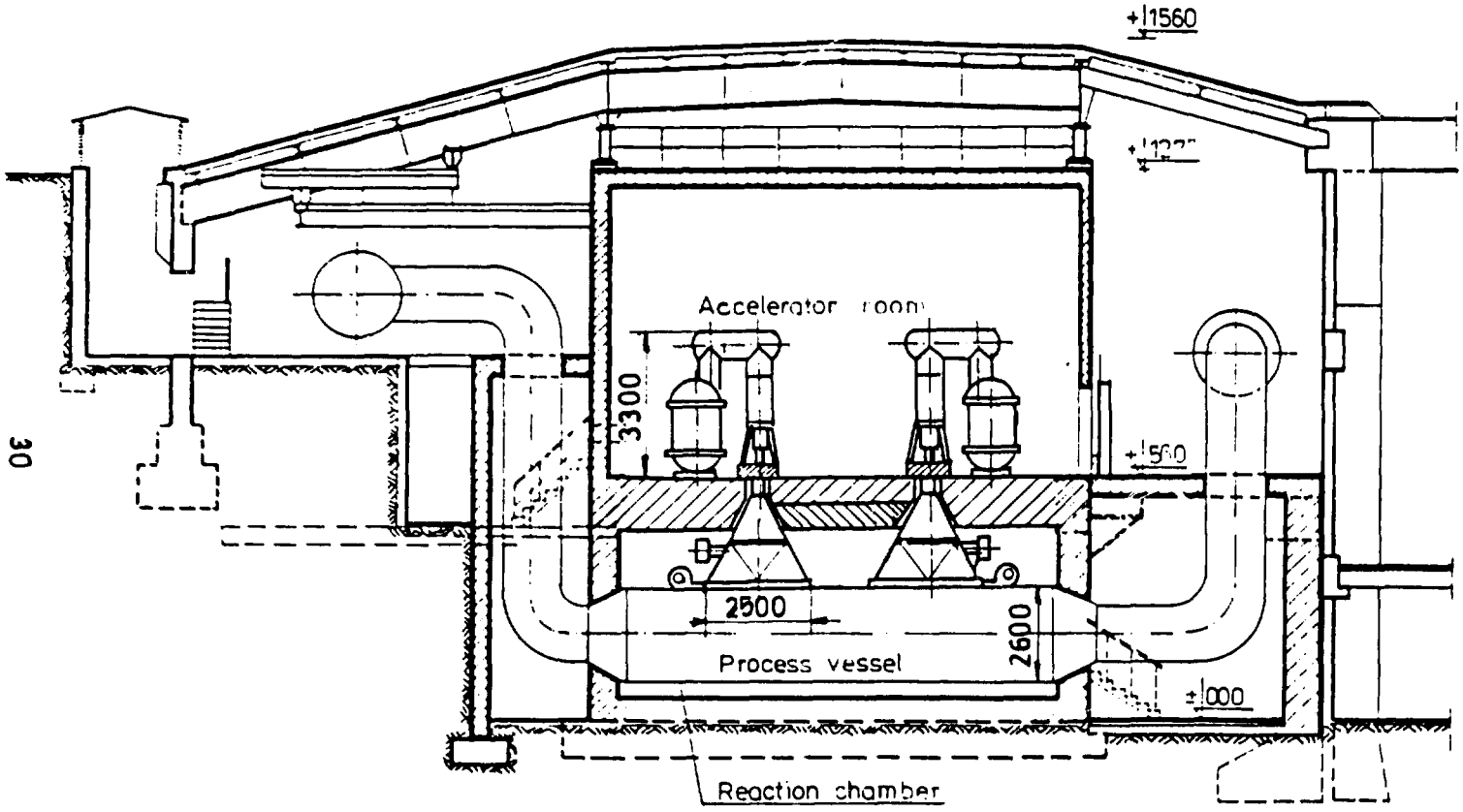


FIG. 2.8. ACCELERATOR ISE-300 , BINP-RUSSIA

proatom

„ POMORZANY" POWER STATION

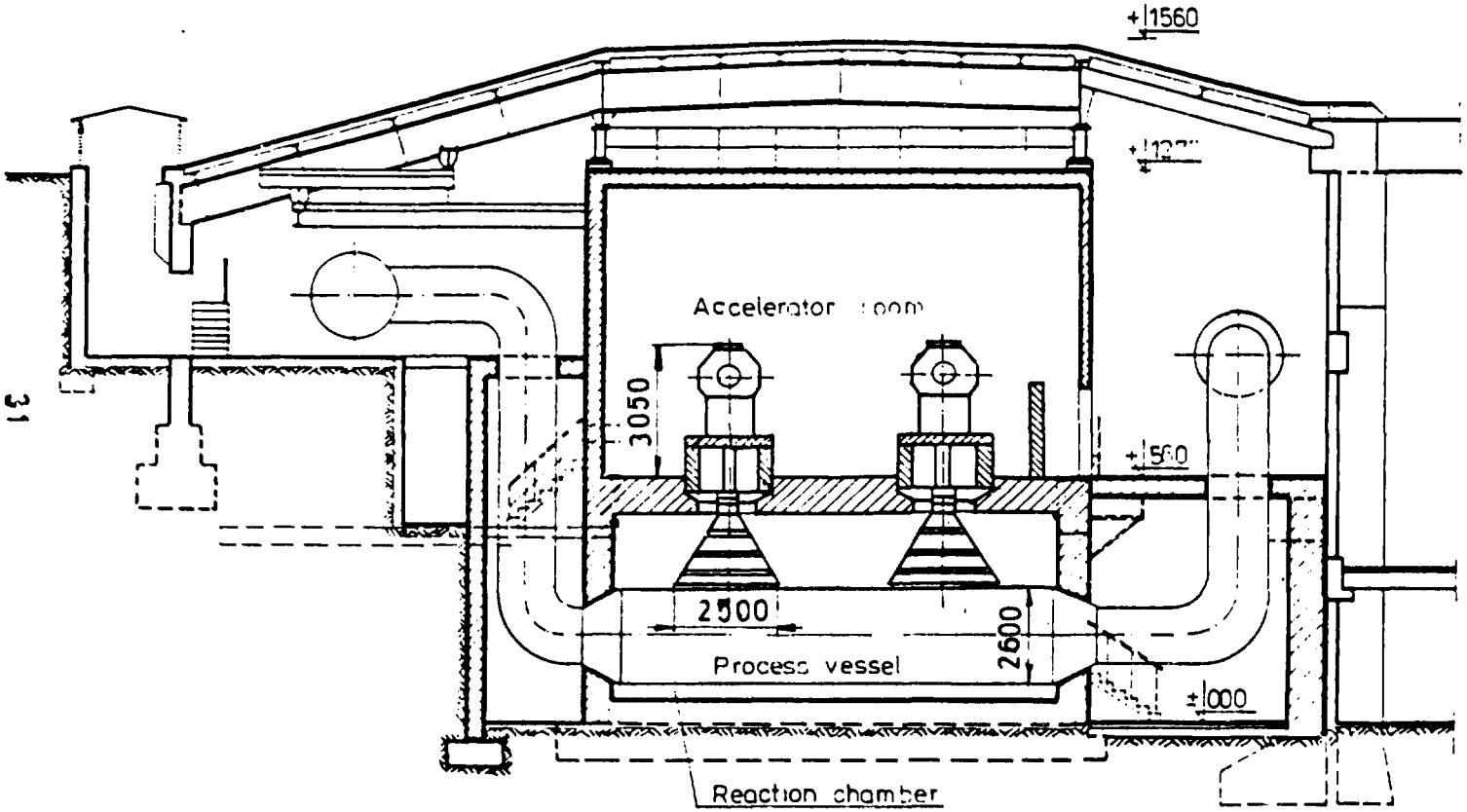


FIG. 2.9. ACCELERATOR AURORA , EFREMOV , RUSSIA

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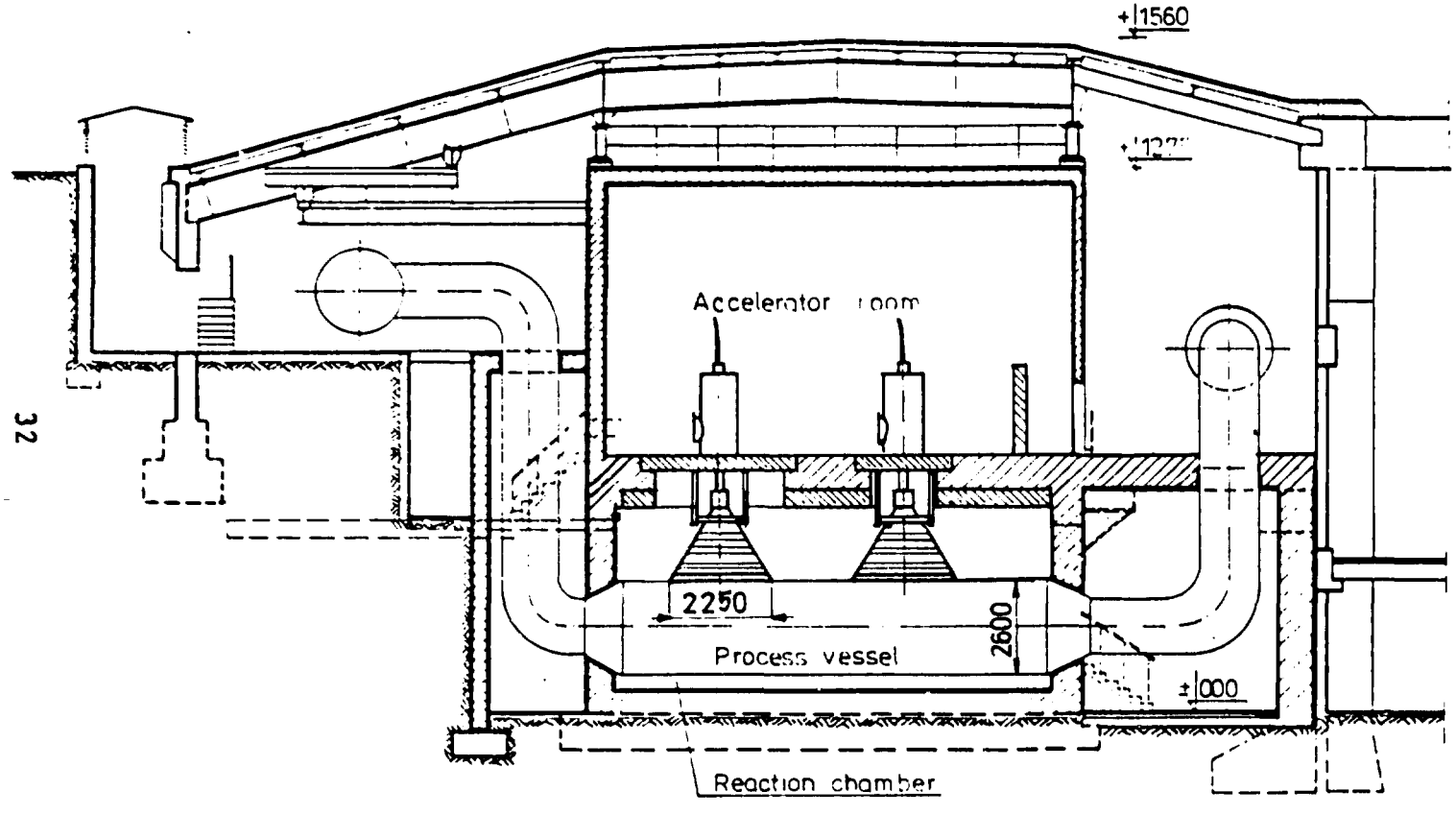

FIG. 2.10. ACCELERATOR NISSIN - High Voltage, JAPAN

proatom

3. TECHNICAL DOCUMENTATION FOR BE (basic engineering) OF THE REACTION CHAMBER TO SUPPORT DETAILED ENGINEERING DESIGN.

3.1. Selection of the chamber configuration and establishment of its size (diameter and length) as a function of gas density and the electron beam range.

Configuration of the reaction chamber is determined by technological assumptions for installation of SO_2 and NO_X removal from flue gases. Its overall dimensions are dependent on:

- the flow volume of treated gas,
- density of the gas,
- type of accelerator chosen,
- selected method of introducing the volumetric gas stream, (one, two or three pipe flow paths).

Height of the reaction chamber depends mainly on the range of the electron beam. It is assumed that for the chamber's window it's possible to achieve maximum 10% energy losses in use of the electron stream. Length and width of the chamber depends on process technology parameters tied to the design volumetric flow of treated flue gas. They indirectly depend on system design so far as electron beam geometry, length and width of the accelerator window, construction and dimensions of the tube. Depending system arrangement (tube parallel or perpendicular to direction of the gas flow) the reaction chamber can have (in cross-section) the shape of a circle, square or rectangle.

For an assumed amount of gas flow equal to 270.000 Nm^3/h and based on the design method, the reaction chamber can be shaped in two alternative ways:

a) circles of diameter 2.6 m with two paths of gas purification (2 X 135.000 Nm^3/h)
b) rectangle with height 2.6 m and one purification path (1 X 270.000 Nm^3/h).

The size of 2.6 m is related to the electron beam penetration and optimal size regarding energy losses.
Length of the chamber depends on residence time to be provided between the first and second stage of electron beam influence on the gas stream.
Based on gase with characteristics described in fascicle No 1 the maximum distance between axes of the first and second stage of influence will equal 7.0 m.
Length of the reaction chamber with above listed process conditions will be in the range of 9.5 - 11.0 m.
The example of the reaction chamber design is presented in fig.3.1. and 3.2.

3.2. Materials of construction (carbon steel alloy steel with anti corrosive coating, and stainless steel).

Chemical reactions in the reaction chamber and duration of exposure of the camber construction to corroding chemicals define need for materials resistant to long term influence of aggressive compounds. Thus the chamber must be made of durable and non-corroding materials. Materials as alloy steels (stainless or acid resistant steel, for instance 1H18N9T - counterpart of USA-304)

An influencing criteria in material selection for the reaction chamber is cost.

Construction in alloy steel will be the most expensive alternative due to material cost as well as high cost of fabrication of this type of steel.
In choosing carbon steel limited durability (faster corrosion) must be anticipated. The materials decision is dependant on budget.

3.3. Window construction.

The reaction chamber must be equipped with the same number of windows as accelerators installed above it. Construction of the window must be of the same material as used for the reaction chamber. Construction of the window must allow quick foil replacement in the case of damage as well as provide a proper method of fastening foil in the frame to be properly and uniformly stretched.
Design of the second window of the chamber can be carried out after selection of the accelerator's type and familiarization with the construction layout of the accelerator window.

It is important to determine the minimum distance between accelerator window and the reaction chamber. Minimization of this distance is recommended (because of loss of electron energy in the zone between windows). On the basis of currently available publications characterizing construction solutions, minimum distance between windows is in the range 50 - 80 mm. This dictance should not be too high due to ozone production and energy losses of the electron beam. The construction of the output device and necessity of the window air cooling don't allow practically to reduce this distance much below 50 mm. The example of accelerator's and reaction chamber window placement is shown in fig. 3.3.

An important construction requirement in design of the reaction chamber window is isolation of window's foil from contact with solid particlate carried by the flue gas. Phenomenon of carrying solid particles is more intensive when efficiency of electro-filters to remove ash from the flue gas decreases. Avoidance of contact of the gas with the window's foil can be achieved by blowing the gas through the slit beneath the foil of the chamber window. Example of the solution is shown in fig. 3.4.
Blowing air beneath chamber window prevent precipitation of solid particles of reaction product (mixture of ammonium nitrate and ammonium sulfate) on the window's foil.

3.4. Selected method of cleaning the chamber walls of deposits (scrapers, water nozzles, water introduction).

To remove deposits (reaction product) from walls of the reaction chamber periodic washing is to be provided with change of wastewater to a disposal system. The suitable method to store and dispose of those wastes should be installed. To accomplish this task the reaction chamber is to be equipped with holes for rotating water nozzles and drainage system to remove wastewater from the bottom of the chamber.

3.5. Water feed to the reaction chamber to increase gas humidity (selection of a nozzle location).

Water injection to the chamber is used to entrance SO_2 removal. In such case suitable stainless steel reaction chamber should be used to prevent corrosive attack of deposits.

3.6. Determination of thermal expansion compensation in the chamber and piping.

Compensation of the chamber is not necessary because influence of the temperature 65°C is not significant for the chamber construction. Elongation of pipe runs will be compensated in the same manner as in professional power industry (expansion joints).

3.7. Composite drawings (BE) of the reaction chamber with principal dimensions and critical provisions in technical project design.

On BE stage it's possible to determine general assumptions for the construction of the reaction chamber. Overall dimensions and requirements for the reaction chamber are shown in fig. 3.1. and 3.2.

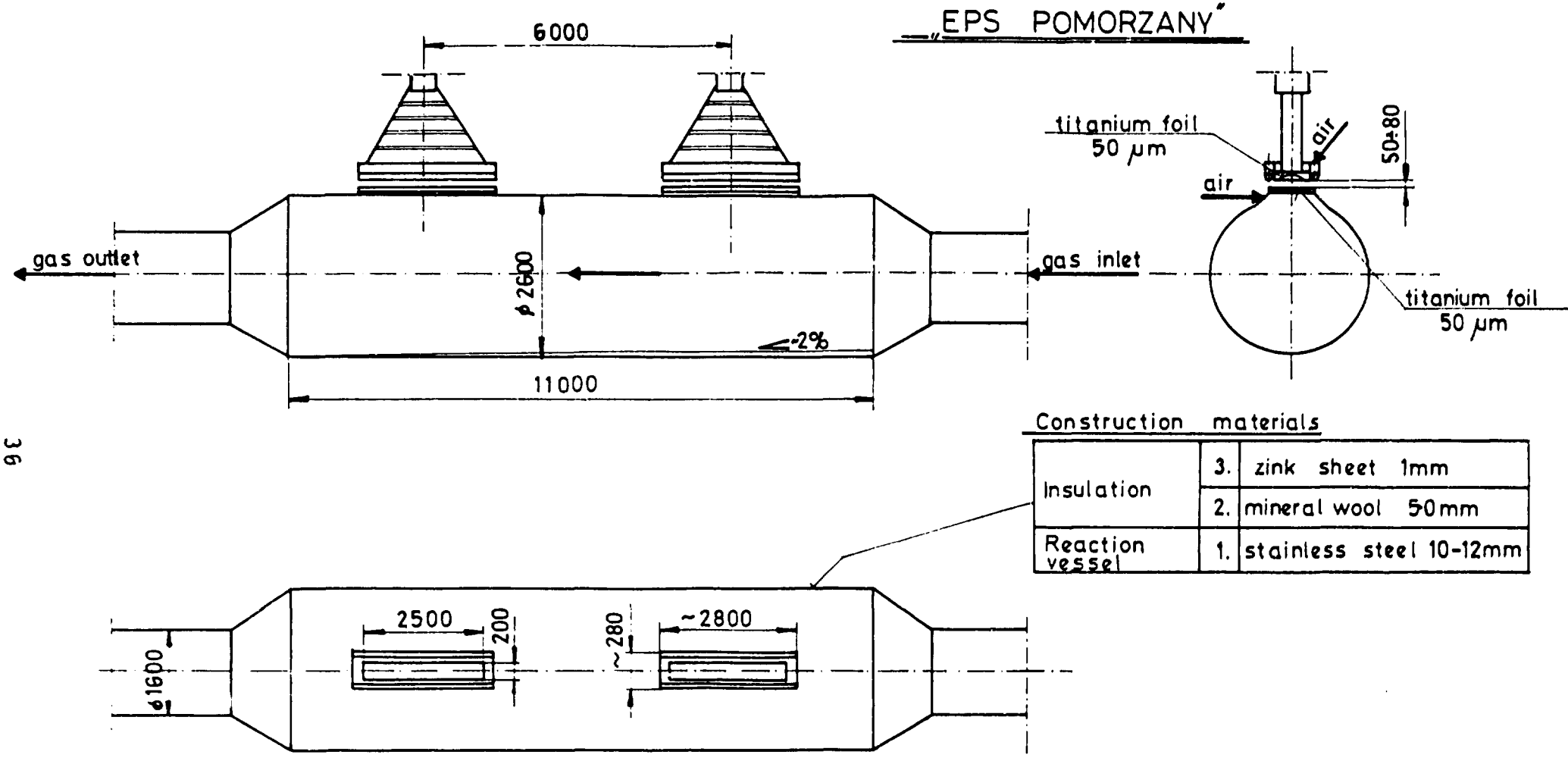

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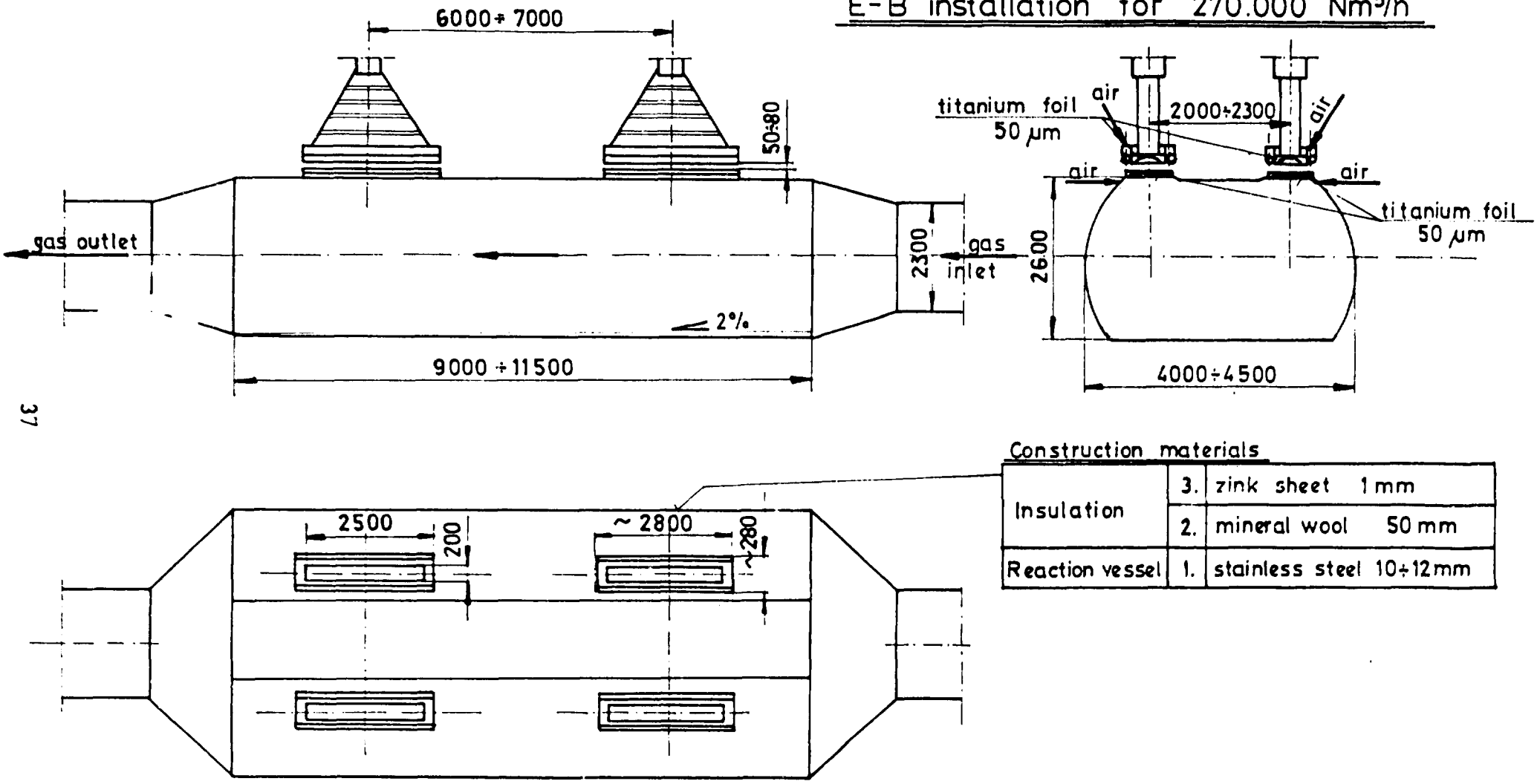
Fig. 3.1. Construction of reaction vessel for 135 000 Nm³/h flue gas

proatom

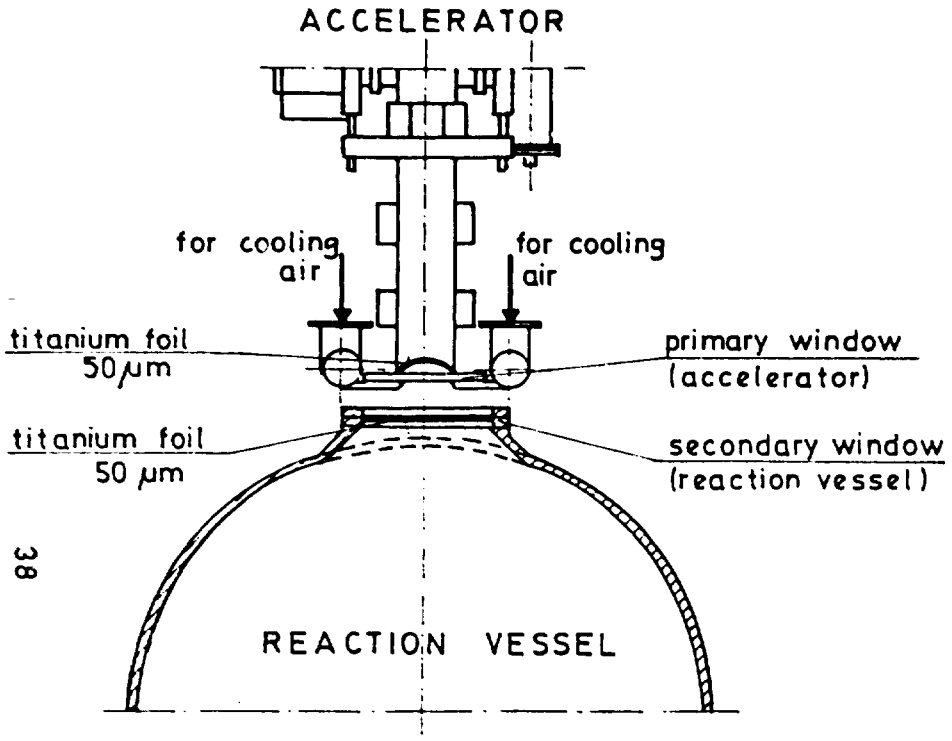


Construction materials

Insulation	3.	zink sheet 1 mm
	2.	mineral wool 50 mm
Reaction vessel	1.	stainless steel 10÷12 mm

Fig.3.2. Construction of reaction vessel for 270 000 Nm³/h flue gas

proatom



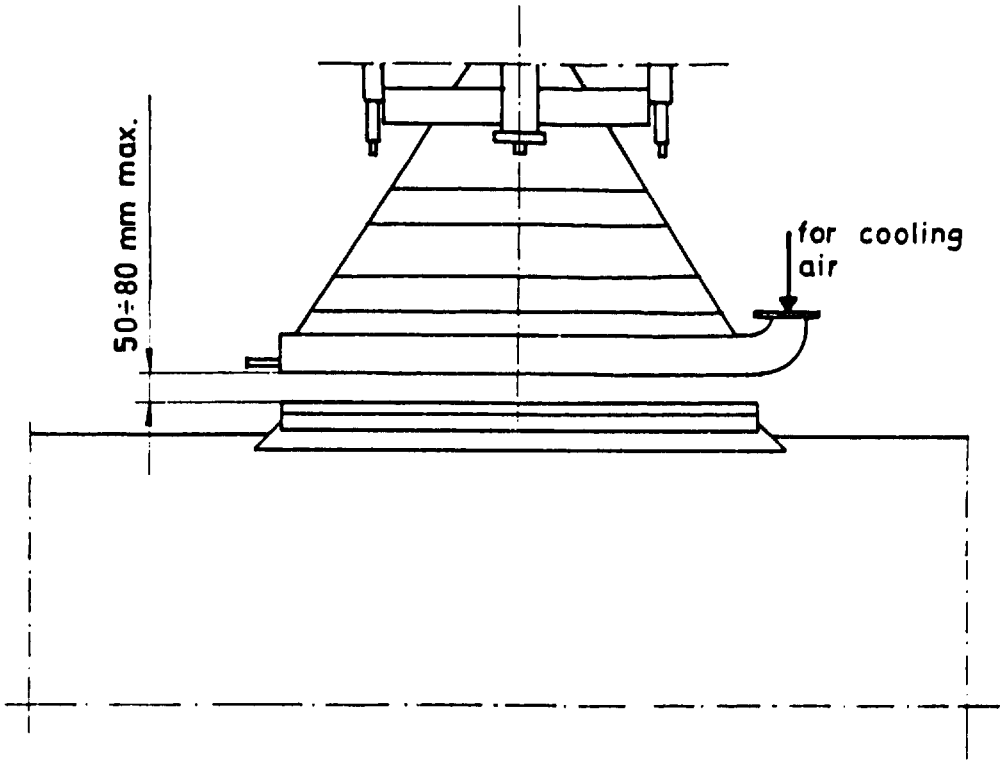


Fig. 3.3. Arrangement of windows

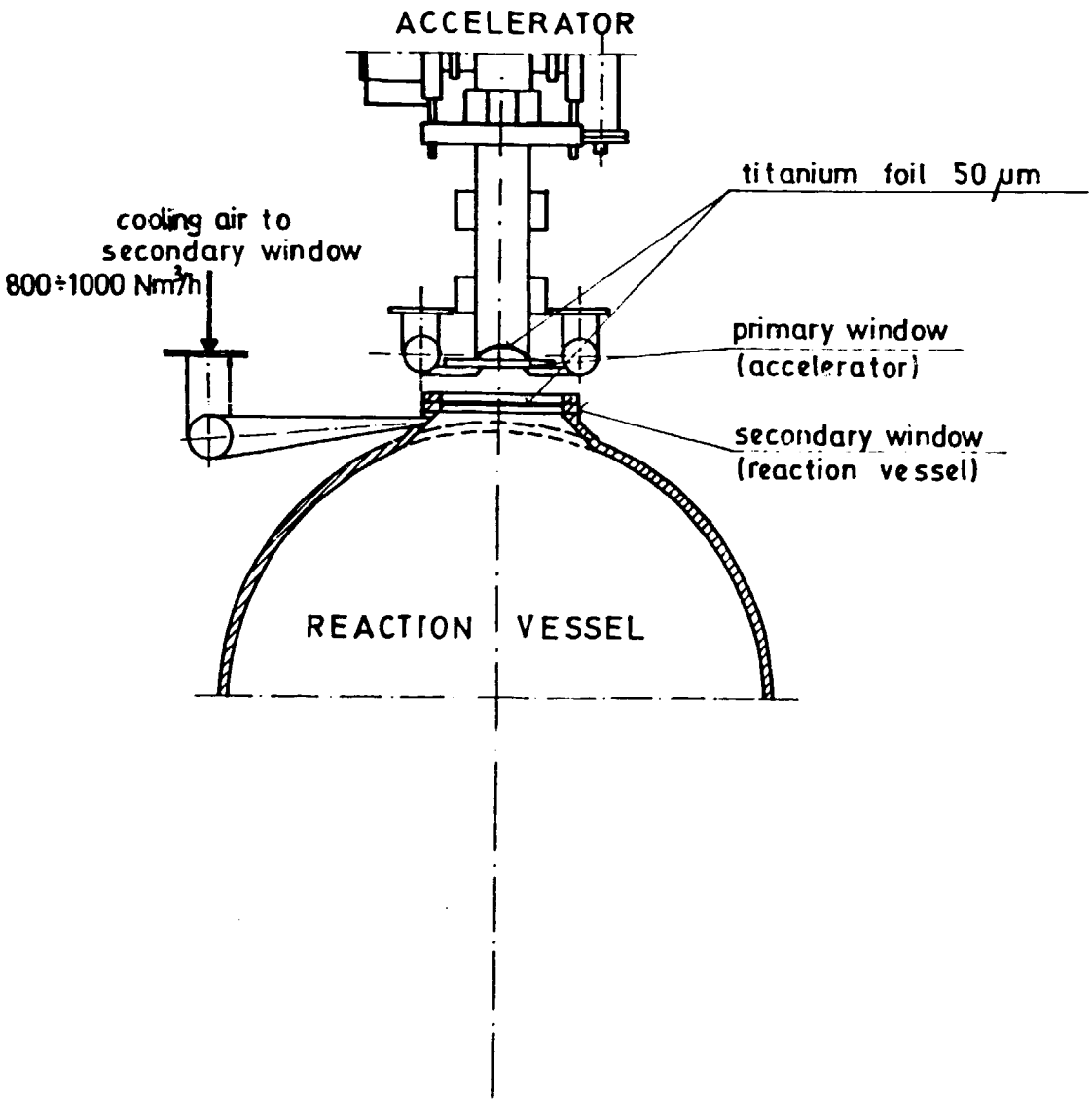


Fig. 3.4 Cooling air system of the secondary window

4. BASIC ENGINEERING OF THE REACTOR BUILDING.

4.1. Selection of ozone removal method:

Ozone originating from air ionization will be removed from the zone between the accelerator window and reaction chamber window. It will be removed by local exhaust fans and ventilators. Depending on local conditions ozone will be evacuated to the atmosphere (stack for ozone) or introduced to the reaction chamber behind second stage of electron influence. The means of ozone removal (schematic) is shown in fig. 4.1.

4.2. Ventilation of the reactor building.

According to regulations and requirements existing in the country for instances in which nuclear techniques are applied it's necessary to design and construct a ventilation system for the following rooms:

- accelerator chamber,
- reaction chamber,
- high voltage generator room.

Ventilation of these rooms must be forced by the mechanical supply - exhaust ventilation system. Amount of air exchange for ventilation of the reaction chamber is equal to 10 - 20 exchanges/hour, for remainig rooms, 6 exchanges/hour, according to radiation protection standards.

4.3. Installation of SF_6 isolating gas.

Installation of SF_6 isolating gas should be characterized in detail by the manufacturer of the accelerators. The manufacturer should supply together with the accelerator the complete system of SF_6 feed and removal assuring that SF_6 will not be released to the atmosphere.

4.4. Accelerator cooling system.

Accelerator systems provided in gas tratment service are equipped with two cooling systems:

- water in a closed system for cooling internal parts of accelerator and tube.
- airbased for blowing air on the accelerator's foil.

Schematic drawing of the accelerator water cooling system is shown in fig. 4.2.

4.5. Selection of generators.

Depending on the specific manufacturer construction requirements may include one of two means of internal isolation of generators:

- oil,
- SF_6.

Choice of specific accelerator in turn fixes the type of generator isolation to be delivered.
Generators filled with oil require additional anti-fire protection.

- hermetic room,
- additional ventilation to remove heat,
- emergency system for dumping of oil in the case of tank leakage.

Schematic drawing of the oil dump system is shown in fig. 4.3.

4.6. Ventilation of high voltage generator rooms.

In high voltage generators room should be installed mechanical supply-exhaust ventilation providing 6 exchanges/hour.

4.7. Ventilation of accelerator rooms.

Accelerator room must be equipped with mechanical supply-exhaust ventilation providing 6 exchanges/hour. Schematic drawing of the ventilation system is shown in fig. 4.4.

4.8. Protection against ionizing irradiation.

Depending on localization of flue gas treatment installation problems concerning the means for protection against ionizing radiation must be detailed individually for each Application. In all site specific instances the requirements of the specific country must be met.
Requirements must be fulfilled concerning:

- radiation shields,
- ventilation systems,
- supply systems,
- signaling and blocking systems,
- alarm systems.

These requirements concerns protection for both operators and other personnel.
Basic laws regulations determining conditions necessary to ensure radiological safety in Poland are:

- Atomic Law - the legal act as amended in 1994.
- Chairman of the Polish Atomic Agency instructions from 1988 concerning estimation of limiting doses.
- Polish standard PN-86/J -80001, Calculations for Permanent Shields.

Also for calculations of thickness of shields for protection against ionizing radiation calculations methodology had been per regulations published in:

- DIN Standard 6847 Teil 2, from 1990.

- NCPR Report No51 - Radiation Protection Design
- Accelerator manufacturer information regarding requirements in protection from radiation resulting from construction of accelerators.

In this text means of solving problems protecting against radiation are presented for Pomorzany Electro-power station. In agreement with those conditioins both trains are independent in sense of radiation pritection what allows to provide necessery service in one train, when the second one is under operation. The details of radiation protection and emergency operation are described in technical project of facility.

4.8.1. Assumptions for shield calculations due to:

a) accelerator operation.

- in each chamber will be installed accelerators with 600 kW power (for instance 2x300 kW)
- accelerators' axes are spaced as far apart as possible in keeping with the length of the reaction chamber and accelerator window.
- operational time of accelerators - 6500 h/year of equivalent full load operation.

b) accelerator maintenance.

- accelerator rooms are accessible only by personnel associated with the flue gas treatment installation
- employees of other departments of the electro-power station (for instance staff of transformer stations) can be present immediately outside of accelerator rooms without danger of exposure to the ionizing radiation.
- during operation of one treatment train the staff can enter (for example to correct accelerator's malfunction) rooms at the level ±0.00 m and +5.50 m of another train (to change titanium foil in accelerator window or titanium foil of the reaction chamber window) without possibility of exposure to the ionizing radiation.

4.8.2. Calculation of shielding walls thickness.

In the phase of "basic engineering" calculations of shields will be performed only for direct radiation and for main directions of imminence. Complete calculations of all shields for direct and diffused radiation will be performed in the technical study after choosing accelerators' type.

In the "basic engineering" were performed calculations of shielding walls thickness for levels ±0.00 m and +5.50 m, and the ceiling between these levels. Preliminary calculations will be carried out assuming application of 800 - 1000 keV, 1200 kW (2 X 2 X 300 kW) accelerators.

According to the estimated calculations to ensure radiological protection of the staff work and fulfilling requirements of radiological protection regulations, existing walls of multi-cyclons chambers should be made thicker up to 40 cm. New walls and the ceiling between levels ±0.00 m and +5.50 m should be made from concrete of thickness 80 cm and density $\rho = 3.2$ g/cm^3. The walls of such a thickness will be made by adding (in appropriate ratio) barite, hematite or magnetite aggregate (ore) to concrete. Estimated required thickness of shielding walls, and preliminary site specific application of local shields is shown at fig. 4.5., 4.6., 4.7., 4.8., 4.9., 4.10.

4.8.3. Types of materials used for shields against ionizing radiation.

Depending on the kind of shield used and the specifics of surface area and cubage requirements the following materials can be used:

- solid brick with density ρ=1.8 g/cm^3
- concrete brick with density ρ=2.3 g/cm^3
- monolithic concrete walls with density ρ=2.35 g/cm^3
- monolithic dense concrete walls with density ρ=3.2 g/cm^3 (admitting barite, hematite, magnetite)
- walls made of lead bricks
- local shields made of lead sheet
- local shields made of steel sheet

To adapt multi-cyclones chambers to meet requirements of accelerators the following shielding material will be used: concrete with density ρ=2.35 g/cm^3, steel plates, lead bricks, (for labyrinths walls) and lead sheet (filling of shielding doors).

4.8.4. Facilities to be supplied to ensure radiological safety.

To ensure radiological safety the following installations will be provided:

- mechanical supply - exhaust ventilation
- mechanical ventilation to remove ozone
- accelerator aerial window cooling system
- reaction chamber window cooling air system
- sound signalling system
- visual signalling system
- mechanical blocking system
- electrical blocking system
- access control system

4.9. Layout of the reaction chamber unit with cooperating installations (parameters and utilities requirements shown).

Schematic drawings of the mode of application of the reaction chamber shown in figs. 4.11. and 4.12.

4.10. Composite drawings (BE) of the reaction chamber unit including arrangements of accelerators, generators and accompanying equipment, to permit detailed engineering design.

Composite drawings of the reaction chamber unit including arrangement of accelerators, generators and accompanying equipment can be prepared after selection of energetic unit and accelerators. For any retrofit installation optimum positioning of each component may be different. Examples of installation layout (reaction chamber and accelerators) are shown in fig. 4.13., 4.14., 4.15., 4.16., 4.17. (to suit site specific conditions at EPS Pomorzany) and in fig. 4.18., 4.19., 4.20. to include additional components (270.000 Nm^3/h).

4.11. Specification of principal non typical and commercially available units.

Reaction chamber unit consists of:

a) accelerators
b) reaction chambers

Accelerators form the group of typical commercially available devices equipped with:

- generator (power supply)
- transformer
- accelerating section
- tube with the window
- control panel
- vacuum pump
- ozone removal unit

Reaction chamber is non typical component, individually tailored. Its dimensions depend on assumed flue gas treatment parameters. The chamber consists of the reaction part and the window with titanium foil. For Pomorzany Electro Power Station the chamber's diameter equals 2.6 m, and the length of the window is 2.25 m. In the chamber two windows with titanium foil will be installed. The ballance of devices dedicated to the reaction chamber includes:

a) among typical devices:
- inlet ventilation fans
- outlet ventilation fans
- water pumps of the primary circulation path
- water pumps of the secondary circulation path
- heat recuperators
- ventilation coolers (for the secondary water circulation path).

b) among non typical devices:
- tanks for demineralized water
- tanks for raw water
- piping supplying flue gas
- piping evacuating flue gas

4.12. Choice of construction materials.

Materials of construction of the accelerator are chosen by the manufacturer. The reaction chamber must be made of stainless steel. (for. example 1H18N95). For the chamber's window titanium foil of 50 μm thickness will be used.

Devices of water cooling system (primary and secondary circulation path) will be fabricated of carbon steel, suitably protected against corrosion.

4.13. Protection against corrosion.

The reaction chamber and accelerators don't require any specific means of protection against corrosion. Such protection is necessary for piping for the ventilation system and ozone removal as well as for water tanks (demineralized and raw water) They will be protected by primer paint coated with chlorinated rubber enamel.

4.14. Estimation of media sources.

Accelerators will be supplied from within the EPS (6kV and 400 V systems)
Depending on accelerator's producer requirements demineralized water system should be applied. Demineralized water will circulate in a closed system. Similarly, secondary circulation water will be supplied with makeup from the EPS water system to match evaporation loss and the amount purged.

4.15. Assumptions for branch designs.

a) In the building part it's necessary to:

- build shielding walls of concrete with density 2.3 and 3.2 g/cm^{3}to protect against ionizing radiation. Thickness of the walls is estimated in Fig. 4.5. - 4.10. Based on assumptions made in their thickness calculation discussed in section 4.8 the walls meet requirements and conditions for radiological protection.
- build auxilliary rooms for accelerator system and radiation chamber such as: control room, the room for supply and exhaust ventilation systems, room for accelerators water cooling system, generator room meeting requirements for anti - fire protection, transformer station for accelerator supply system and auxiliary devices.

b) electrical installation

Schedule of required power for devices of the accelerator system and reaction chamber for 6 kV and 0.4 kV supply sources separately is shown in Table 2.

c) connections of external supply systems

- electrical supply will be provided from rooms No 11 and 13 in Fig. 4.14. Detailed layout of systems interconnections will be shown in technical designs. Scheme of electrical supply is shown in Fig. 4.21.
- cooling water supply encompasses two systems: primary using demineralized water and secondary using raw water. Scheme of the water cooling systems is shown in Fig. 4.2. Water for secondary circulation system will be supplied by existing EPS water circuit.

d) Assumptions for monitoring and automatic control and for data acquisition design.

Detailed description of monitoring, automatic control and data acquisition systems is discussed in fascicle No 8 of the study. In the accelerators control system requirements and recommendations of the manufacturer must be fulfilled. General control, signalling and blocking system match radiological protection regulations of the specific country.

The system consists of:

- automatics of opening and closing of shielding doors ,
- automatics of turning on and off ventilation ,
- audible signalling of turning on of accelerators,
- visual signalling of turning on of accelerators ,
- signalling of blocking of operation of shielding doors.

Table 2.

Group of receivers	Installed power	Coefficient			Calculated power		
		kz	cos φ	tgφ	P kW	Q kVar	S kVA
1	2	3	4	5	6	7	8
6 kV receivers Accelerators 2 sets	1334	0.8	0.8	1	1067	800	1334
0.4 kV receivers							
Auxiliary devices of accelerators	356.4	0.8	0.8	0.75	285.0	214.0	356.4
Ventilation and pumps	148.0	0.7	0.8	0.75	104.0	78.0	130.0
Lights	10.0	0.8	0.95	0.33	8.0	2.6	8.4
Total on 0.4 kV	514.4				379	295	494
Total	**1848.4**	**0.8**	**0.8**	**1**	**1464**	**1095**	**1828**

One has calculated that installation of flue gas purification is characterized by the following parameters:

Installed power supply 6 kV -1134.0 kW
Calculated power supply 6 kV -1067.0 kW
Installed power supply 0.4 kW -514.0 kW
Calculated power supply 0.4 kW -397.0 kW

Total power on 0.4 and 6 kV

Installed power -1648.0 kW
Calculated power -1464.0 kW

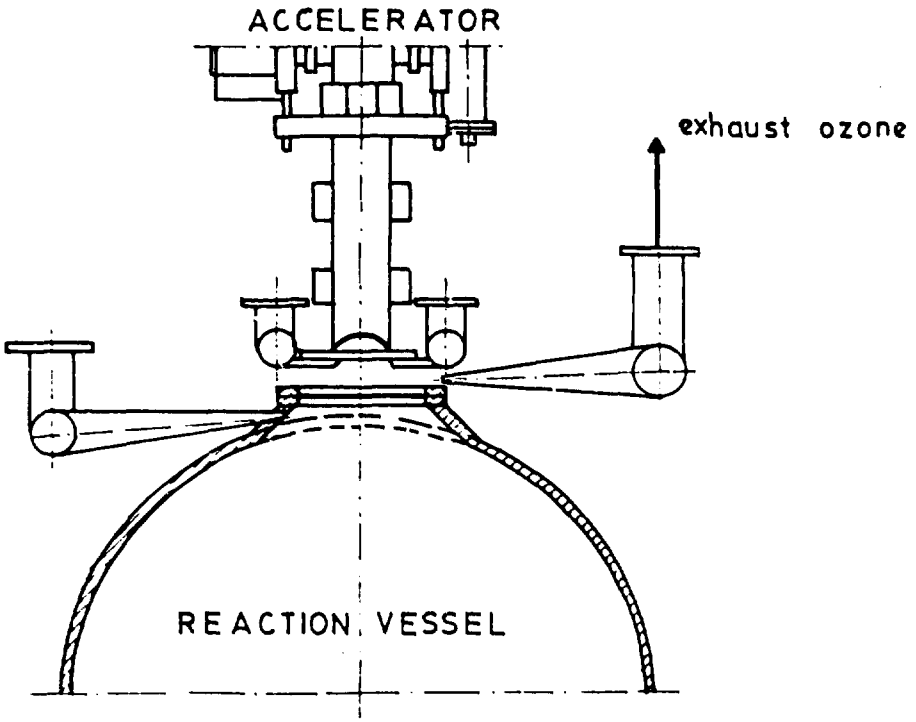
5. Costs calculation for supply of the reaction chamber system.

Building of the reaction chamber system is connected with necessity to purchase devices and preparation of rooms together with necessary installations.

Costs are: (in thousand USD)

- accelerators	2.900
- accelerator building	1.100
- reaction chamber	500
- shielding walls	400
- water cooling system	150
- ventilation system	200
Total	**5.250**

In the above calculation costs of purchased devices, materials for constructing non typical parts, assembly, and transport are included, excluding VAT.



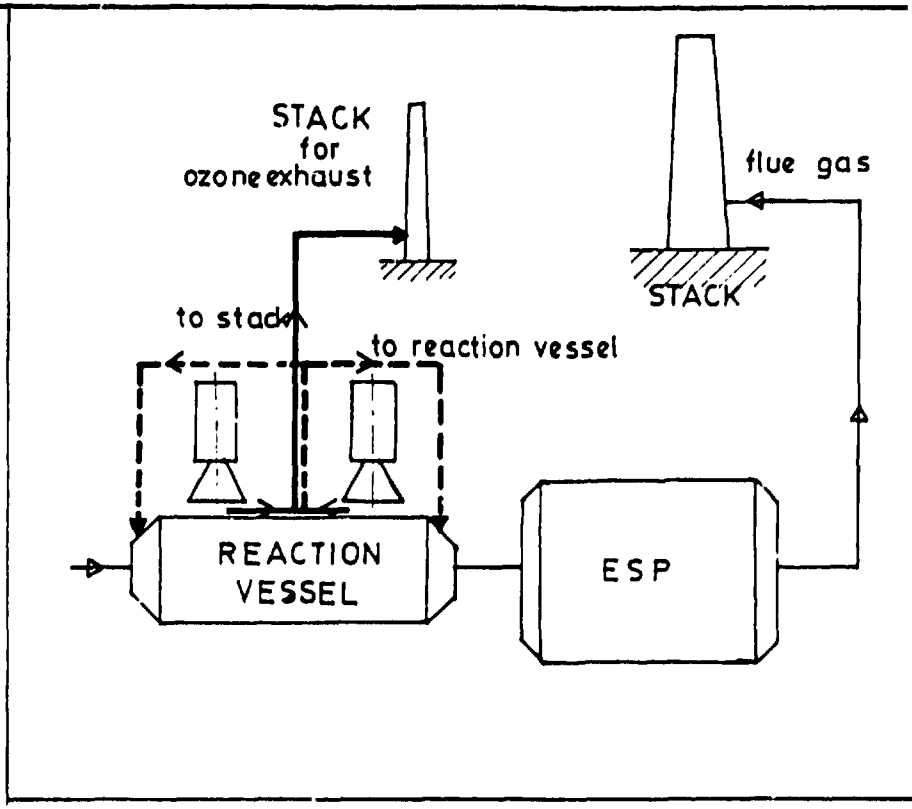


Fig. 4.1. Scheme of ozone exhaust system

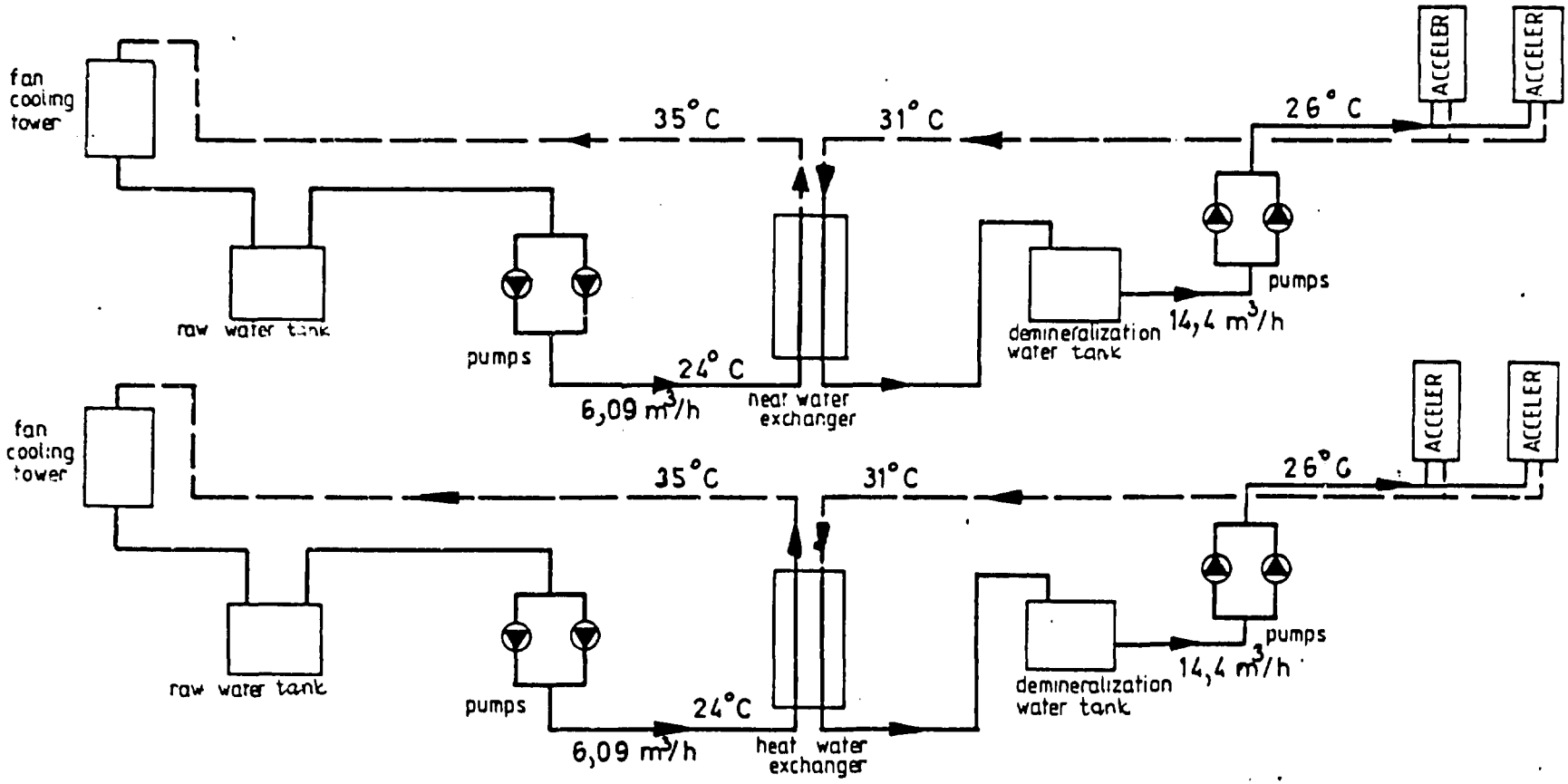


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Fig. 4.2. Scheme of cooling water system

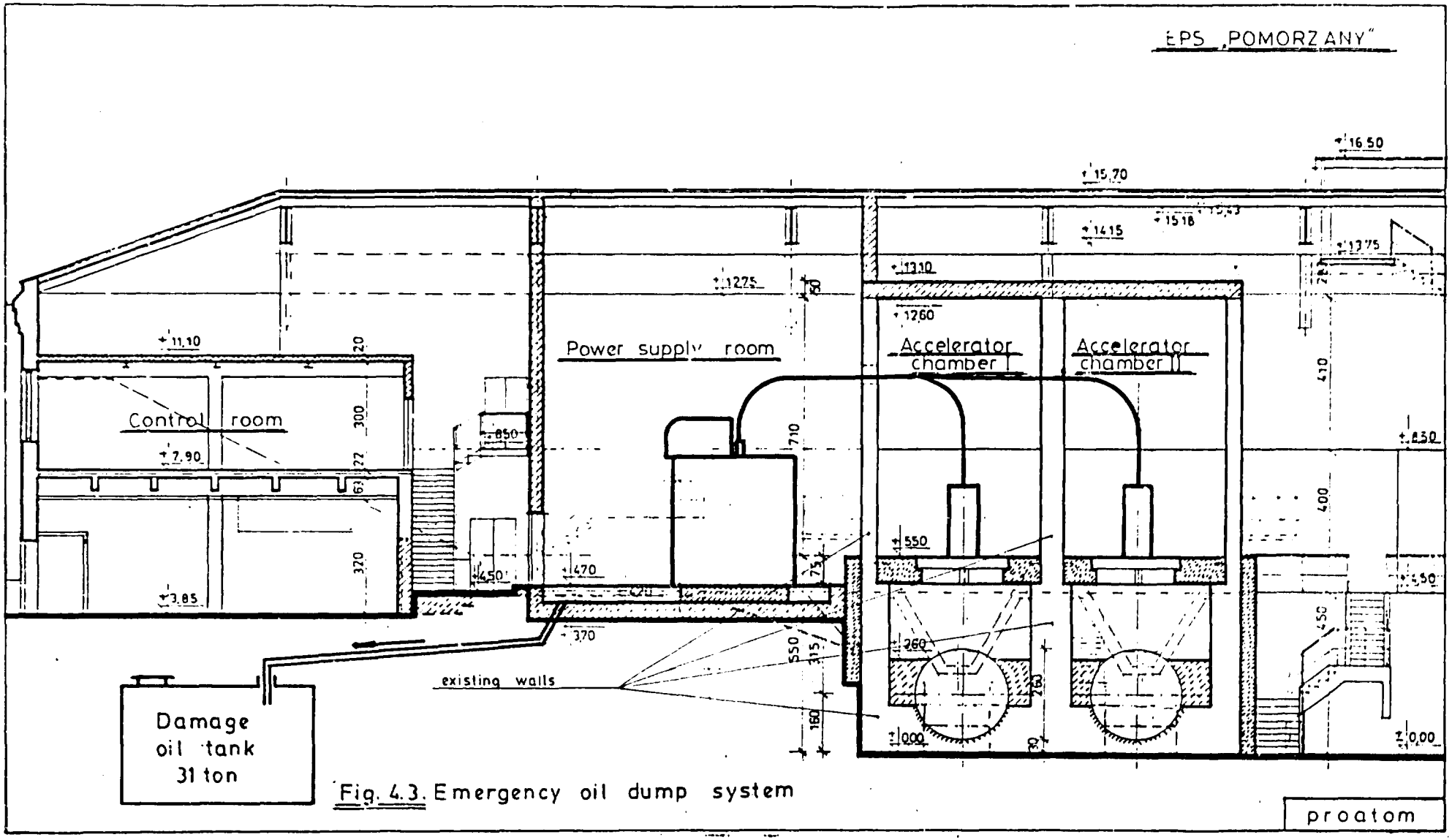

Fig. 4.3. Emergency oil dump system

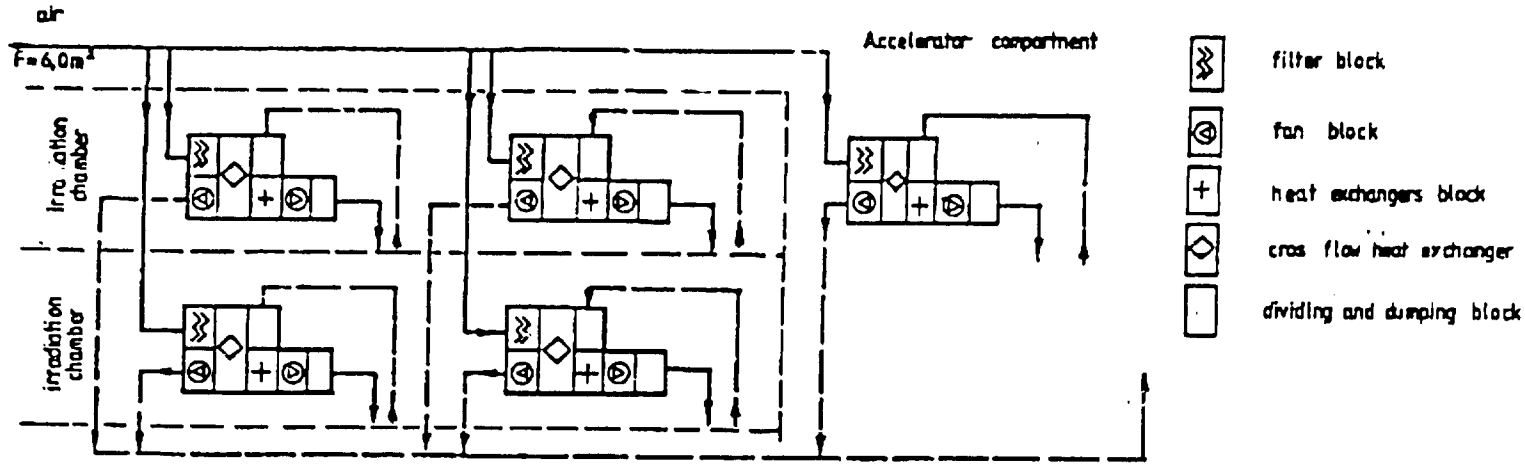

Fig. 4.4. Ventilation system with cross-flow heat exchanger

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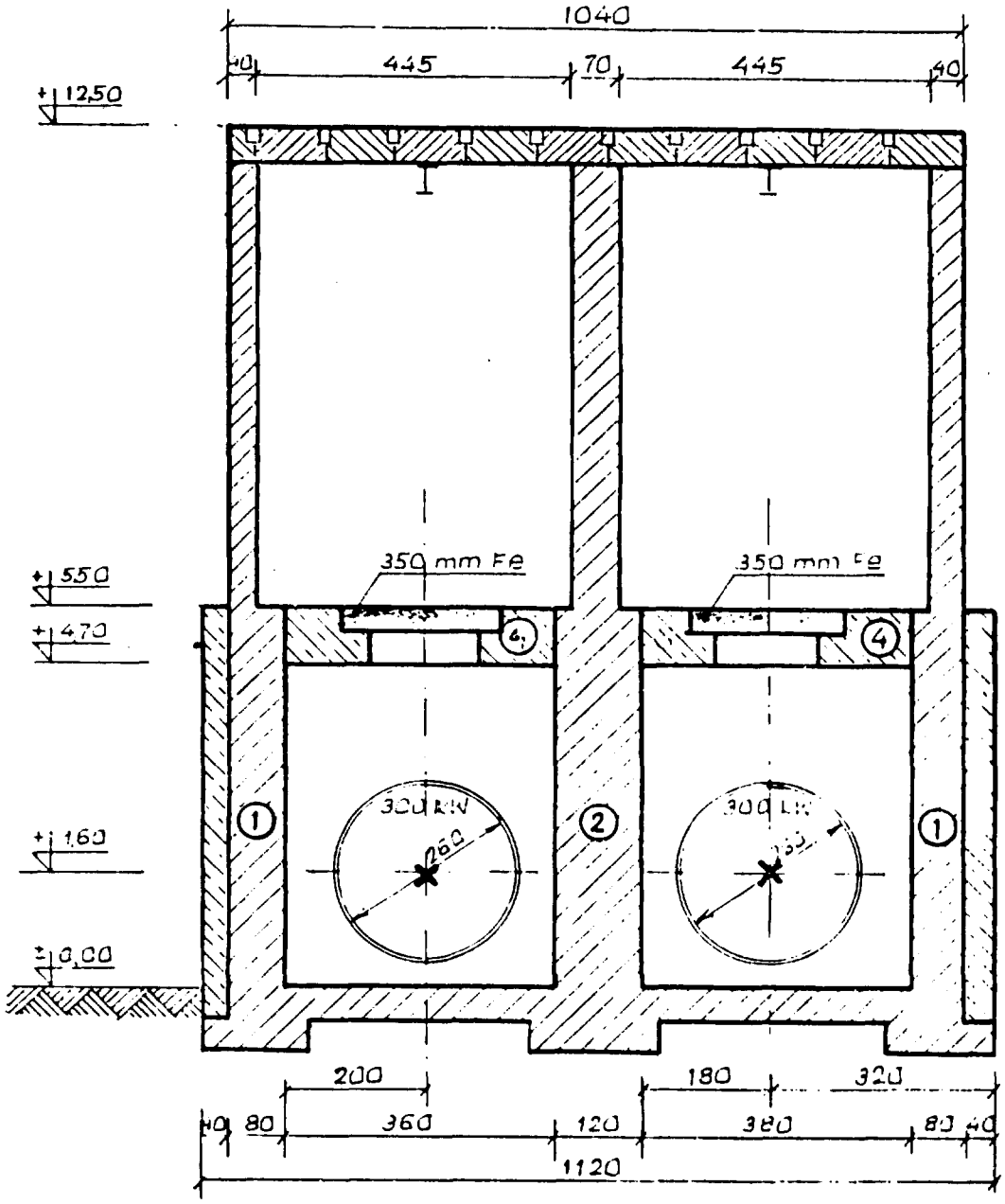

Fig. 4.5. Display of shielding walls

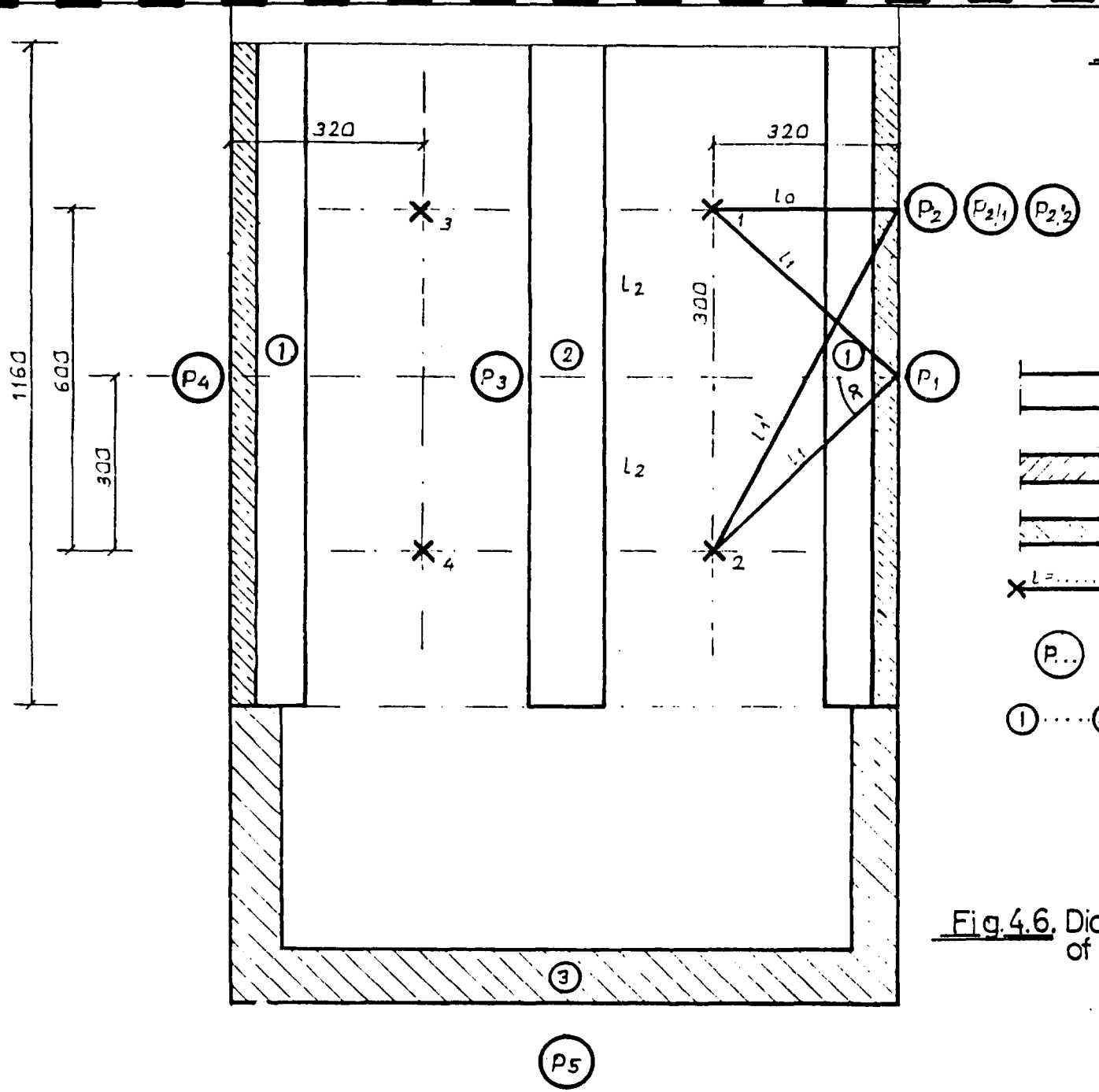

Fig.4.6. Diagram for evaluation of shielding walls

I – I

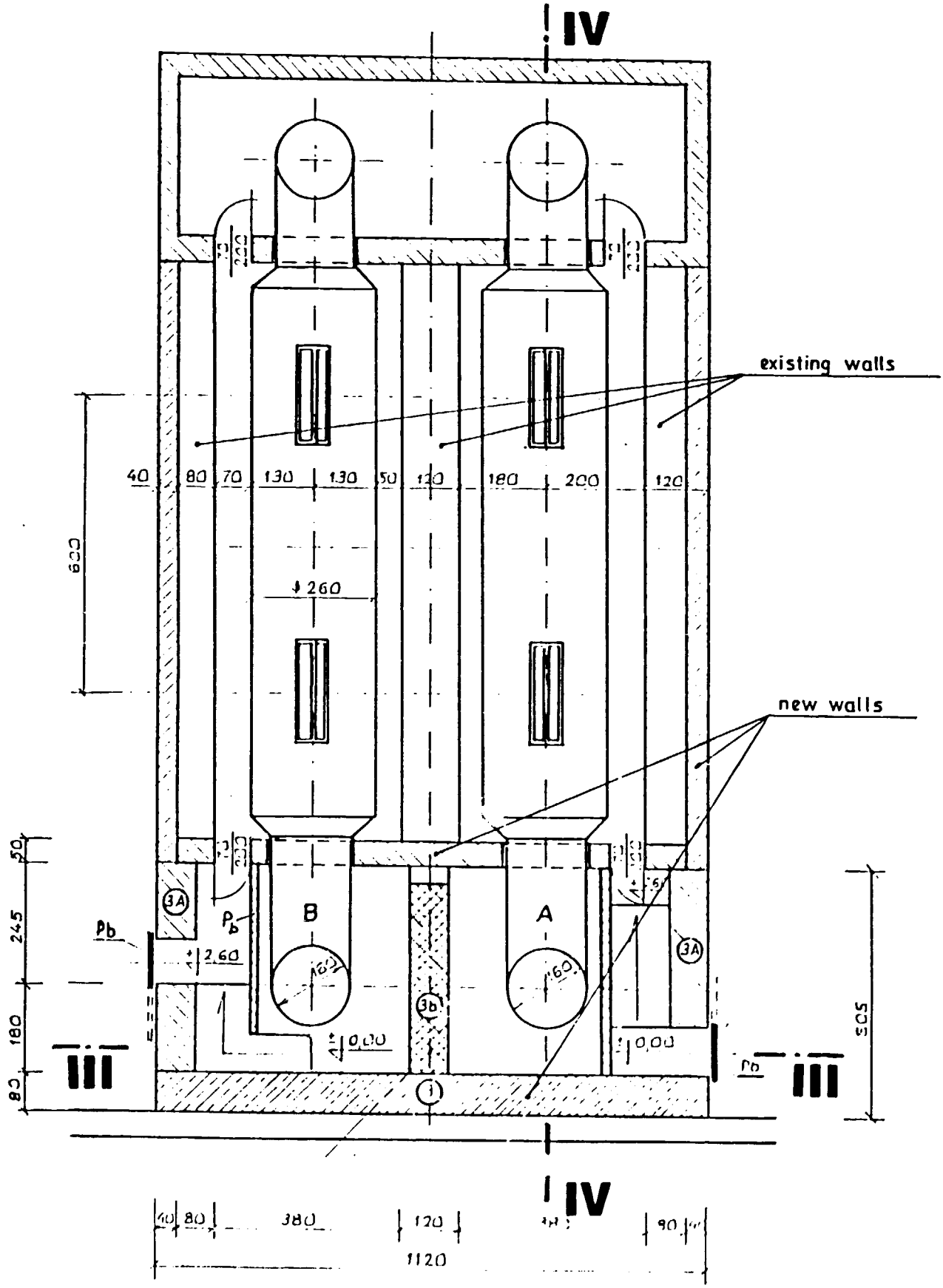

Fig. 4.7. Shielding design - level ±0,00

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III – III

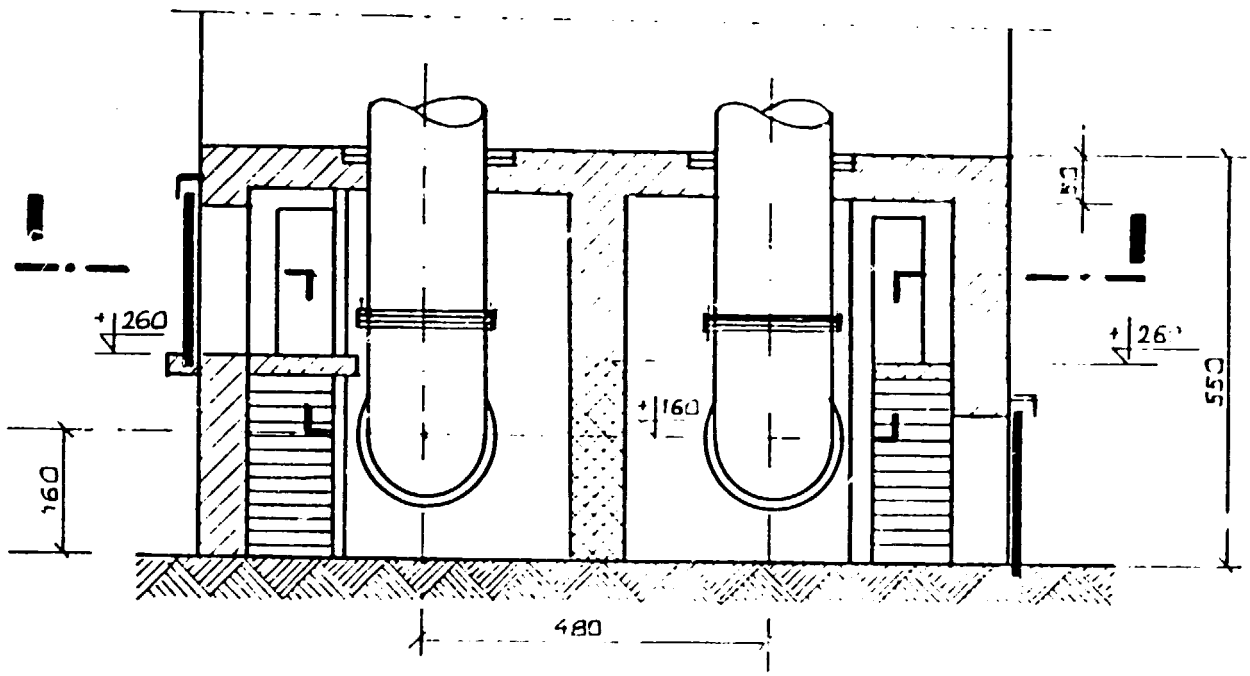


Fig. 4.8. Shielding design cross-section III-III

V - V

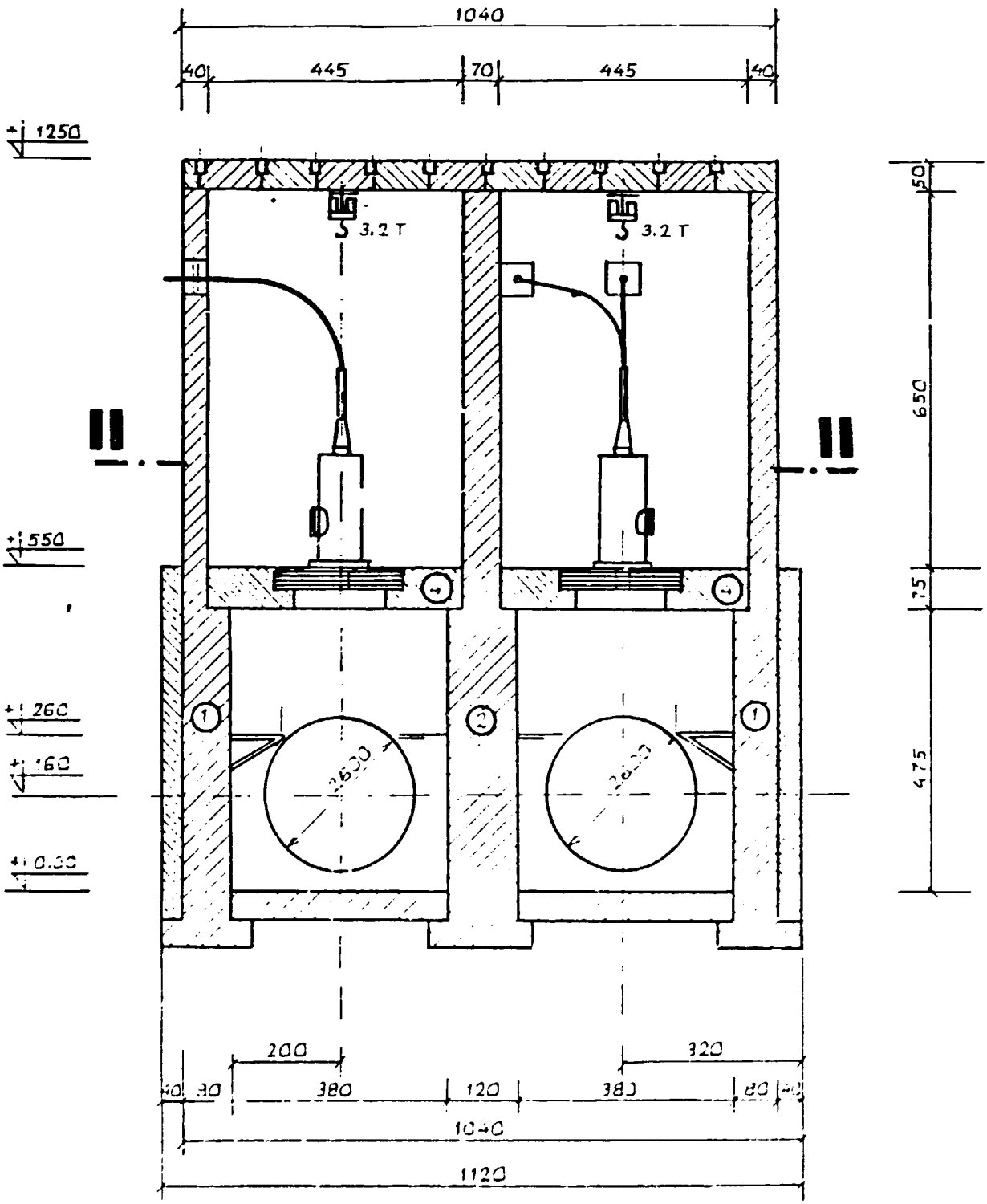


Fig. 4.9. Shielding design cross-section V-V

IV-IV

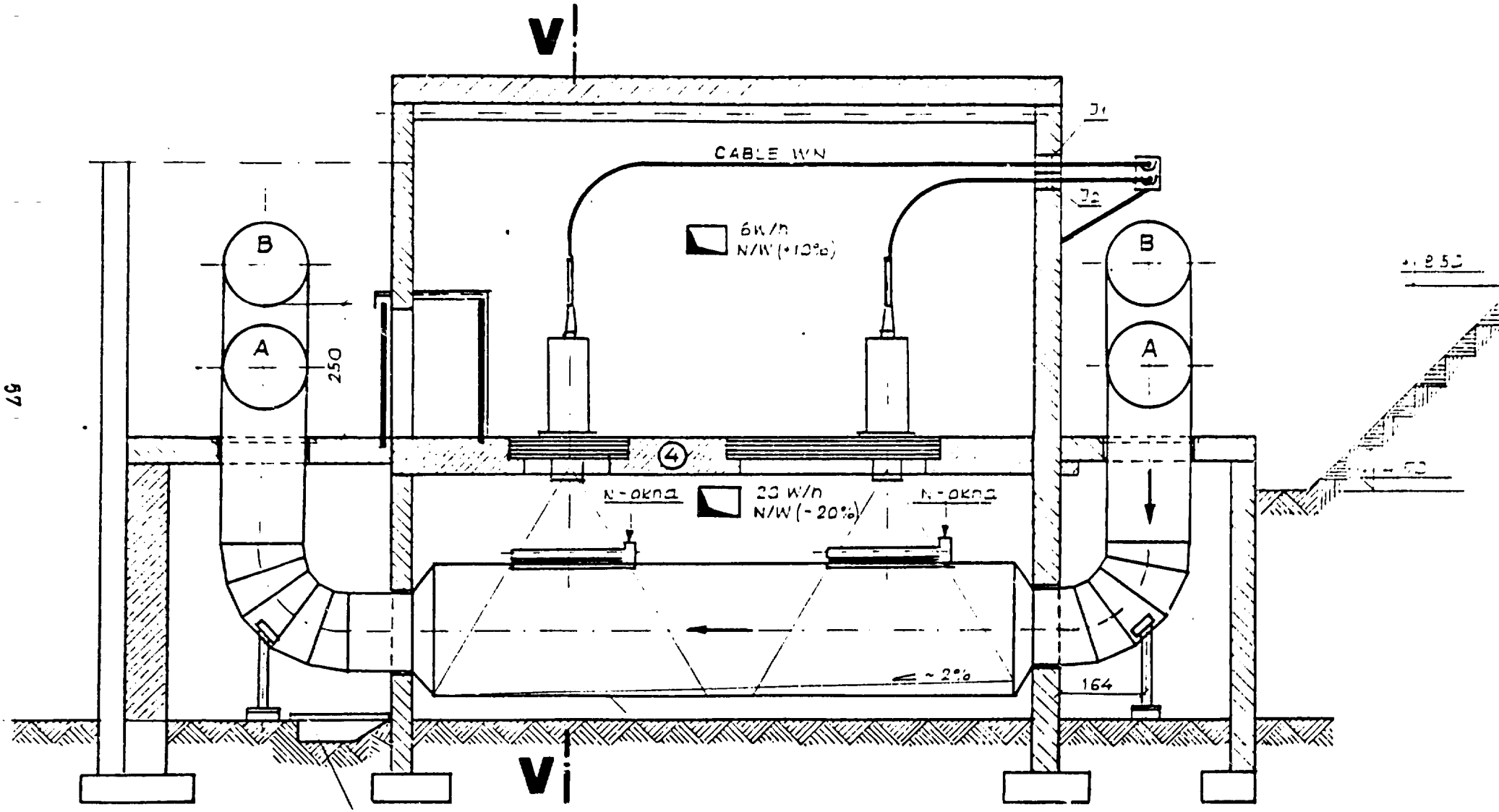
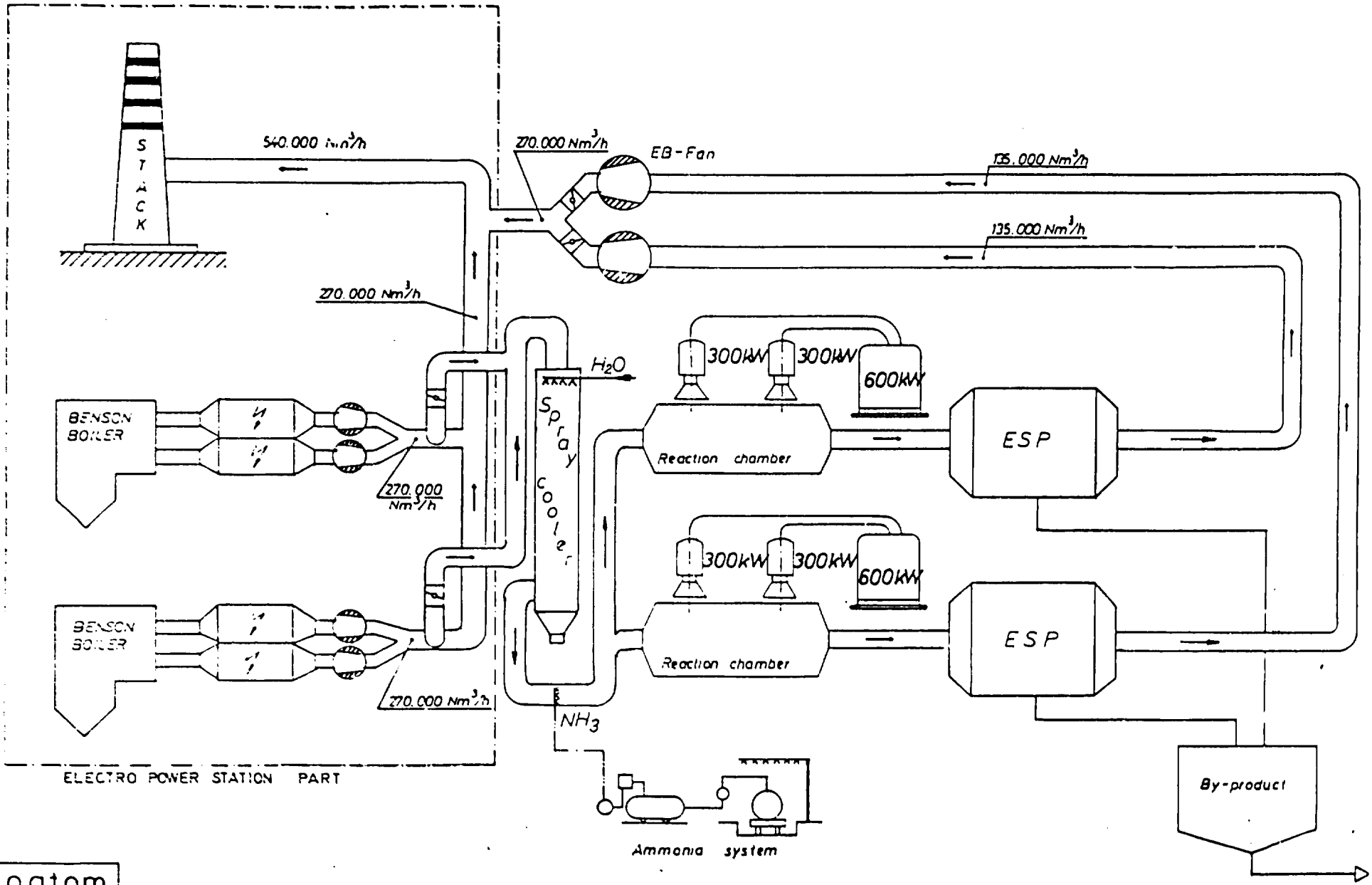


Fig. 4.10. Shielding design longitudinal section IV-IV

Fig. 4.11: EPS „POMORZANY" - Szczecin - Process schematic



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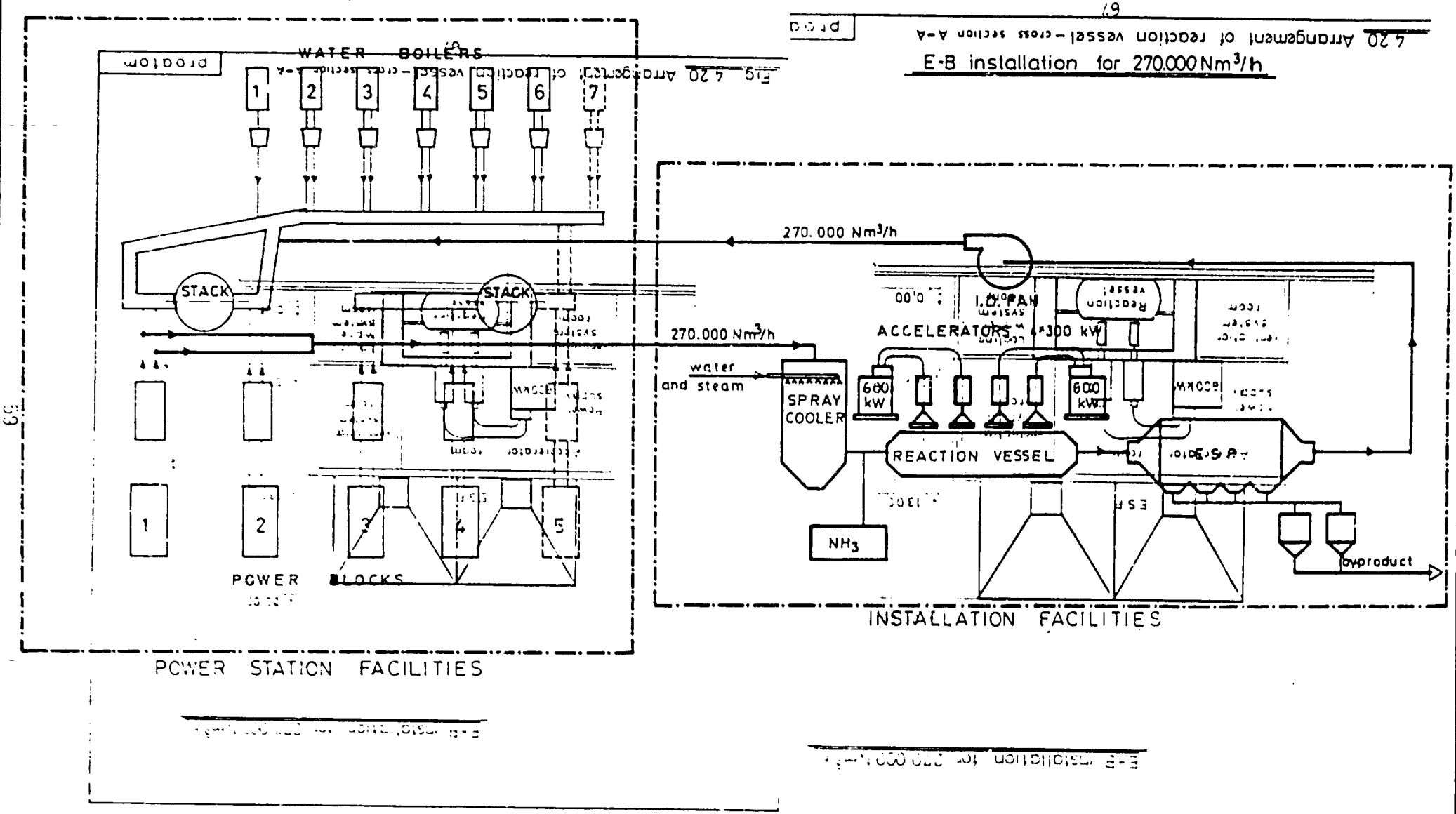

Fig. 4.12. Process schematic

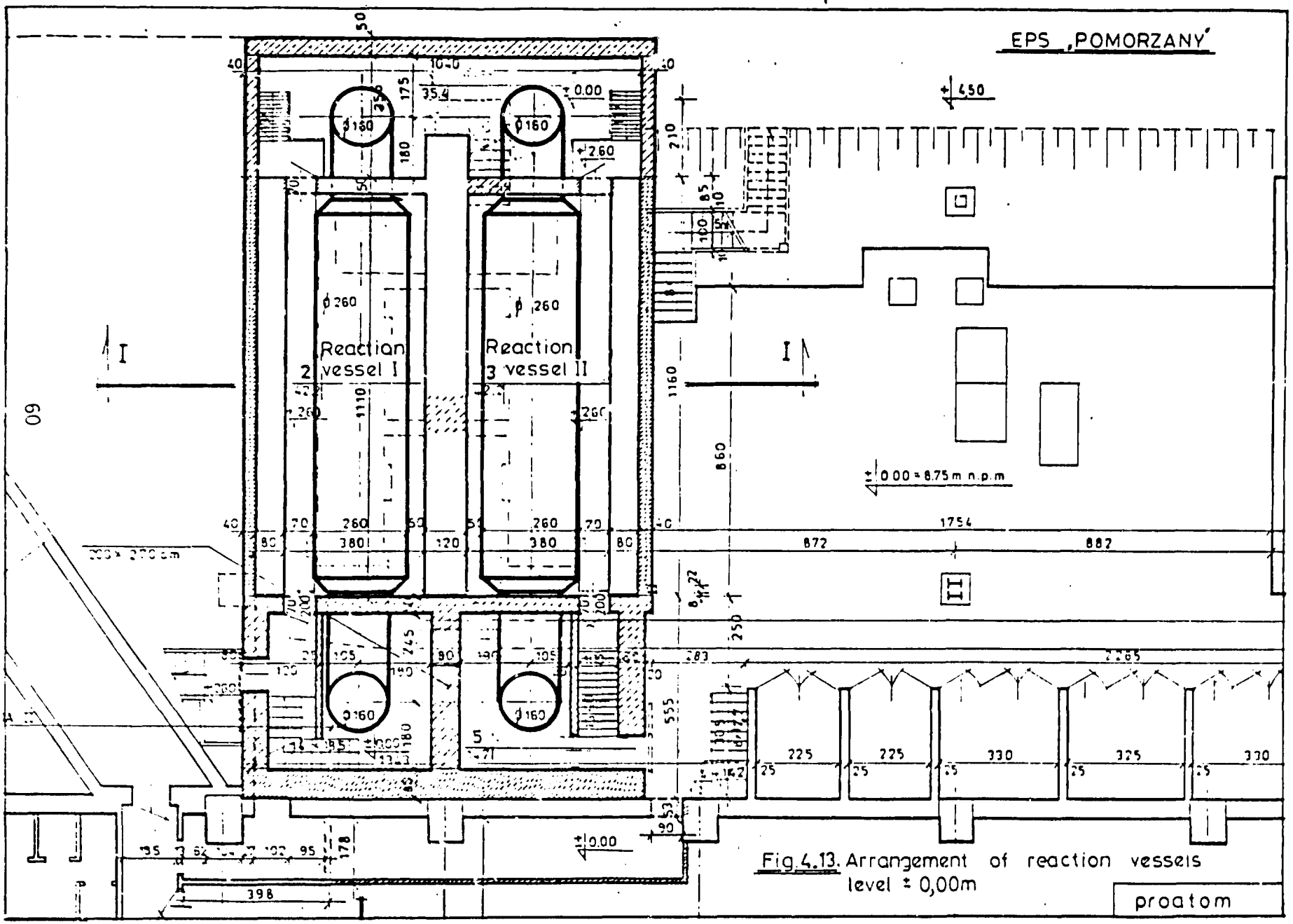

Fig. 4.13. Arrangement of reaction vessels level ± 0,00m

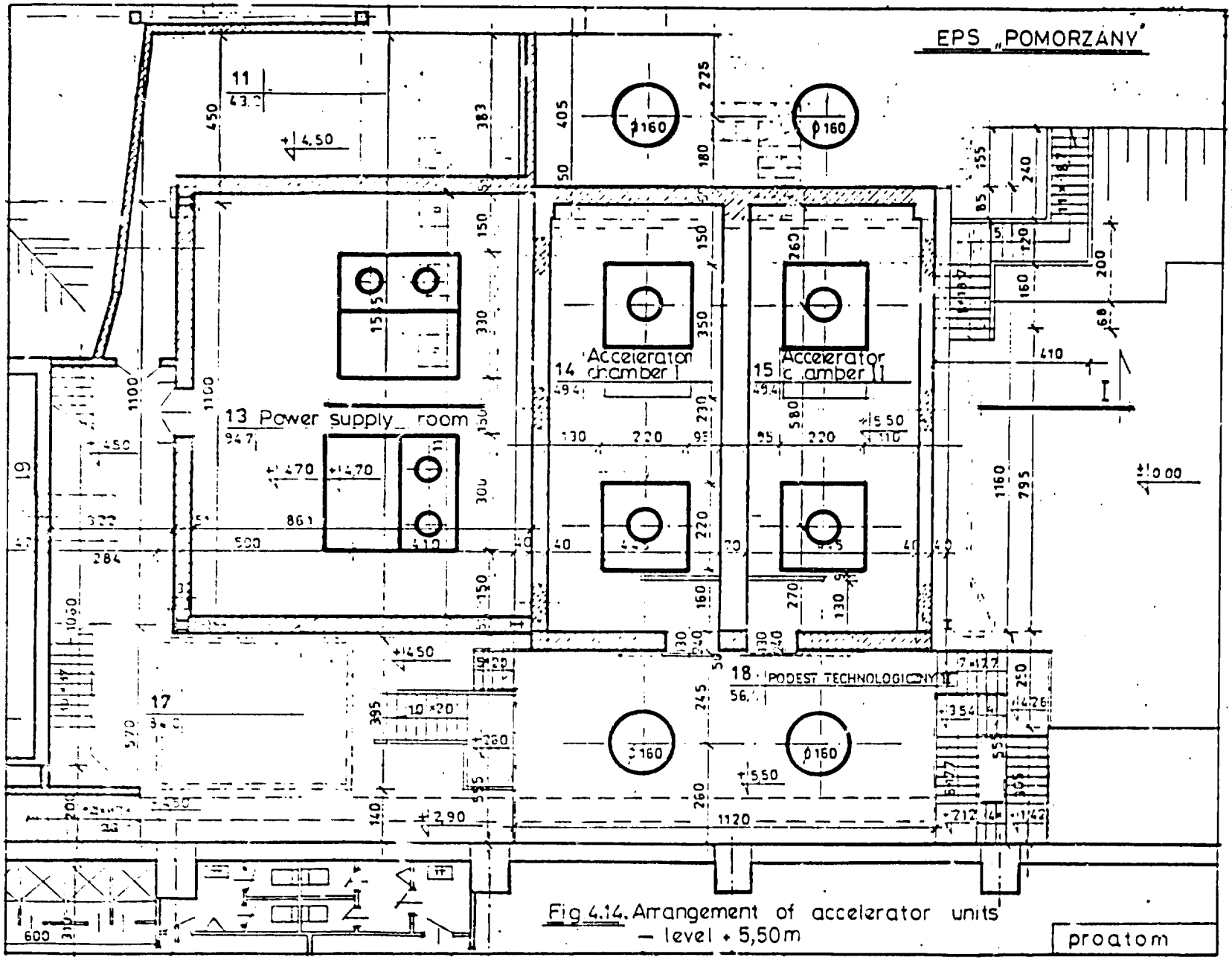

Fig 4.14. Arrangement of accelerator units — level + 5,50 m

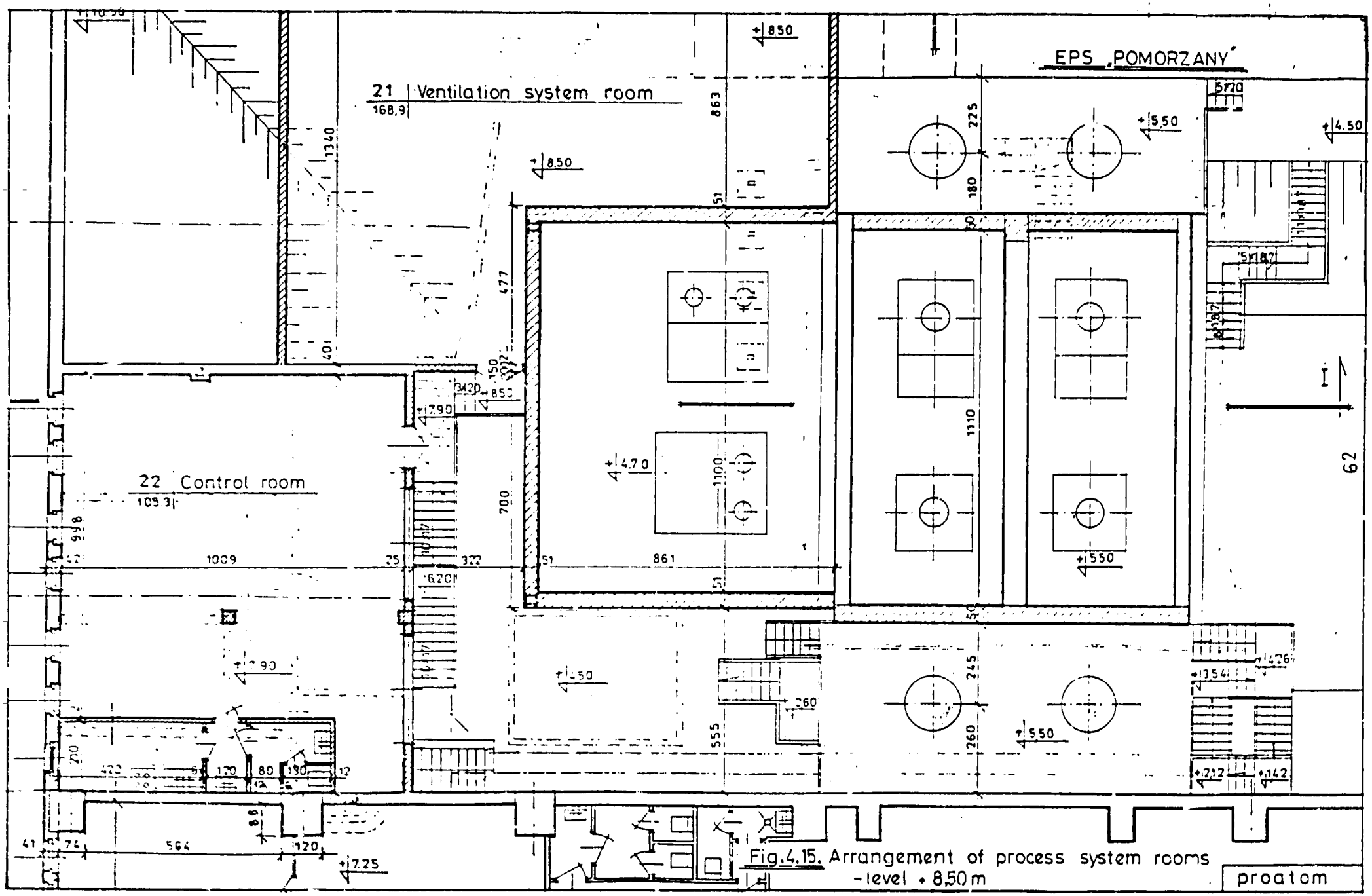

Fig.4.15. Arrangement of process system rooms - level + 8,50 m

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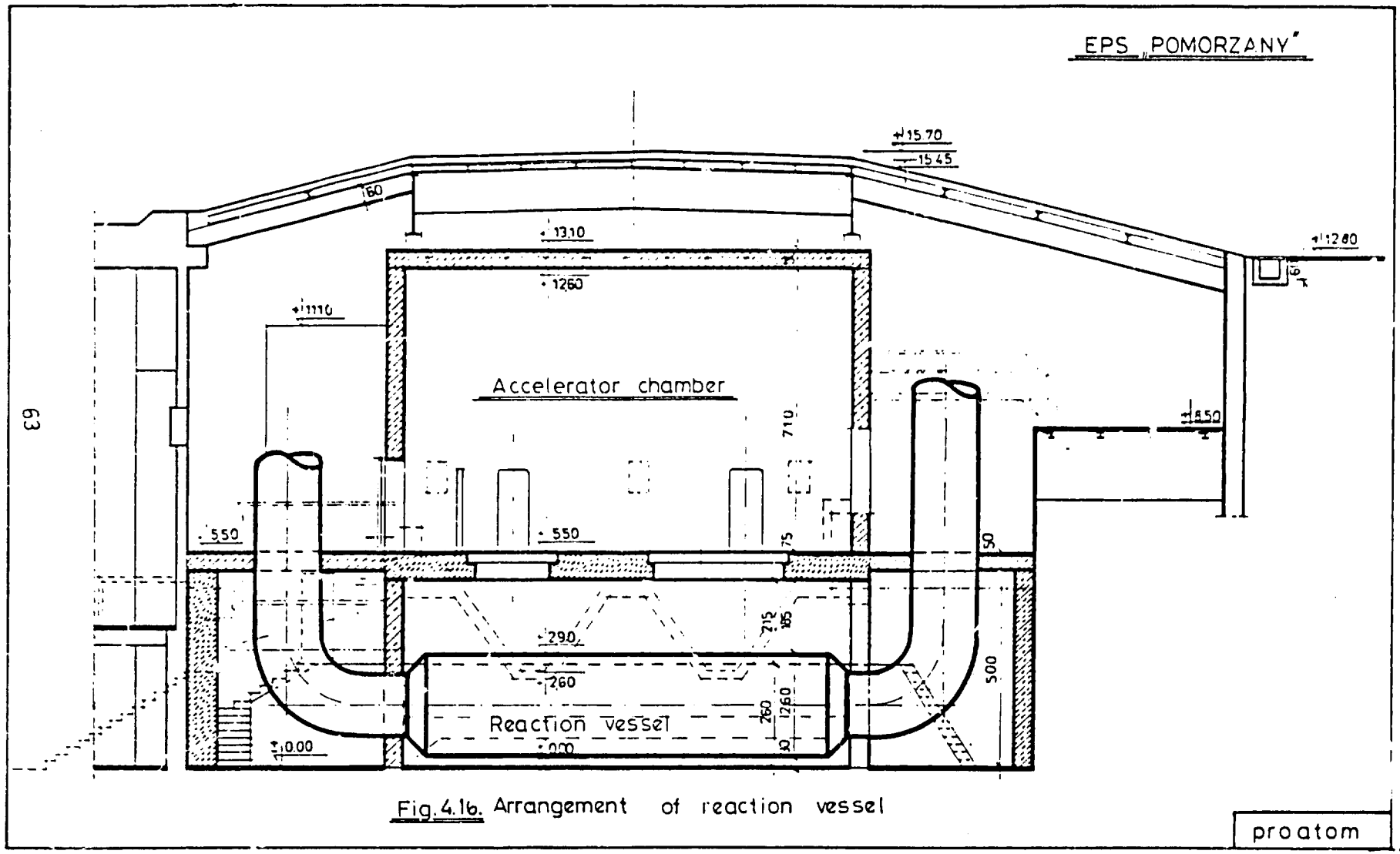

Fig. 4.16. Arrangement of reaction vessel

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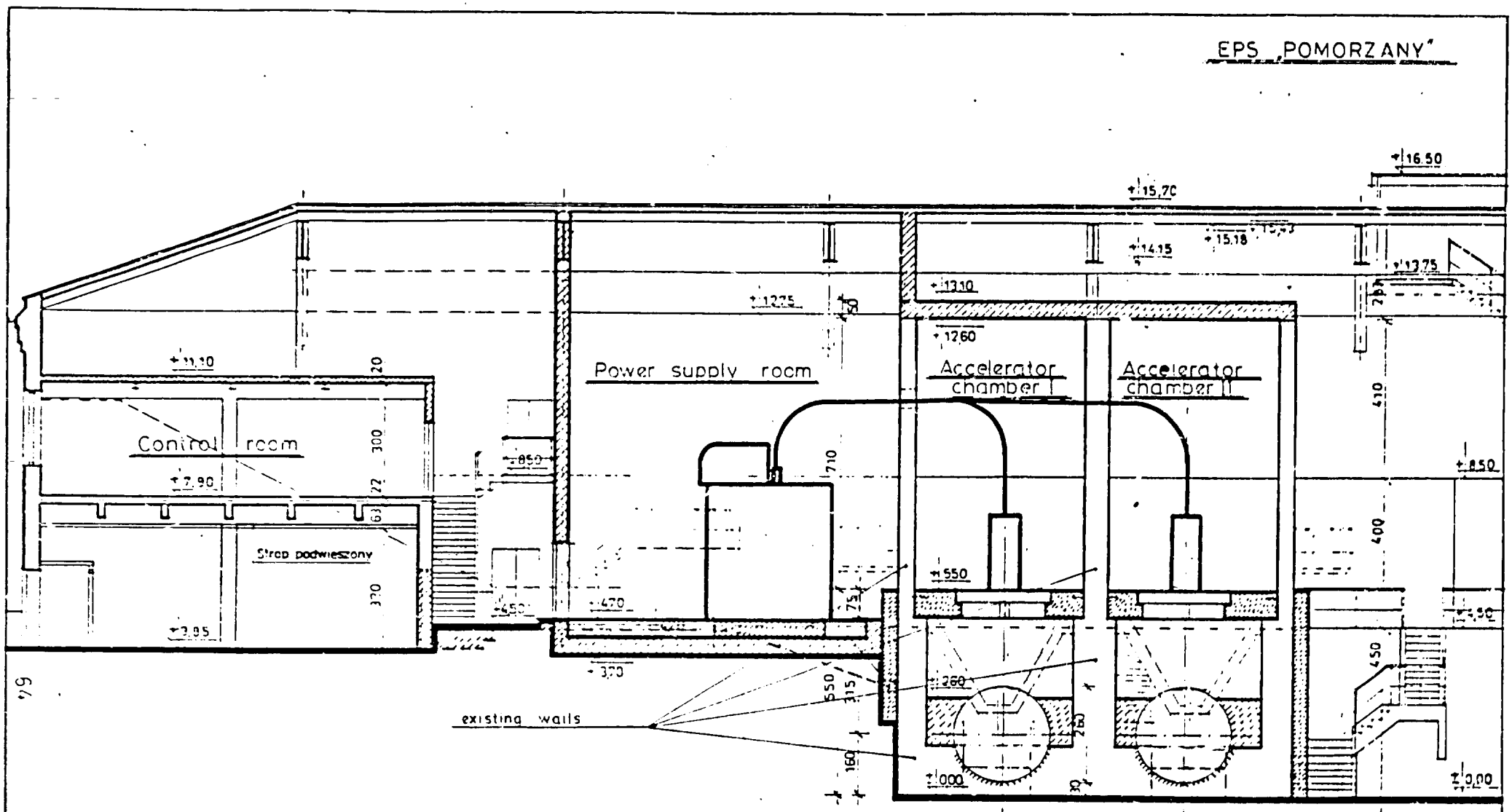

Fig. 4.17. Arrangement of reaction vessels - cross-section I-I

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E-B installation for 270.000 Nm^3/h

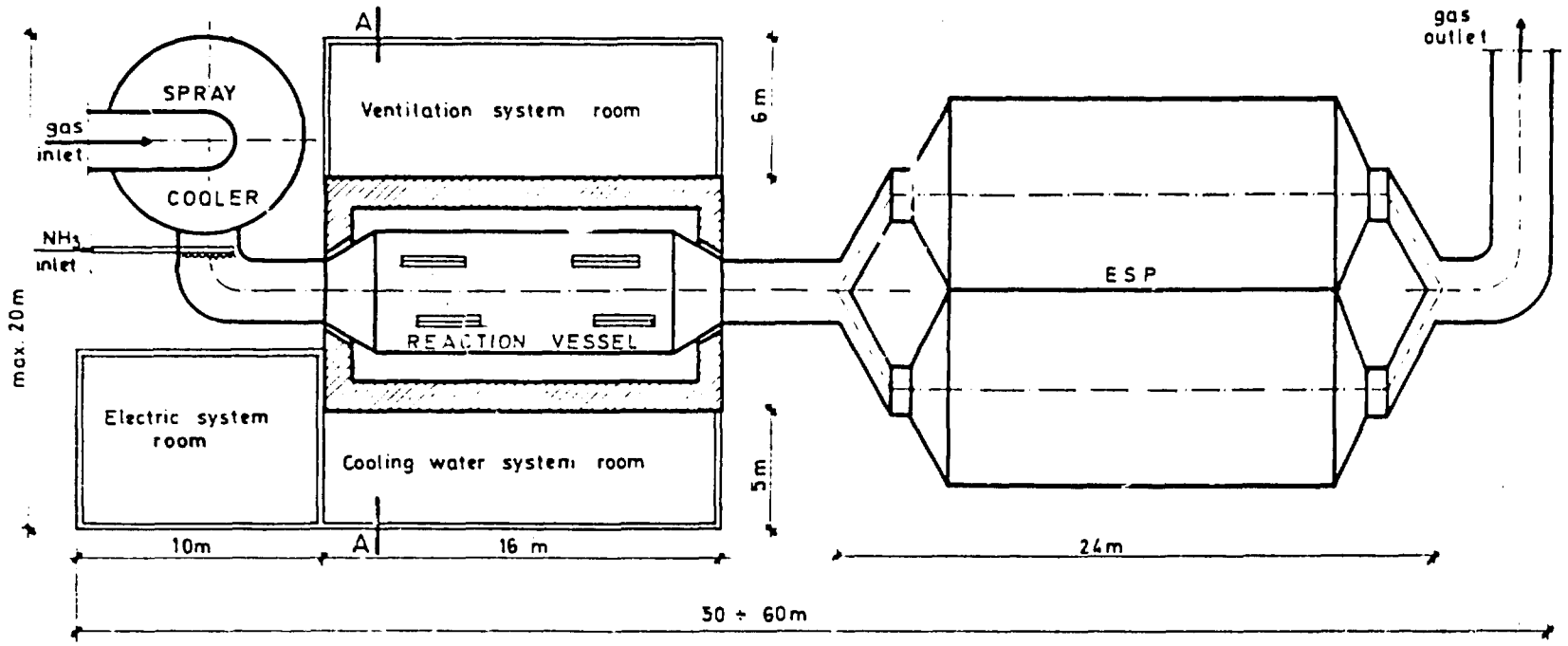

Fig. 4.18. Arrangement of reaction vessel – level ±0,00

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E-B installation for 270.000 Nm³/h

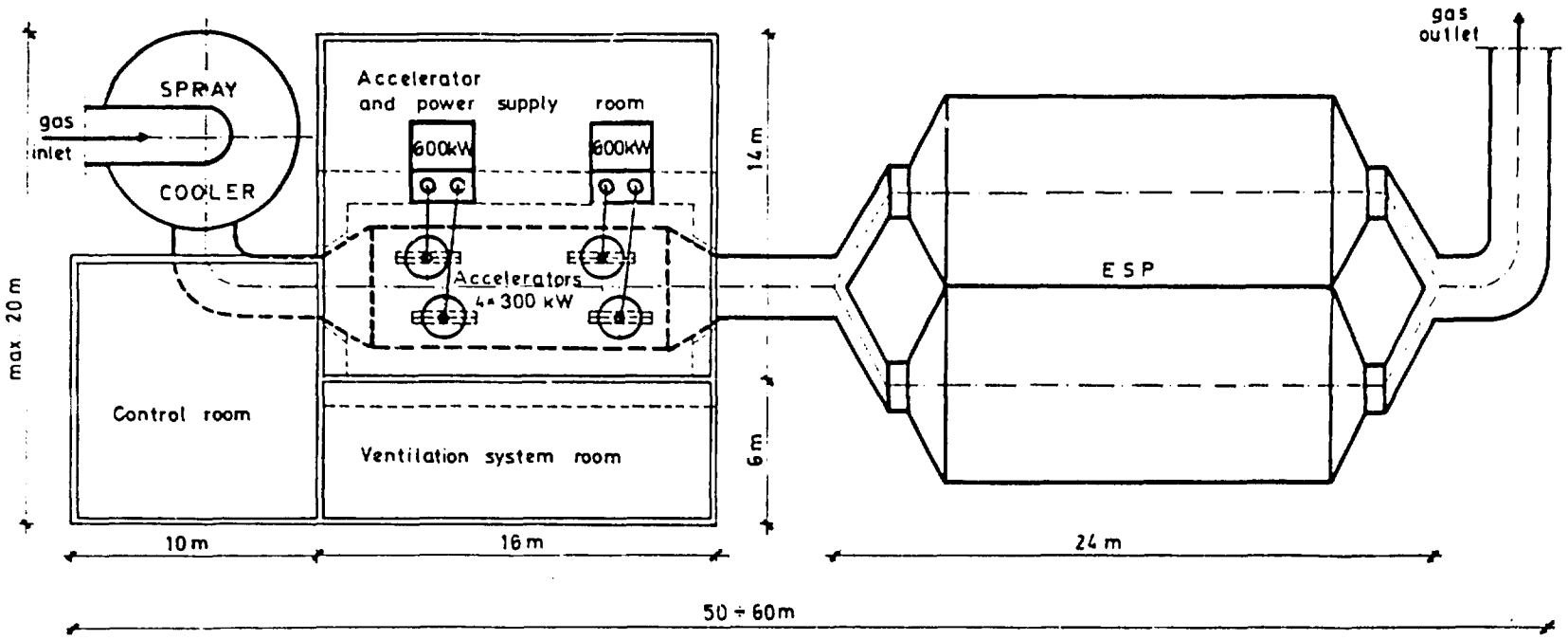

Fig. 419. Arrangement of accelerator units – level +5,00m

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E-B installation for 270.000 Nm^3/h

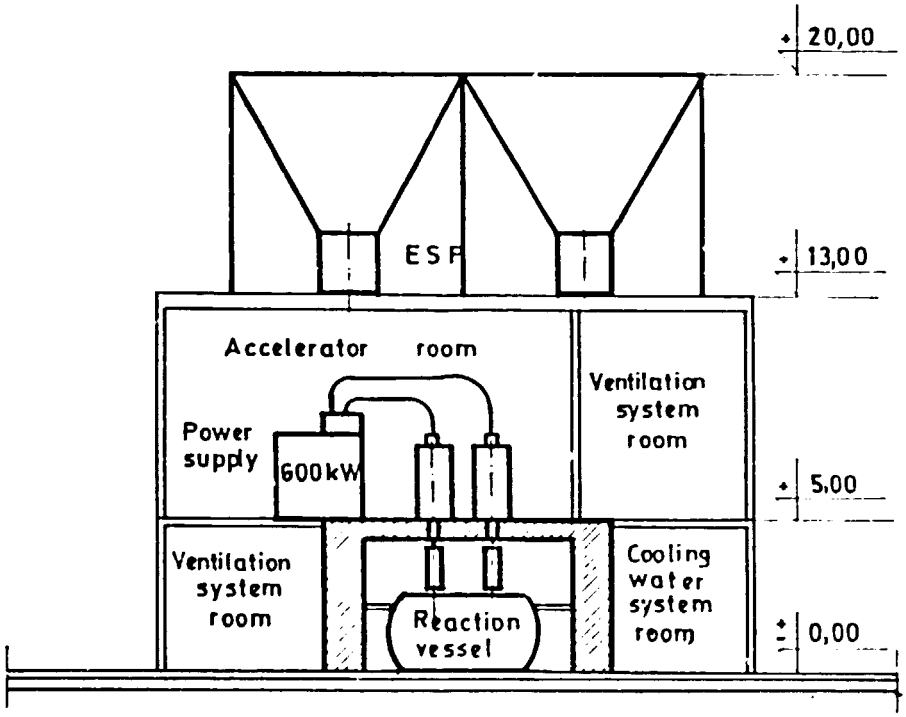

Fig. 4.20 Arrangement of reaction vessel – cross section A–A

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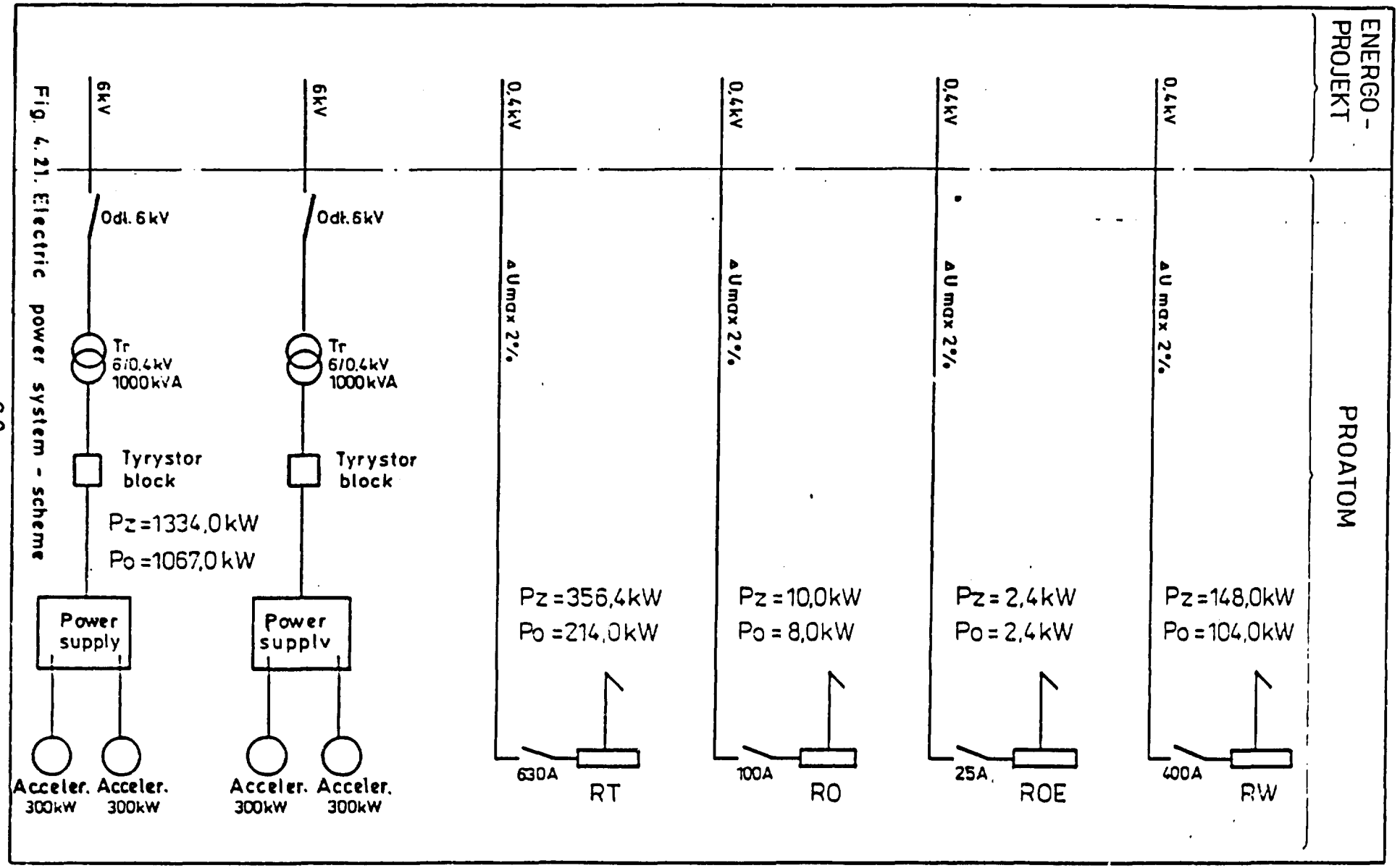

Fig. 4.21. Electric power system - scheme

This volume has been prepared by:

Consulting Engineers - Power Engineering Study and Design Company, „Energoprojekt - Warszawa SA"

Engineering Design Of An Electron Beam (EB) Flue Gas Purification Industrial DemonstrationPlant

Basic Engineering.

Volume 5

By-product filtration.

Warsaw, January 1996

No. of Volume	List of Volumes	Author
Volume 0	Executive Summary	
Volume I	Process Technology	INCT
Volume II	Gas Conditioning Unit	INCT
Volume III	Ammonia storage and dosing unit	Energoprojekt-Warszawa
Volume IV	Reaction chamber	Proatom
Volume V	By-product filtration (ESP)	Energoprojekt-Warszawa
Volume VI	By-product removal from filter, its transportation and conditioning	Energoprojekt-Warszawa
Volume VII	Flue gas ducts. Emission of flue gases to atmosphere	Energoprojekt-Warszawa
Volume VIII	Measuring, monitoring and control system	SINS
Volume IX	Electrical power supply units	Energoprojekt-Warszawa
Volume X	Composite documentation	Energoprojekt-Warszawa
Volume XI	Balances	Energoprojekt-Warszawa

Authors of this volume:

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3. J.Roszkowski	Energoprojekt W-wa

Volume 5

By - product filtration

Contents

1. Introduction

This volume covers the Electrostatic Precipitator (ESP) for by-product removal from the Electron Beam Flue Gas Treatment Plant.

2. System function Design criteria

2.1 System function

The function of ESP is to precipitate the by-product particles from flue gases after electron beam treatment and to limit stack emission of particulate matter.

2.2 Design criteria

ESP has to be at the world present know-how level regarding - materials, construction, sizing, high voltage equipment, control units, operational reliability and maintenance.
ESP shall have efficiency at least 99,2 % to limit the dust emmission to max. 20 mg/Nm^3. ESP will be located outdoors, so the design has to consider local climatic conditions, proper insulation throughout and electrical heating of hoppers to prevent by-product caking by hygroscopic water vapour take up.
Under winter design ambient conditions, insulation shall maintain temperature of metal in contact with flue gas at a temperature that is at least 20 ^{o}C above the flue gas water dew point temperature.
The area under the ESP has to be enclosed by means of sheet metal walls and concrete floor.
ESP has to be constructed as one chamber with two inlets and two outlets flanges.
Chamber design pressure must be at least ± 3500 Pa.
Flange to flange pressure loss has to be max. 200 Pa

3. Purchasing of ESP

In the scope of technical design, the inquiry for ESP shall be prepared and shall be sent to several well cognizant ESP suppliers.

The most economical and technically acceptable tender will be accepted after evaluation process, and a purchase contract will be signed.

4. Operating conditions

Flue gas flow	284 000 Nm^3/h
Nominal flue gas inlet temperature	90 °C
Flue gas inlet temperature	70 - 90 °C
Max. flue gas inlet temperature	100 °C
Flue gas inlet composition	
- SO_2	0,31 g/Nm^3
- NO_x	0,12 g/Nm^3
- O_2	6,6 % volume
- CO_2	7,4 % volume
- H_2O	11 % volume
- NH_3	< 0,05 g/Nm^3
- by-product	ca 2,5 g/Nm^3
By-product composition	
- $(NH_4)_2 SO_4$	70 %
- $NH_4 NO_3$	26 %
- fly ash	2 %
- moisture	2 %
By - product particle size	75 % < 1 μm

5. ESP performance

According to preliminary selection, the expected ESP has to be as follows.

ESP will be consist of one steel casing, approximately 21 m long and 17 m wide.

The total height of ESP will be approximately 23 m and will include 14 m of casing, 6,5 m of conical hoppers, with 2,5 m vertical space allowance at the bottom to accommodate by-product handling equipment.

Gas distribution baffle system supplied at ESP inlet will assure adequately even gas flow distribution over the entire flow cross-section area.

Rapping mechanisms including drives, will be provided for the entire ESP including inlet, discharge electrodes, collecting electrodes and outlet.

ESP will have the proper number of access doors and access ways consisting of stairs, platforms and handrails. High voltage transformer - rectifier power supply sets will be located on the ESP roof and be directly connected to the discharge electrode systems.

Control units based on microprocessors will provide all necessary instrumentation, controls and immediate indication (by alarm) of upset conditions such as high temperature in the rectifier, high primary current to the rectifier, low or high precipitation voltage and back corona, and high by-product level in hoppers.

Hot air flushing system will assure that each individual electrical insulator inside the ESP will remain free of deposits.

6. Scope of supply

The scope of supply has to encompass the complete ESP ready for operation.

The following items are to be included:

- precipitator casing,
- slide bearing assemblies,
- supporting steel structure,
- conical hoppers complete with heaters,
- discharge electrode systems,
- collecting electrode systems,

- inlet gas flow distribution system,
- rapping mechanisms complete with drives,
- access doors and access ways including stairs, platforms, and handrails,
- high voltage transformer-rectifier units,
- electrical insulators complete with hot air flushing system,
- control units (based on microprocessors),
- foundation and civil works,
- erection ,
- installation of thermal insulation and lagging,
- conduct of acceptance test,
- technical documentation,
- operating and maintenance instruction,
- 2 years spare parts.

This volume has been prepared by:

Consulting Engineers - Power Engineering Study and
Design Company „Energoprojekt - Warszawa SA"

Engineering Design Of An Electron Beam (EB) Flue Gas Purification Industrial DemonstrationPlant

Basic Engineering.

Volume 6

By-product removal from filter, its transportation and confectioning.

Warsaw, January 1996

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Volume 0	Executive Summary	
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Volume IX	Electrical power supply units	Energoprojekt-Warszawa
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3. J.Roszkowski	Energoprojekt W-wa

Volume 6

Product removal from filter, its transportation and conditioning

Contents

1. Introduction

This volume covers by-product handling system within the scope of Electron Beam Flue Gas Treatment Plant including temporary warehouse.

2. System function. Design criteria

2.1. System function

The function of the system is to receipt by-product from electrostatic precipitator, temporary storage, in dry bulk shape or bagged, and loading for dispatching.

2.2. Design criteria

- Average operation time of Flue Gas Treatment Plant: 6500 hours per year.
- Nominal capacity of by-product production: 700 kg/hour.
- By-product composition
  - $(NH_4)_2SO_2$ 70 %
  - NH_4NO_3 26 %
  - fly ash 2 %
  - moisture 2 %
- Temporary storage capacity has to enable 5 months operation of Flue Gas Treatment Plant without final dispatching of by-product.

3. Operating conditions

Because of fact, that fertiliser factory works mainly in summer and power plant works with its biggest output in winter, the by - product will be produced mainly in winter but will be needed mainly in summer.

So because of m/a reasons, buffer store of several month capacity must be ~ 3000 ton. Because of lack of free place on power plant's area, it is impossible to built store yard on site. The proper place for this purpose is the ground near ash disposal yard. By - product will be carried from loading point by means of lorries or containers, discharged in feeding point and stored in roofed building in pile shaped by means of belt conveyors system.

4. System description

4.1. Installation under ESP

Under each hopper of ESP, the put cut valve, the rotary valve and the screw conveyor (situated along side the hopper) will be installed. The screw conveyors will deliver by - product to the belt conveyor leading to the loading point.

4.2. Loading point

The belt conveyor leading from under ESP will deliver the by - product to lorry or container.

4.3. Buffer store yard

Material transported to buffer store yard will be discharged on feeding point and delivered by means of bucked and belt conveyors system to stock pile. Feeding point will be designed in shape of conic chute of ~ 10 m^3 capacity. Material from chute will be discharged on flat belt conveyor, situated under the chute. Than by means of system conveyors (bucked, belt, reversible belt) stock pile will be shaped. System of conveyors will have capacity ~ 15 t/h. Pile will have dimensions: L ≅ 42,0 m, W ≅ 18,0 m, H ≅ 8,0 m. Pile of material will be situated in roofed closed building of overall dimensions: L ≅ 54,0 m, W ≅ 24,0 m, H ≅ 12,0 m. The stock pile will be discharged by means of front loader delivering product directly to lorries or belt conveyor, transporting material to loading point.

The reversible conveyor working over stock pile can deliver by-product either to pile or to bagging machine. Small quantity of material can be bagged and small bag store (500 ton) will be located in the building and will be served by means of fork lift.

5. Scope of delivery and works

5.1. Delivery will cover all needed commercial equipment (according to item 6).

5.2. Works will cover erection works and works connected with manufacturing of non commercial equipment.

6. List of equipment

6.1. Commercial

1. Installation under ESP
   - cut valve,
   - rotary valve,
   - screw conveyor,
   - belt conveyor.
2. Loading point
   - belt conveyor,
   - flap drive.

3. Buffer store yard

- conveyors,
- bagging machine,
- fork lift,
- front loader,
- central vacuum cleaning installation,
- vent installation,
- hoisting devices.

6.2. Non commercial

1. Installation under ESP

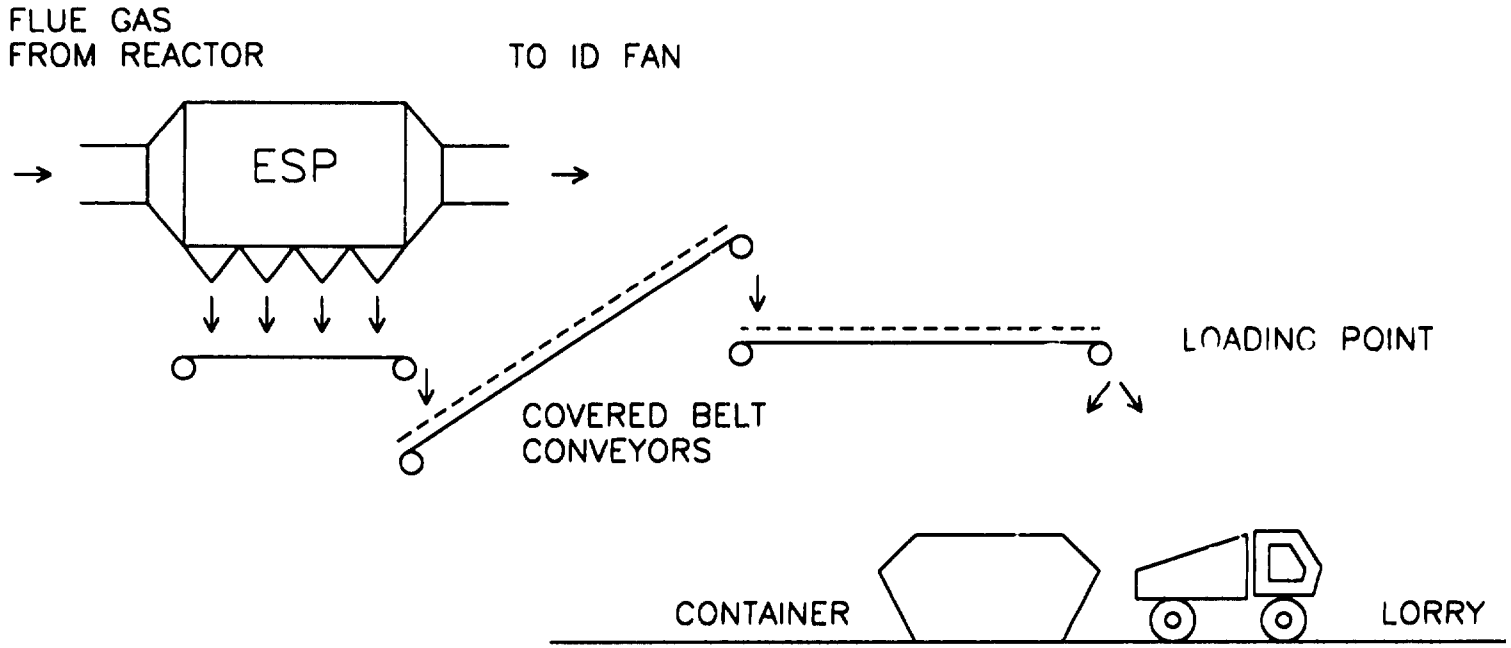
- steel structures,
- platforms,
- stairs.

2. Loading point

- steel structures,
- stairs,
- platforms,
- chutes,
- flap.

3. Buffer store yard

- chutes,
- steel structures,
- platforms,
- stairs.



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"ENERGOPROJEKT" - WARSZAWA" S.A.
Warszawa, ul.Krucza 6/14

Nr archiwalny: 1 131 116

Przedsięwzięcie: Symbol P-0174 | Nr WOI | Branża | Tom 6 | Zeszyt | Edycja

Nr. poz. w tomie

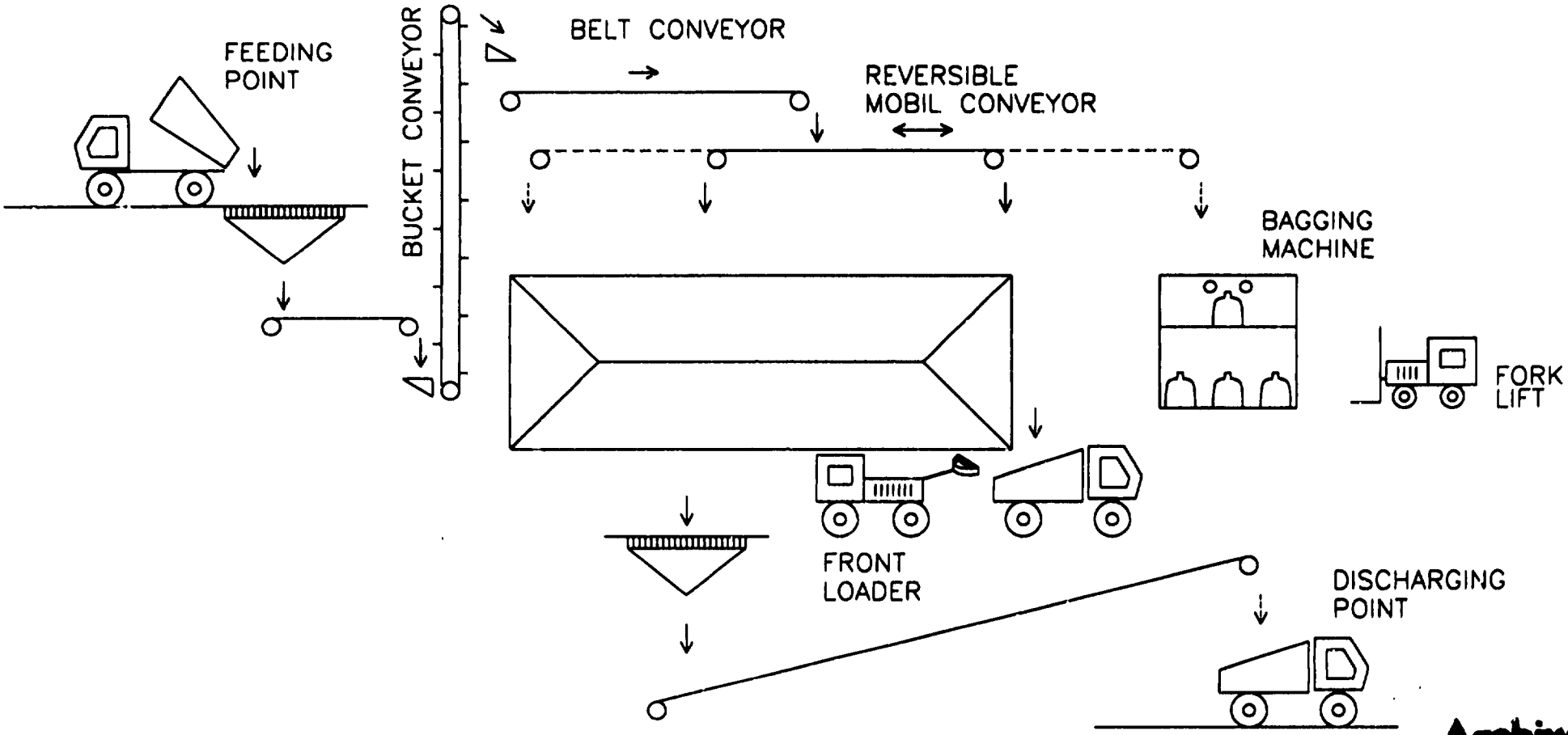
INDUSTRIAL DEMONSTRATION PLANT
OF ELECTRON-BEAM PROCESS
FOR FLUE GAS TREATMENT
OF THE ELECTRIC POWER STATION
"POMORZANY" - SZCZECIN POLAND

SCHEME OF BY-PRODUCT
HANDLING SYSTEM
-OF POWER PLANTS AREA-

Data	Podziałka	Faza	Format	Przesunięcie	Czas przech.
06.95.			A4	RK	

Zastępuje rys. Nr
Zastąpiony przez rys.

Projektował	L.Kosiński		Sprawdził	Z. Radomski
Wykonał			Kier. proc.	Z. Radomski
Kreślił	POM3.DWG		Gł. proj.	



Archiwum

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"ENERGOPROJEKT"® - WARSZAWA" S.A.
Warszawa, ul.Krucza 6/14

Nr archiwalny 1 131 117

Nr. porz. w tomie

Przedsięwzięcie	Symbol	Nr WOI	Branża	Tom	Zeszyt	Edycja
	P-0174			6		

INDUSTRIAL DEMONSTRATION PLANT OF ELECTRON-BEAM PROCESS FOR FLUE GAS TREATMENT OF THE ELECTRIC POWER STATION "POMORZANY" - SZCZECIN POLAND

BUFFER STOCK YARD -SCHEME-

Data	Podziałka	Faza	Format	Przewiń	Czas przech.
09.95.			A4	RK	

Zastępuje rys. Nr
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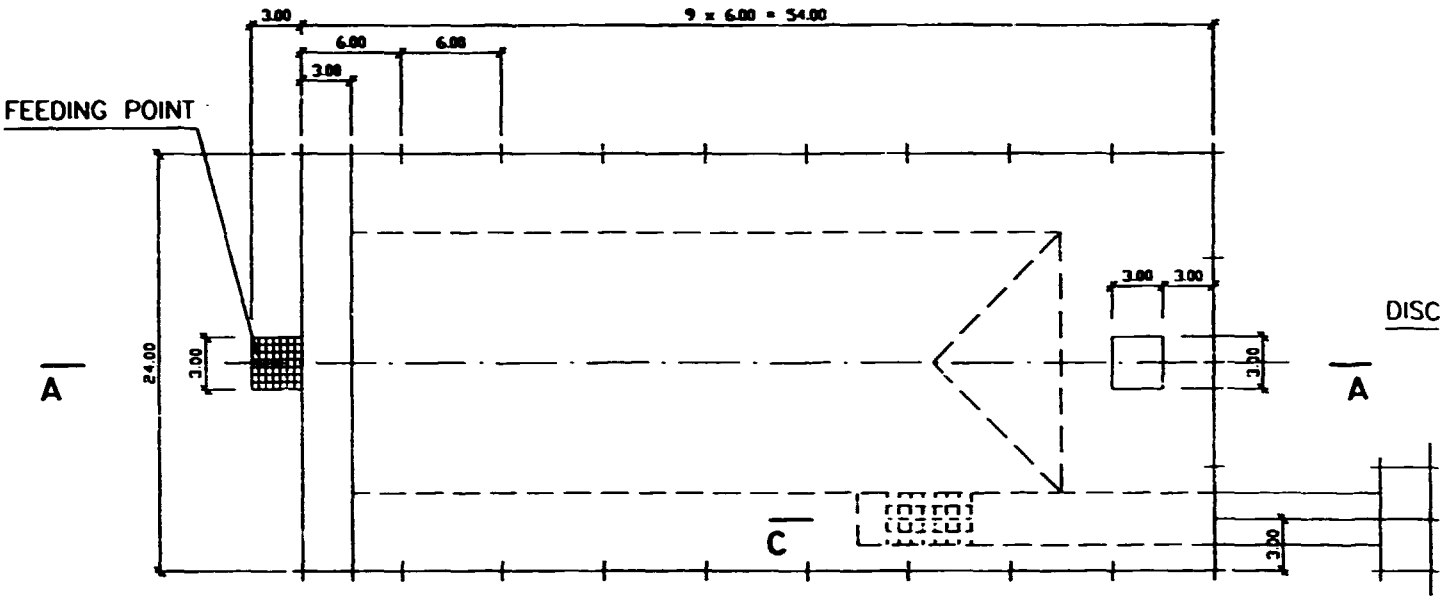
Wykonał			Kier. prac.	Z. Radomski	
Kreślił	POM2.DWG		Gł. proj.		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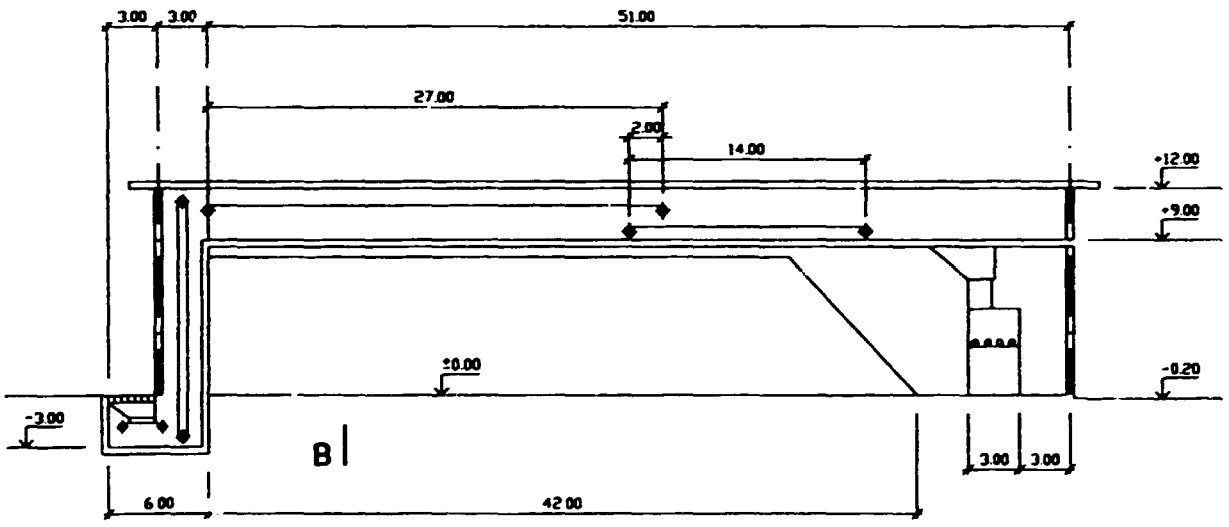
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Doc 1

DISCHARGING POINT

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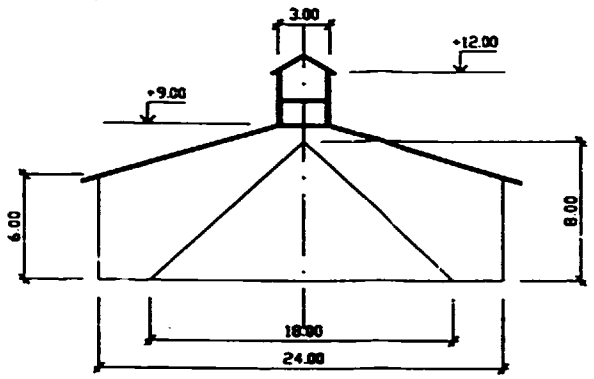

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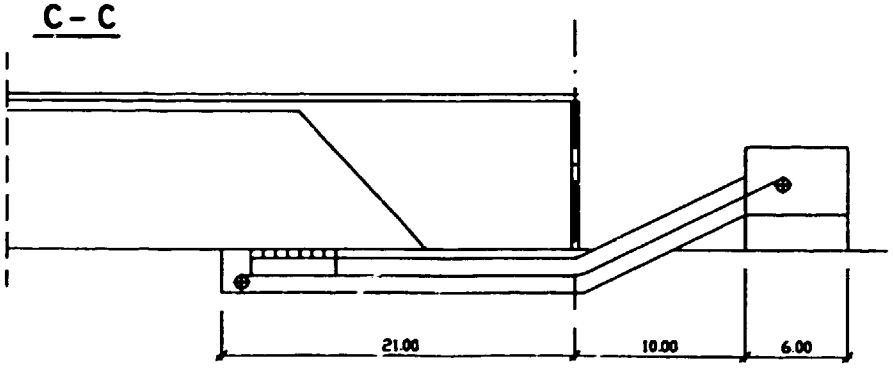

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INDUSTRIAL DEMONSTRATION PLANT OF ELECTRON-BEAM PROCESS FOR FLUE GAS TREATMENT OF THE ELECTRIC POWER STATION "POMORZANY"-SZCZECIN POLAND **BUFFER STORE BUILDING LAYOUT**	Data 09.95.	Podziałka –	Faza	Format A3	Przesłał RK	Cros przech.	
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	Projektował: L.Kosiński			Sprawdził: I. Radomski			
	Wykonał:			Kier. proc.: I. Radomski			
	Kreślił: POM7.DWG			Gł. proj.:			

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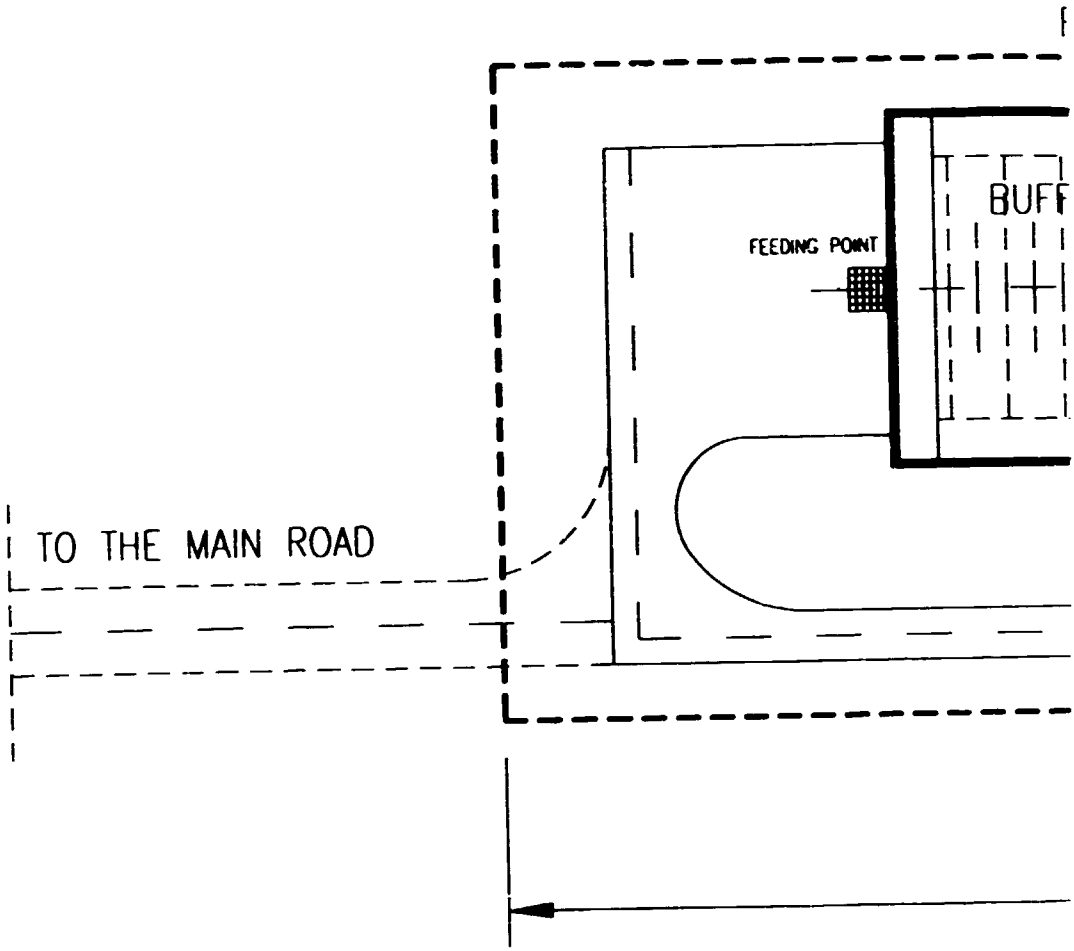

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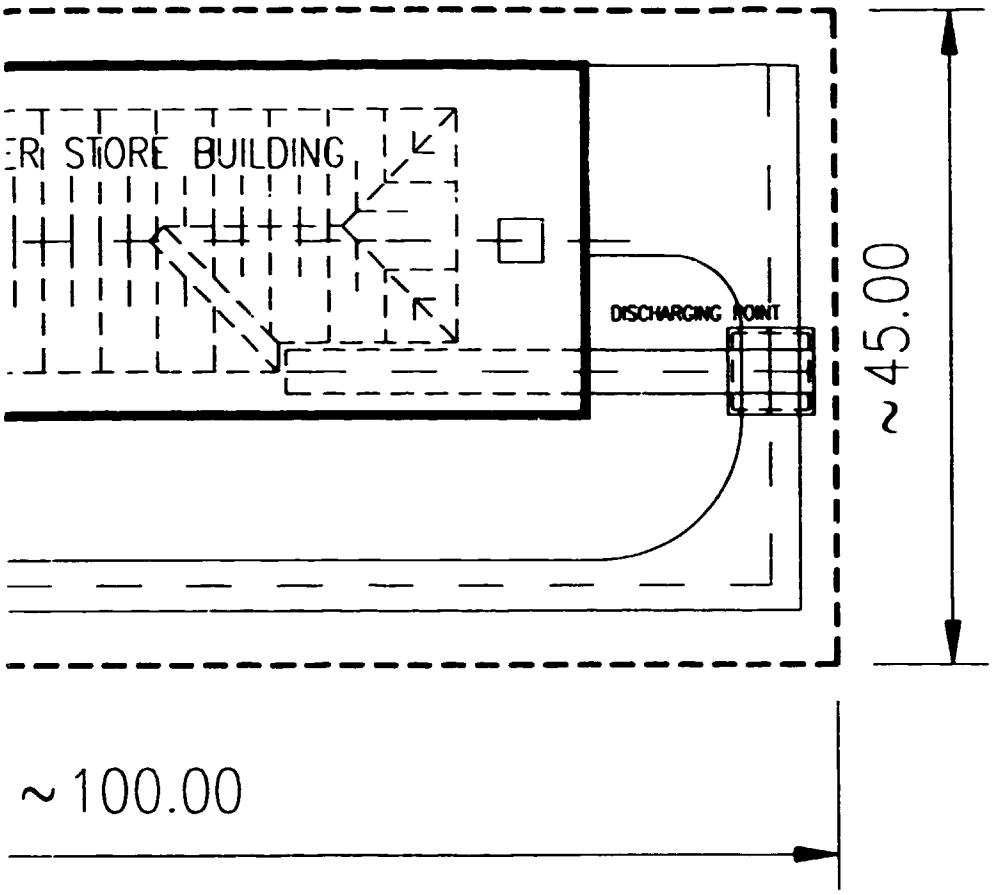

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Architekt

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	Projekt. mgr inż. Zb. Warakomski		Sprawdził	mgr inż. J. Drabczyk		
LAYOUT OF THE AREA OF THE BUFFER STORE BUILDING	Wykonał		Kier. proc.	mgr inż. R. Kołakowski		
	Kreślił		Gł.proj.			

This volume has been prepared by:

Consulting Engineers - Power Engineering Study and Design Company, „Energoprojekt - Warszawa SA"

Engineering Design Of An Electron Beam (EB) Flue Gas Purification Industrial DemonstrationPlant

Basic Engineering.

Volume 7

Flue gas ducts.
Emission of flue gases to atmosphere.

Warsaw, January 1996

No. of Volume	List of Volumes	Author
Volume 0	Executive Summary	
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Volume X	Composite documentation	Energoprojekt-Warszawa
Volume XI	Balances	Energoprojekt-Warszawa

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2. Z.Radomski	Energoprojekt W-wa

ENERGOPROJEKT - WARSZAWA S.A.	Industrial Demonstration Plant of Electron-Beam Process for Flue Gas Treatment at the Electric Power Station "Pomorzany" Szczecin, Poland **Flue gas ducts** **Emission of flue gas to atmosphere**	P-0174 Code	1 131 108 A Achival No
		7 - 3 / 14 Volume - page pages	

Contents

1. Introduction

This Volume covers the flue gas duct system together with selection of auxiliary Induced Draft fan and protection of the existing ducts and stack against corrosion for E-Beam process flue gas treatment in Pomorzany Power Plant.

2. System function. Design criteria

2.1. Flue Gas Data

The flue gas system for E-Beam process of flue gas treatment - shown on the diagram drawing No 1131104 and layout drawings No 1131105÷1131107 - collects part of the flue gas from the two 142,5 MWt Benson boilers at the outlet of Induced Draft Fans and after their cooling and humidification in a spray tower leads them to E-Beam Process Vessels for sulphur and nitrogen oxides removal.

At the outlet of cooling-humidifying tower the ammonia vapour is added to the flue gas to form ammonium salts from the sulphuric and nitric acids produced in the reaction chambers during sulphur dioxide and nitrogen oxide oxidation. From these vessels the flue gases are guided to additional electrostatic precipitator (ESP) for by-product collection and further through the Booster Induced Draft (ID) Fan to a common (for treated and untreated gases) flue gas duct. Mixed in the common flue gas duct gases are further led to the existing concrete stack.

The quantity of flue gas flowing to E-Beam process for treatment for sulphur dioxide and nitrogen oxides removal is foreseen as 270 000 Nm^3/h, constituting 50÷60 % of the maximum amount of gas from two existing 142,5 MWt Benson steam boilers.

It is foreseen that the quantity of flue gas directed to the E-Beam Process will be constant with varying Pomorzany Power Plant load in so far as this operating means able to maintain stack inlet temperature above that required to protect the existing construction from acid attack. When only one boiler is in operation sufficient flue gas will be by-passed to maintain required stack temperature.

Flue gas parameters calculations are made for following coal data :

- heating value	22,8	MJ/kg
- ash contents	21,8	%
- sulphur contents	1	%
- humidity	7,8	%

Water vapour contents of raw wet flue gases was calculated as 42,3 g/kg, which equals 6,9 % vol. flue gas humidity at the inlet to the system.

2.2. Type of Operation

Continuous operation of the system is expected with annual operating time equivalent to 6500 full load hours.
The Pomorzany Power Plant is utilized for co-production of heat and electric power. During peak load in the winter months two additional existing water heating boilers each with the capacity of 139,5 MWt are used for extra heat production. It means that the amount of flue gases cleaned in the E-Beam process vessels changes is a little as 28 % of all flue gases directed to one existing concrete stack 160 m high.

2.3. System Requirements

The flue gas taken for the E-Beam Process Treatment from the common flue gas ducts after the existing induced draft fans is to be cooled to 80°C and humidified to 11% vol. water contents. For intermittant short terms periods but in continuous service will exit at 65°C.

Due to the high initial temperature of raw flue gas from 145 to 170 °C - an average 160 °C, the cooling process by the water evaporation increases the water vapour contents in the flue gas to 11÷12.1 % vol. for nominal operating conditions and to 11÷12.1 % vol. when the flue gas temperature downstream of cooling tower decreases to 65 °C.
After the reaction chambers the flue gases will be extracted from dry powdery ammonium salts. This by-product will be collected by the new electrostatic precipitator.

To provide the necessary pressure head for flue gas flow an auxiliary booster Induced Draft Fan is installed in the system.

3. Operating conditions

3.1. Nominal Parameters

Nominal quantities of flue gas to E-Beam Process vessels is 270 000 Nm^3/h. The flue gas treatment process is foreseen for minimal flue gas flow 150 000 Nm^3/h.

Nominal temperature of flue gas at the inlet to the process vessel is 80°C, but it is possible to run process at temperature range from 65°C to 90°C, for which the protection system of ducts walls is designed.

The amount of water vapour contents in the flue gas directed to the E-Beam process will be no less than 10,5% vol.

In the reaction chambers during the E-Beam process the flue gas temperature increases about 10°C - to 90°C for nominal operating conditions.

By-product dust emission after the by-product electrostatic precipitator (ESP) is required to be no more than 20 mg/Nm^3.

The design pressure of the flue gas ducts was taken as ±350 mm WG.
The flue gas balance sheet flow diagram for nominal operating conditions is shown on the drawing No 1131104.

3.2. Principle of Operation

Flue gas exiting By-product ESP enters auxiliary ID Fan. This fan overcomes Electron Beam system pressure drop and maintaines a negative system pressure.
Flow control is achieved by the fan inlet vanes angle adjustment. The system will be remotely controlled to maintain the required flue gas flow.
To maintain the minimum flue gas temperature in the existing stack for the mixture of raw and treated gases the flow of flue gas through the tratement system will be limited to the amount for which the gas mixture temperature will be no less than 110 °C.

The flue gas temperature downstream of the cooling-humidificating tower will be controlled changed by water delivering control valve according to temperature indication.
Water vapour contents in the flue gas will not be controlled but measured by humidity indicator.

For sulphur and nitrogen oxides removal from the flue gases is necessary to provide ammonia feed vapour to the flue gas ducts after the cooling-humidificating tower. The ammonia contents will be regulated by special control system actuating the control valve in the ammonia delivery pipeline.

Start and shutdown of the process system together with the emergency stop is foreseen by on/off booster fan operation. Shut-off dampers at the system inlet and outlet are intended only to afford maintenance.

4. System description

4.1. Flue Gas Ducts and Auxiliaries

The flue gas duct system is designed from carbon steel sheets with necessary anticorrosive lining. The system will be equipped with auxiliaries as shut-off dampers, expansion joints, dust hoppers, access doors, measuring nozzles, thermal insulation, supports, etc.

Because of the expected sulphur trioxide contents in the flue gas after cooling-humidifying tower for water vapour contents (about 11% vol.) and low flue gas temperature, the special protection lining system in the duct downstream of the tower to E-Beam process vessels is designed.

The amount of SO_3 in the treated flue gas is specified as below 0,1 mg SO_3/Nm^3. One ppm of SO_3 will cause an acid point of 110°C. The equilibrium condensing acid is directly related to the surface temperature and ranges from 50 to 70 % at 80°C. For anticorrosive protection of this duct synthetic resin lining will be applied with the glass fibre flakes as an additives for the resin.

In the reaction chambers the sulphur trioxide combines with the ammonia to form ammonium salts. The amount of sulphur trioxide after the E-Beam Process Vessels is specified as less than 0,1mg/Nm^3, what is equivalent to 0,03 ppm. For this amount of SO_3 the dewpoint temperature can be estimated as 55÷65°C results mainly from water vapour contents in the gas. For this reason the ducts downstream of the reaction chambers are not designed to be anticorosive protected by special lining.

In connecting part of the raw and treated flue gas ducts, the clean and contamined gases are mixed to form the homogeneous temperature gas with sulphur dioxide contents to 1000 mg/Nm^3. The mixing gas duct element will be constructed with special turning and splitter vanes made of stainless steel and internal walls protection synthetic resin lining. Similar protection will be made for duct downstream of the mixing element to the existing stack.

The concrete stack will be exposed to the mixture of raw and treated gases. For nominal flue gas flows from two Benson boilers only (without the operation of the water boilers) the gas temperature in the stack will be about 112-118°C.

Due to the applied flue gas treatment principle of operation for which the flue gas mixture temperature at the stack inlet will be no less than 110°C, the existing stack is not planned to be protected by special lining.

The design layout of the flue gas ducts system including cooling tower and by-product ESP, shown on the drawings No 1131105÷7, was designed in the way to fulfill the requirements of E-Beam process, enable easy access to system devices and ducts and achieve minimal pressure drop in the system.

4.2. Fan selection

Booster ID-Fan, which produces the necessary total dynamic head to overcome gas drop of the treatment system, is positioned downstreem the by-product ESP. The fan is specified for the calculated pressure drop of the system with the maximal quantity of flue gas the coresponding gas temperature and density.

Double inlet centrifugal type fan design is selected, with two-speed motor drive and inlet control guide vanes.

4.3. Power Consumption

The power consumption of the flue gas ducts is reflecting power used in Booster fan operation.

The average hour electricity consumption for the selected fan the is calculated as **470 kWh.**

5. Scope of supply

The E-Beam process flue gas ducts system comprises untreated and treated gas ducts including auxiliary booster induced draft fan between the outlet and inlet flanges of the existing collecting flue gas duct.

The system includes the following ducts:

- untreated flue gas duct from the outlet of collecting duct after the boilers induced draft fans to the flue gas inlet to cooling-humidifying tower,
- ducts with cooled and humidified flue gas ducts from the outlet of cooling-humidifying tower to E-Beam reaction chambers,
- treated flue gas ducts with by-product dust from the outlet of E-Beam reaction chambers to the inlets of by-product electroprecipitator,
- flue gas ducts from the outlets of by-product electroprecipitator to the inlet of auxiliary ID fan,
- flue gas ducts from the outlet of auxiliary ID fan to the inlet flange of common flue gas ducts in the vicinity of existing stack.

The flue gas ducts system also comprises

- the mixing element that combines raw and treated flue gases,
- required expansion joints, flue gas dampers, turning vanes and splitter vanes, access door frames for maintenance, supports, flanges, sealing and fixing parts, dust hoppers, measuring nozzles, condensate removal system, etc.,
- thermal insulation of ducts,
- means of cleaning and washing ducts.

Anticorrosive protection of ducts which is described in the point 5.3.

Detailed Technical Specification

5.1.1. Untreated flue gas duct from the outlet of existing collecting duct to the inlet to cooling-humidificating tower.

The operating conditions of the duct in the first part of the duct system are similar as in the existing ducts. The flue gas is hot - above its acid dewpoint.

The duct will be made from 6 mm thick carbon steel plate and stiffened with structural steel; the duct inside walls will not be anticorrosive protected by special lining.

The duct dimensions was calculated as 2,8 x 2,7 m, for which the gas velocity will be 15,7 m/s at full load.

The layout of the duct was designed to counteract flow disturbances in the common flue duct. In the first part of the designed duct its cross-section will be enlarged to the dimensions of the existing common flue gas duct for full flow of gases from two boilers. Further the duct cross-section will be reduced to the required size. A duct shut-off damper inserted in flue gas duct permits isolation of the gas treatment system from the common duct after the existing ID fans.

5.1.2. Cooled and humidified flue gas ducts from the outlet of cooling-humidificating tower to the E-Beam reaction chambers.

The flue gases removed from the cooling-humidificating tower are cooled to the temperature 80^{o}C and humidified to 11÷12 % vol., that is below the acid dewpoint. It is necessery to provide anticorrosive protection of the flue gas ducts between the cooling tower and reaction chambers.

The duct will be made from 6 mm thick carbon steel plate and stiffened with structural steel. The duct inside walls will be anticorrosive protected by synthetic resin lining.

The duct dimensions was calculated as 2,7 x 2,6 m for which the gas velocity will be 14,5 m/s at nominal system load.

5.1.3. Treated flue gas ducts with by-product dust from the outlet of E-Beam reaction chambers to the inlets of by-product electroprecipitator.

Between the reaction chambers and by-product electroprecipitator the flue gas ducts will work in conditions of desulphurized gas flow with by-product dust and high water contents. The duct walls are exposed for flue gas flow with very low sulphur trioxide contents of and wet by-product dust what may cause some problems because of stick properties of by-product.
For this reason it is planned only the cleaning-washing system for ducts walls or special slide lining choosen exactly for the by-product physical properties to eliminate the sticking of by-product to the duct walls.

The gas velocity was selected so as to limit the settlement of by-product in the ducts.

The duct will be made from 6 mm thick carbon steel plate and stiffened with structural steel.

The duct dimensions was calculated as 2,6 x 2,5 m for which the gas velocity will be 16,5 m/s at nominal system load.

5.1.4. Flue gas ducts from the outlets of by-product electroprecipitator to the inlet of booster ID fan.

Downstream of the electroprecipitator (ESP) the ducts will be exposed on similar operating conditions as upstream but with small contents of dust - about 20 mg/Nm^3.

The ducts will be made from 6 mm thick carbon steel plate and stiffened with structural steel. The duct walls will be not inside anticorrosive protected by special lining.

The dimensions of two ducts between ESP and ID-fan was calculated as 2,4 x 1,8 m for which the gas velocity will be 12,4 m/s at nominal system load.

5.1.5. Flue gas ducts from the outlet of auxiliary ID fan to the inlet flange of common flue gas ducts in the vicinity of existing stack.

The operating conditions of ducts are the same as between ESP and booster ID-fan.

The duct will be made from 6 mm thick carbon steel plate and stiffened with structural steel. The duct walls will be not inside anticorrosive protected by special lining

The duct dimensions was calculated as 2,8 x 2,8 m for which the gas velocity will be 13,6 m/s at nominal system load.

5.1.6. Common flue gas duct of raw and treated gases

The mixer of raw and treated gases will be specially designed to assure rapid and adequate mixing of two flows. The mixer element and common flue gas duct to the stack will be anticorrosive protected.

5.1.7. Expansion joints

Fabric expansion joints, high chemical resistance, for compensation of axial and lateral movements of the flue gas ducts are predicted. The expansion joints consist of several layer of material - the textile carrier (base structure) and coating (flexible and tight) - which protects the textile carrier.

5.1.8. Auxiliaries

- adequate access ports with locking clamps (clear width min. 800 mm) for entering ducts are foreseen,
- measuring nozzles for the necessary inspection measurements,
- condensate removal system from the ducts,
- shut-off dampers with auxiliaries,
- required ladder/staging for maintenance work ,
- turning vanes and splitter vanes to streamline the flow,
- by-product hoppers with capacity not less than 8 and everly distribute hours storage equipped with pipe connection for attaching to by-product removal piping system,
- thermal insulation consist of glass wool coating with the required support structure; the casing will be made of aluminium plates,
- surface protection against atmospheric corrosion a corrosion-proof lining is applied to the sandblasted internal surface,
- supporting steel structures, platforms, galleries, stairways, ladders and walkways which conform the Polish Civil Engineering Standards; the supporting steel structure will be designed to carry all live and dead loads and temperature stresses, including loads from access platforms, walkways etc.

5.2. Booster Fan

Double inlet centrifugal type fan was selected as Booster Induced Draft Fan. Selected fan is destined to the boiler flue gases at maximal temperature 150^0C and dust contents to 500 mg/Nm^3.
The fan will be equipped with two speed motor drive, double inlet control vanes with control unit, bearing system, foundation bolts and nuts, inlet boxes, coupling and coupling guard.

Selected fan is produced by FAWENT - POLAND, type WPWD-160/1,4C

The concrete foundation will be constructed separately according to the fan requirements and ground conditions.

Fan technical data

flow rate	m^3/s	104
density	kg/m^3	1,25
flue gas temperature	^{0}C	65
flue gas max. temperature	^{0}C	110
total fan pressure head	Pa	2600
efficiency	%	80
power required at fan shaft	kW	440
nominal speed	min^{-1}	735/585
drive motor		
motor power	kW	550/300
motor speed	min^{-1}	735/585
fan weight (without motor)	kg	19 300
motor weight	kg	4 500

5.3. Surface Protection

The one flue gas duct according to specification in the point 5.1. will be anticorrosive protection lined with the reinforced synthetic resin. The lining in the ducts will be applied by spraying to reduce the lining cost.

Due to possible high flue gas temperature in the duct system the vinylester resins are foreseen. The glass fibre in form of flakes will be used as an additives for the resin, what also improves the ruggedness and antidiffusivity of the lining.

5.4. Stack Refurbishment

Refurbishment of existing stack H=160 m made from reinforced concrete with inner brick lining is not foreseen. The stack shaft from the lining side should be only repaired and it is planned the everly-year inspection of the stack inner lining.

5.5. Engineering and Services

For the erection and assembly flue gas system project the following parts of engineering and services will be performed

- calculations of the system working parameters,
- design of all parts gas ducts system,
- working drawings, manuals and as build documentation,
- erection and assembly principles,
- technical supervision and testing

6. List of equipment

6.1. Commercial equipment

Booster ID Fan

The fan supplier FAWENT -POLAND, marking type of fan - WPWD-160/1,4C

Double inlet centrifugal type fan in service with boiler flue gas at maximum temperature 150°C and dust contents to 500 mg/Nm^3.

The fan is equipped with two speed motor drive, double inlet control vanes with control unit, bearing system, foundation bolts and nuts, inlet boxes, coupling and coupling guard.

Fan technical data

flow rate	m^3/s	104
total fan pressure head	Pa	2600
gas density	kg/m^3	1,25
flue gas temperature nom./max	°C	65/110
fan efficiency	%	80
nominal speed	min-1	735/585
drive motor power	kW	550/300
fan weight (without motor)	kg	19300
motor weight	kg	4 500

6.2. Non-commercial equipment

6.2.1 Flue gas ducts

Flue gas ducts carbon steel plates made of with reinforcement from structural steel

the ducts' surface	approx.	2500	m^2
the ducts' weight	approx.	250	ton

6.2.2. Flue gas ducts supporting structure

the supporting structure weight	approx.	50	ton

6.2.3. Flue gas ducts expansion joints

fabric expansion joints	approx. quantity	15	off

6.2.4. Flue gas ducts shut-off dampers

motor operated louvers type dampers	2800x2700 mm	2	off
hand operated louvers type dampers	∅ 1900 mm	4	off

6.2.5. Flue gas ducts heat insulation

thermal insulation consist of glass wool coating with the required support structure and casing with aluminium plates;

the insulation thickness	approx.	120/70 mm

6.2.6. Flue gas ducts anticorrosive insulation

The flue gas ducts anticorrosive protection insulation will be made from the reinforced synthetic vinylester resin with the glass fibre flakes.

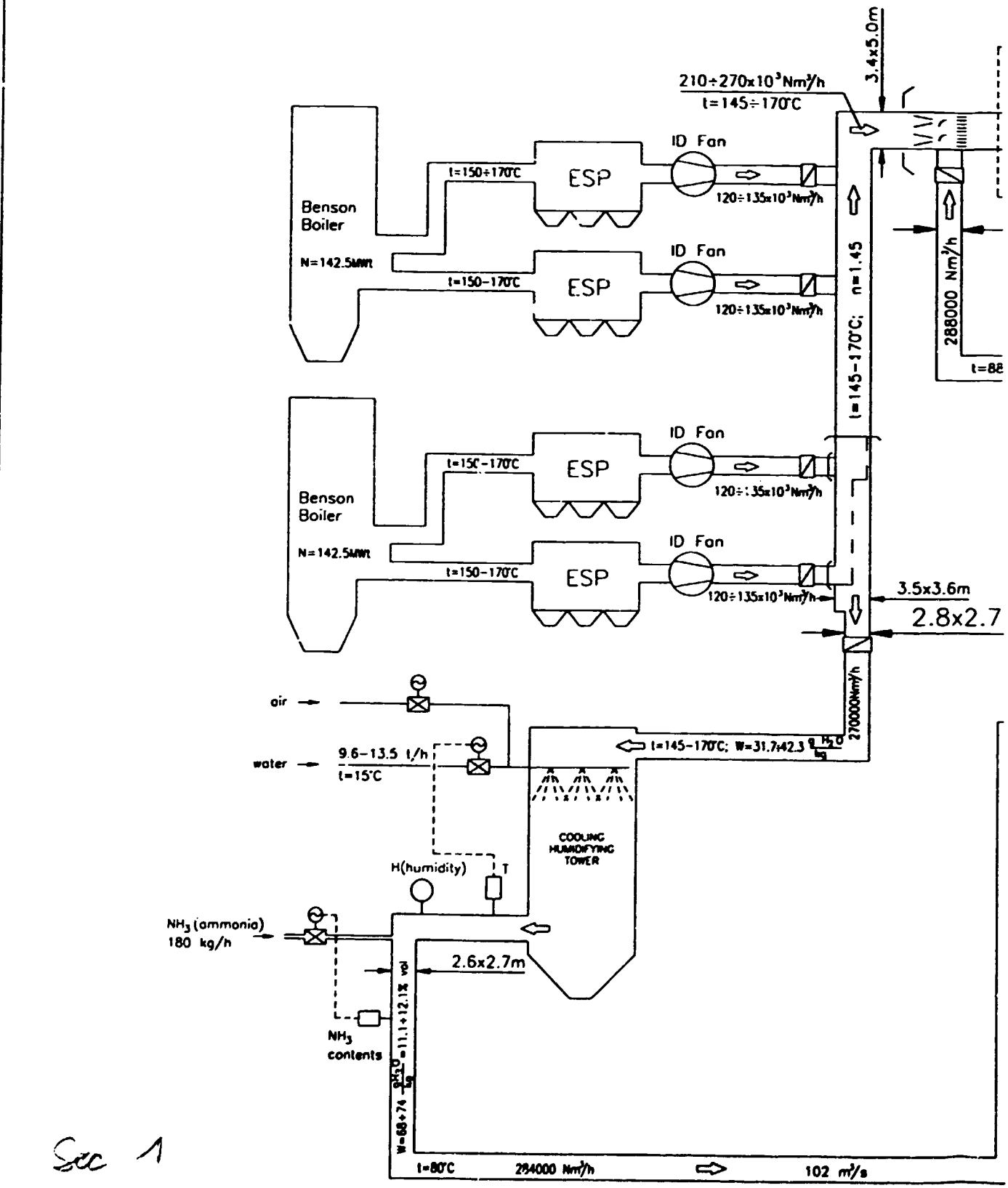
6.2.7. Flue gas ducts supporting structure foundations

Monolith concrete supporting structure foundations are planned of total volume 200 m^3

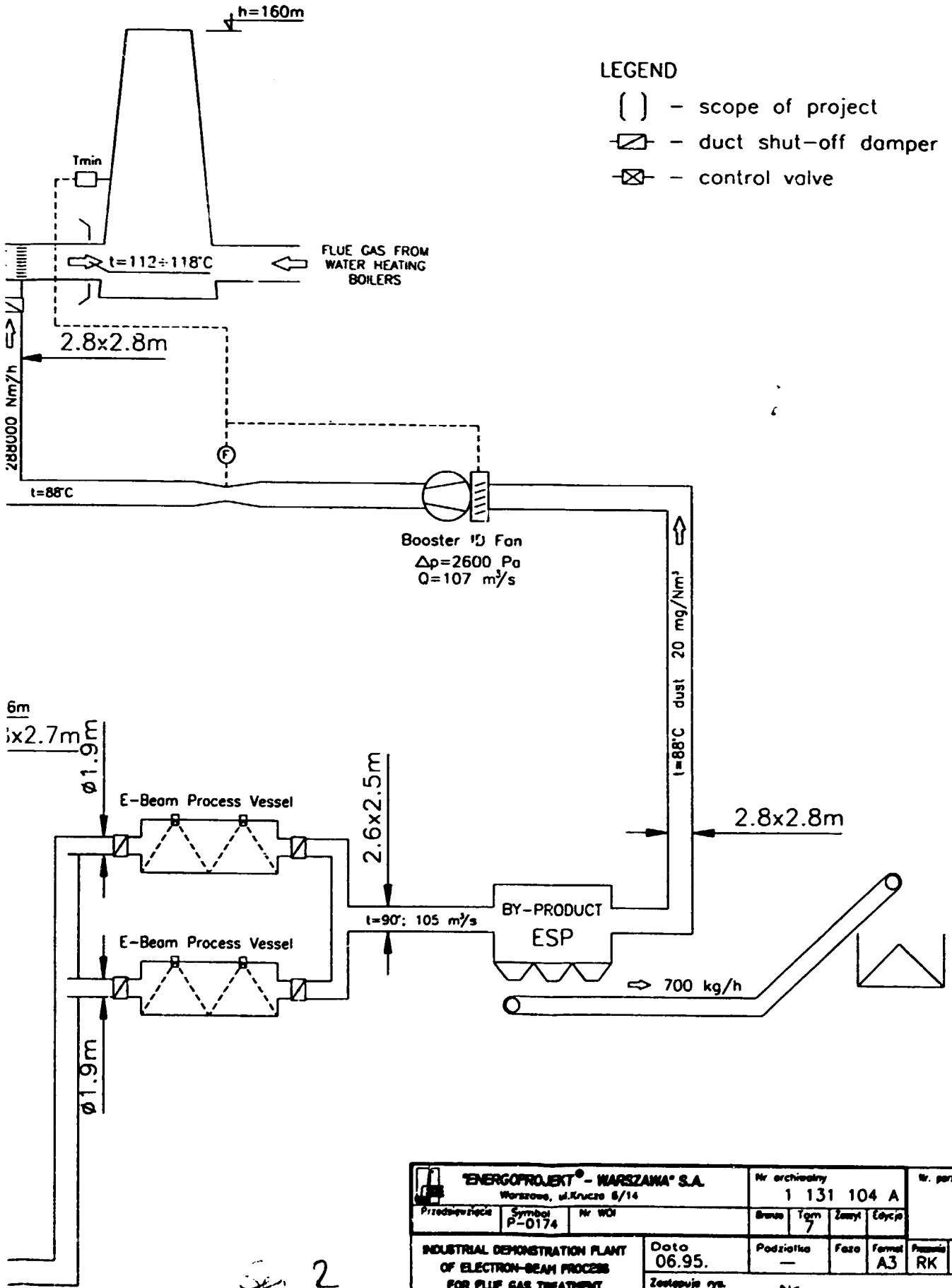
6.2.8. Fan foundation

Fan foundation will be designed individually from monolith concrete.
The approximate volume of fan foundation was calculated as 60 m3

6.2.9. Stack refurbishment according to point 5.4.


210÷270x10³Nm³/h
t=145÷170°C
3.4x5.0m
Benson Boiler
N=142.5MWt
t=150÷170°C
ESP
ID Fan
120÷135x10³Nm³/h
t=150-170°C
Benson Boiler
N=142.5MWt
t=150-170°C
ESP
ID Fan
120÷135x10³Nm³/h
t=145-170°C; n=1.45
288000 Nm³/h
t=88
3.5x3.6m
2.8x2.7
270000Nm³/h
air
water
9.6-13.5 l/h
t=15°C
t=145-170°C; W=31.7÷42.3 g H₂O/kg
COOLING HUMIDIFYING TOWER
H(humidity)
T
NH₃ (ammonia)
180 kg/h
2.6x2.7m
NH₃ contents
W=68÷74 g H₂O/kg
=11.1÷12.1% vol
t=80°C
294000 Nm³/h
102 m³/s

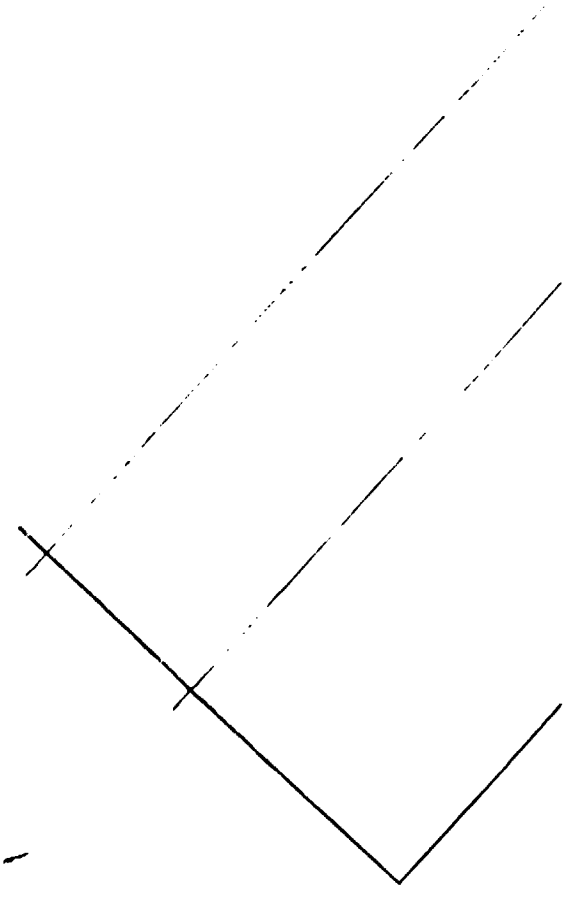
Sec 1



"ENERGOPROJEKT"® – WARSZAWA" S.A. Warszawa, ul.Krucza 6/14			Nr archiwalny 1 131 104 A				Nr. perz. w tomie 1
Przedsięwzięcie	Symbol P–0174	Nr WOI	Branża	Tom 7	Zeszyt	Edycja	
INDUSTRIAL DEMONSTRATION PLANT OF ELECTRON-BEAM PROCESS FOR FLUE GAS TREATMENT OF THE ELECTRIC POWER STATION "POMORZANY" – SZCZECIN POLAND FLUE GAS DIAGRAM	Data 06.95.		Podziałka —	Faza	Format A3	Przesłał RK	Czas przech.
	Zastępuje rys. Zastąpiony przez rys.		Nr				
	Projektował	J. Raszkowski		Sprawdził	Z. Radomski		
	Wykonał			Kier. prac.	Z. Radomski		
	Kreślił	POM1.DWG		Gł. proj.			

2

Sec 1



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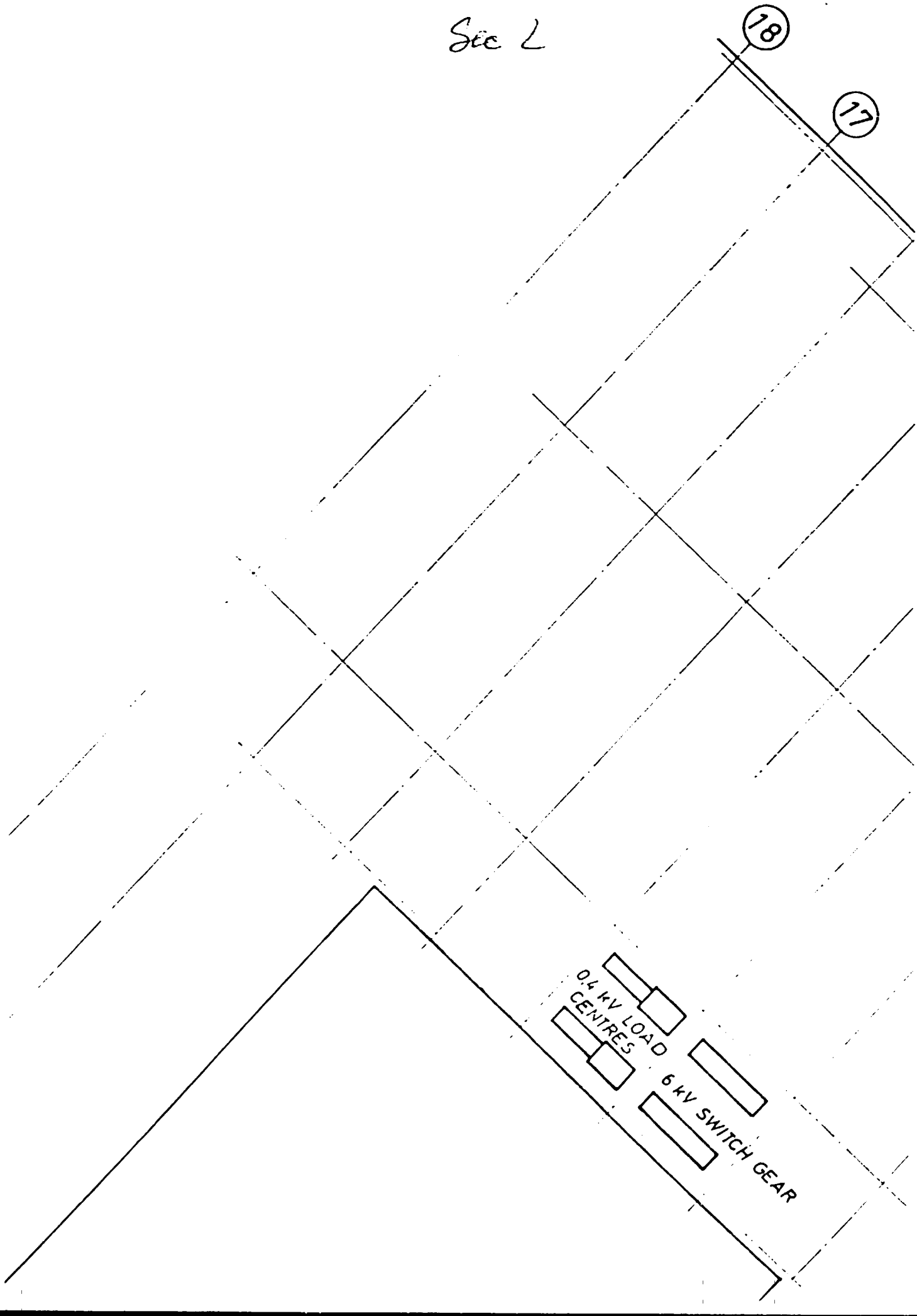

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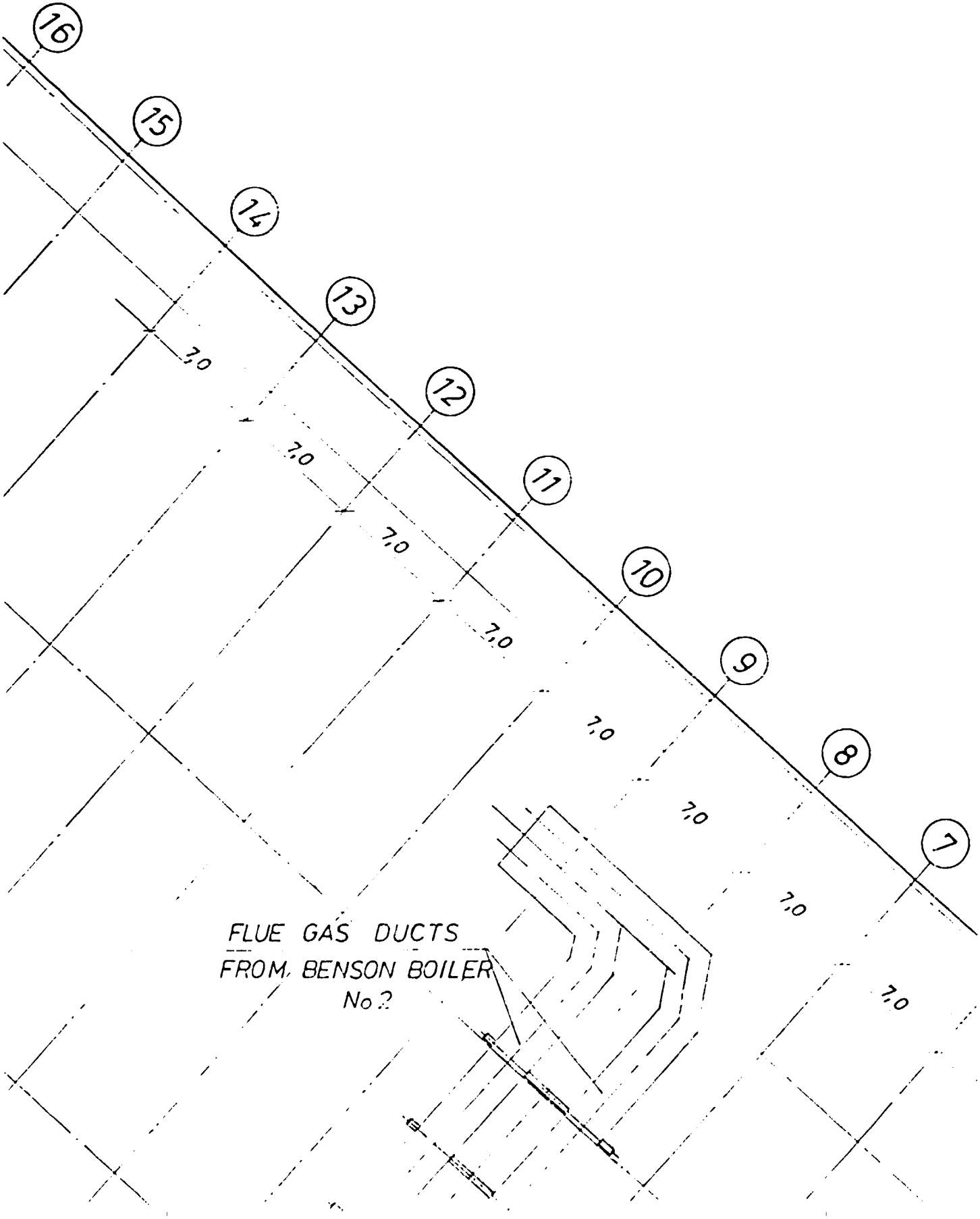
16
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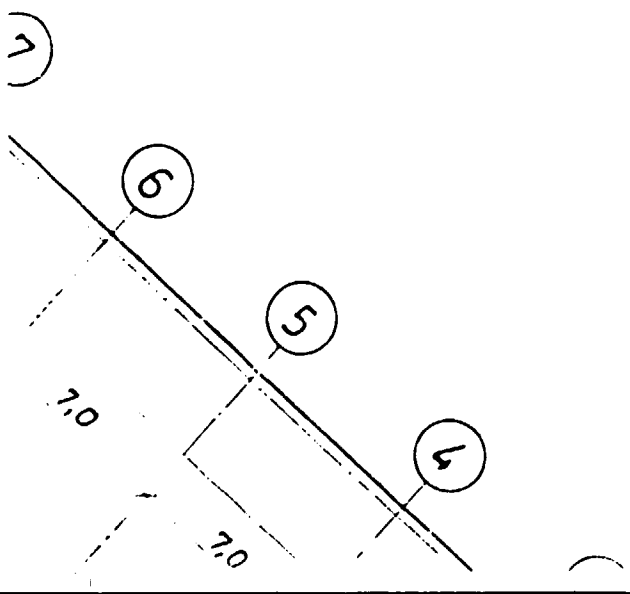
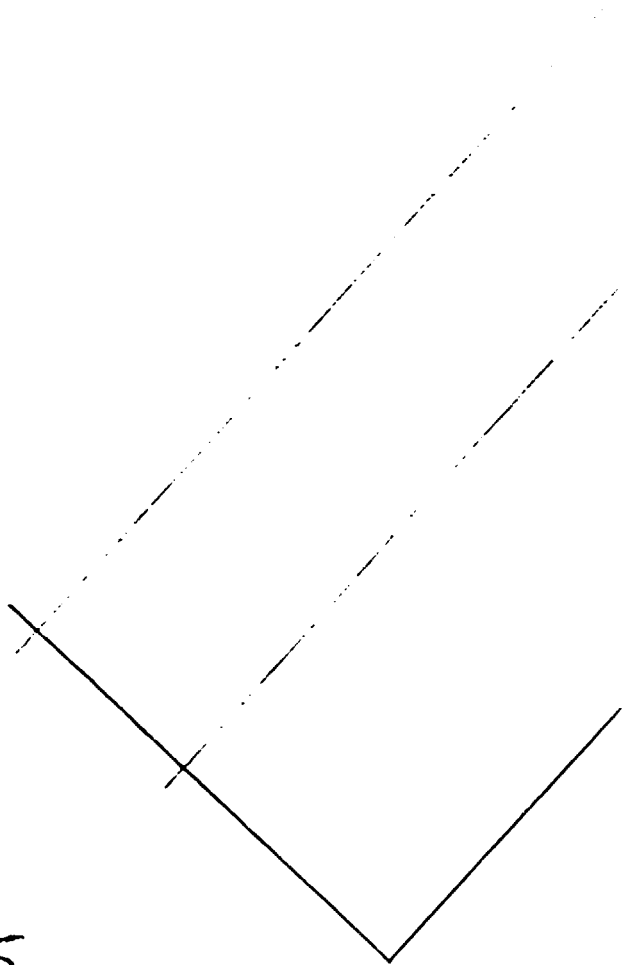
FLUE GAS DUCTS
FROM BENSON BOILER
No 2

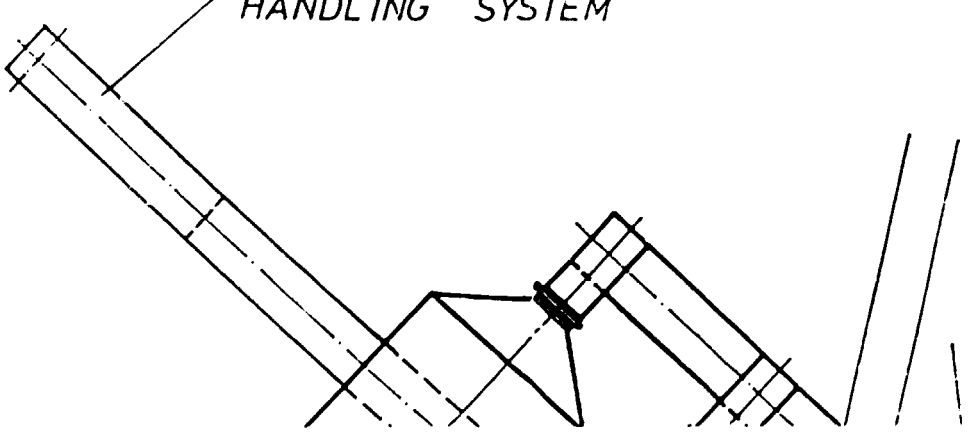
Sec 4

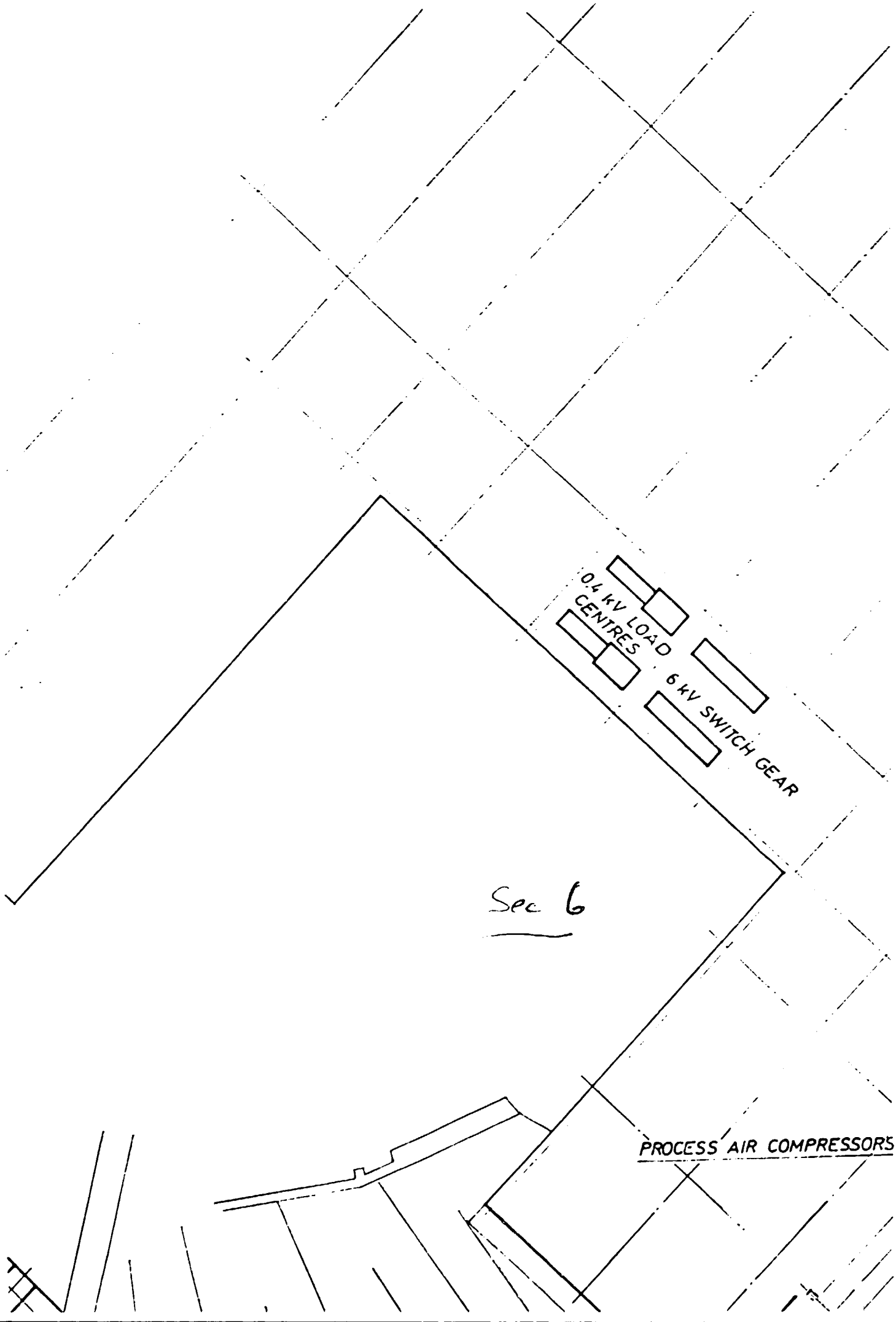


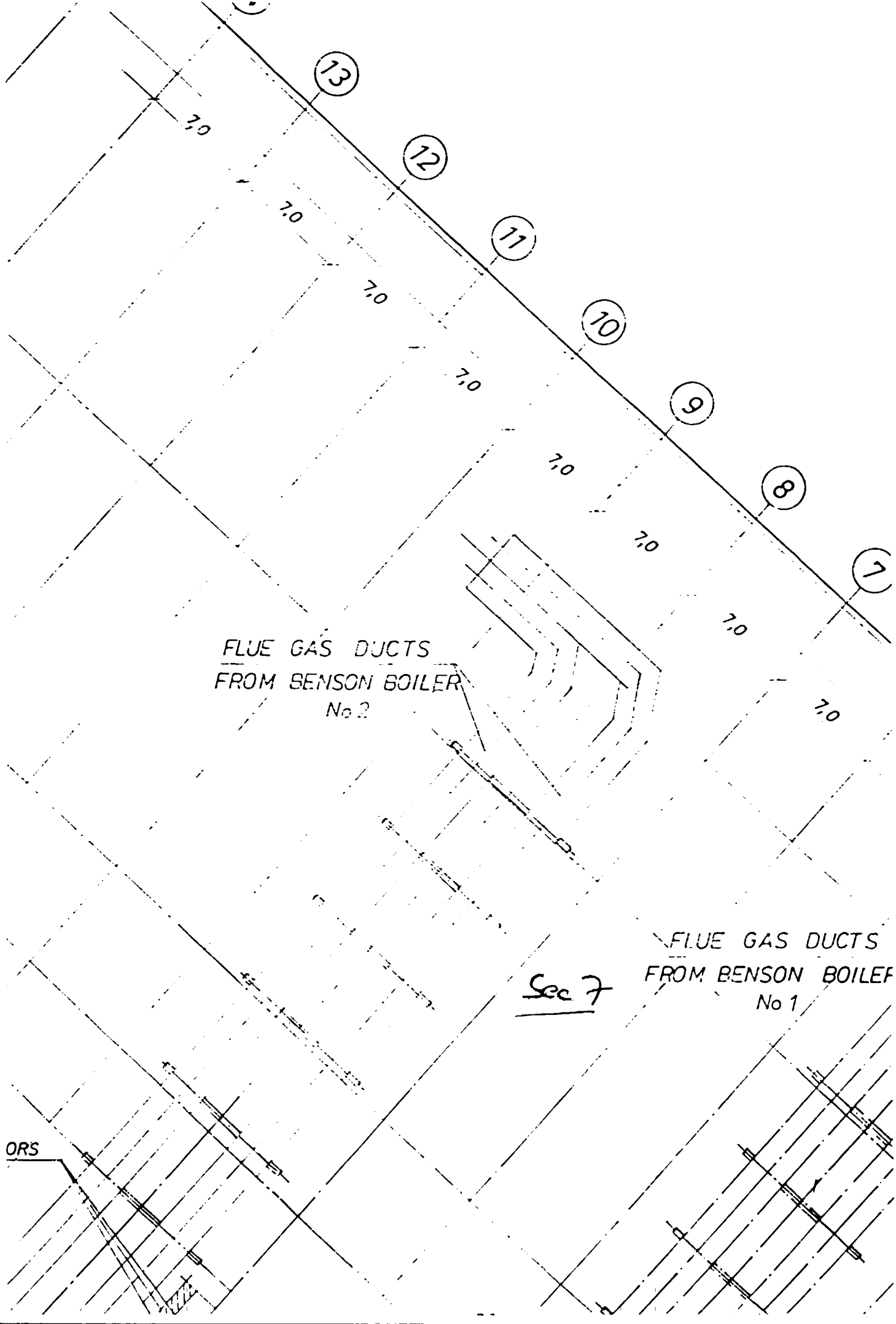


Sec 5

BY – PRODUCT
HANDLING SYSTEM




0.4 kV LOAD CENTRES
6 kV SWITCH GEAR
Sec 6
PROCESS AIR COMPRESSORS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FLUE GAS DUCTS
FROM BENSON BOILER
No 2
FLUE GAS DUCTS
FROM BENSON BOILER
No 1
Sec 7
ORS

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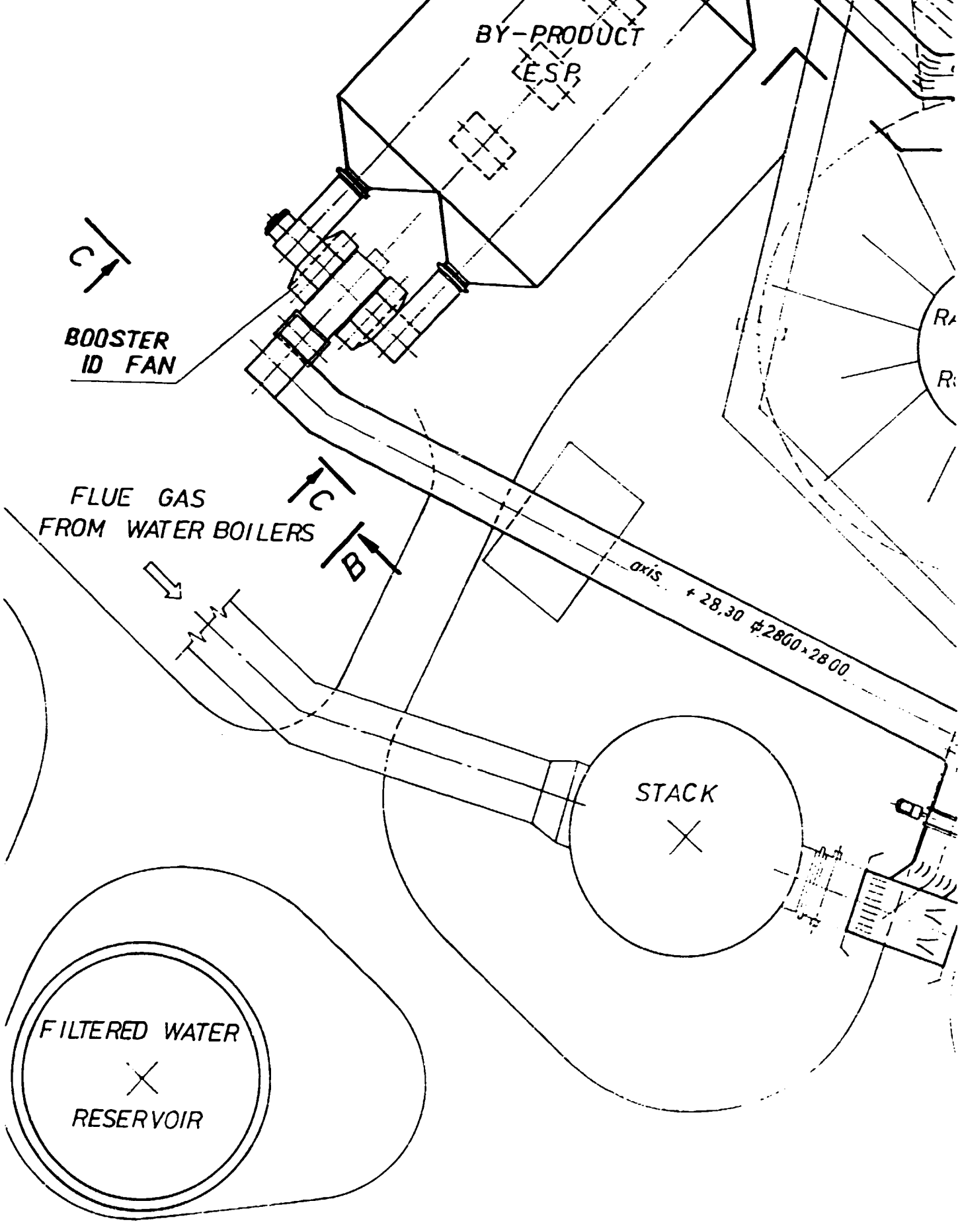
BY-PRODUCT
E.S.P.
C
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FLUE GAS
FROM WATER BOILERS
C
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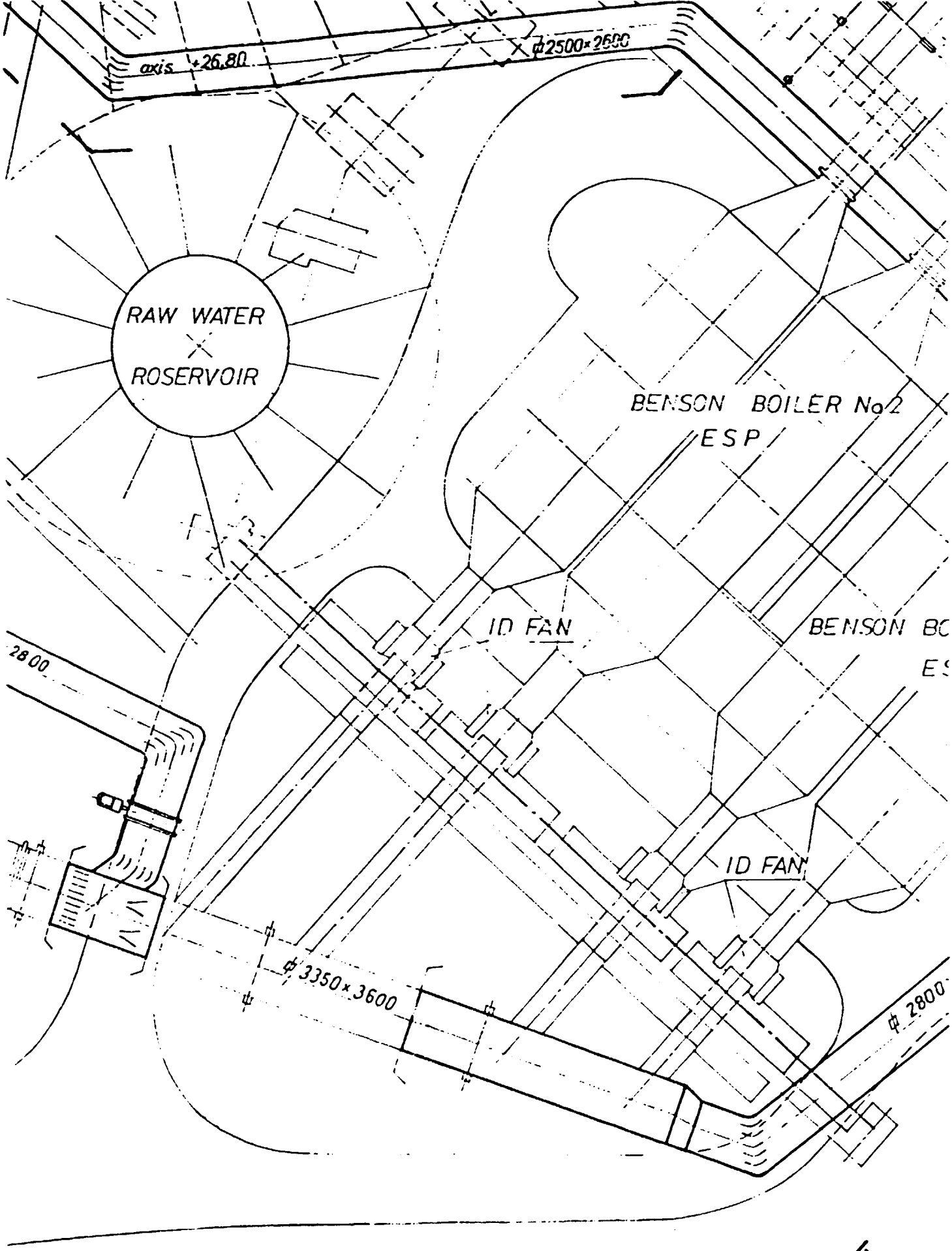
STACK
FILTERED WATER
RESERVOIR

Sec 9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φ2500×2600
RAW WATER
RESERVOIR
BENSON BOILER No2
ESP
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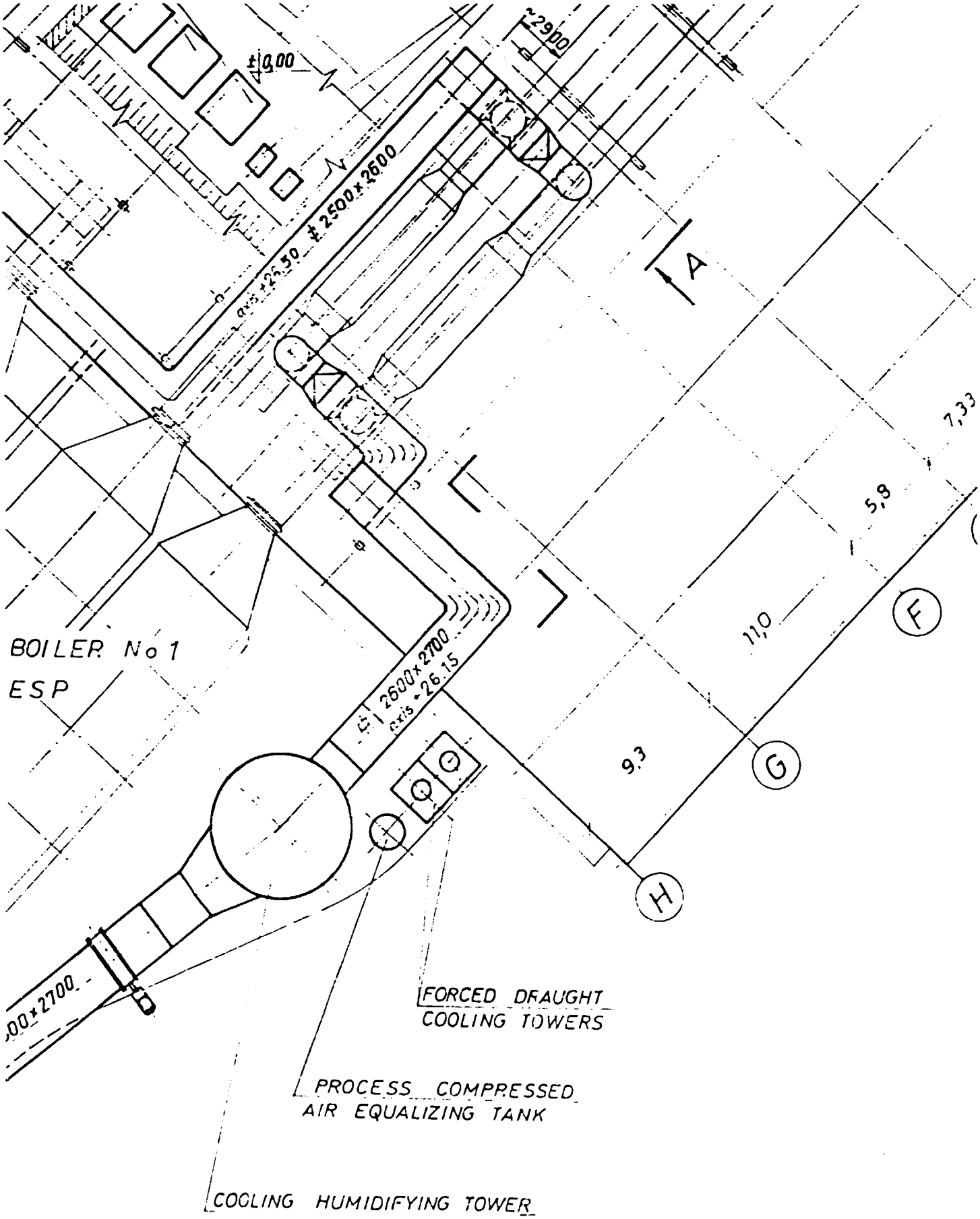
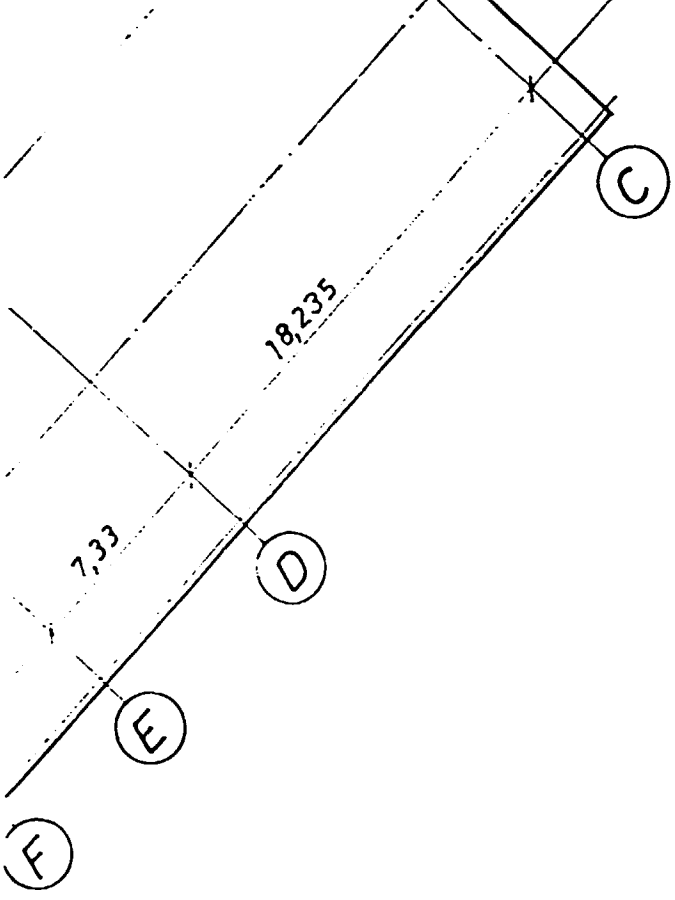
BENSON BC
ES
2800
ID FAN
φ3350×3600
φ 2800
A

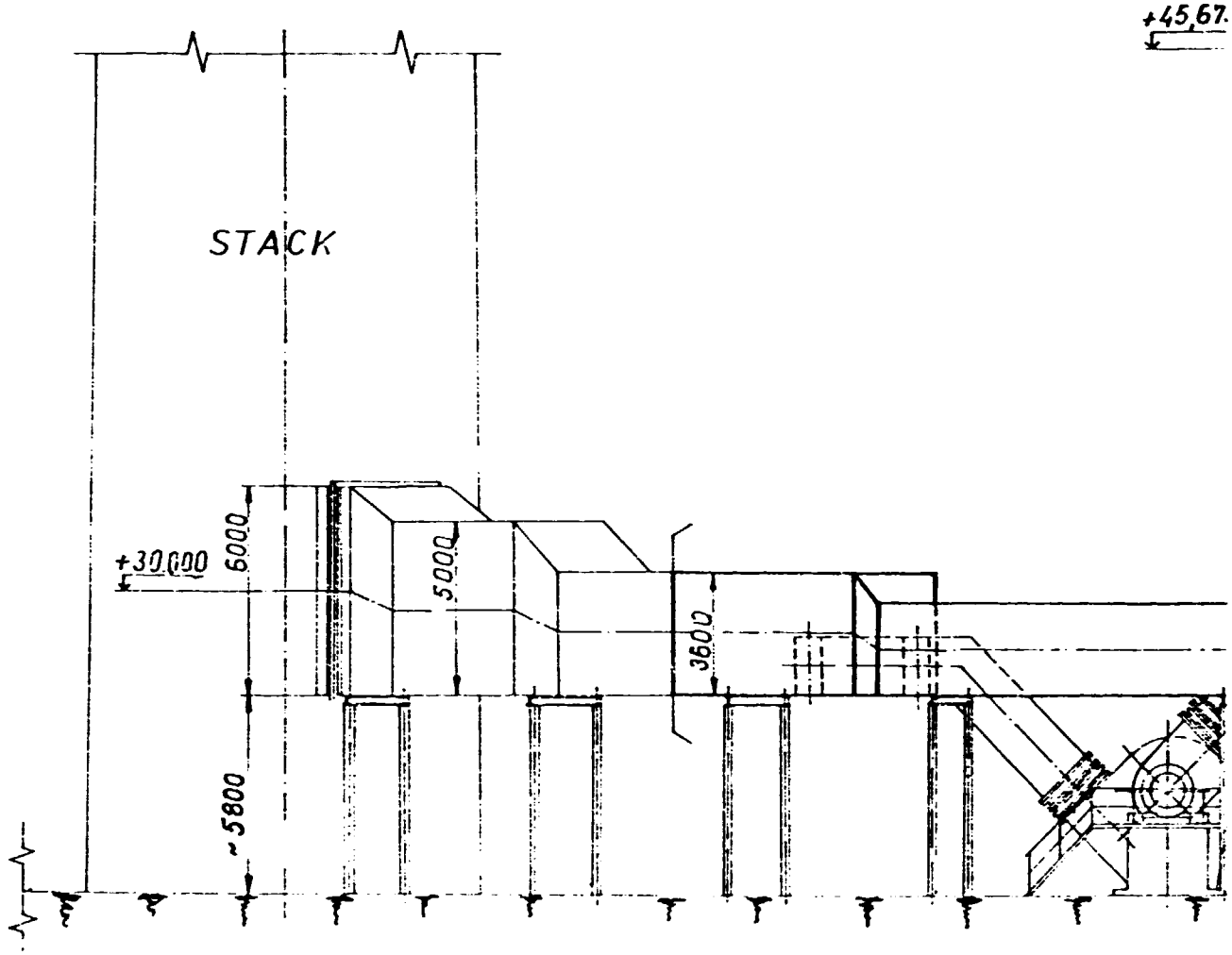
Sec 10


±10.00
2900
±2500×2600
axis +26.50
A
7,33
5,9
11,0
F
BOILER No 1
ESP
2600×2700
axis +26.15
9.3
G
H
FORCED DRAUGHT
COOLING TOWERS
PROCESS COMPRESSED
AIR EQUALIZING TANK
COOLING HUMIDIFYING TOWER



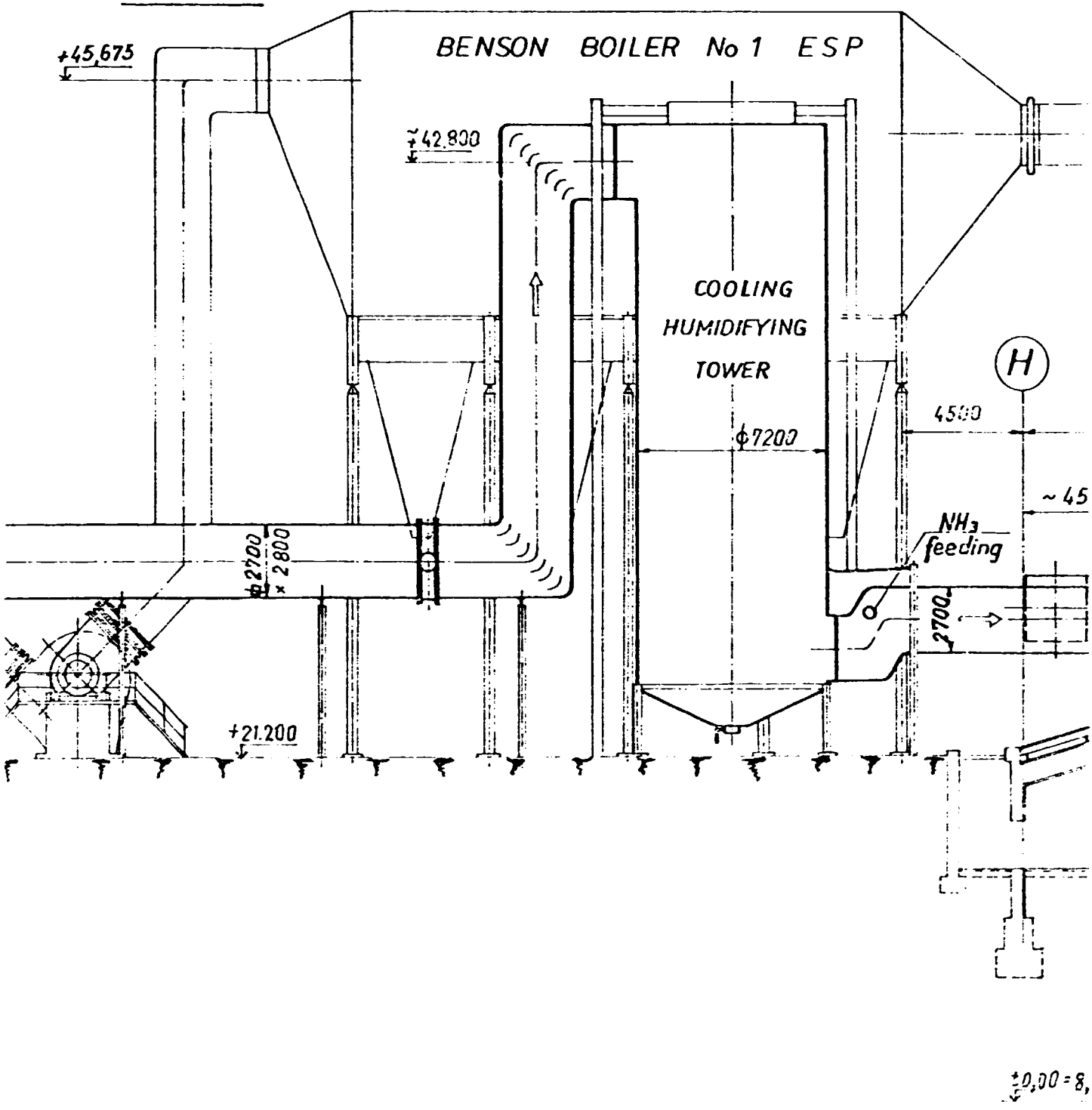
Sec 12

"ENERGOPROJEKT®- WARSZAWA" S.A. Warszawa, ul.Krucza 6/14			Nr archiwalny 1 131 105				Nr. porz. w tomie 2
Przedsięwzięcie	Symbol P-0174	Nr WOI	Branża	Tom 7	Zeszyt	Edycja	
INDUSTRIAL DEMONSTRATION PLANT OF ELECTRON-BEAM PROCESS FOR FLUE GAS TREATMENT OF THE ELECTRIC POWER STATION "POMORZANY"-SZCZECIN POLAND GENERAL LAYOUT	Data 06.95.		Podziałka 1:250		Faza	Format A1	Pracownia TR
Zastępuje rys. Zastąpiony przez rys.			Nr				
Projektował	J. Roszkowski		Sprawdził	Z. Radomski			
Wykonał			Kier. prac.	Z. Radomski			
Kreślił			Gł. proj.				



SEC 1

A — A



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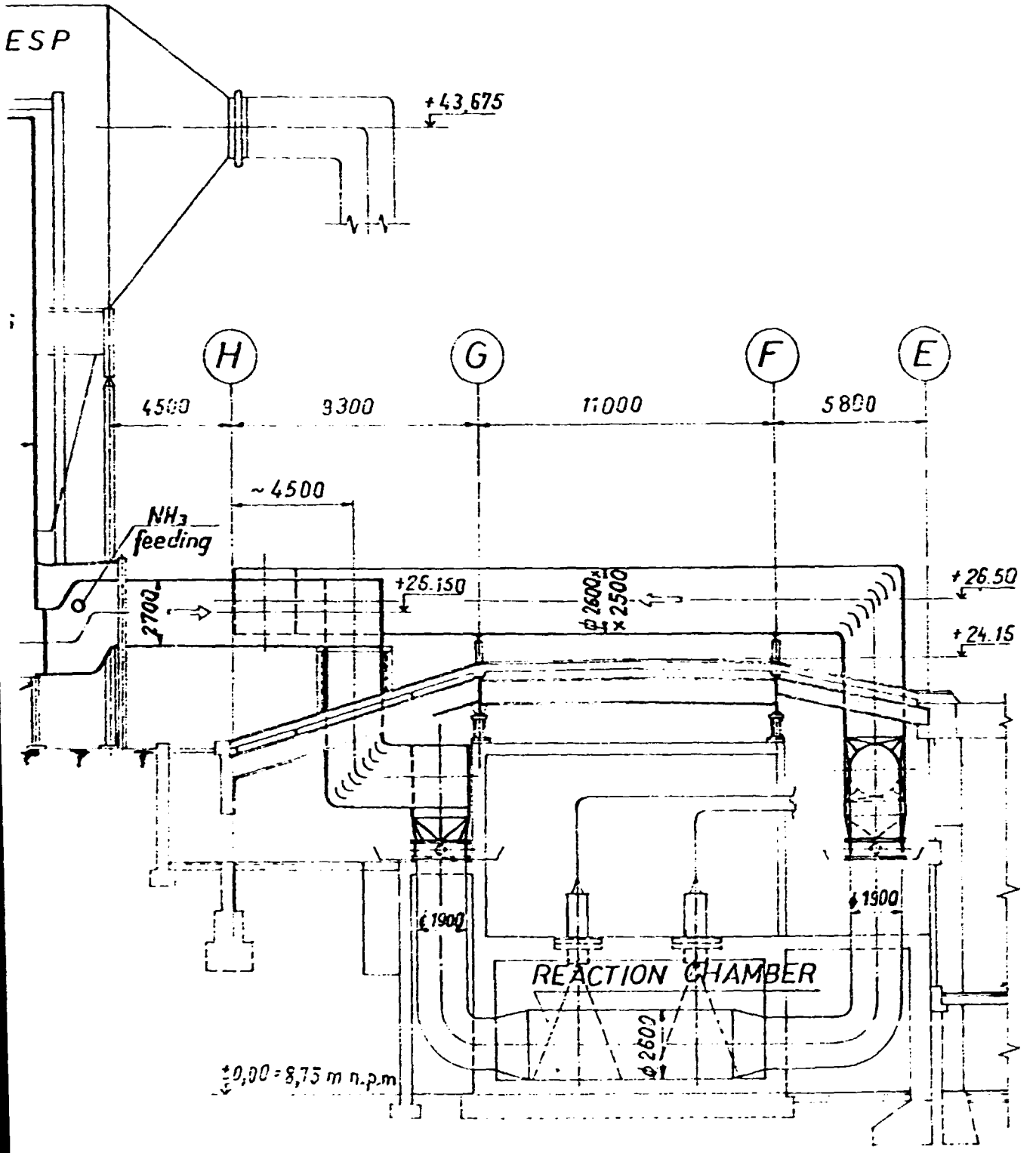
"POMORZANY"
FLUE G
LAYOUT CRO



Sec 2

"ENERGOPROJEKT®- WARSZAWA" S.A. Warszawa, ul.Krucza 6/14			Nr archiwalny 1 131 106				Nr. porz. w tomie 3	
Przedsięwzięcie	Symbol P-0174	Nr WOI	Branża	Tom 7	Zeszyt	Edycja		
INDUSTRIAL DEMONSTRATION PLANT OF ELECTRON-BEAM PROCESS FOR FLUE GAS TREATMENT OF THE ELECTRIC POWER STATION "POMORZANY"-SZCZECIN POLAND **FLUE GAS SYSTEM LAYOUT CROSS-SECTION A-A**	Data 06.95.		Podziałka 1:200		Faza	Format A2	Pracownia TR	Czas przech.
	Zastępuje rys. Zastąpiony przez rys.		Nr					
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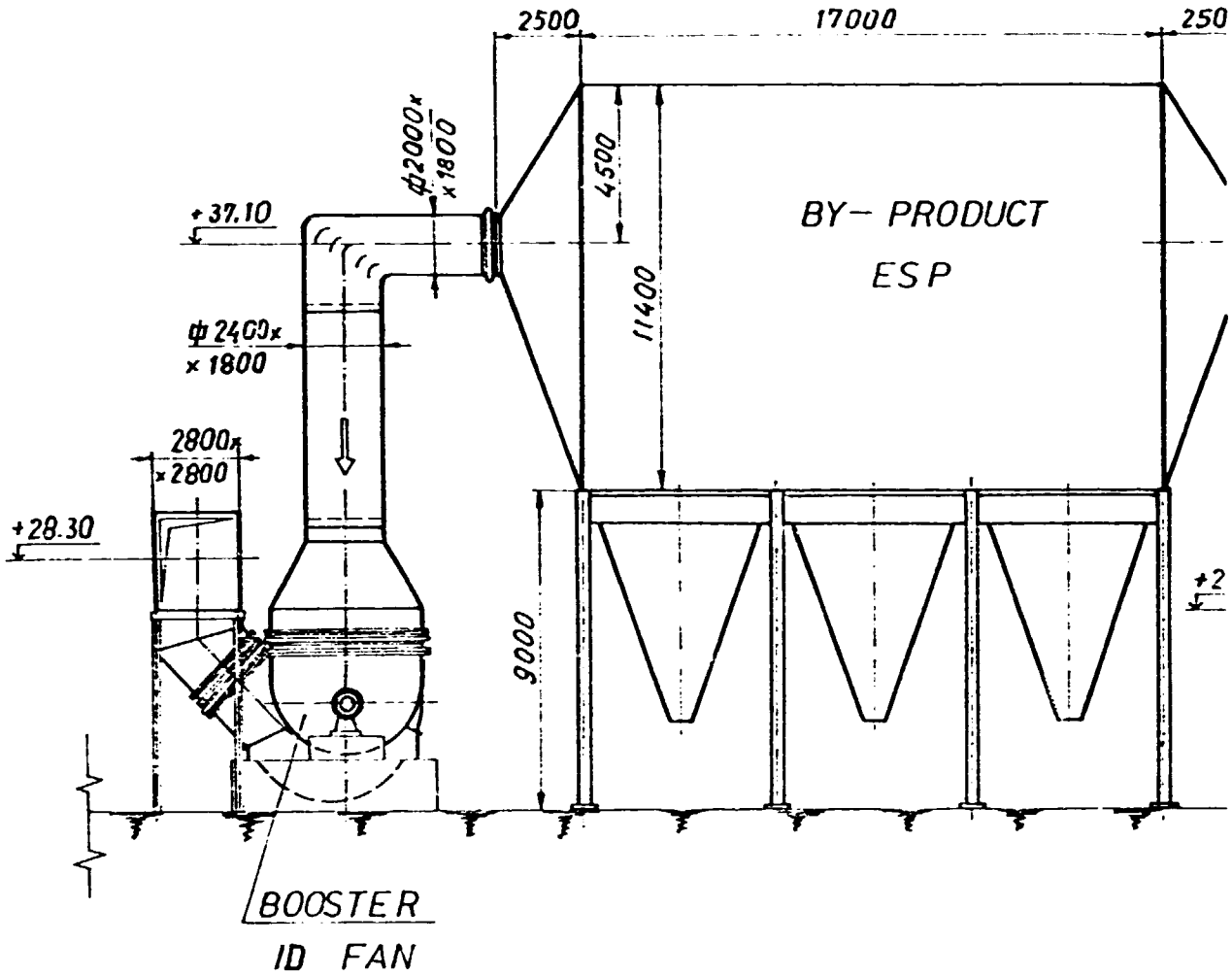
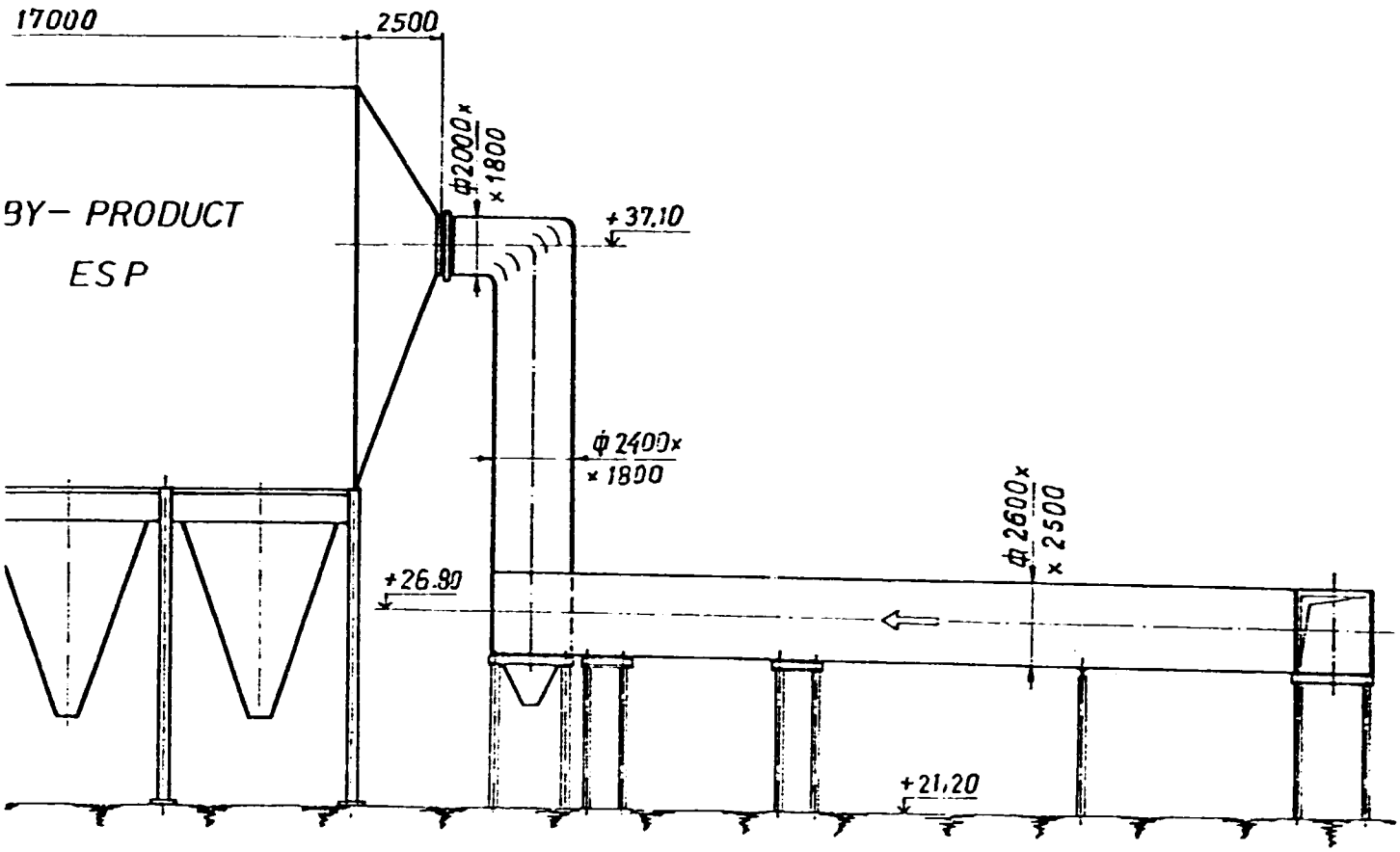
	Wykonał				Kier. proc.	Z. Radomski		
	Kreślił				Gł. proj.			

B — B


2500
17000
250
φ2000x
x1800
4500
11400
+37.10
BY- PRODUCT
ESP
φ2400x
x1800
2800x
x2800
+28.30
9000
+2
BOOSTER
ID FAN

See 1

B — B


17000
2500
Φ2000×
×1800
+37.10
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Φ2600×
×2500
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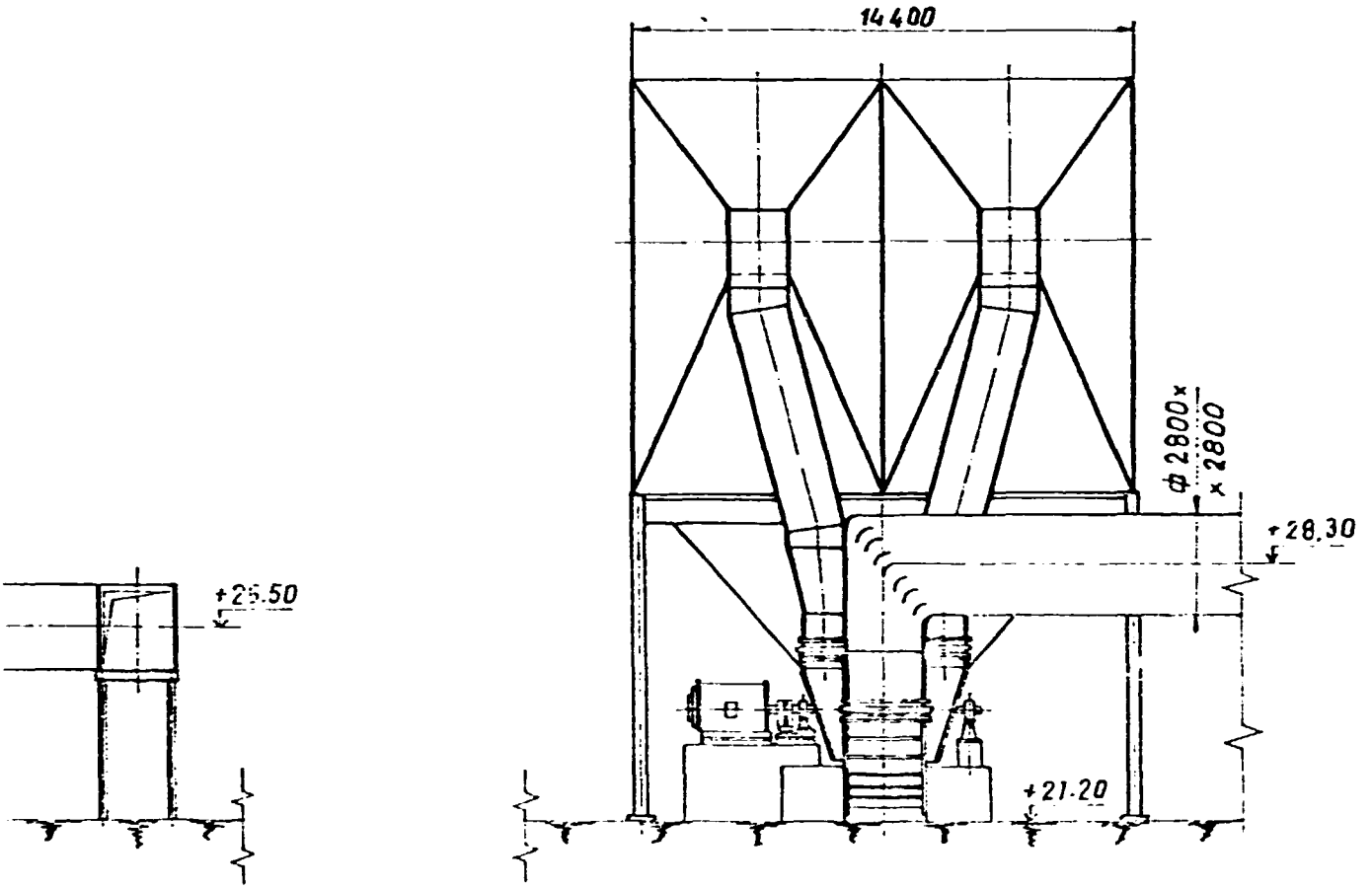
+21.20

Sec 2

C — C



Sec. 3

"ENERGOPROJEKT®- WARSZAWA" S.A. Warszawa, ul Krucza 6/14			Nr archiwalny 1 131 107				Nr. porz. w tomie 4	
Przedsięwzięcie	Symbol P-0174	Nr WOI	Branża	Tom 7	Zeszyt	Edycja		
INDUSTRIAL DEMONSTRATION PLANT OF ELECTRON-BEAM PROCESS FOR FLUE GAS TREATMENT OF THE ELECTRIC POWER STATION "POMORZANY"-SZCZECIN POLAND **FLUE GAS SYSTEM** **LAYOUT CROSS-SECTION B-B, C-C**	Data 06.95.		Podziałka 1:200		Faza	Format A3	Pracownic TR	Czas przech.
	Zastępuje rys. / Zastąpiony przez rys.		Nr					
	Projektował	J. Roszkowski			Sprawdził	Z. Radomski		
	Wykonał				Kier. proc	Z. Radomski		
	Kreślił				Gł. proj.			

This volume has been prepared by:

IPJ Soltan Institute for Nuclear Studies. Otwock-Swierk

Engineering Design Of An Electron Beam (EB) Flue Gas Purification Industrial DemonstrationPlant

Basic Engineering.

Volume 8

Measuring, monitoring and control system.

Warsaw. January 1996

No. of Volume	List of Volumes	Author
Volume 0	Executive Summary	
Volume I	Process Technology	INCT
Volume II	Gas Conditioning Unit	INCT
Volume III	Ammonia storage and dosing unit	Energoprojekt-Warszawa
Volume IV	Reaction chamber	Proatom
Volume V	By-product filtration (ESP)	Energoprojekt-Warszawa
Volume VI	By-product removal from filter, its transportation and conditioning	Energoprojekt-Warszawa
Volume VII	Flue gas ducts. Emission of flue gases to atmosphere	Energoprojekt-Warszawa
Volume VIII	Measuring, monitoring and control system	SINS
Volume IX	Electrical power supply units	Energoprojekt-Warszawa
Volume X	Composite documentation	Energoprojekt-Warszawa
Volume XI	Balances	Energoprojekt-Warszawa

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CONTENTS

BASIC ENGINEERING STUDY

8. Measuring, monitoring and control system (MMCS)

1. **Elaboration of a computerized measuring, monitoring and control system (MMCS).**
   - 1.1. Data collection (technological units specifications as a basis for a preliminary project of the MMCS).
   - 1.2. Assumptions for the system.
     - **1.2.1. Functions and aims of the system.**
     - **1.2.2. Measuring and process monitoring subsystem.**
     - **1.2.3. System characteristics and prospects.**
   - 1.3. System construction and location.
   - 1.4. Measuring and control instrumentation, computer equipment (including selection criteria).
     - **1.4.1. Subsystem of flue gas uptake and transportation to the analyzers.**
     - **1.4.2. Flue gas analyzers.**
     - **1.4.3. Dust concentration measuring devices.**
     - **1.4.4. Flue gas flow rate devices.**
     - **1.4.5. Computers.**
   - 1.5. Executional elements of system control.
   - 1.6. System control management (SCM).
     - **1.6.1. Control of the process steps.**
     - **1.6.2. Management of continuous and periodic measurements.**
     - **1.6.3. Functioning of the MMCS.**
     - **1.6.4. Functioning of the microprocessor software.**
2. **Transient states analysis (startup, shutdown, effects of minor failures and breakdown).**
3. **Determination of the required spare equipment and service (spare parts for two year operation).**

4. Means of carrying out emergency actions.
5. Coupling of control and monitoring system herein with the existing control and alarm system at the "Pomorzany" Power Plant with consideration of environmental protection requirements.
6. Cost listing and execution scheduling.
7. Specification of the Figures and Tables.

1. Elaboration of a computerized measuring, monitoring and control system (MMCS).

1.1. Data collection (technological units characteristics as a basis for a preliminary project of the MMCS).

The scheme of the MMCS is shown on Fig. 8.1., 8.2. The monitoring and control system will have a distributed structure. This means that the computers and modular measuring units of the individual technological systems, situated in the different places, will be connected together by a common serial bus.

The modular-microprocessor units, situated in cassettes (measuring units) realize under the control of the host computer, the control functions related to the following technological systems:

- inlet of the flue gas to the E-Beam installation
- humidification (dosage of water, water steam, and compressed air)
- ammonia dosage
- accelerators and a process vessel
- by-product electrostatic precipitator (ESP)
- system of the final product transfer
- ventilating system
- outlet system
- environmental monitoring system

The microprocessor units situated in the cassettes will allow the measurement, control and stabilization of the parameters of the individual technological systems (Fig. 8.3.).

In Tables 8.1., 8.2., 8.3., 8.4., the specification of the measurement points, process parameters, flue gas parameters and regulation parameters are shown, respectively in accord with the requirements presented in Chapt. I – VI.

Mode 1 – flue gas inlet from one boiler

- inlet	x1
- humidification	x1
- NH_3	x1
- process vessel	x1 (4 accelerators in series)
- by-product electrostatic precipitator	x1
- ventilator	x1
- product transfer	x1
- environmental monitoring	x1

Fig. 8.1. SCHEME OF THE MEASUREMENT POINTS

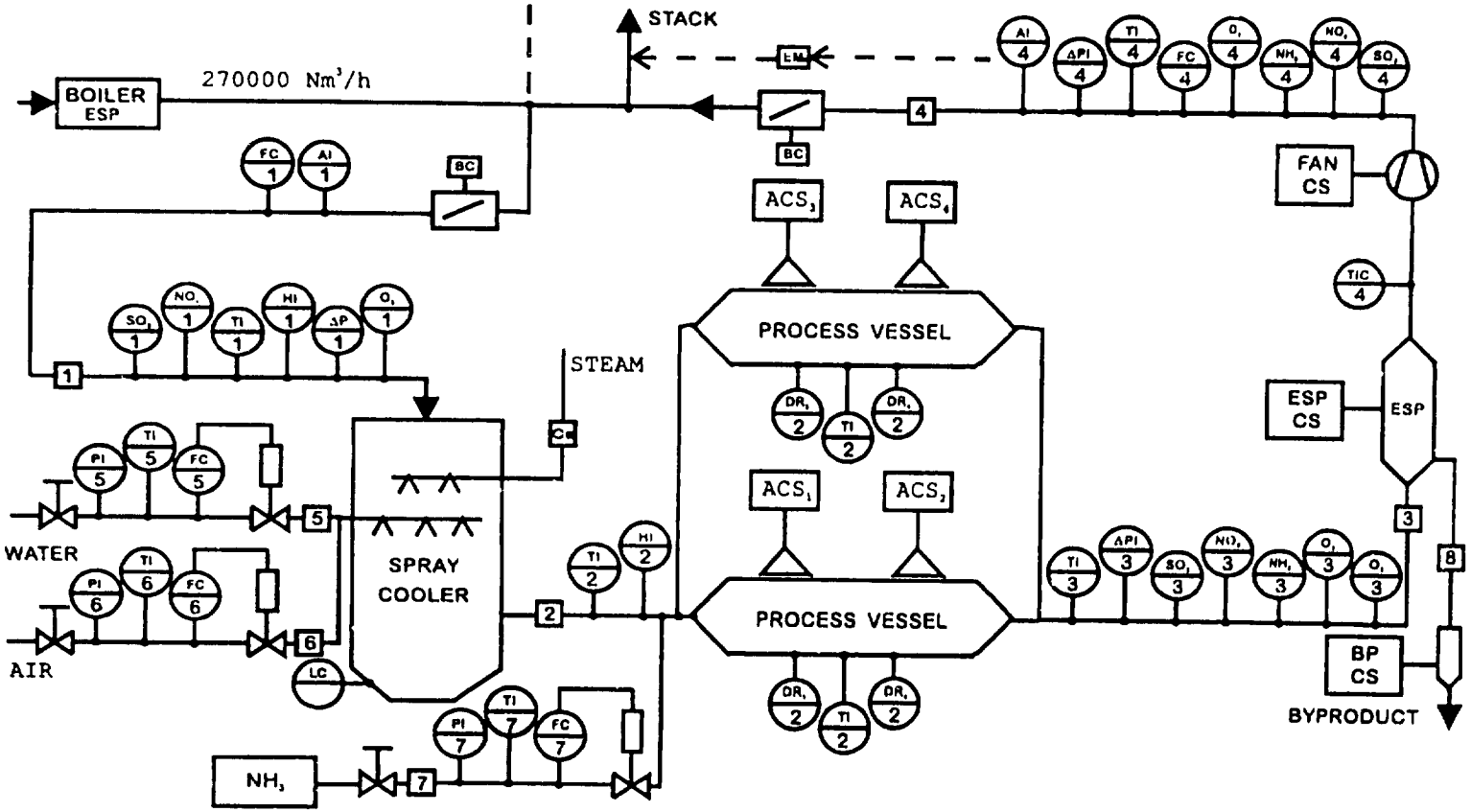
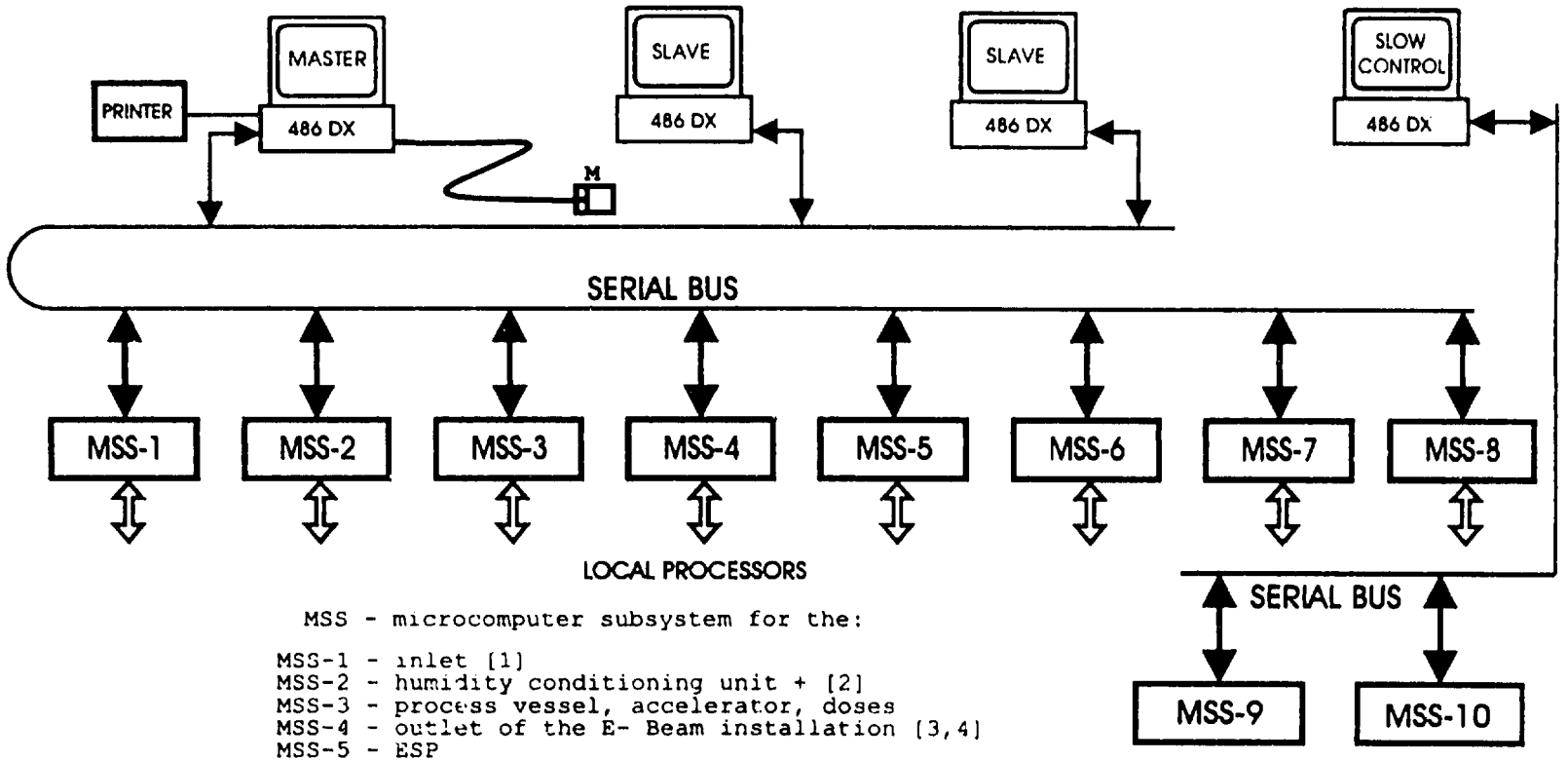


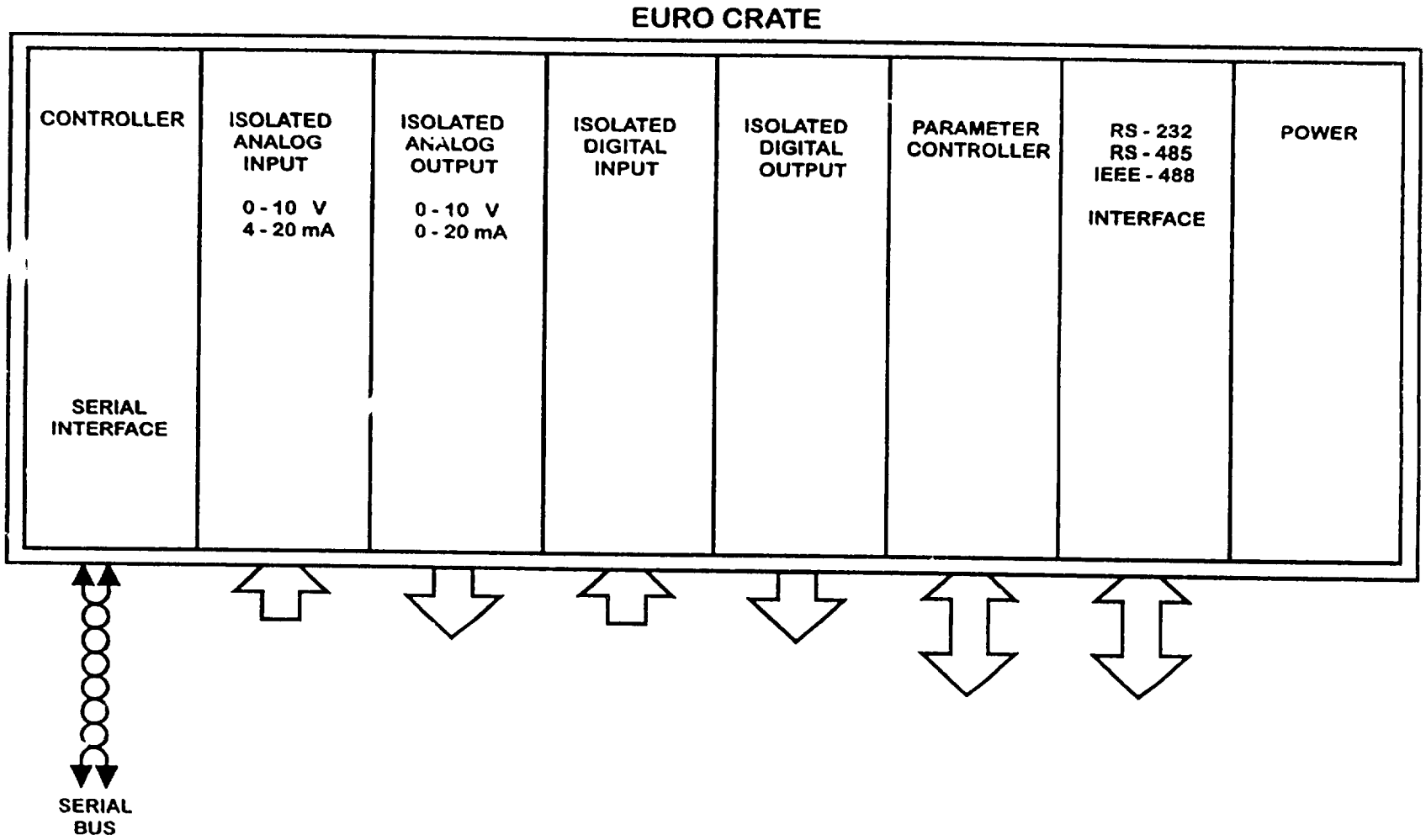
Fig. 8.2. COMPUTER CONTROL SYSTEM



MSS - microcomputer subsystem for the:

MSS-1 - inlet [1]
MSS-2 - humidity conditioning unit + [2]
MSS-3 - process vessel, accelerator, doses
MSS-4 - outlet of the E- Beam installation [3,4]
MSS-5 - ESP
MSS-6 - environmental monitoring [EM]
MSS-7 - NH_3 [7]
MSS-8 - BP transfer [8]
MSS-9,10 - quality control units

Fig. 8.3. Module processor unit



Mode 2 – flue gas inlet from two boilers

- inlet	x2
- humidification	x1
- NH_3	x1
- process vessel	x2 (4 accelerators, two in one vessel)
- by-product electrostatic precipitator	x1
- ventilator	x1
- product transfer	x1
- environmental monitoring	x1

At Pomorzany EPS will be realized Mode 2.

Table 8.1. The specification of the measurement point.

No	Name of the parameter [flow sheet location]	Signal			Remarks
		analog	digital in/out	regula-tion	
1	2	3	4	5	6
1.	Inlet [1]	30	50	2	
2.	Humidity conditioning unit + [2]	20	60	5	
3.	Process vessel + accelerator	15	10	4	
4.	[3] + [4]	90	20		
5.	ESP	12	80		
6.	Fan	10	50	2	
7.	NH_3 [7]	12	50	2	
8.	BP collection	10	45		
9.	[EM]	15	60		
10.	Σ, including reserve	250	750	20	

Table 8.2. The specification of the process parameters.

No	Name of the parameter	Medium	Number of the parameters	Measuring range	Remarks
1	2	3	4	5	6
1.	Temperature	- flue gas	7÷9	0÷200 °C	
		- water	1	0÷100 °C	
		- steam	1	50÷150 °C	
		- ammonia	1	0÷ 50 °C	
		- compressed air	1	0÷ 50 °C	
		- ambient	1	0÷ 50 °C	
2.	Pressure	- flue gas (ΔP)	7÷9	0÷10 kPa	
		- water (P)	1	0÷10 atm	
		- steam (P)	2	0÷10 atm	
		- ammonia (P)	1	0÷20 atm	
		- compressed air		0÷ 1 MPa	
		- ambient	1	900÷1060 hPa	
3.	Flow	- flue gas	4	0÷ $4 \cdot 10^5$ Nm^3/h	
		- water		0÷ 20 tonne/h	
		- steam		0÷ 10 tonne/h	
		- ammonia		0÷ 300 kg/h	
		- compressed air		0÷4000 Nm^3/h	
4.	Humidity	- flue gas	1	0÷10 % (Vol)	
		- flue gas	1	0÷20 % (Vol)	
5.	Level measurement unit	- water and sludge	1	0.6 m	

Table 8.3. The specification of the flue gas parameters.

No	Name of the parameter	Number of the parameters	Measuring range	Remarks
1	2	3	4	5
1.	Inlet [1]			
	- SO_2	2	0 ÷ 1500 mg/Nm^3	
	- NO_X	2	0 ÷ 1000 mg/Nm^3	
	- O_2	2	0 ÷ 10 / 20 %	Few ranges.
	- CO	2	0 ÷ 1000 mg/Nm^3	
	- fly ash	2	0 ÷ 500 mg/Nm^3	
2.	Outlets [3] and [4]			
	- SO_2	1	0 ÷ 1500 mg/Nm^3	[3] Periodical measurements (see Fig. 8.18.).
	- NO_X	1	0 ÷ 1000 mg/Nm^3	
	- CO	1	0 ÷ 1000 mg/Nm^3	
	- O_2	1	0 ÷ 10 / 20 %	
	- NH_3	1	0 ÷ 250 mg/Nm^3	[4] Continuous measurements.
	- N_2O	1	0 ÷ 200 mg/Nm^3	
	- O_3	1	0 ÷ 100 mg/Nm^3	
	- fly ash [4]	1	0 ÷ 100 mg/Nm^3	
3.	Environmental monitoring			
	- SO_2	1	0 ÷ 1500 mg/Nm^3	On the stack or treated gas duct, before or after mixing with untreated flue gas.
	- NO_X	1	0 ÷ 1000 mg/Nm^3	
	- CO	1	0 ÷ 1000 mg/Nm^3	
	- O_2	1	0 ÷ 10 /20 %	
	- NH_3	1	0 ÷ 250 mg/Nm^3	
	- O_3	1	0 ÷ 100 mg/Nm^3	
	- fly ash	1	0 ÷ 500 mg/Nm^3	

Table 8.4. The specification of the regulators.

No	Name of the parameter	Number of the parameters	Range of regulation	Remarks
1	2	3	4	5
1.	- flow of the flue gas inlet [1]	2	0.5 ÷ $4 \cdot 10^5$ Nm^3/h	
	- flow of the water [5]	2	0 ÷ 20 tonne/h	
	- flow of the steam	4	0 ÷ 10 tonne/h	
	- flow of the ammonia [7]	2	0 ÷ 300 kg/h	
	- flow of the compressed air [6]	2	0 ÷4000 Nm^3/h	

A distinct monitoring subsystem equipped with proper sensors (for example power supply voltage, inlet water pressure, inlet ammonia pressure) controls the system data basis sufficient to start the operation.

The system with the distributed structure, often referred to as the shared intelligence structure, is controlled by one host (operator) computer that determines the operational parameters and collects the data from each subsystem.

An important aspect of the whole control system is the manner, in which the subsystems are connected together. In this document, it is specified that the subsystems will be connected by the serial, industrial transmission line (bus), which will be constructed to allow for electric potential differences between the ground and the signals at diverse points. These bus and the sensor signals can be expected to be situated at higher potentials because of humidity, high voltage supplies, atmospheric discharges.

Locations of measuring points [1, 2, 3, 4] (Fig. 8.1.) are determined by technological and environmental reasons.

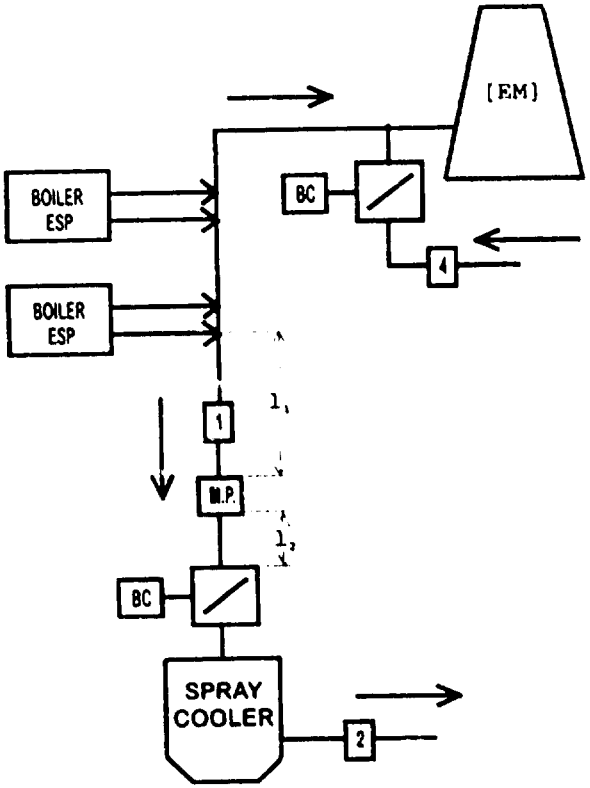
There are additional requirements for the location of the points to fulfill credibility of the measurements:

- the measuring probes and sensors have to be situated so as to avoid possibility of interference,
- gas stream flow should be reasonably uniform across the flow cross-section (Fig. 8.4. and 8.5.).

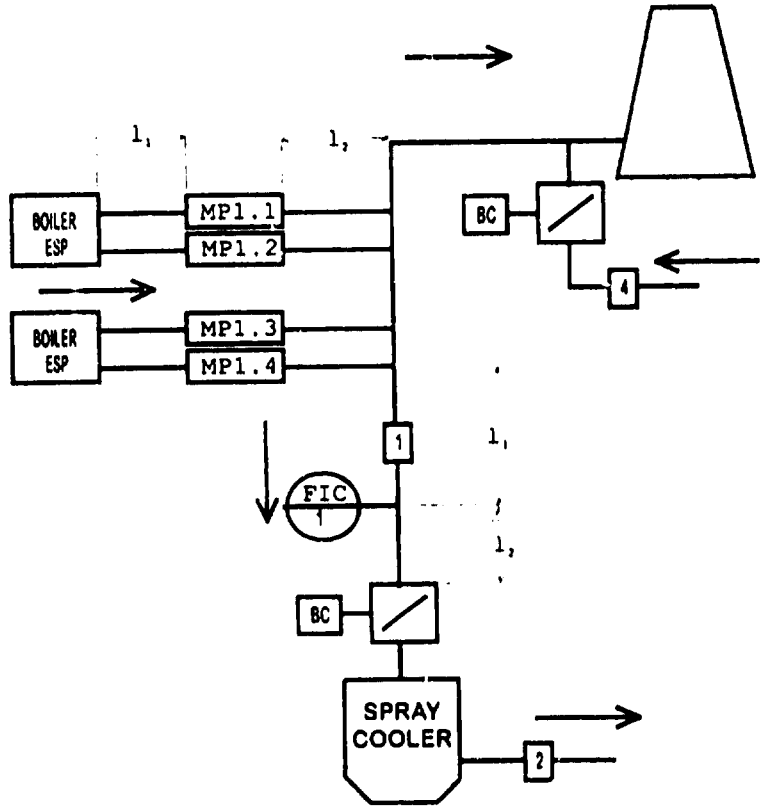
These requirements are to be fulfilled by project design making it thereby possible to use the measuring point [1] and [4] for environmental monitoring (Fig. 8.6. and 8.6a.).

Fig. 8.4 Location of the measurement points for the inlet unit [1]

Option 1 [EM] after mixing of the flue gas



Option 2 [EM] before mixing of the flue gas



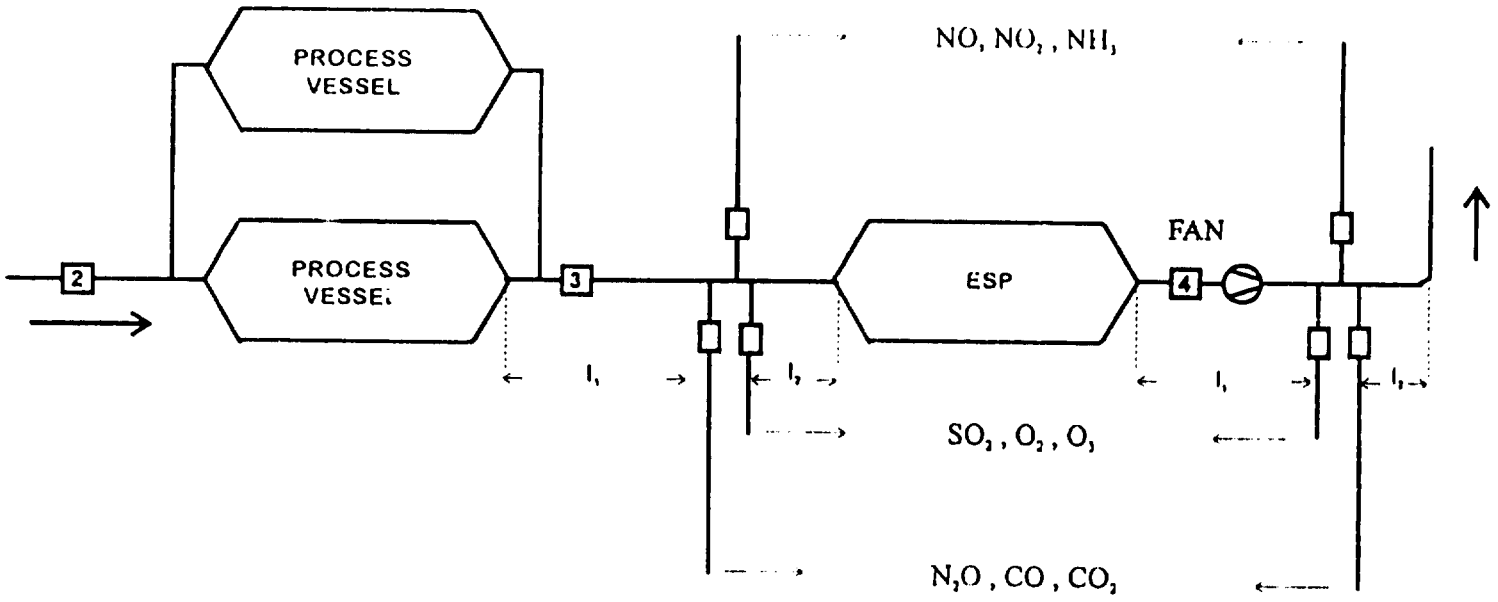
BC - bolt controller
M.P. - measurement points of:
T, ΔP, H, A, F, SO_2, NO, CO, O_2

l_1, l_2 - length
d - hydraulical diameter
S - cross section
p - perimeter

$$d = \frac{4S}{p}$$

$l_1 \geq 3d$
$l_2 \geq 1d$

Fig. 8.5. Location of the measuring points for monitoring of the concentration of SO_2, NO_x, CO, CO_2, O_2, NH_3, N_2O and O_3 (outlet of the process vessel and ESP [3,4])



d - hydraulical diameter
S - cross section
p - perimeter

$$d = \frac{4S}{p}$$

$l_1 \geq 3d$
$l_2 \geq 1d$

Fig. 8.6. Environmental monitoring scheme (option 1), [E.M.] after mixing of the flue gas

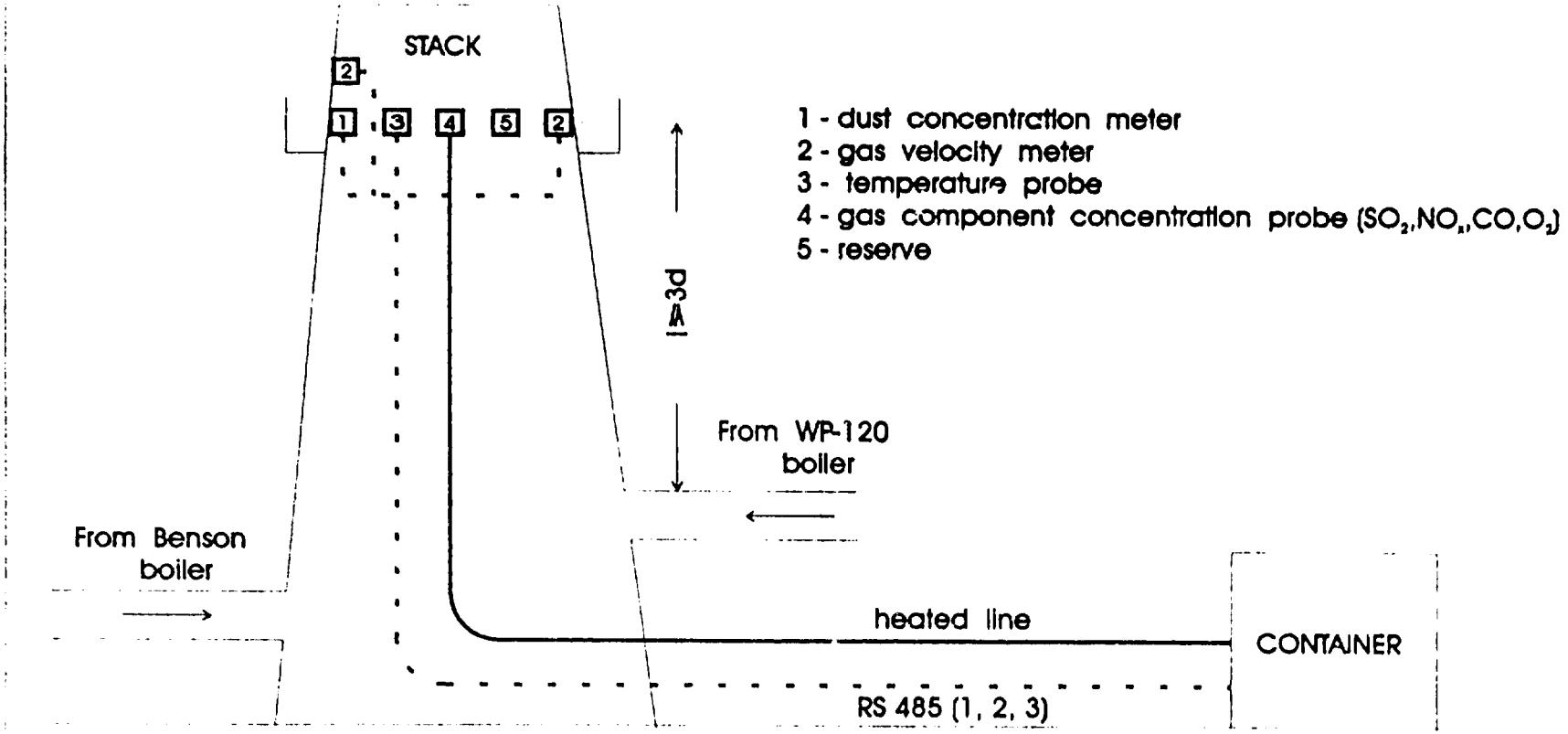
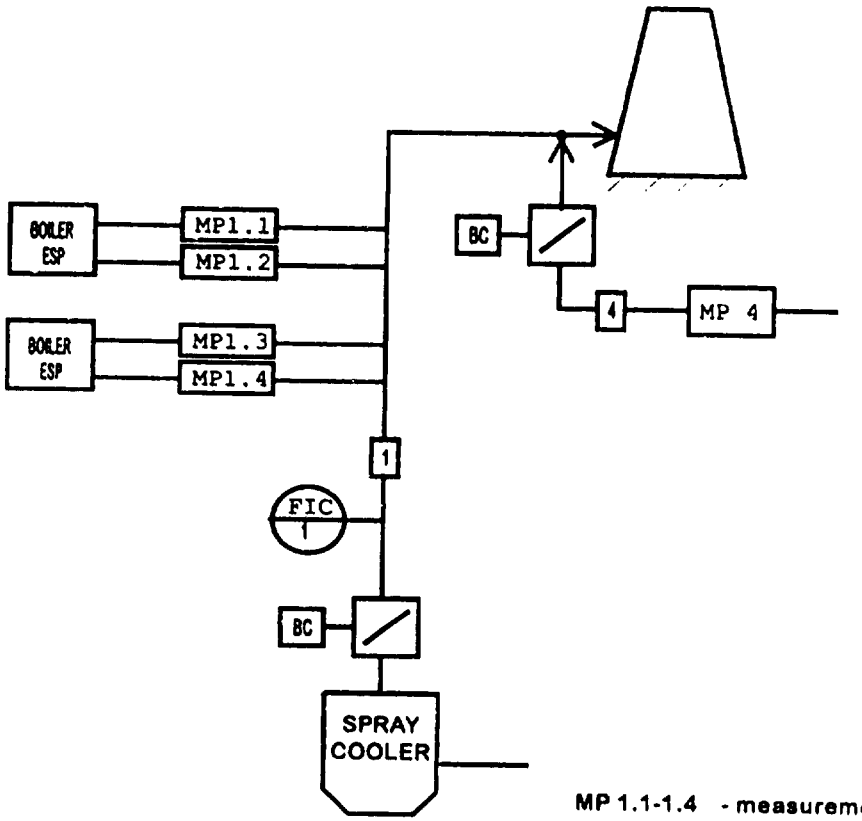


Fig. 8.6a. Environmental monitoring scheme (option2), [EM] before mixing of the flue gas



MP 1.1-1.4 - measurement points of:
T, ΔP, H, A, F, SO_2, NO_x, CO, O_2
MP 4 - measurement point of:
T, ΔP, A, F, SO_2, O_2, O_3, NO, NO_2, NH_3, N_2O, CO, CO_2

To fulfill complete control of process, the monitoring and control system has to analyse at least of 250 input analogue signals, 50 output analogue signals, and 750 digital binary signals, and control at least of 20 regulators automatically.

1.2. Assumptions for the system.

1.2.1 Functions and aims of the system.

The technology of simultaneous removal of nitrogen oxides and sulphur dioxide using the method of electron beam irradiation impose broad requirements on the control and stabilization of process parameters. The efficiency of these control processes is strongly connected with the correlations between the parameters (electron dose, temperature and humidity of flue gas, amount of ammonia and initial concentrations of SO_2 and NO_x, see Chapter I).

The proposed system has a multilevel structure in which every level has an individual task that is combined with tasks of other levels.

The system is prepared for the following aims:

a) control to achieve the correct operation of the installation (in agreement with supposed algorithms):

Using on-line data obtained from continuous or periodic measurements, the system is able to control transient conditons (start-up, shut-down, changes in operation and breakdown of the installation).

The system procedures ensure:

1. automatic dosage, control and regulation of the flow of:
   - flue gas,
   - water,
   - water steam,
   - compressed air,
   - ammonia;

2. control of the operation of the following units:
   - inlet and outlet of flue gas,
   - humidifier,
   - ammonia delivery,
   - accelerators,
   - by-product electrostatic precipitators,
   - transfer of the final product,
   - ventilator;

3. control and regulation of the electron dose (different values for individual accelerators).

The host (MASTER) computer is responsible for optimisation of the treatment process. It collects data, sends proper instructions to the measuring units, and allows:
- visualization of the analogue and digital signals and control,

- synopsis of the process,
- storage of data,
- preparation of reports concerning consumption of the electrical energy, water, water steam, ammonia and compressed air,
- preparation of reports concerning operational conditions of the installation.

b) measuring and monitoring of process parameters, concentrations of gas pollution and dust:

Data in the form of diagrams and plots from the prior day (week) allow:

- continuous or periodic presentation of the values of T, P, ΔP, H, F, and, (for some measurement points) the reference values of O_2 and CO_2, and flue gas velocities,
- continuous presentation of particulate loading at the inlet and outlet of the installation,
- continuous presentation of SO_2, NO_X and CO concentrations at the inlet and SO_2, NO_X, NH_3, N_2O, O_3, O_2, CO, CO_2 concentrations at the outlet of the installation,
- periodic presentation of measurements of SO_2, NO_X, N_2O, O_3, O_2, CO, CO_2 at the outlets of the reactor vessels,
- monitoring of emergency and breakdown situations,
- sorting and condensation of data,
- acquisition, storage and evaluation of data (analogue and digital signals) obtained from sensors, converters and analyzers,
- environmental monitoring (according to the requirements of the regulatory authorities),
- data transmission from and to the control units,

c) supervision (according to assumed algorithms) of the correct and safe operation of the installation:

An important aim of the system is a continuous control of the system parameters that are essential for security of and avoidance of damage to the installation (fire, flooding, explosion). An isolated computer (SLOW CONTROL), together with the measuring unit detects:

- maximum value of temperature in:
  - power supplies,
  - electronics units,
  - selected points of the installation,
- maximum value of current and voltage in:
  - power supplies,
  - electronics units,
  - accelerators,
- pressure values in:
  - water, water steam, compressed air and ammonia delivery systems,
- humidity in selected points (concentration of water and water steam),
- fire risk in selected points,
- leakage and flooding (ammonia, water).

d) transmission of data and monitoring of process parameters outside of the control room (directory, administration):

The computer system is to work in the computer network. Thus, data collected on-line during operation of the installation can be received at remote locations by authorized parties.

e) error-free operation of the system in the case of the power failure:

The measuring system is equipped with units (UPS), that will supply power for up to 4 hours in the case of an external power failure.

1.2.2. Measuring and process monitoring subsystem.

A subsystem collects and converts into electrical signals the information about the process parameters in a continuous or periodic manner. Data obtained from sensors, converters and analyzers are transmitted to the computer units (process level).

Because of the dispersed location of the E-Beam system computers, the measuring system consists of measuring subsystems that interact with the host computer. Digital data transmission is performed by means of the serial industrial and reliable line. A subsystem task is to measure the parameters, and to control and regulate (PID) the parameter values according to the requirements set by the host computer. Before transmission of the data to the host MASTER computer, at the level of the subsystem electronics, a calibration of the parameter is performed (i.e. transformation of the raw data into fixed values of the parameter). The calibration functions and algorithms are constructed by help of the host computer and sent to the microprocessor measuring units in a table format.

It is possible for the operators to observe via diode displays the magnitudes of the selected parameters at the subsystems.

1.2.3. System characteristics and prospects.

The system allows continuous, automatic and error-free operation of the installation for at least one period of boiler operation, i. e. campaign, (without a general revision).

The applied industrial serial bus, which eliminates noise disturbance, connects different measuring subsystems with computers and allows presentation of the data on many computer monitors. An operator can decide which of the parameters (direct or derived from the others) are to be observed on the monitor. All parameters are stored at the same time.

One computer fulfills the main role (MASTER – the host computer). Other ones fulfill the auxiliary functions (SLAVE, up to 20 computers) – see Fig. 8.2. The system functioning is possible only with one of them operating as MASTER and others serving at the same time as

SLAVE. The same program is installed on all the computers. Thus at any time (failure – for example) the MASTER computer can be easily replced by a SLAVE one.

The host (MASTER) computer controls the whole system. Using this computer the operator can manipulate the technological process. In this computer, the data are analysed according to the process algorithms and all commands needed for the operation of the industrial installation are sent from it automatically, or by hand. This computer allows presentation and storage of the data.

The auxiliary (SLAVE) computers collect and present data only. Some additional calculations based on the collected data can be performed by them. For this purpose the standard programs like EXCEL can be used.

The computers are linked to the network like ETHERNET, and in this way, they can be situated in different places (control room, directory, measuring points).

Final configuration will be defined during preparation of the technical documentation considering technical and economic reasons.

The system has the following aims:

1. Checking if the installation is ready to operate.

Before the start-up of the technological process, the system checks (by reading of the proper sensors) the conditions of the individual systems (supply voltages, water pressure, ammonia pressure – for example). If any parameter is not correct then the start-up procedures are blocked and a special report is announced. These parameters are controlled during the operation of the installation as well.

2. Control of the process parameters.

During the installation operation, the data describing the parameter values of different systems are collected with the frequency of 1 Hz. They are collected by one or more computers, stored and presented on the computer monitors. Stored data afford control of the correctness of the installation operation and, means to eventually send corrective signals to the execution devices of the systems.

3. Data presentation.

The data obtained from the operation of the installation are presented on-line on several monitors to allow the operator to overview the process control by observation of the most important parameters.

The system finds all divergences of the parameter values automatically and fixes the reasons for them.

4. Breakdowns.

An additional aim of the system is to find and indicate potential breakdown (no power, magnitude of currents, voltages or temperatures above thresholds).

If the emergency situation is found by the SLOW CONTROL subsystem, and the reason for it is sent to the host computer, then the proper algorithms cause emergency shut-down of the installation systems (closing of the inlets, accelerators switching-off, power shut-down, starting of the fire-extinguishing system). The computer of the SLOW CONTROL subsystem periodically reads parameter data and gives messages about unacceptable values. The subsystem program specifies three safety thresholds:

- magnitude of the parameter above the expected value,

An operator is informed about this situation by a sound signal calling for a proper decision.

- unwarranted exceedance,

The computer of the SLOW CONTROL system sends the message to the host computer, calling for it to switch off the installation automatically.

- breakdown exceedance,

The computer of the SLOW CONTROL system causes an emergency shutdown. Then it switches on the alarm signals (automatic indication of problem source) and security facilities (if applicable: fire-extinguishers, for example).

1.3. System construction and location.

The specifics of the gas treatment process requires that distributed measuring and control systems have to be applied. Every measuring system contains its own complex of monitoring and control devices. The microprocessor units of the system play the role of local controllers and measuring units. Because of security reasons (overvoltages) and noise distortions, the connection between measuring points and computers is achieved by a lightguide line or galvanically isolated (optoisolation) wire line (up to 2 km).

Units of the measuring systems are situated in closed racks resistant to dust, humidity and acid environment. The construction of the units utilizes the cassette modular system.

The whole modular system consists of several unit types because of the possibility of easy replacement:

- cassette controller of the measuring system (cassette control and linking to the computers – an interface with the optoisolation to the serial, industrial main bus),
- measuring unit of the analogue parameters (optoisolation),
- readout unit of the digital data (optoisolation),
- PID controller,
- GPIB and RS-232, -422, -485 interfaces (optoisolation).

The analogue and digital input/output signals will fulfill the $0 \div 10$ V voltage and $4 \div 20$ mA current standards. Every signal will be galvanically isolated (isolation up to 1000 V) from all others and from the ground as well.

A very important part of the system is proper installation of the measurement points, calibration of the system parameters and regulation of the controllers.

1. **Installation**, determined by selection of the proper measuring standard and cabling, should guarantee registration of the data with minimal noise level. In the system, where a large noise level is expected, proper (dependent on the noise characteristic) filters should be installed. System selection is to be made in the detailed engineering stage.

2. **A calibration** of the systems is to be done after the installation is completed and will be performed in two stages:
   - calibration of the registration devices (ADC and DAC converters)
   - calibration of the complete measuring system.

   Using this method the global linearisation of all elements of the system will be possible and thus will afford means, for example, to quickly ascertain ageing of the sensors.

3. **Regulation** of the controllers is possible after subsystem installation.

   Some regulation processes are very slow (temperature change) and depend on many other parameters (measurement points). They have to consider specifics of the specific physical installation.

To ensure safe operation of the installation, the electromagnetic valves for water, water steam, air and ammonia supply have to be constructed and arranged in such a way that they will be closed automatically in event of a breakdown or power failure.

One can estimate that the engineering costs will be as high as 50% of the measuring, monitoring and control system cost.

Requirements for the measuring units:

- VME standard (or other one of comparable quality),
- cassettes with power supplies that send data about the cassette temperature, current and voltage,
- modules:
  - cassette controller,
  - SERIAL BUS interface (optoisolation) – RS-485,
  - 12 bit 0.1% accuracy multimeter with the possibility of the individual control (calibration tables),
  - IN/OUT converter 0 ÷ 10 mV, 0 ÷ 1 V, 0 ÷ 10 V, 0 ÷ 20 mA into 0 ÷ 10 V with optoisolation,
  - 48 inputs digital data receiver with optoisolation,
  - 48 outputs digital data transmitter with optoisolation,
  - PID regulator with optoisolation,
  - GPIB, RS-232, -422, -485 interface with optoisolation.

Requirements for the SERIAL BUS:

- industrial RS-485 standard,
- double lightguide line.

Application of the distributed, microprocessor-based systems increases the speed and reliability of operation of the total system. The microprocessor system connected with every system point is, in addition, an independent, autonomic computer that performs commands of the host (MASTER) computer.

The computer software comprises many programs and has to control many functions of the system. There are two basic elements: a main program and microprocessor computer programs for the subsystems.

The process control program is installed in the operator host (MASTER) computer, and in all auxiliary SLAVE computers. Control is possible from the host computer only. In the auxiliary computers, only the options of presentation of the running and stored data can be selected.

One of them can perform data acquisition and storage to prevent data loss. At any time the host computer can be replaced by one of the auxiliary ones.

1.4. Measuring and control instrumentation, computer equipment (including selection criteria).

For monitoring and controlling the installation the reliable and accurate measurement of flue gas parameters at critical points is indispensable. The selection of measuring equipment (particularly that for flue gas chemical analysis) should consider the specifics of the treatment process, namely:

- at the installation inlet

SO_2 and NO_X concentrations in flue gas are high and exceed emission levels required in the future by regulations. From a coal-fired boiler only two types of nitrogen oxides are emitted: nitric oxide (NO) and nitrogen dioxide (NO_2). NO is the dominant constituent of NO_X (about 98%). The following flue gas parameters should be continuously measured at the installation inlet: the concentration of SO_2, NO/NO_X, O_2 and CO, humidity, fly ash loading, temperature, negative pressure, and gas volume flow. The measured values will make it possible to determine:

- the amount of ammonia to be added to flue gas before its entry to the process vessel,
- flue gas irradiation dose,
- water amount to be added to flue gas in humidifier,
- the required efficiencies of SO_2 and NO_X removal from flue gas.

The main factors which complicate the flue gas composition measurement at the installation inlet are: water vapour – about 5% (V – by volume), fly ash loading, CO_2, CO and O_2 concentrations.

- downstream the humidifier

Here humidity of flue gas is increased to 10 ÷ 12 % (V). It must be measured at the humidifier outlet. The elevated humidity of flue gas complicates gas analysis both at this point and subsequent ones. Before the process vessel inlet gaseous ammonia is introduced to a flue gas stream in a near stoichiometric amount.

- at the irradiation (process) vessel outlet

As a result of physico-chemical processes accompanying flue gas irradiation by electron beam an essential change of flue gas composition occurs. The stream that leaves the irradiation vessel is a multicomponent three-phase system. The gas phase is characterized by significantly reduced SO_2 and NO concentrations, a slightly increased NO_2 concentration, the presence of unreacted ammonia and nitrous oxide – N_2O (a gas treatment by-product) and nearly unchanged CO_2, CO, O_2, N_2 and water vapour content. The liquid phase is composed of sulphuric acid and nitric acid aerosols. The solid phase is formed of a final product particulate (ammonium sulphate and nitrate). This particulate matter consists of hygroscopic particles of diameter primarily in the range 0.4 to 4 μm.

The magnitude of above mentioned changes of flue gas composition depend on irradiation dose and gas humidity at the irradiation vessel inlet.

Dominant factors that – at this point – make gas composition measurement difficult are: ammonia, elevated humidity (~12 % (V)), submicron-size hygroscopic particulate of the final product and aerosols. In most cases it is necessary to measure the similar concentrations of SO_2, ammonia and nitrogen oxides. It is anticipated that, during the operation of the installation, flue gas composition is to be determined at this point only periodically for comparision with measurements after the by-product electrostatic precipitator.

The measurements at the irradiation vessel outlet will be done:
- in failure situations,
- in investigations aimed at optimizing system performance.

- after the by-product electrostatic precipitator

Nearly 99.5% of final product particulate mass is removed by the electrostatic precipitator. The other flue gas parameters are not changed. At this point
- efficiencies of SO_2 and NO_X removal from flue gas in the installation,
- the ecological noxiousness of leaving flue gas. (This factor for whole istallation is judged after the treated gas is mixed with the untreated Benson boiler gas.)

should be determined. In this connection, continuous measuring of SO_2, NO/NO_X, NH_3, N_2O, CO, CO_2, O_2 concentrations, humidity, dust content, temperature and flue gas volume flow (discharge volume) are anticipated.

1.4.1. Subsystem of flue gas uptake and transportation to the gas analyzers.

In any measurement of the emission of gaseous or solid impurities in the flue gas, four steps are distinguished:
- the extraction of a representative flue gas sample, requiring satisfactory location of a measuring point on a straight, uniform, flue gas duct-run, the proper depth of probe insertion, and the appropriate selection of sample suction parameters,
- the transport of the extracted sample to an analyzer in such a way that the characteristic species of interest are not changed (adequate transport and sample conditioning systems),
- gas analysis of the flue gas sample,
- verification of reliability of measurement by testing the calibration of the whole measuring path with standard gases.

To obtain reliability and adequate accuracy of flue gas composition analysis, the following requirements should be met:
- the representativity of the extracted flue gas sample (gas sample should reflect the mean values in a measuring section),
- all elements of the measuring path that come into contact with flue gas must be a gas tight and should be chemically resistant (Teflon and stainless steel are recommended),
- all gas tramp components that are not the subject of measurement but may influence results should be removed from the extracted sample. (This is done in a flue gas conditioning system. These components – e.g. fly ash – may impede sample transport to an analyzer

and within it or they may change the analysed concentration during sample transport – e.g. water vapour).

Due to the above mentioned characteristics of the flue gas treatment process, it is intended that two distinctly different system designs for sampling and conditioning of flue gas should be used for the installation inlet and the by-product electrostatic precipitator outlet.

The installation inlet.

Typical probes used in monitoring the emission of gaseous components of flue gas may be expected to be serviceable. A ceramic filter with pore diameter of about 10 μm is suggested for the initial filtration of extracted gas. It should retain the major part of the residual fly ash content of flue gas after the power station electrostatic precipitators. In order to avoid condensation of water vapour from the extracted flue gas the probe, initial ceramic filter and heated gas line are kept at a temperature t_1 higher than the sulphuric acid dew point temperature of flue gas being analysed. The scheme of the proposed sample gas conditioning system is shown in Fig. 8.7.

In this system

- water vapour is removed from flue gas in a cooler with an automatic condensate discharge,
- the flow of the dehumidified sample gas is stabilized by means of a diaphragm pump, a diaphragm filter with a humidity senser and a flue gas sample pressure controller,
- the flow rate of sample gas is adjusted to gas analyzer requirements by means of a regulating valve and rotameter,
- the sample gas is filtered before its introduction to the analyzer by means of a fine filter with pores of 0.1 μm diameter.

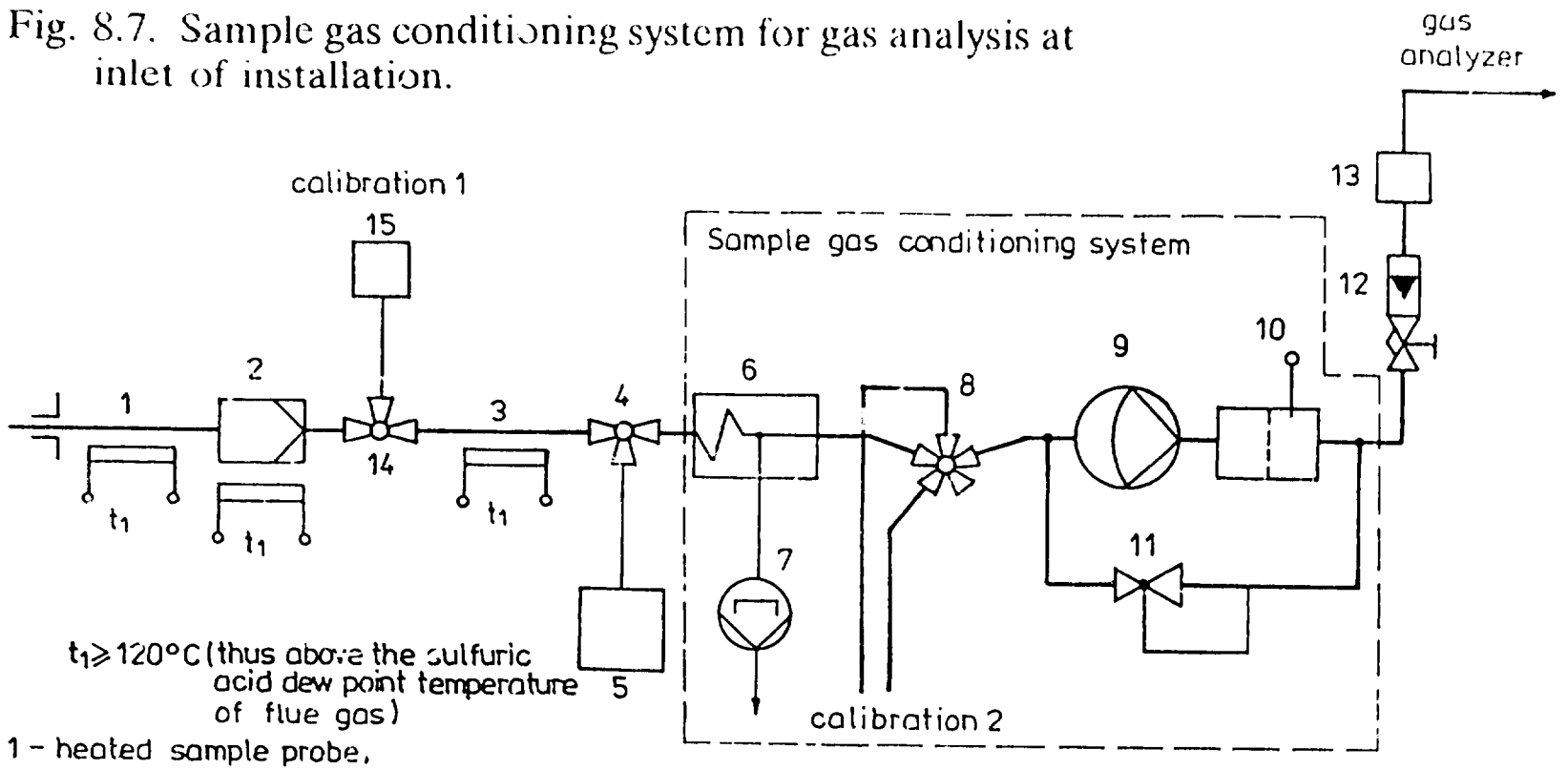
Trace amounts of fly ash and other impurities will be collected in the inlet parts of the measuring system during its continuous operation. Means for a periodic blow-back of, so called, zero air is provided so as to control this build up and to clear the probe, preliminary filter and heated gas line. This air should be dry and free from dust and gaseous SO_2, NO, NO_2, CO, CO_2, and hydrocarbons. Its supply pressure should be 6 bar. Ready-to-use devices for zero-air generation (supply) are available from many manufacturers. The fly ash content and humidity of the inlet flue gas are low. Thus zero-air blow-back every 4 hours is judged to be adequate.

The installation outlet.

Identical systems for flue gas sampling, transport and conditioning are to be used both after the electrostatic precipitator and the irradiation vessel. This is presented in Fig. 8.8. The system differs from that at the installation inlet in the following respects:

- A ceramic (preliminary) filter with pores of 1 μm diameter is to be used to trap particles of the final product. This may be a single filter with filtration area greater than 120 cm^2 or the set of two filters: a first one coarse with pores of about 10 μm and the next one fine with pores of about 1 μm diameter.
- The outlet flue gas contains unreacted ammonia which reacts readily, particularly in lower temperatures, with SO_2. To avoid this reaction during sample gas transport to an analyzer

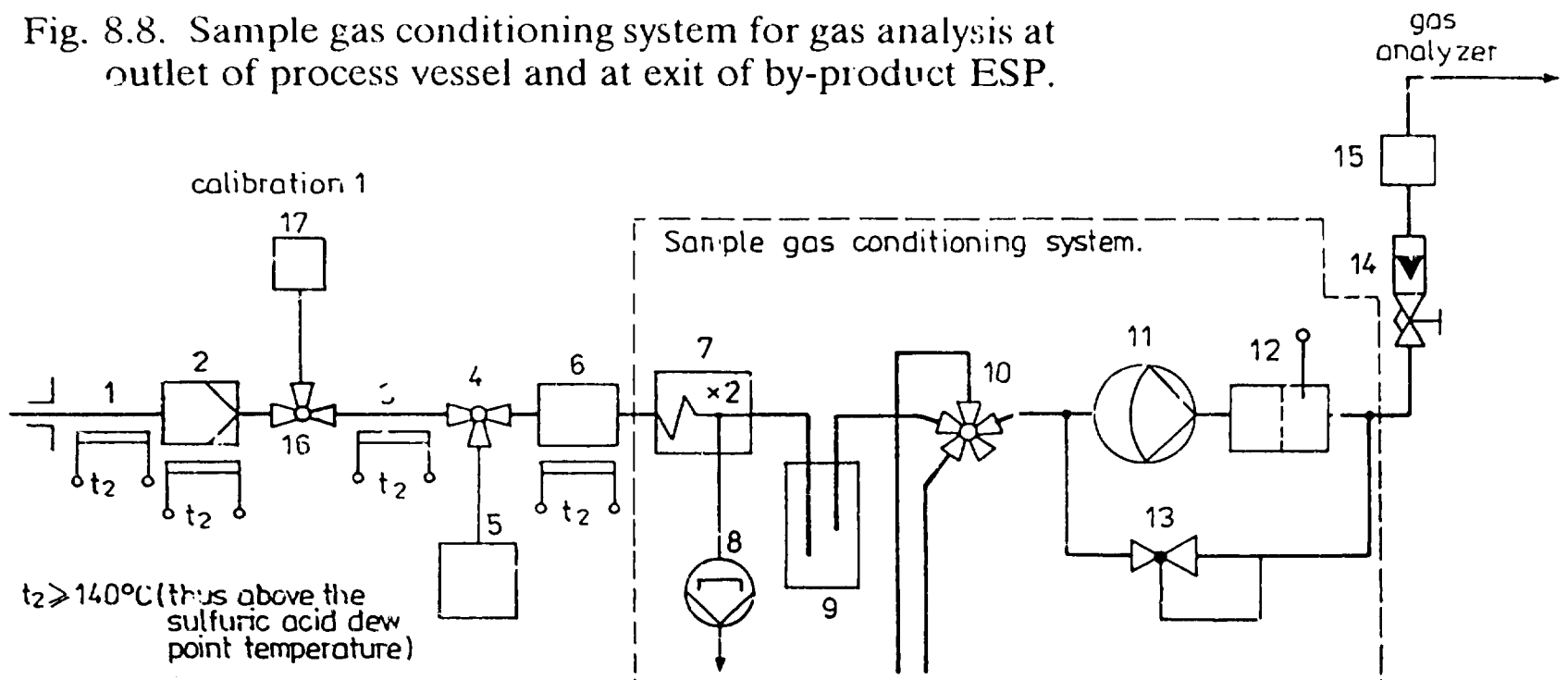
Fig. 8.7. Sample gas conditioning system for gas analysis at inlet of installation.



$t_1 \geqslant 120°C$ (thus above the sulfuric acid dew point temperature of flue gas)

1 - heated sample probe,
2 - heated ceramic filter ($\leqslant 10\mu m$),
3 - heated sampling line,
4 - 3-way valve for connection of blow-back,
5 - zero air supply,
6 - sample gas cooler,
7 - automatic discharge of the condensate,
8 - feeding of test gases,
9 - diaphragm pump,
10 - diaphragm filter ($\leqslant 1\mu m$) with condensate sensor,
11 - pressure controller,
12 - flow monitor (~200 l/h),
13 - disposable filter (installed near gas analyzer),
14 - 3-way valve for calibration,
15 - standard gases.

Fig. 8.8. Sample gas conditioning system for gas analysis at outlet of process vessel and at exit of by-product ESP.



$t_2 \geq 140°C$ (thus above the sulfuric acid dew point temperature)

1 - heated sample probe,
2 - heated ceramic filter (≤1 µm),
3 - heated sampling line,
4 - 3-way valve for blow-back,
5 - zero air supply,
6 - ammonia scrubber,
7 - sample gas cooler,
8 - automatic discharge of the condensate,
9 - acid filter,
10 - feeding of test gases,
11 - diaphragm pump,
12 - diaphragm filter with condensate sensor,
13 - pressure controller,
14 - flow monitor,
15 - disposable filter (≤ 0,1 µm) installed near gas analyzer,
16 - 3- way valve for calibration,
17 - standard gases.

as well as sulphuric acid condensation, ingoing parts of the system (the probe, preliminary filter and heated gas line) are to be maintained at a temperature t_1 that is higher than the sulphuric acid dew point temperature.

- Due to high flue gas humidity (~12% (V)) a sample will passed through a two-step cooler with automatic condensate discharge after each stage.
- An acid filter should be placed after flue gas cooler to trap sulphuric and nitric acids aerosols.
- Blow-back should be twice as frequent as for the installation inlet.
- Owing to the hygroscopic, submicron-size nature of final product particles present in the flue gas, the preliminary filter should be replaced every two weeks of continuous operation.
- Before the flue gas conditioning system a scrubber is positioned to selectively absorb any given gas component. For instance, ammonia is an interfering factor when SO_2 concentration is to be measured. In this instance ammonia is selectively scrubbed from sample gas in an ammonia scrubber. Conversely, when ammonia content is to be determined, an SO_2 scrubber is incorporated in the system.

1.4.2. Flue gas analyzers.

At the installation inlet and outlet (after by-product electrostatic precipitator, ESP) flue gas will be analysed continuously, with periodic analysis at the irradiation vessel outlet. The measurements of flue gas composition after the ESP are aimed at – among others – evaluation how harmful the outlet gas is for environment (ecological noxiousness). They should be done in accordance with local regulations.

Requirements to met by the analyzers to be used include:

- maximum measuring range should be equal to 150% of maximum expected concentration under design conditions;
- the upper limit of the measuring range should be such that it is at least 50 times the detection limit;
- the drift, plus or minus, should not exceed 2% of the measuring range for the zero point, and 1% of the span per month operation;
- the minimum range of operating temperature should be between +5°C to +35°C;
- when the ambient temperature changes by 10 °C within the permissible ambient temperature range, the magnitude of the zero point drift should not be greater than 2% while that of the span should not exceed ±3% of the analyzer measuring range;
- the cross sensitivity (the influence of other flue gas components) should not be higher than 4% of the measuring range;
- the effect of sample temperature and pressure on analyzer readings should not exceed 2% of the measuring range;
- the analyzers should be equipped with a system for zero point ("zero") indication calibration and "span" indication calibration;
- provision is necessary such that calibration may also be started externally (a remote starting); the analyzers should be equipped with RS 422 to make possible their interaction with a modular computer;

- analogue signals from the analyzers should be of the current type within the range of 4 ÷ 20 mA.

Following analyzer types, which make use of the specific chemical and physical properties of the flue gas components, are presented for measuring concentrations of specific gas components:

SO_2 concentration – analyzers based on the principle of UV pulsed fluorescence or NDUV analyzers;

$NO/NO_X/NH_3$ concentrations – chemiluminescent analysis with two converters (molybdenum and stainless steel). To diminish water vapour, CO and CO_2 influence on concentration measurements the pressure inside the analyzer reaction chamber has to be maintained at the level of a few mm Hg (absolute).

O_2 concentration – paramagnetic analysis or use of a zirconium probe;

O_3 concentration – UV photometer;

$N_2O/CO/CO_2$ concentrations – NDIR analysis with an electronic correction of observed level of N_2O on the basis of indications regarding the two other components.

The measuring sets to be used in the control system are presented in succeeding Figures. It is planned to connect all sets by RS with modular computers.

Concentration of flue gas O_2 will be measured at selected points for the purpose of monitoring the gas tightness of the entire flue gas circuit.

In Fig. 8.9. the gas analyzer system at the inlet of the installation is shown. The measuring of CO concentration at this measuring point gives an indication of potential flue gas soot content and the effectiveness of pulverized coal combustion in the boiler.

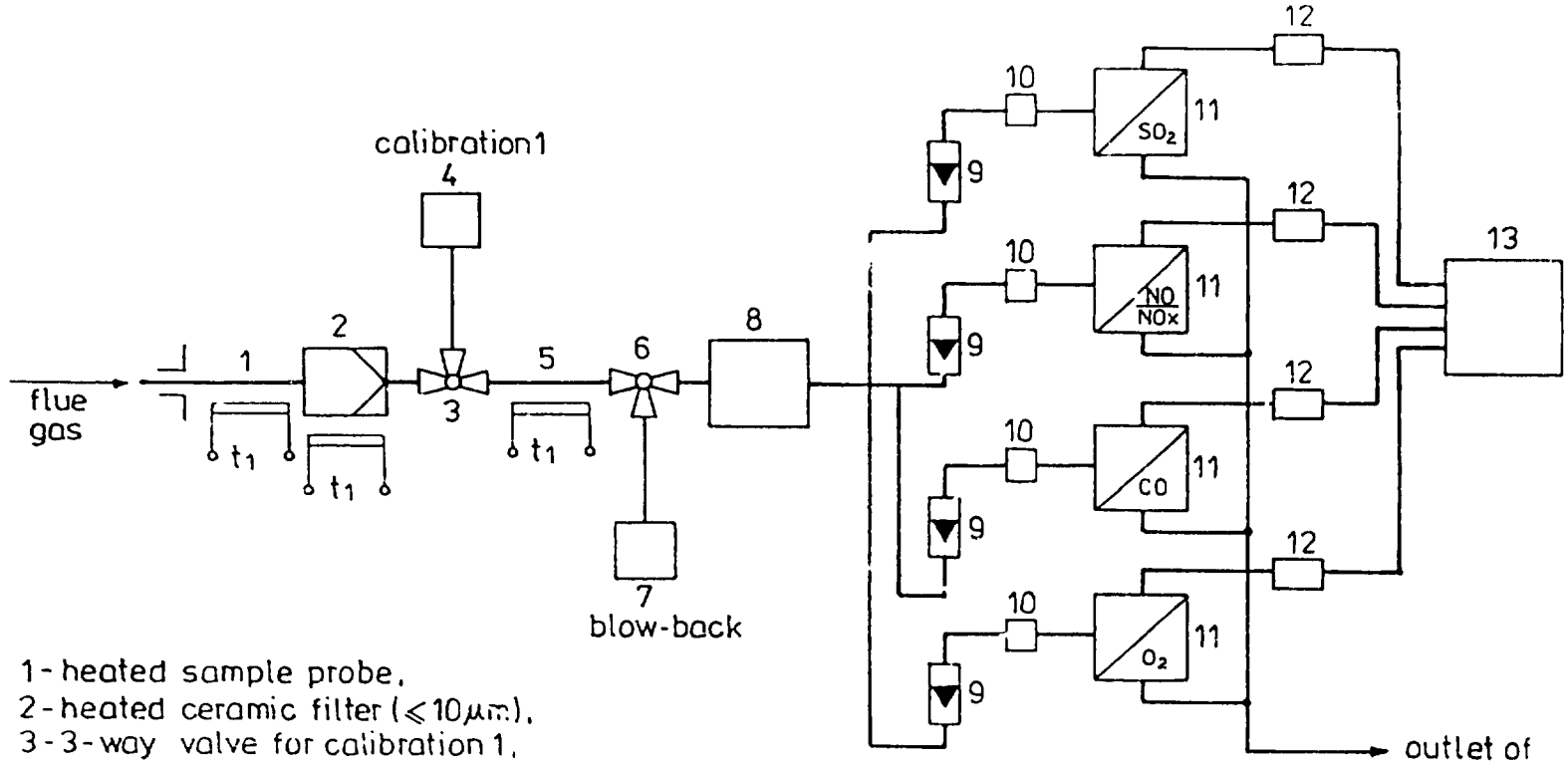
The outlet (after the by-product electrostatic precipitator) composition of flue gas is to be measured with the following sets of analyzers:

- a set to determine concentrations of SO_2, O_2 and O_3, as shown in Fig. 8.10. The ammonia scrubber is used for selective absorption of unreacted ammonia, which would interfere with spectral measurement of these three flue gas components.
- a set to quantify concentrations of $NO/NO_X/NH_3$ as shown in Fig. 8.11. This set includes an SO_2 scrubber since ammonia reacts with SO_2. Chemiluminescent analyzer with two converters is included. The stainless steel converter is kept at temperature 825°C and used to convert ammonia and NO_2 to NO. The molybdenum converter is kept at temperature 325°C to convert NO_2 to NO. NO concentration analysis is carried out directly in the chemiluminescent chamber of the analyzer. The analysis of a flue gas sample is carried out according to the following procedure: The inlet flue gas sample is divided into three equal parts at the analyzer inlet. One part flows to the chemiluminescence chamber where NO concentration is measured. A second part passes to the molybdenum converter and thereafter is mixed with the first part. This allows the determination of NO_X concentration.

$$NO_X = NO + NO_2$$

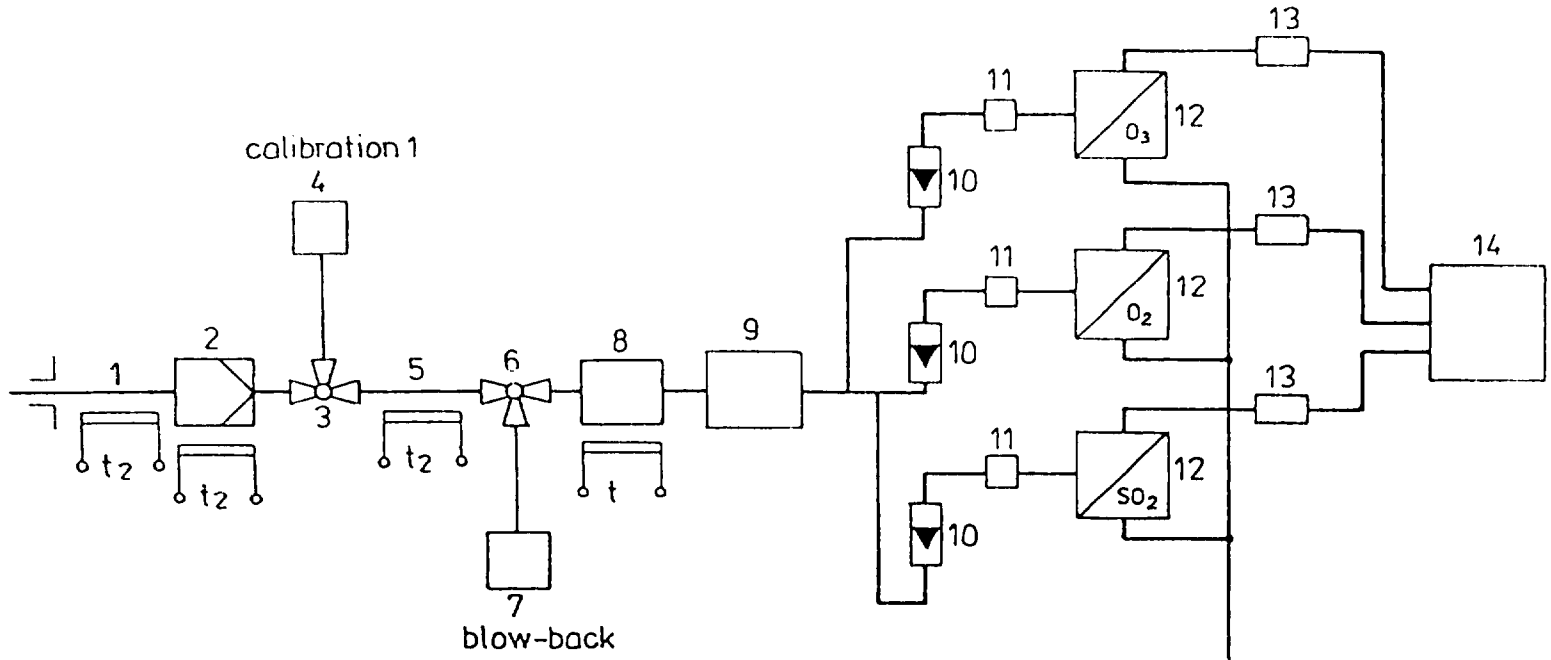
The third part of sample gas goes through the stainless steel converter, and thereafter is mixed with the first part in the chemiluminescent chamber, and then is used to determine

Fig. 8.9. Gas analyzer system at inlet of installation.



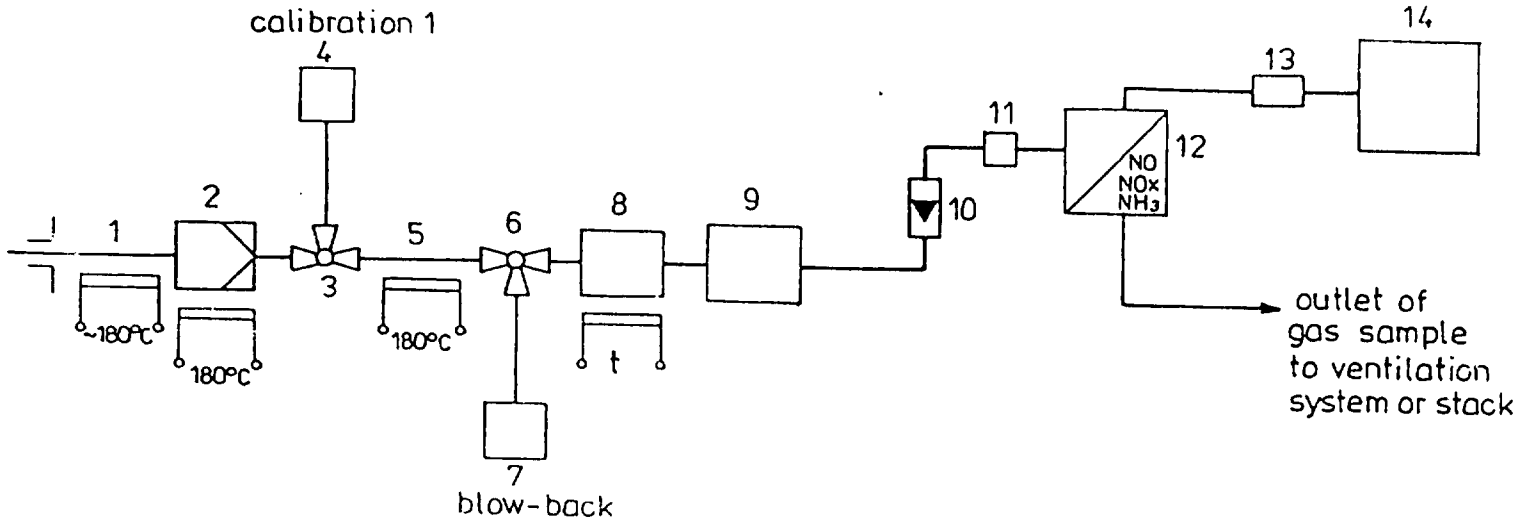
1 - heated sample probe,
2 - heated ceramic filter ($\leqslant 10\mu m$),
3 - 3-way valve for calibration 1,
4 - standard gases,
5 - heated sampling line,
6 - 3-way valve for blow-back,
7 - zero air supply,
8 - sample gas conditioning system,
9 - flow meter,
10 - disposable filter ($\geqslant 0{,}1\mu m$),
11 - gas analyzer,
12 - RS 422,
13 - modular computer.

Fig. 8.10. System of gas analyzers for measurement of SO_2, O_2, and O_3 concentration at process outlet.



1 - heated sample probe,
2 - heated ceramic filter ($\leqslant 1\mu m$),
3 - 3-way valve for calibration,
4 - standard gases,
5 - heated sampling line,
6 - 3-way valve for blow-back,
7 - zero air supply,
8 - ammonia scrubber,
9 - sample gas conditioning system,
10 - flow meter,
11 - disposable filter ($\geq 0{,}1\mu m$),
12 - gas analyzer,
13 - RS 422,
14 - modular computer.

Fig. 8.11. System for measurement of ammonia slip, NO, NO_x at process outlet.



1 - heated sample probe,
2 - heated ceramic filter ($\geq 1{,}0\mu m$),
3 - heated 3-way valve for calibration;
4 - standard gases,
5 - heated sampling line,
6 - heated 3-way valve for blow-back,
7 - zero air supply,
8 - SO_2 scrubber,
9 - sample gas conditioning system,
10 - flow meter,
11 - disposable filter ($\geq 0{,}1\mu m$),
12 - NH_3 gas analyzer,
13 - RS 422,
14 - modular computer

$$N_t = N_{NH_3} + NO_x$$

concentration. A microprocessor calculates the individual concentrations of NO, NO_2 and NH_3 from these three measured signals.

- a set to measure N_2O, CO and CO_2 concentrations (Fig. 8.12.) according to the following procedure: Nitrous oxide is produced in the process vessel by flue gas irradiation in the presence of ammonia. The measurement of N_2O concentration is influenced by SO_2, NH_3, CO and CO_2. To ensure reliability and adequate measurement accuracy the following means are used: While in the case of SO_2 and ammonia measurement applicable removal from the flue gas sample is carried out using scrubbers placed at outlet of a heated gas line, for N_2O concentration measuring three-component analysis will be used. The two other components are CO and CO_2. This set is to be equipped with a microprocessor to correct N_2O indications according to CO and CO_2 indications.

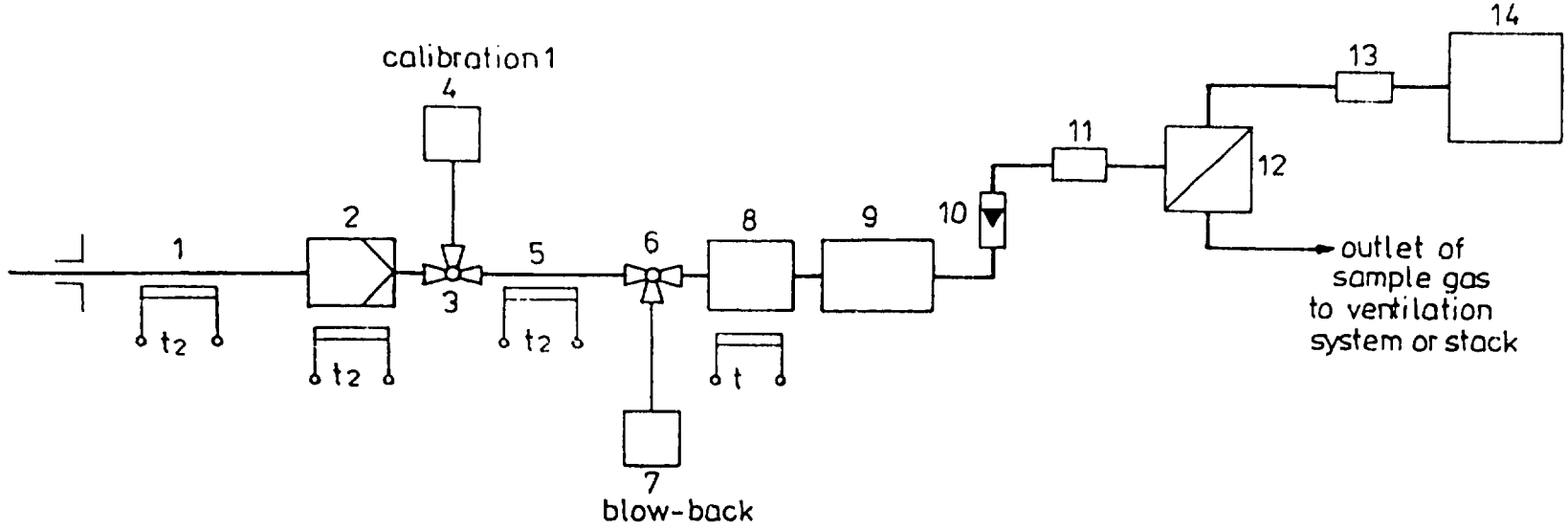
1.4.3. Dust concentration measuring devices.

The dust (total solid particulate) concentration measurements are to be performed at the installation inlet and outlet (after by-product electrostatic precipitator). Dust measurements at the inlet indicate the amount of dust brought to the installation by flue gas. Inlet fly ash is undesirable because it enhances metals content of the final product. It is a practical limit on allowed particulate loading at the inlet to installation. When fly ash loading exceeds a prescribed level flue gas is to be diverted to the stack. Thus the continuous monitoring of the dust level at the installation inlet is a key procedure. Output signal from dust meter is to be connected to control system of input flap valve of the installation. These requirements are completely fulfilled by optical analyzers measuring absorption of light flux running through a flue gas stream. Measurement after the by-product electrostatic precipitator indicates the effectiveness of the E-Beam installation in controlling particulates.

A dust meter should meet the following requirements:

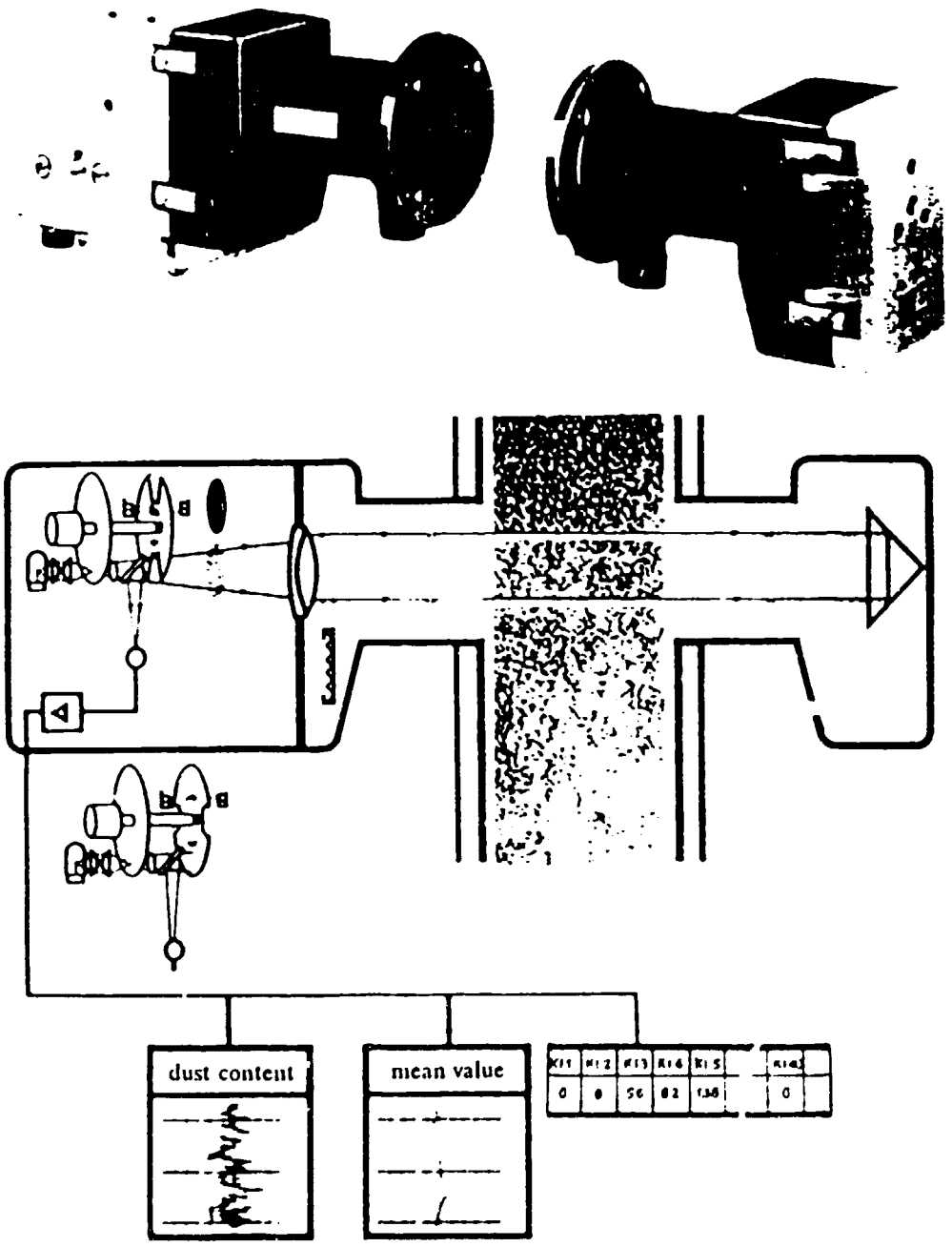
- the maximum measuring range should amount to 150% of expected dust level under design conditions. The maximum measuring range capacity of the both dust meters should equal 150 mg/m^3.
- detection limit should not exceed 5% of the upper measurement limit. If needed to increase accuracy the dust analyzer is to be operated with at least twice the normal amount of light flux passing across the flue gas stream. Such a meter consists of emitter, reflector and receiver (Fig. 8.13.) with an adequate calibration set.
- the minimum range of local ambient temperature is from −20 °C to 50 °C.
- magnitude of drift, plus or minus, of the zero point and span per month should not be greater than 2% of the full scale.
- 10°C rise of surroundings temperature within the prescribed ambient temperature range shall not induce zero instability greater than ±2% and that of the span ±3% of the maximum measuring range of the meter.
- the influence of sample gas temperature and pressure on meter indication should not exceed 2% of the measuring range.
- the meter should be equipped with a calibration system. It is required that calibration is periodically checked automatically. Many meters perform this function each hour.

Fig. 8.12. System for measurement of N_2O, CO and CO_2 concentration at process outlet.



1 - heated sample probe,
2 - heated ceramic filter (≤10μm),
3 - 3-way valve for calibration 1,
4 - standard gases,
5 - heated sampling line,
6 - 3-way valve for blow-back,
7 - zero air supply,
8 - ammonia and SO_2 scrubber,
9 - sample gas conditioning system,
10 - flow meter,
11 - disposable filter (≤0.1μm),
12 - gas analyzer,
13 - RS 422,
14 - modular computer.

Fig. 8.13. Principle of dust concentration monitor.



- the meter should be equipped with means to prevent dust settlement on optical elements. Usually such type analyzers are equipped with two jet blowers with air filters that ensure cleanness of optic elements of the sender and receiver (Fig. 8.14.).
- the meter should be equipped with RS 422 for interaction with a modular computer. A dust meter usually measures extinction value. For absolute quantification in units of mg/Nm^3 parallel measurement of dustiness by other – usually gravimetric method – should be carried out. To permit such measurement two measuring pipestubs should be provided in the flue gas duct, suitable for use by a dustiness gravimetric meter. Measuring stubs should be placed at least 500 mm from the measuring path. The measuring and calibration devices must not affect one another.

1.4.4. Flue gas flow rate devices.

Flue gas flow rate is a principal parameter characterizing any gas cleaning installation. Its value is directly used to calculate: required flue gas irradiation dose, ammonia feed rate, water feed rate and SO_2 and NO_x removal efficiency. High accuracy of measurement is called for. Flue gas flow rate will be measured at two cross sections: at inlet to the installation and after the by-product electrostatic precipitator (at outlet of installation). The maximum inlet flue gas flow rate is approximately 300000 Nm^3/h. The inlet duct diameter will be equal to 2 m. Two optional solutions of measuring sets are proposed for flue gas flow rate measuring.

In the first case flue gas flow is determined by measuring of mean velocity of gas in flue gas duct by use of ultrasonic waves. The measurement principle is shown in Fig.8.15. Flow rate is calculated from the duct cross-sectional area and measured gas velocity. On opposite sides of the duct must be provided means for use of a supersonic transmitter and receiver installation.

The requirements regarding flue gas flow velocity meter are as follows:

- the measuring range should be matched with the expected flue gas flow velocity such that the latter is 2/3 of measuring range,
- the drift of zero point and span drift should not exceed ±2% of the measuring range.
- in comparison with recommended value span drift should not exceed ±1% of measuring range as a result of increase of ambient temperature of 10 °C,
- the meter is to operate in an ambient temperature of from −20 °C to +50 °C.

In the second case it is proposed to install in the duct a ram effect pipe with vertical sensor in its centre to measure pressure drop. (Fig. 8.16.) It is a recently commercially developed measuring orifice plate recommended for gases containing particulate solid (dustiness) and insensitive to moisture condensation. Many suppliers guarantee measuring error ±1% of flow rate. Advantageously the vertical sensor may be removed for cleaning. The sensor should be so maintained, regularly, even when the dust content of flue gas is low. The proposed scheme of the measuring set together with the correction for flue gas density variation due to temperature and pressure fluctuation in the gas duct is shown in Fig. 8.17.

The decision which of the two alternative sets will be used is to be taken at the stage of a technical design. Flue gas duct accessibility, the possibility of installing two ultrasound

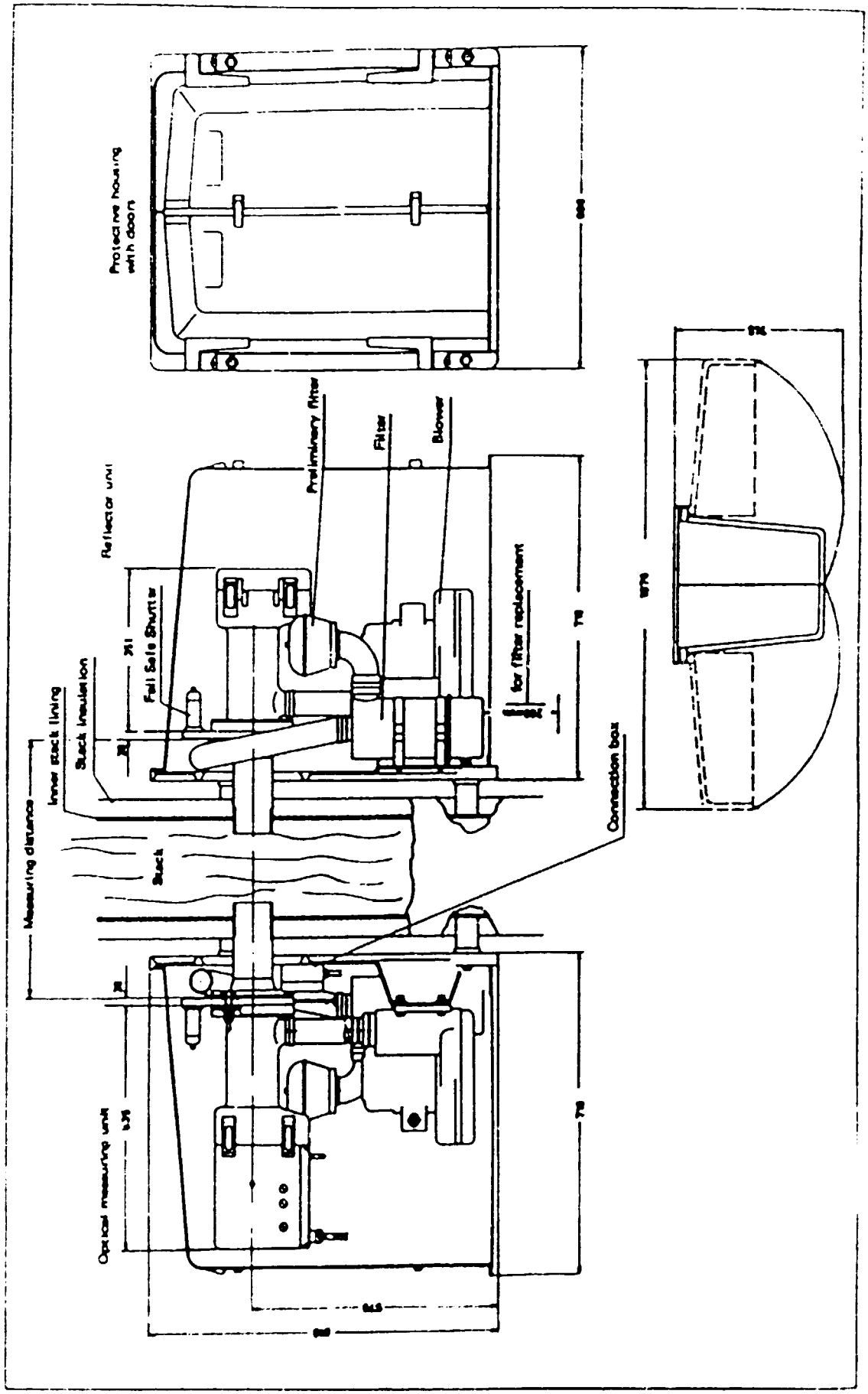


Fig. 8.14. Set-up of dust concentration monitor.

Fig. 8.15. Gas velocity monitor principle.

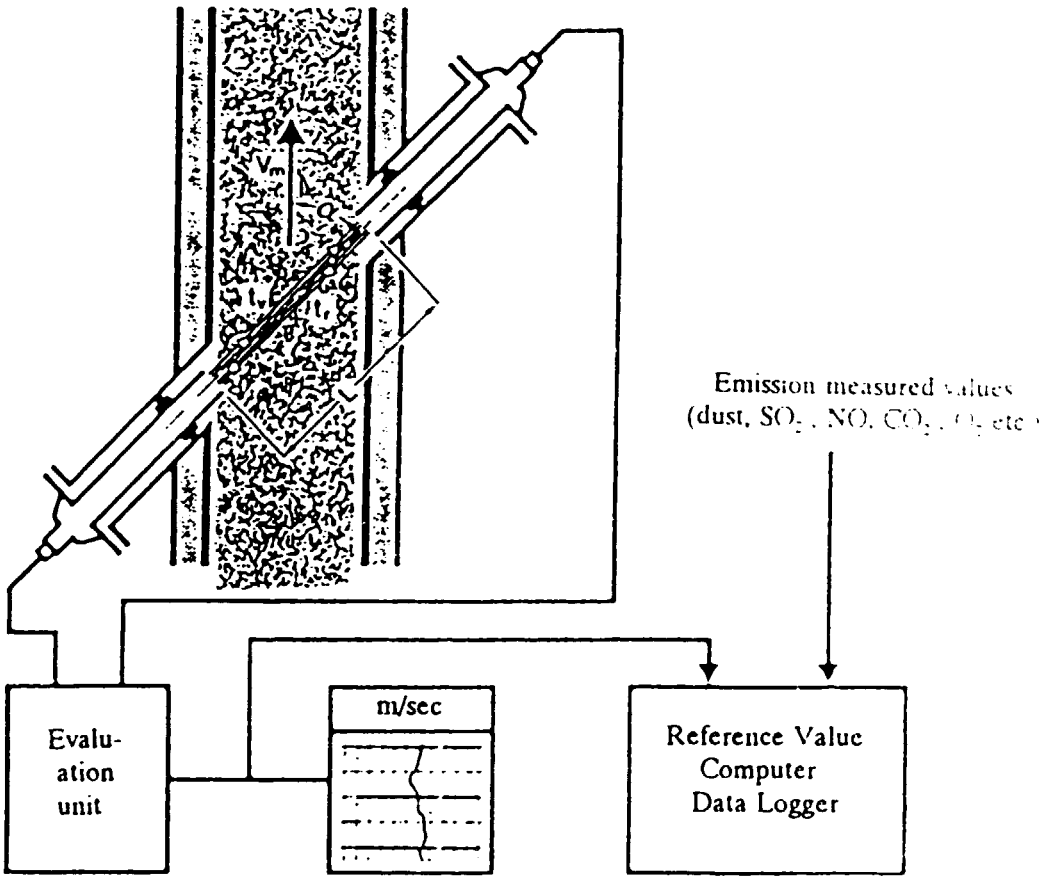
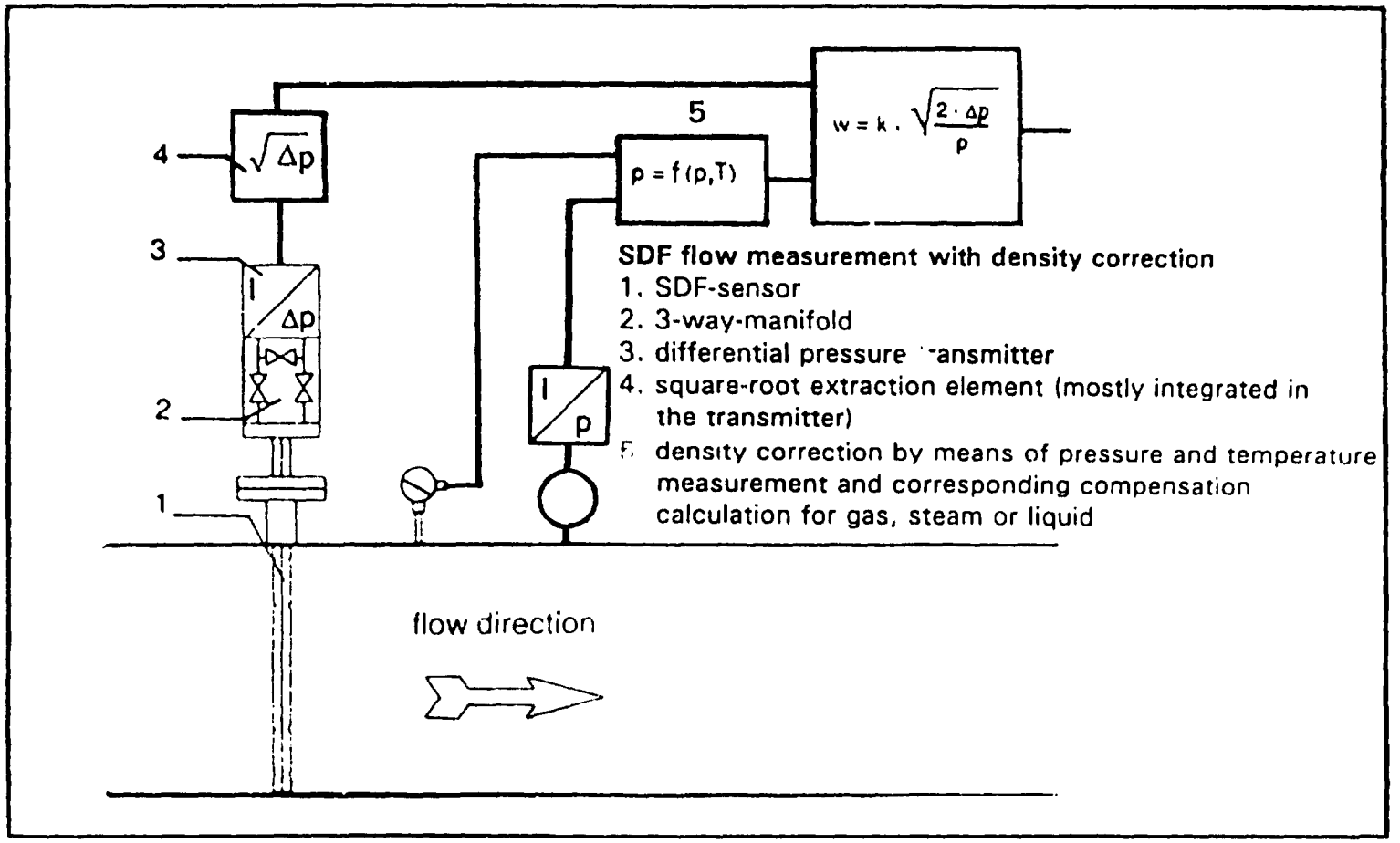


Fig. 8.16. SDF flow sensors.

pitostatic tube sensors for
gaseous media,
saturated and superheated steam,
liquids

Fig. 8.17. Measuring chain of flue gas flow meter with correction of density variations due to changing temperature and pressure of gas.



transmitters and receivers around the duct, vibrations inside it, and necessary straight segments will be essential factors.

1.4.5. Computers.

The electronics is selected to fulfill industrial measuring standards (to be achieved in a gas cleaning process treating an inlet stream with substantial himidity, acidity and dustiness).

The process parameters monitoring and control, and data acquisition are under charge of VME-standard microcomputer systems. But the computer functions, either MASTER or SLAVE, are data presentation, storage as well as executing of the operators commands (MASTER only).

Example configuration of IBM PC standard computer, that may perform the functions is shown below:

Requirements for the computer equipment (IBM PC standard):

- 486 DX, 100 MHz microprocessor,
- 32 MB RAM, 32 bit (bit parity control),
- 1 GB hard disk,
- 1.44 MB floppy disk, 2 units,
- 17" color monitor,
- keyboard, mouse,
- graphic card
- ETHERNET card,
- SERIAL BUS (industrial) card with optoisolation,
- Windows operational system (Windows 95, OS-2),
- EXCEL program,
- laser printer for A4 paper,
- ink jet printer for fanfold form paper.

1.5. Executional elements of system control.

General principles and criteria of main importance in selection of the control elements for industrial installation should be applied for all technological components and control systems. **In particular, selection of the following elements of the technological control and process interaction should be subject of analysis:**

- stabilization unit to fix the flue gas flow quantitatively,
- flue gas conditioning unit to maintain a constant temperature and humidity of gas treatment,
- automatic dosage unit for ammonia,
- accelerator power regulation unit,
- unit for final product transfer,
- unit of the gas composition monitoring at the inlet and outlet.

The selection criteria for these most important units should emphasize:

- high quality of indications,
- high sensitivity of the reaction (high accuracy class),
- taking into account changing of the weather conditions,
- resistance to adverse working conditions (temperature, dustiness, humidity),
- indication reproducibility,
- resistance to corrosive environment,
- applicability in the computer network of interactions and computer data registration,
- professional construction,
- breakdown free operation,
- long term service,
- ease of upkeep and service maintenance,
- possibility of non-failure continuous operation,
- minimization of dimensions and weight,
- ready availability of spare parts and service,
- easy calibration,
- effective information transfer and reaction via control signals,
- compatibility of data acquisition system with existing systems in the power plant (boilers).

1.6. System control management (SCM).

Chapt. 1.1. – 1.6. presents the specifications of the elements and units of the measuring, monitoring and control system (MMCS), specification and location of measurement points. Management and technical aspects of the MMCS are presented below.

1.6.1. Control of the process steps.

a) flue gas inlet

Regulation of the flue gas flow is performed using the damper (regulation of the cross section) at the installation inlet. The flow value is measured by a hypersonic method or a special orifice. The signal from the ADC is sent to the process controller (process level) and to the operator system, which automatically corrects the flow according to the specified algorithms. The signals from the temperature, pressure, humidity and dustiness sensors are sent to the controller (MSS-1) as well. This regulation unit can be adapted to the three different options of a gas intake:

- a total flue gas is sent to the purification installation,
- some part of the flue gas is sent to the installation and the rest is sent to the stack,
- the gas is taken from two boilers (for example, a substantial portion of the flue gas flow is taken from each of the two Benson boilers – this option will be realized at EPS Pomorzany).

It is anticipated that the control system of the ventilator will be connected to the MSS-1 controller.

b) humidification system

Temperature and humidity of flue gas after adiabatic cooling have very large influence on the efficiency of gas cleaning. The humidification procedure is defined in Chapt. II, which dictates the requirements for the control system.

Control of dosage of water, steam and compressed air is performed by a system that consists of control valves and temperature, pressure and humidity meters. This system is equipped in the autonomous control unit (MSCS). A temperature meter in the measurement point [2] will give the control signal for this system.

The control algorithms will be obtained using the equations [4, 8] of Chapt. II.

c) an ammonia delivery system

An ammonia dosage is controlled by a precise flow controller. The following three values are the control parameters:

1. A stoichiometric rate of feed of ammonia.
2. An amount of ammonia delivered to the installation.

3. An amount of ammonia emission to the stack.

ad 1. A stoichiometric concentration of ammonia is calculated from the initial data – flue gas flow, concentration of SO_2 and NO_X at the inlet and a stoichiometric coefficient F defined in the following way:

$$F = \frac{C_{NH_3}}{C_{NO_x} + 2 * C_{SO_2}}$$

where C are the concentrations of NH_3, SO_2 and NO_X, expressed in moles.

ad 2. The amount of ammonia supply derived from the applicable stoichiometric coefficient is maintained at a specific level by a precise controller and ammonia meter (Mass-Flow controller).

ad 3. An analyzer system positioned at the outlet of the installation will be equipped with an NH_3 analyzer to monitor ammonia concentration continuously.

An ammonia delivery system will be equipped with a controller (process level) connected with the operator system and safety unit.

d) electron beam dose control

Dose control is achieved by making use of the measurements of the electron beam parameters – see Chapt. IV. The control algorithms are obtained from the equations [1.1., 1.2.], Table 1.1. and Fig. 1.1. – 1.5. given in that Chapt. The additional effect of a serial of the accelerators in increasing of the NO_X removal efficiency will be taken into account according to eq. [15] of Chapt. I.

Optimal utilization of electron beam power in this industrial, demonstration installation will require proper calibration to be performed in the start-up period in conjunction with installation of probes to periodically measure beam intensities within the reactor vessels. The accelerators are equipped with factory-supplied autonomous controllers. Nevertheless (at the process level) a special controller of the total dose, dependent on the process parameters, should be installed.

e) It is assumed that the by-product electrostatic precipitator will be equipped by the supplier with required controllers (process level) that will be connected to the operator system (see Chapt. V).

f) Transport and storage of the final product (ammonium salts) – see Chapt. VI.

1.6.2. Management of continuous and periodic measurements.

The measuring unit at the outlet of the treatment plant will play a principal role in the control of the plant under normal operating conditions. At this location all signals are produced, that represent:

- normal operation (in agreement with the specified algorithms) of the treatment process,
- disruptions in the process and breakdown situations (such as leakage from any point of the installation, incorrect humidification operation or ammonia dosage, damage to the reactor vessel window etc.),
- trends leading to disruptions (such as temperature, pressure or humidity drifts, abrupt changes of flue gas, water, and ammonia flows and electron dosage).

A very important function of the system is proper management that results in rapid identification of the reasons for any abnormalities, technological deviations or breakdown situations.

The functional arrangement of the system is indicated by Fig. 8.18. and 8.19. Abnormalities in boiler operation are to be identified by periodic (by a switching method) measurements of the gas concentrations of SO_2, NO_X, NH_3, O_3, N_2O and CO and reference values of O_2 and CO_2 at the outlet of the process vessel.

Because of extremely difficult conditions for measurement at the process vessel outlet (high concentration of submicron-size, hygroscopic and aggressive components), it is anticipated to install probe at this point continuously washed by a blow-back air stream, and automatically connected to the analyzers for only short periods (15 ÷ 30 min) 2 – 3 times per day, all of this to control correctness of the collection and transport of the flue gas.

Management of the measurements at the inlet to the installation plays an important role during primarily transient stages, particular in the start-up period. During normal operation, this part of the system monitors the inlet flue gas parameters. With several inlet channels the automatic switching metnod can be applied (multiple probes, one analyzer).

A system of adequate data management, permits minimization of the number of analyzers and decreases cost.

Fig. 8.18. Scheme of the gas analyzers connection at inlet of installation.

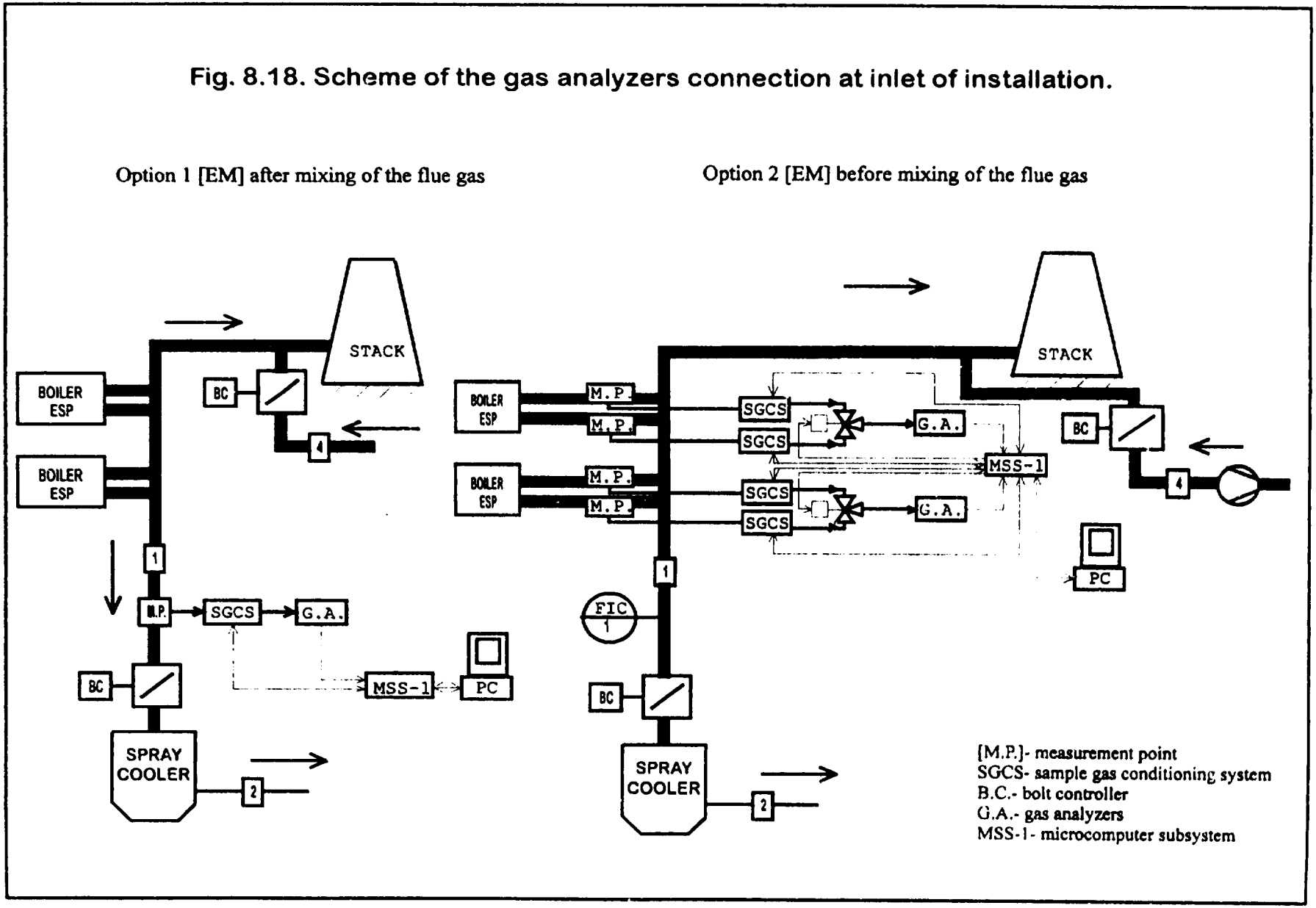
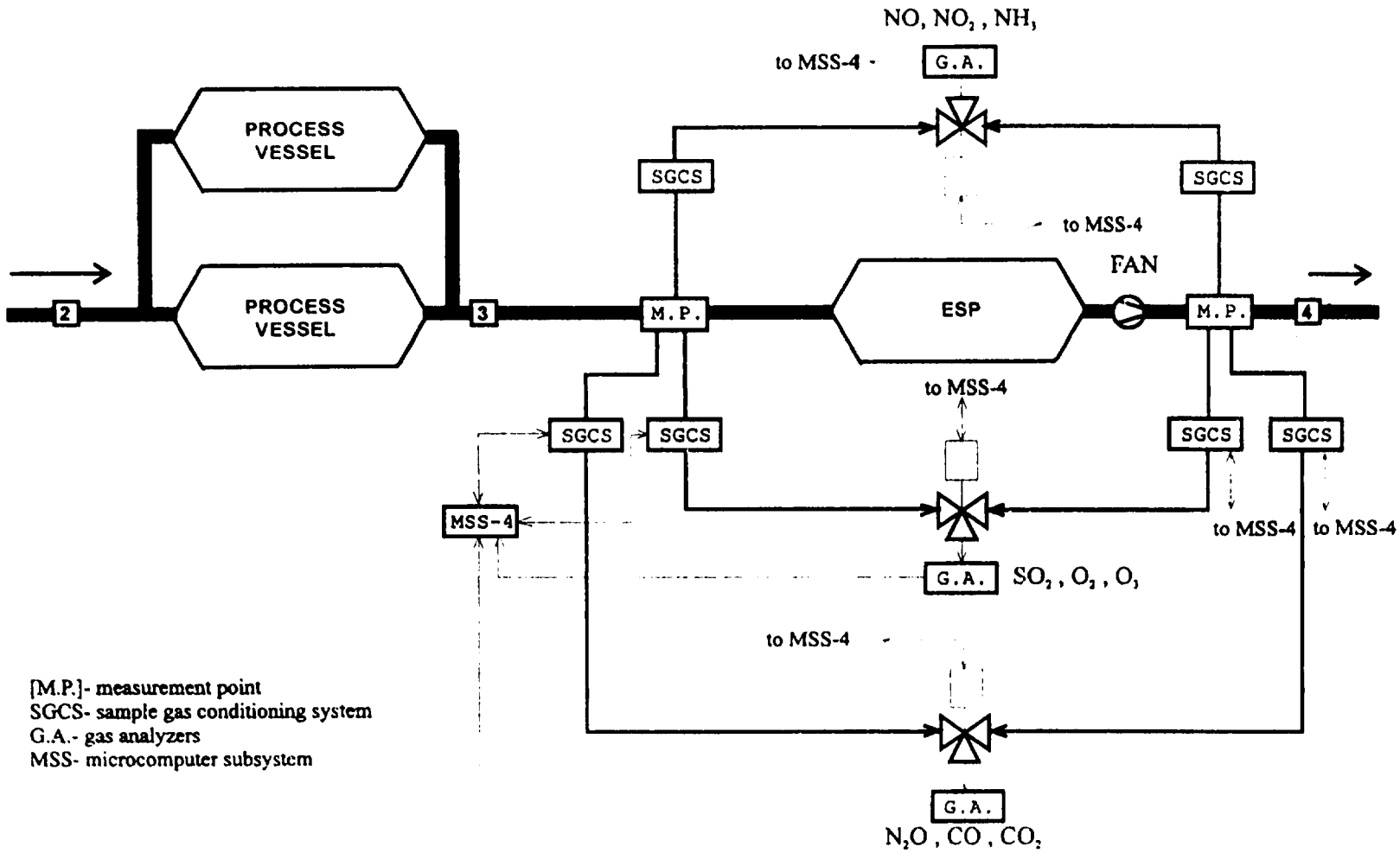


Fig. 8.19. Scheme of the gas analyzers connection at outlet of installation



1.6.3. Functioning of the MMCS.

a) Start-up of installation.

The operator introduces data reflecting operating conditions from the keyboard or uses the configuration files from hard disk.

After switching on of the start-up option, the computer automatically checks to determine if the installation is ready to work, and in accordance with individual technological algorithms, begins to switch on the system units sequentially. The operational steps or inadvertent errors are presented on the monitor as the text comments to assist the operator in making proper instructional decisions.

At this stage, the data are sent to the microprocessor systems. They control the technological installation according to set requirements. The status of the system is reported back by the host computer.

b) Storage and archives of the data.

When the gas cleaning process is running, the data that describe its status, are read by the computers with the frequency of 1 Hz, presented on the monitors and stored on the hard disk to serve as the compressed files.

The data file is preceded by a text protocol of the process conditions. In this protocol, there is information concerning the fixed pa.ameters that govern the process.

If monitoring is perfomed by many computers the data are stored on the disk of any selected computer. They are protected from loss by an automatic or manual transfer to magnetic or optical storage devices.

Together with these specific parameter data, information concerning emergency situations, time and lengths of breakdowns etc. is stored as well.

An emergency situation is defined as one in which the limits for magnitude of any of the parameters are exceeded (overflow).

c) Data presentation.

The data obtained by the computers are presented in the form of plots (histograms) that on the diagrams and as the numbers on the synoptic schemes of the installation show time dependence of the parameters.

The parameters presented on plots may be simple data (temperature – for example) or may be a result of evaluation of an array of data. Up to five figures can be seen on the monitor with the possibility of selection of any parameter. Data are presented for an hour, day or week period, as selected by the operator. The information about actual value of the parameter is shown on every plot in the form of a diagram of the actual amplitude and the number.

The limits of the parameters are presented by double thresholds on the diagrams and plots. First pair of thresholds (lower and upper ones) shows an allowed range; second pair defines the breakdown conditions. If there is an overflow of the first pair, an operator is informed by a change of the screen colour or by a buzzer; in the second case, the installation is shut down automatically.

The figures can be zoomed both in value and time. There are two linear markers, which can be moved into any position. Using the first one, the value of the parameter can be read out for any time; the second one (together with the first one) is used to read out the differences dP and dP/dt to observe the trends in parameter changes.

A system allows digital presentation of the actual parameters of the technological (synoptic) schemes of the installation. These schemes are organized in a hierarchical manner, i.e. one can proceed from a general to a more specific one. It is easy to replace the schemes by the plots and go back. The selection of a definite measuring point (up to 5) in the scheme changes automatically into a plot presentation.

Any selected data can be printed out (on A4 or fanfold form paper).

d) Breakdown situations.

In the case of the breakdown situation the special program algorithms set the automatic, emergency shutdown sequence. The sirens, blockades and fire-extinguishing systems are switched on in a fire risk situation.

A record every breakdown situation is stored on files. A full documentation of the shutdown procedure is presented together with the values of parameters.

e) Parameter calibration.

The main program can be used for a calibration of measuring units. There are possible tabular, linear or multiparameter (up to the third order) calibrations. Calibration sets are stored as special files (tables). They are used by the main program or are sent to the microprocessor units. These sets are specially secured against access by any external party.

1.6.4. Functioning of the microprocessor software.

A proper functioning of the installation is strongly dependent on the microprocessor software. The programs are written in a C language, and after compilation, are stored in the special program memories of the microprocessor systems (cassette controllers of measuring units).

a) Linking (data transmission).

The microprocessor subsystems of the measuring units are connected to the computers by a common serial bus. The special transmission protocols make possible correct transmission under conditions of strong electromagnetic noise and long distances.

The connection between computers and measuring units is bidirectional. The subsystem has to accept the computer data and on request sends them back.

b) Data acquisition.

Every subsystem reads the data with the 1 Hz frequency. If the calibration has been performed according to the calibration set, obtained from the host computer, the actual values are stored in the memory after eventual evaluation of the complex parameters. The subsystem is ready to send these values to the host computer at any time. Some parameters are shown on the diode displays of the units.

c) Controllers and regulators.

The subsystem electronics controls the process parameters by switching on or switching off of the proper valves, or by holding them at an intermediate position. These are single operations, and depend on the process requirements, for example, switching on of the main water valve.

Regulators control the processes in a different way. The value of the parameter is kept within the specified limits by continuous regulation, for example, of the ammonia valve. This control is automatic and achieved in two stages. In the first one, the values of the main parameters are set from the operator console or obtained from the file prepared in advance. Remaining parameters are calculated (optimized) by a computer, taking into account, in addition, the data obtained from the installation. They are then send to the execution electronics devices (regulators) of the systems.

In the second stage the control is taken over by the autonomous, microprocessor regulator of the systems. This regulator has the task of bringing the parameter value back to the assumed magnitude.

2. Transient states analysis (startup, shutdown, effects of minor failures and breakdown).

The installation will be controlled with minimum influence of the operator in normal operating conditions. To fulfill this requirement, the MMCS is to be applied.

Particularly for use during the first year of exploitation provision for hand control is made because of the prototype nature of the installation. This supplemental, manual system will be useful, in particular, for controlling the installation during transient states.

As an example, shown below is the procedure for the normal startup and shutdown of the installation.

Startup of installation.

1. Startup of electrical power supply:
   a) main unit of installation,
   b) measuring – control racks,
   c) computer system,
   d) flue gas analyzers (sampling, transport and flue gas analysis),
   e) accelerator control (vacuum system and power supply of accelerators is switched on permanently),
   f) humidification system,
   g) ammonia dosage,
   h) by-product electrostatic precipitator (ESP) system,
   i) product transfer system.

Required warming up minimum time of the equipment, above:
   a) 5 min,
   b) 5 min,
   c) 2 min,
   d) 30 min,

After warming up of a, b, c, and d, the measurement of flue gas dustiness (after the electrostatic precipitators of the power plant) is to be activated for approximately 15 min, the duration depending on the extent of concentration pulsations. A mean value should be determined based on a minimum of 10 cycles. If the mean dust concentration is below the specified limit, the flue gas inflow dampers are opened and the measurement and control of the flue gas flow is started to establish appropriate flow rate (10 ÷ 15 min).

2. Switching on of the measurements of:
   a) concentration of SO_2, NO_x, O_2, CO and CO_2 at the inlet, after the reaction vessel and the electrostatic precipitator (20 ÷ 25 min) to ensure freedom from leakage at the

individual installation points. If the results of these measurements are acceptable, the following values are calculated from the mean concentrations of SO_2 and NO_x:
- an amount of ammonia to be fed to the flue gas before the radiation vessel,
- radiation doses of flue gas to get the presumed removal of SO_2 and NO_x.

Then the electron beam currents for individual accelerators will be determined.

b) flue gas humidity at the inlet to the installation and after the humidification vessel. Then the parameters of the flue gas humidification system will be determined.

3. After warming up of the humidification system, the entire system is switched on. The humidity is measured before and after humidification to establish the prescribed outlet value.

4. After warming up of the whole installation, switching on:
   - ammonia dosage,
   - accelerators,
   - by-product electrostatic precipitator and product transfer system. After parameter stability is achieved the continuous operation of the installation is begun.

Shutdown of the installation.

1. Switching off the humidification system.
2. Switching off the ammonia dosage.
3. Switching off the electron beam of the accelerators.
4. Observation of the indications of the meters in all installations – after 1, 2, 3, the flue gas composition should be almost identical at any point.
5. Transfer of all measuring systems into a "zero" status. The air blowback is then switched on to all flue gas collectors for 20 min and the analyzers are set to zero.
6. Swiching off power supplies of all measuring and control systems. Closing of all analysing flue gas collectors.
7. Swiching off power supplies of the computers.
8. Swiching off the main power of the installation drives.

3. Determination of the required spare equipment and service (spare parts for two year operation).

1. Sample gas probe with ceramic filter and with temperature controllers (0 ÷ 200 °C) – 3 pieces (one with a ceramic filter with the pore size of 10 μm and two with the pore size of 1.0 μm).
2. Heated sample gas line with temperature controller (0 ÷ 200 °C) – 2 pieces.
3. Sample gas cooler (surface mounting case for three gas paths of stainless steel) with automatic condensate drains – 2 pieces.
4. Sample gas conditioning unit – 2 pieces.
5. Zero air supply unit (zero air flow of 20 l/min, without SO_2, NO, NO_2, O_3, CO and hydrocarbons) – 2 pieces.
6. 3-way valve, heated (0 ÷ 180 °C) for calibration or for blow-back – 4 pieces.
7. Portable air compressor – 1 piece.
8. Portable SO_2, NO_X, CO, O_2, gas analyzer with electrochemical sensors – 1 piece.
9. Portable set for flue gas measurement temperature, velocity, pressure drop, humidity – 1 set.
10. Teflon tubing 6/8 – 1 set.
11. Tube fitting for above Teflon tube necessary for connection to the gas analyzer – 1 set.
12. Standard gases.
13. Platinum resistant thermometer Pt-100 – 2 pieces.
14. Pressure converter – 2 pieces.
15. Drives of the control valves.
16. One set of the electronic modules.
17. Spare parts for the dust meter and flowmeter.
18. Printer spare parts.
19. Cassette VME with power suppliers – 1 piece.
20. Cassette controller – 1 piece.
21. 12 bit multimeter – 1 piece.
22. IN/OUT analog signals converter – 5 pieces.
23. Digital inputs data receiver – 2 pieces.
24. Digital outputs data transmitter – 2 pieces.
25. PID regulator – 2 pieces.
26. GPIB, RS-232, -422, -485 interface.

During the installation operation some failures (breakdowns) of flue gas analyzers can occur. To analyse the flue gas, approximately 10 analyzers will be used. To repair these units as fast as possible, procurement activity shall select the most economical of the following two alternatives:

- to get an agreement with the analyzer producers to remove the failures within 24 h;
- to buy the following spare analyzers:
  - SO_2 gas analyzer – 1 set,
  - NO/NO_X gas analyzer – 1 set,
  - O_2 gas analyzer (paramagnetic) – 1 set.

4. Means of carrying out emergency actions.

Specification of the most important emergencies is presented in the Table 8.5. To deal with such happenings, special autonomous system (SLOW CONTROL) will be installed.

It will be possible to determine these means during the technical documentation preparation.

Table 8.5. Specification of the most important emergencies.

No.	Name of emergency	Features	Procedure (immediate)
1	2	3	4
1.	Breakdown of fly ash ESP.	Rapid increase of particulate loading at the installation inlet, signalization.	Automatic closing of flue gas inflow to the installation.
2.	Damage to the accelerator window.	Loss of vacuum in the accelerating tube.	Automatic switching off of the accelerator.
3.	Damage to the process vessel window.	Change of all flue gas parameter (ΔP in particular) in the prosess vessel and upstairs, signalization.	Automatic switching off of the accelerator, closing of the flue gas inflow to the process vessel.
4.	Leakage from the ammonia supply system.	Exceeding of ambient NH_3 concentration above the alarm level, alarm.	Automatic switching off the NH_3 supply system and isolation of the ammonia reservoir.
5.	Excessive leakage from the water, or compressed air supply systems.	Signalization and location of the damage.	Automatic closing of the medium, switching off of the humidifier and the installation.
6.	Disablement (seizure) of the inflow control elements for flue gas, water, compressed air or ammonia.	Location of the damaged element.	Transfer into hand control.
7.	Disablement of the pumps, fans, heaters etc.	Signalization.	Automatic cut-off of flue gas inflow, switching off of the installation.
8.	Disablement of by-product ESP.	Signalization.	Automatic cut-off of flue gas inflow, switching off of the installation.
9.	Disablement of final product transfer from ESP.	Signalization.	Transfer into hand control.
10.	Change of process parameters exceeding limits (T, ΔP, H, F, I, concentration of SO_2, NO_x, NH_3, O_2, O_3 etc.).	Signalization of the emergency situation.	Computer analysis of the reasons.

5. Coupling of control and monitoring system herein with the existing control and alarm system at the "Pomorzany" Power Plant with consideration of environmental protection requirements.

The measuring, monitoring and control system (MMCS) – its functions, aims, construction, location and system engineering is to be supplied so as to afford ready integration with the general control system of boilers.

6. Cost listing and executional scheduling.

No	Specification of the measurement unit	Quantity each		Total price USD***		Remarks
		Option 1	Option 2	Option 1	Option 2	
1	2	3	4	5	6	7
1.	Inlet* [1], including:			120,000	320,000	
	- gas analyzers (SO_2, NO_X, CO, O_2)	1	2			
	- dust concentration monitor	1	4			
	- flue gas flowmeter	1	4			
	- calibration unit	1	1			
	- sample gas delivery system supply.	–	2			
2.	Outlet of the process vessel and ESP** [3,4], including:			350,000	350,000	
	- analyzer of the NO / NO_X / NH_3	1	1			
	- analyzer of the N_2O / CO / CO_2	1	1			
	- analyzer of the SO_2 / O_2 / O_3	1	1			
	- sample gas delivery systems	3	3			
	- dust concentration monitor	1	1			
	- flue gas flowmeter	1	1			
	- calibration unit	3	3			
	- heated 3/2 valve (180 °C).	3	3			
3.	Environmental monitoring* [EM], including:			120,000	–	
	- gas concentration analyzer (SO_2, NO_X, CO, O_2)	1	–			
	- dust concentration monitor	1	–			
	- gas flowmeter	1	–			
	- sample gas delivery system	–	–			
	- calibration unit.	1	–			
4.	Computer equipment and software.			250,000	280,000	
5.	Auxiliary equipment (T, ΔP, P, gas velocity, humidity converter and another components).			150,000	180,000	
6.	Spare parts and standard gases.			120,000	150,000	
7.	Installation, testing and calibration.			180,000	120,000	
8.	Technical project (documentation coordination and supervision).			150,000	150,000	
			TOTAL	1,440,000	1,550,000	

*) Remarks on the next page.

*) Proposals for the environmental monitoring solutions were formulated in accordance with polish regulations and standards (which may insignificantly differ from those of the other countries).

**) Proposals elaborated for solutions of the technological monitoring and control are based on the experience gained in pilot installation at EPS Kawęczyn. But final division into on-line and off-line measurements will be made when start procedures are completed.

***) Expences are evaluated according to offers of the firms having agencies and service in Poland.

7. Specification of the Figures and Tables.

This volume has been prepared by:

Consulting Engineers - Power Engineering Study and
Design Company „Energoprojekt - Warszawa SA"

Engineering Design Of An Electron Beam (EB) Flue Gas Purification Industrial DemonstrationPlant

Basic Engineering.

Volume 9

Electrical power supply units.

Warsaw, January 1996

No of Volume	List of Volumes	Author
Volume 0	Executive Summary	
Volume I	Process Technology	INCT
Volume II	Gas Conditioning Unit	INCT
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Volume 9

Electrical power supply unit

Contents

Drawing	Archiv. No
Single line diagram	1 131 122

1. Introduction

This volume covers electric supply system for Electron Beam Flue Gas Treatment (EB FGT)

2. System function. Design criteria

The electric power system shall provide:
- consistent supply of electric power to all consumers of the EB FGT process and ancillary systems,
- lighting for all compartments and areas designated for accommodation of the process equipment.

The electrical system shall be fed from the existing at Pomorzany Power Station auxiliary supply scheme. Two interconnecting trains shall be applied, each of them capable to cover the total demand.

The equipment shall be selected taking into account existing short circuit levels. Large consumers, 200 kW and above shall be fed from o kV network. Motors and other loads less than 200 kW shall be fed from 230 / 400 V distribution network. The respective 6 / 0,4 kV transformers shall be included in the power supply system. The system is to operate permanently. Maintenance operation or fault of any part of the supply trains shall not involve an interruption of power supply to the process.

3. Operating conditions

A summary of the consumers is given in the following table.

Voltage	Load	Switch. Gear	P installed kW	P simul. op. kW	cosφ -	Q kVAr	D kVA	S kVA
6 kV	Accelerators	OS	1334	1334	0.9	727	688	1688
	Main Fan	OS	550	550	0.9	266	0	611
	Total		1884	1884		993	688	2299
0.4 kV	Technological Equipment for Accel.	1S	356.4	214	0.8	160	0	268
	Light	2S	10	8	1	0	6	10
	Fans and Pumps associated with Accel.	3S	148	100	0.8	75	0	125
	Electrostatic precipitator	4S	92	92	0.9	45	63	120
	Motors assoc. with ESP (14+2+2+2+2)	4S	18.6	10	0.8	7.5	0	13
	Heaters associated with ESP	4S	100	87	0.9	65	0	109
	By-product management	4S, 6S	70	65	0.8	49	0	81
	Flue gas humidification	4S	330	220	0.8	165	0	275
	Ammonia storage and dosing unit	5S	90	90	0.8	68	0	113
	Measurement & Control	2S	25	20	1	0	8	22
	Total		1150	906		590	77	1084
Total power			3034	2790		1583	765	3298

P - active power
Q - fundamental harmonic reactive power
D - deactive power (associated with non-sinusoidal current wave forms)
S - apparent power

Taking into consideration expected overrating of the motors in respect to the shaft power, non coincidental peak load appearing in diverse groups of equipment , as well as average efficiency factor, the peak load has been determined as:

active power P = 2,26 MW,
apparent power S = 2,67 MVA.

Taking into account the above, average operation time in year 6500 hours and variability of load, the expected energy consuption per year is:

13,2 GWh.

4. System description

4.1. Power supply system

Power supply system as shown in single line diagram consist of the following elements:
- sectioned 6 kV switchgear,
- two main 0,4 kV switchgears, each associated with an incorporated dry type transformer, these switchgears are considered to distribute power to 0,4 kV network;
- system of local switchgears (Motor Control Centres - MCCs) and Distribution Boards (DBs), designated to supply diverse processes and auxiliary sub-systems.

The markings of the particular parts of the proposed power system (switchgears, MCCs) as shown in the diagram constitute extension of the existing in Pomorzany PS. The 6 kV switchgear OS will be supplied from existing General Auxiliary Switchgear OE - sections A and B. The said switchgear OE is interconnected with 110 kV substation by means of two transformers, each rated for 25 MVA. Such a connection can provide sufficient power to supply EB FGP. However, it will be necessary to extend one section of existing Switchgear OE and make some replacements in other to receive free cubicles for supply trains of EB FGP.

The supply units for EB accelerators will be equipment with separate 6 / 0,4 kV transformers.

4.2. Switchgear 6 kV

6 kV Switchgear will be metal clad type with draw - out circuit breakers. The Switchgear will incorporate all protection and control devices.

4.3. Low voltage switchgears

Main 0,4 kV Switchgears shall be metal enclosed type with draw - out cassettes. Incoming and coupler will be equipped with heavy duty circuit breaker. Outgoing feeders will be implemented with adequately rated load switches and HRC fuses.
Subsidiary 0,4 kV switchgears (MCC) generally will be of the same performance as the main Load Centres. Outgoing feeders to the motors will be equipped with fuses and contactors. All the feeders will be accommodated in separate draw - out cassettes.

4.4. Lighting and power outlet system

Modern lighting system will be applied in all premisses and compartments accomodating the EB process equipment. The fluorescent tube lamps will be implemented for the basic lighting.
Emergency lighting will be arranged by means of incandescent lamps and will be fed from existing 220 V DC network.
Outdoor areas will be iluminated by means of mercury vapour or sodium discharge lamps.
Adequate number of 1 and 3 please power outlets will be provided to enable maintenance and service of the process equipmen

4.5. Protection against electric shock. Earthing system

All electrical equipment will have proper degree of protection, at least IP 54. All exposed metal parts will be connected to the protective conductor. 6 kV system will operate with isolated neutral point. 0,4 kV will be solidly grounded. TN - C - S system (acc to IEC 364 - 1) will be applied. Short circuits will be imidiately cleared - out. Futhermore, the lines for power outlet sockets and for other electrical hand operating devices will be equipped with fast operating residual current circuit breakers.

4.6. Location of equipment

Main electrical equipment, in this range 6 kV switchgear OS and 0,4 kV Load Centres will be accomodated in the existing Power Station building at el. + 12,3 m between axis D - E and 12 ÷ 14. Respective premises are not used and according to the preliminary agreement with Power Station authorities they may be adopted for the said above switchgears. Local MCCs and DBs will be located close to the respective subsystems.

5. Scope of delivery and works

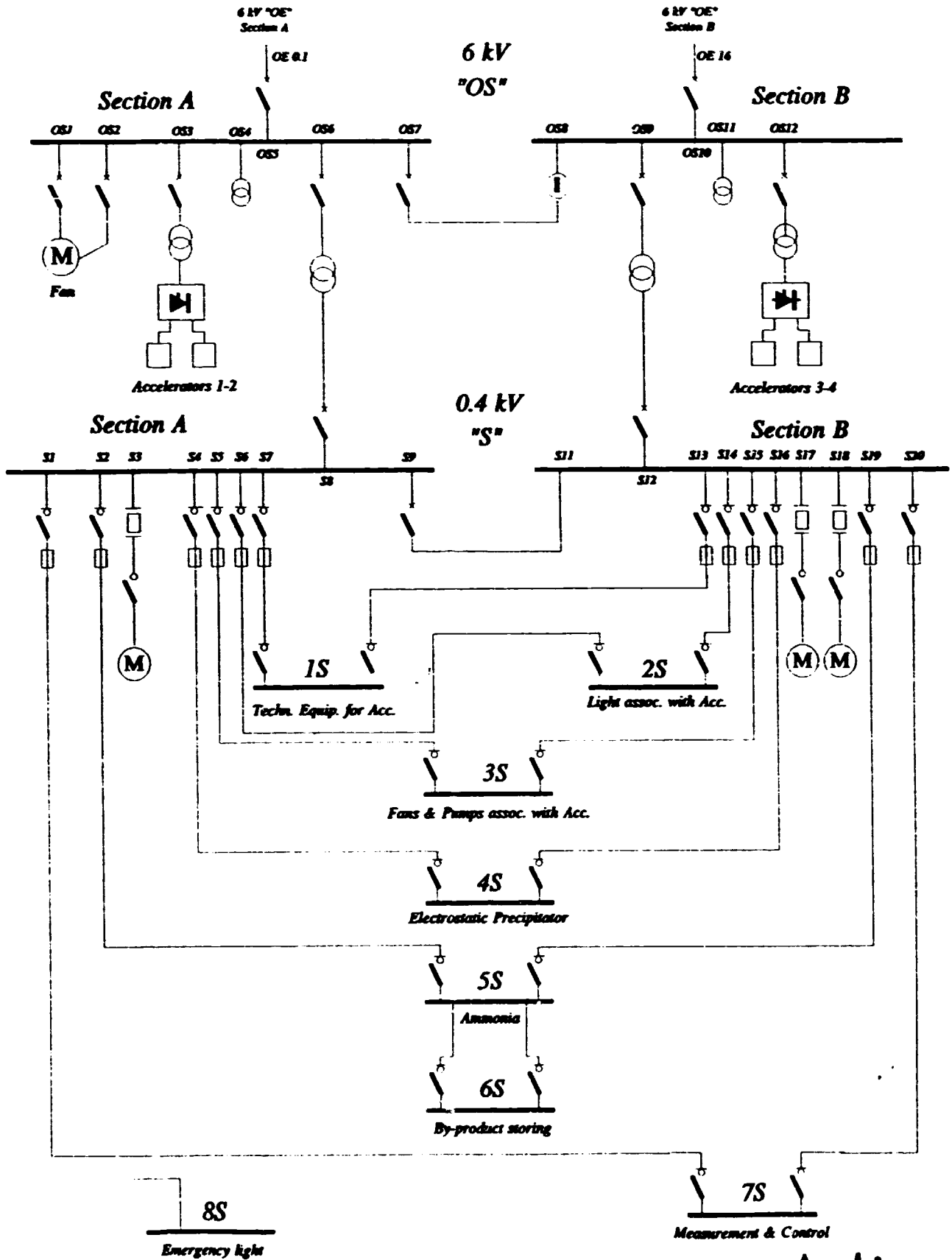
To complete the electric power supply system as a whole the following equipment erection works and services shall be covered:

- 6 kV and 0,4 kV switchgears, MCCs and DBs,
- lighting system,
- power outlet system,
- medium voltage, low voltage and control cabling installation completed with supporting structure (racks, trays, ladders, shafts),
- erection, tests after erection, putting into operation.

All parts of equipment are of standard performance easily available in Poland.

6. List of equipment

- Switchgear	6 kV
- Switchgear	0.4 kV
- Subsidiary Switchgear	0.4 kV
- Transformer	6kV/0.4kV/1MVA
- Transformer	6kV/0.4kV/630kV A
- Power Cables	6 kV
- Power Cables	1 kV
- Control Cables	
- Grounding	
- Light	



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Przedsięwzięcie	Symbol P-0174	Nr WOi	Branża	Tom 9	Zeszyt	Edycja	
INDUSTRIAL DEMONSTRATION PLANT OF ELECTRON-BEAM PROCESS FOR FLUE GAS TREATMENT OF THE ELECTRIC POWER STATION "POMORZANY"-SZCZECIN POLAND	Data 06.95.	Podziałka	Faza	Format A4	Pozycja RK	Czas przech.	
ELECTRICAL POWER SUPPLY UNIT SINGLE LINE DIAGRAM	Zastępuje rys. Zastąpiony przez rys. Nr						
	Projektował G.Błajszczak		Sprawdził Z. Radomski				
	Wykonał		Kier. proc. Z. Radomski				
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Volume 10

Composite documentation

Contents

Drawings	Arch. No
- Overall flow diagram	1 131 124
- Flue gas diagram	1 131 104 A
- General layout	1 131 105
- General layout - cross section	1 131 106
- General layout - cross section	1 131 107
- Process water & compressed air flow diagram	1 131 120
- Electrical power supply unit - single line diargam	1 131 122
- Schematic diargam of ammonia management	1 131 110
- Layout of the buildings and installations of ammonia storage	1 131 111
- Layout of the area of ammonia storage and dosing unit	9 58 673
- Scheme of by-product handling system of power plants area	1 131 116
- Buffer stock yard - scheme	1 131 117
- Buffer store building layout	1 131 118
- Layout of the area of the buffer store building	958 674

1. Introduction

This volume generally presents the Industrial Demonstration Plant of Electron Beam (EB) Process for Flue Gas Treatment at the Electric Power Station "Pomorzany" - Szczecin, Poland.

2. General description of the EB process

EB process belongs to the second generation of the technology of simultaneous removal from flue gas, both sulphuric and nitric oxides, in a dry process.
Overall flow diagram, see the drawing No 1 131 124.
Flue gases from Bensor. boilers to the EB process is taken after electrostatic precipitators and induced draft fans.
The main flue gas parameters are as follow:
- volume 270 000 Nm^3/h
- temperature 145 ÷ 170 °C
- flue gas contents:

SO_2	1,1 g/Nm^3
NO_x	0,6 g/Nm^3
CO	0 % vol.
CO_2	8 % vol.
O_2	7 ÷ 8 % vol.
N_2	to the balance
H_2O	5 % volume
fly ash	0,08 g/Nm^3

In the EB process, flue gas enters at first the evaporative spray cooler and reaches optimal process parameters: temperature 80 °C and humidification 10 - 12 %. The spray cooler is operated with a dry bottom, it means that all water injected into the flue gas becomes evaporated.
After spray cooler, the gaseous ammonia, being prepared in a separate storage and dosage unit, is introduced into the flue duct. Flue gas with optimal temperature, humidification and ammonia content, proceeds then the reaction chamber, where in turn it is irradiated by a beam of high - energy electrons. Irradiation and subsequent chemical interaction in the flue gases produced a mixture of ammonium - sulfate and ammonium nitrate solids - by-product of the process - suspended in the flue gas. Flue gas pass then the special electrostatic precipitator in which the by-product is precipitate.

Clean flue gas is then, by booster fan, proceeds to the flue duct and after mixing with raw flue gas proceeds to the stack. By-product, the mixture of ammonium sulfate and ammonium nitrate will be collected in the buffer storage and then will be sold as initial product in the production of artificial fertilizers.

3. Layout of equipment

Equipment location is shown at the drawings 1 131 105, 1 131 106, 1 131 107.
Large dimension equipment such as, cooling tower, electrostatic precipitator, buster fan and flue gas ducts are located outdoor.
The other equipment: accelerators, reaction chambers, process water pumps, air compressors and electrical equipment are located indoor in the buildings between axis D-E-F-G-H and 1-15.
Location of buffer storage of by-product and ammonia storage and dosing unit is foreseen at the deposit area about 300 to 400 meters from Power Plant.
However analysis of ammonia storage and dosing unit shows that it is unconvenient from length of liquid ammonia suction pipe point of viev. Ammonia store should be located nearer the railway tract and it is recommended to find a more convenient place.

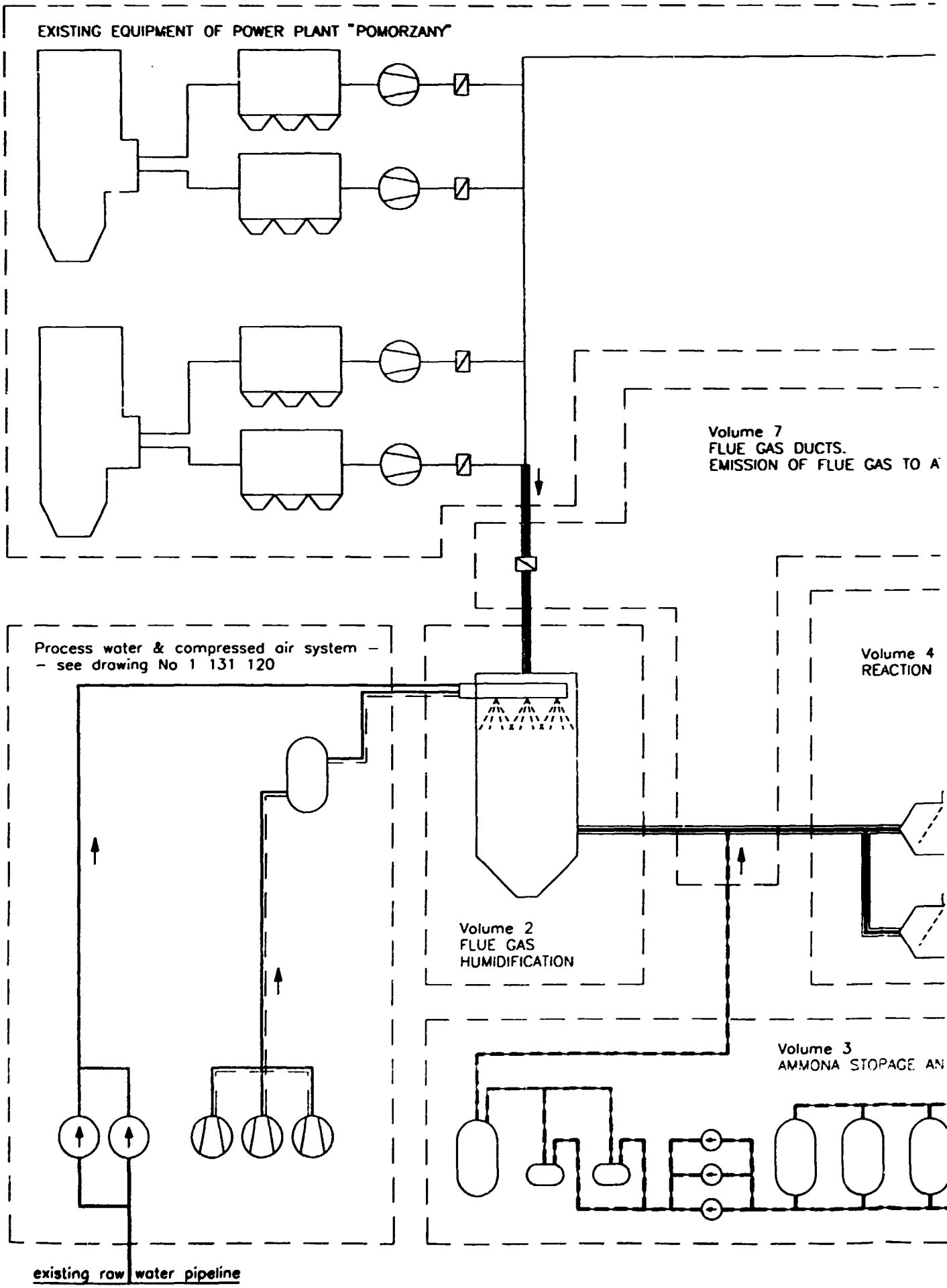
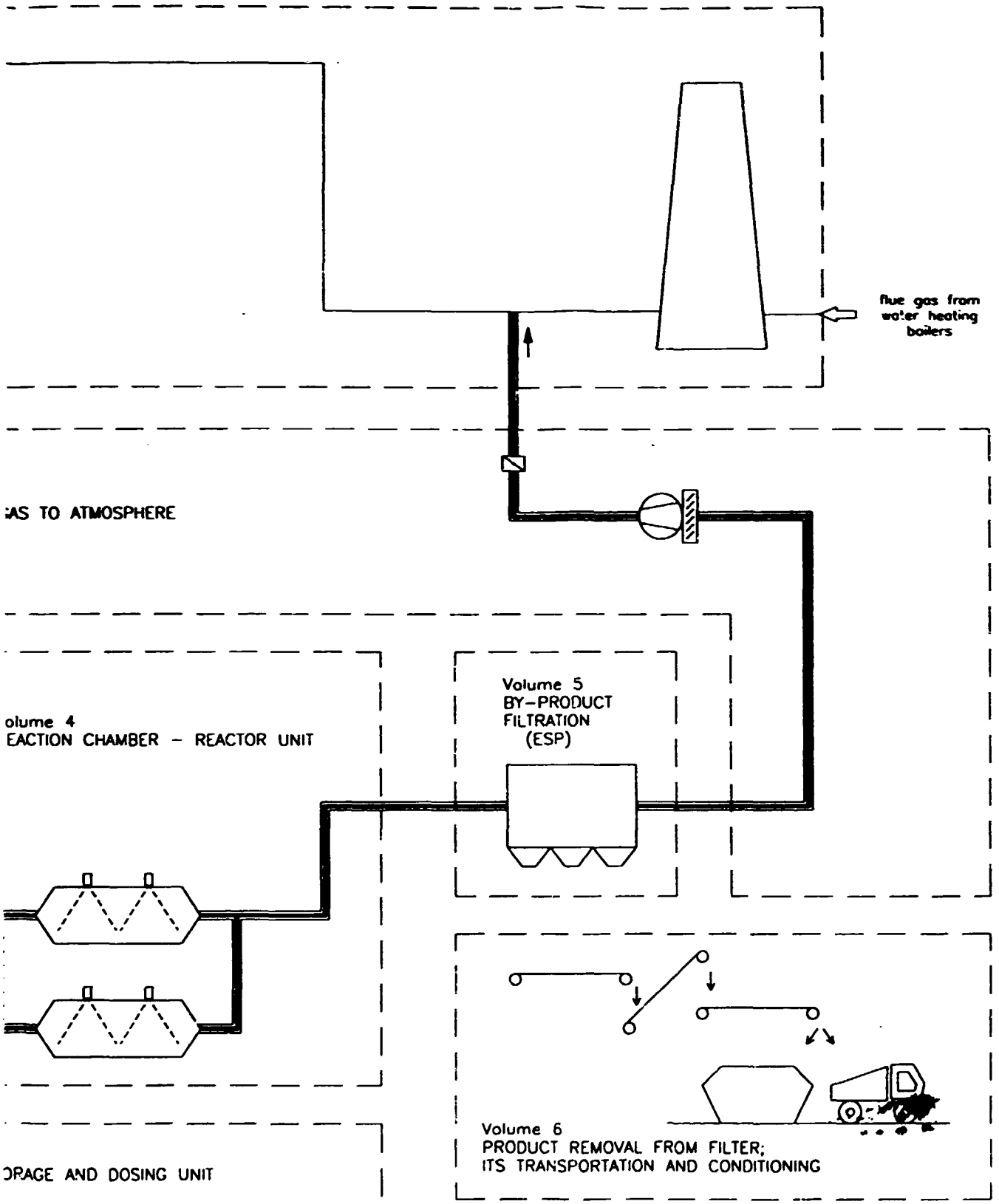

EXISTING EQUIPMENT OF POWER PLANT "POMORZANY"
Volume 7
FLUE GAS DUCTS.
EMISSION OF FLUE GAS TO A
Process water & compressed air system –
– see drawing No 1 131 120
Volume 4
REACTION
Volume 2
FLUE GAS
HUMIDIFICATION
Volume 3
AMMONA STOPAGE AN
existing row water pipeline

Fig 1



Poz.	Nazwa części	Ilość	Materiał	Nr normy lub rysunku	Jedn. miara	Ciężar w kg	Uwagi

"ENERGOPROJEKT®- WARSZAWA" S.A.
Warszawa, ul.Krucza 6/14

Nr archiwalny 1 131 124

Nr. part. w tomie 1

Przedsięwzięcie	Symbol	Nr WOI	Branża	Tom	Zeszyt	Edycja
	P-0174			10		

INDUSTRIAL DEMONSTRATION PLANT OF ELECTRON-BEAM PROCESS FOR FLUE GAS TREATMENT OF THE ELECTRIC POWER STATION "POMORZANY" - SZCZECIN POLAND

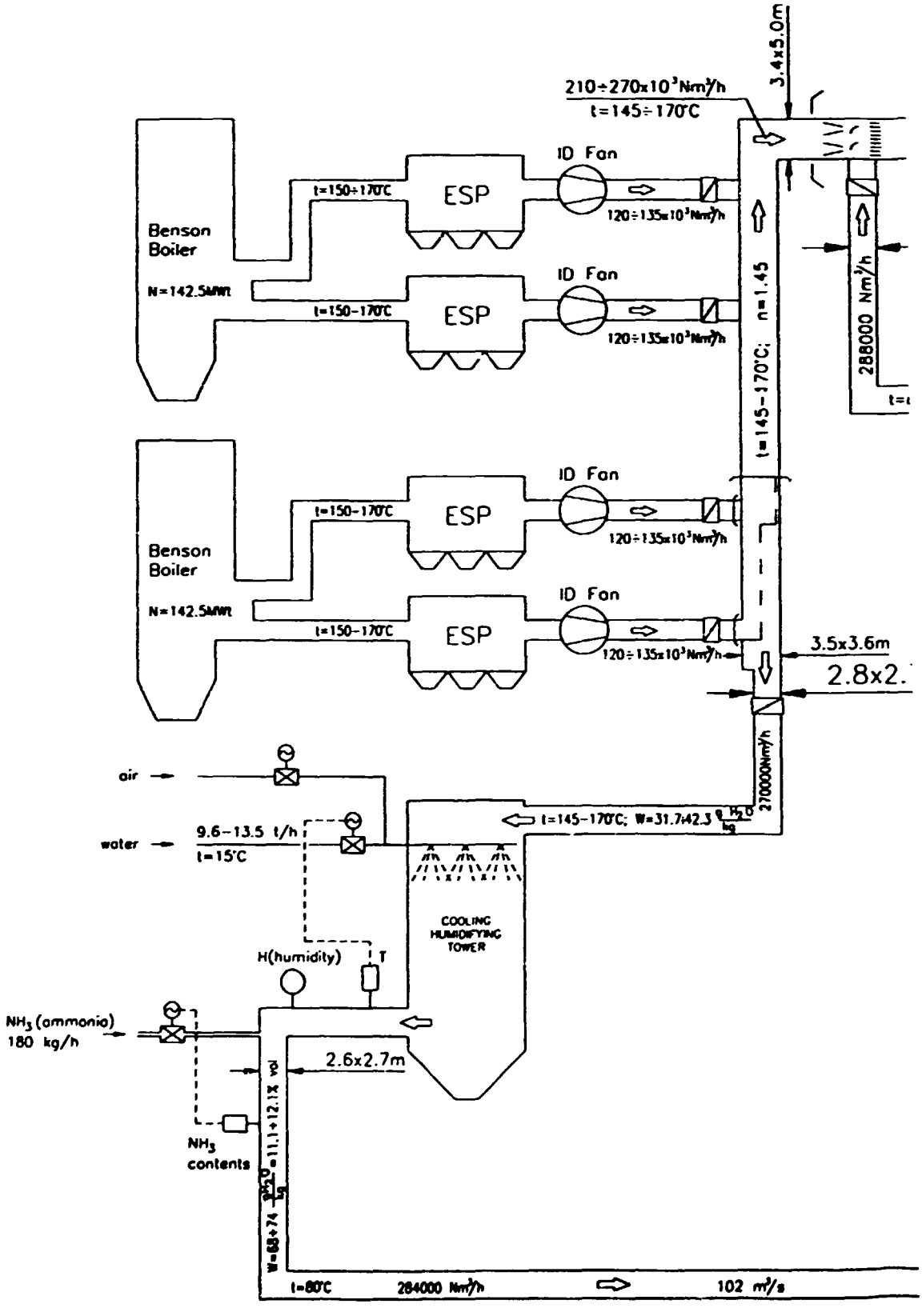
OVERALL FLOW DIAGRAM

Data	Podziałka	Faza	Format	Przesunięcie	Czas przech.
09.95.	—		A3	RK	

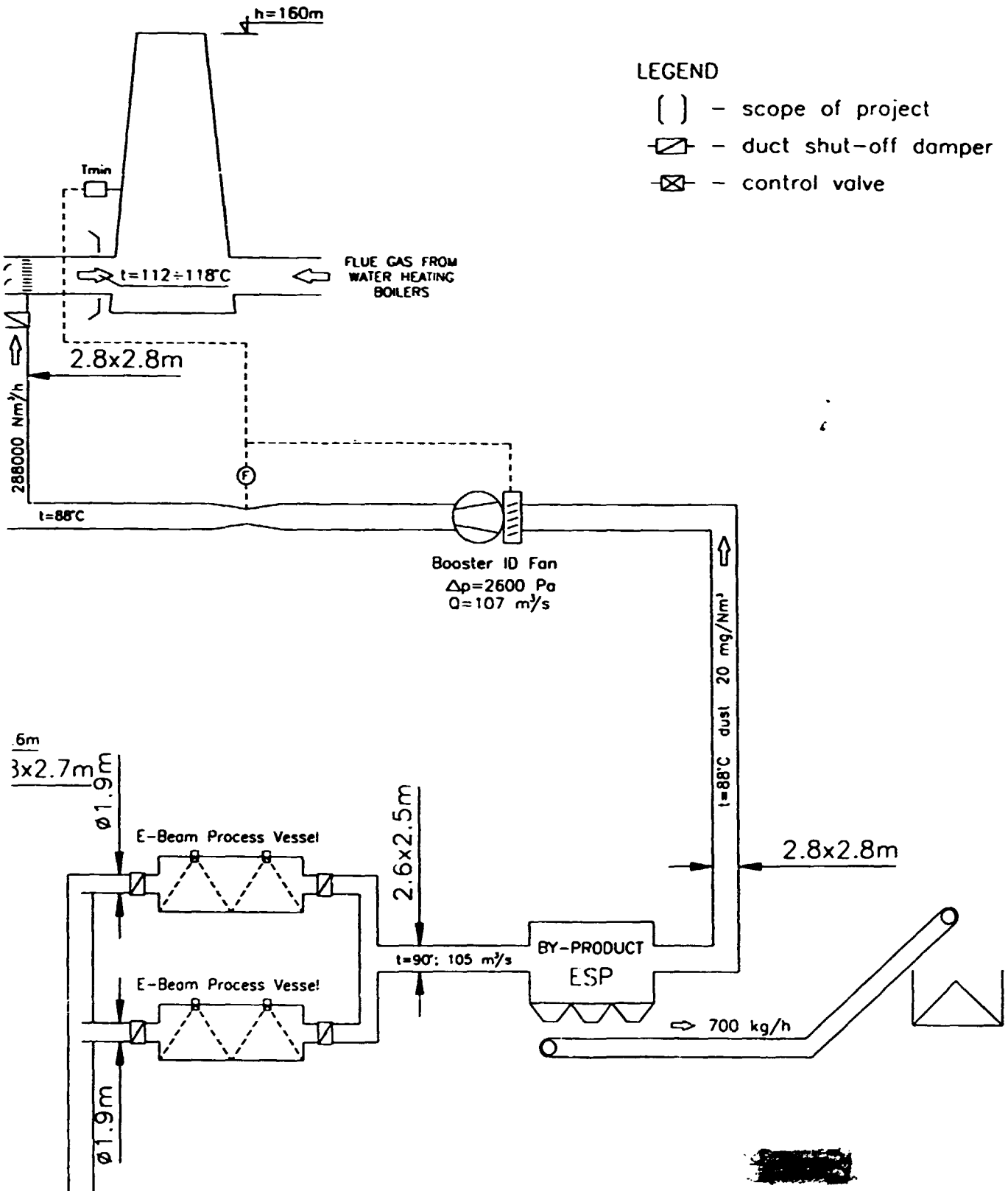
Zastępuje rys. Nr
Zastąpiony przez rys.

Projektował	M.Cyron		Sprawdził	Z. Radomski
Wykonał			Kier. proc.	Z. Radomski
Kreślił	POM5.DWG		Gł. proj.	

Sca 2


3.4x5.0m
210÷270x10³Nm³/h
t=145÷170°C
ID Fan
ESP
t=150÷170°C
120÷135x10³Nm³/h
Benson Boiler
N=142.5MWt
t=150-170°C
t=145-170°C; n=1.45
288000 Nm³/h
3.5x3.6m
2.8x2.
air
water
9.6-13.5 t/h
t=15°C
t=145-170°C; W=31.7÷42.3
270000Nm³/h
COOLING HUMIDIFYING TOWER
H(humidity)
T
NH₃ (ammonia)
180 kg/h
2.6x2.7m
NH₃ contents
t=80°C
284000 Nm³/h
102 m³/s

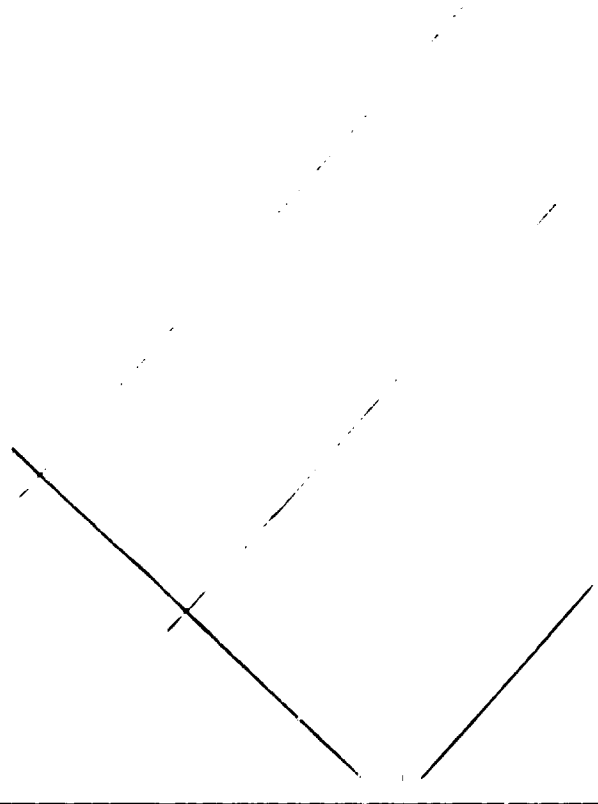
Sec 1



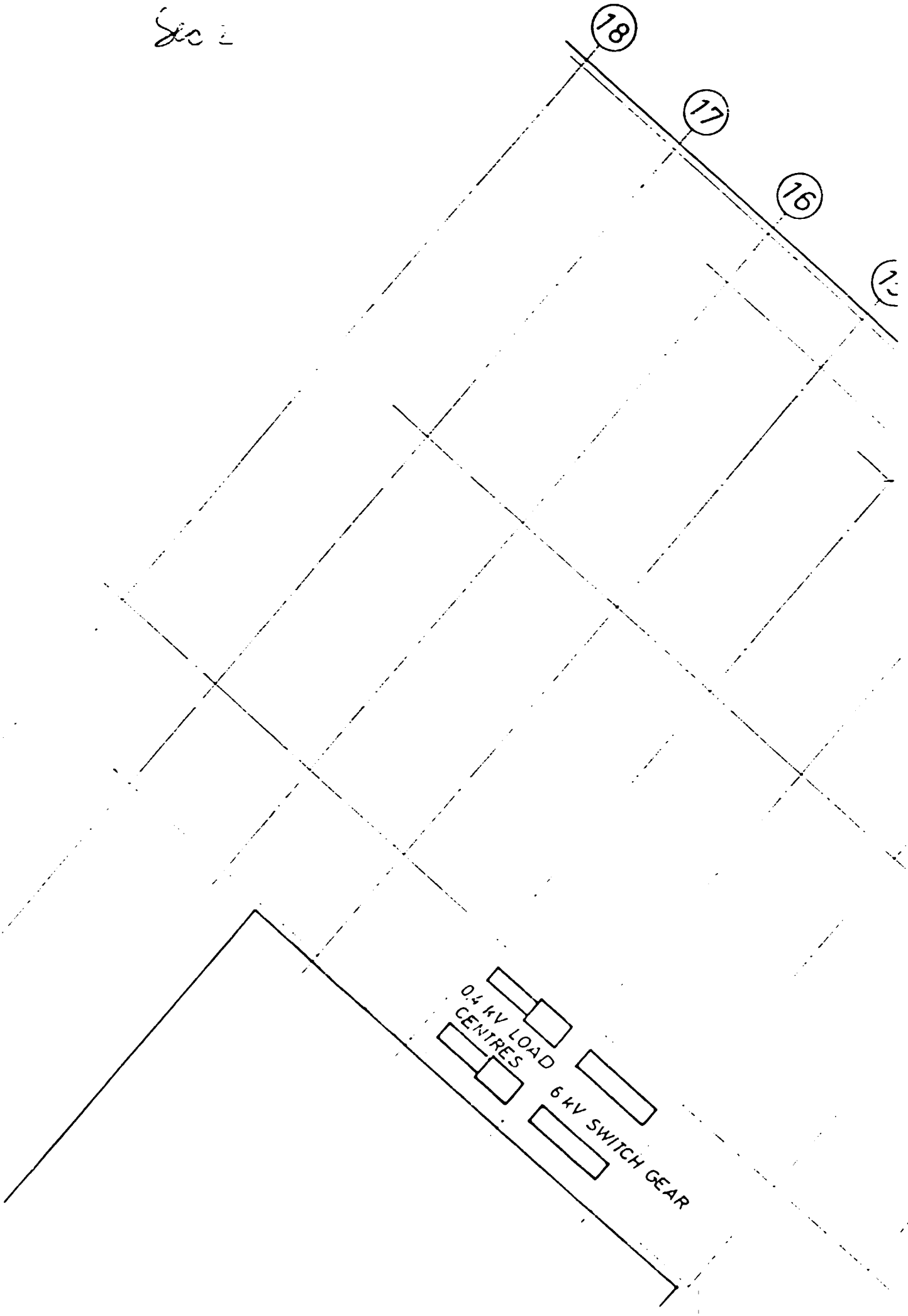
[redacted]

"ENERGOPROJEKT"® – WARSZAWA" S.A. Warszawa, ul.Krucza 6/14			Nr archiwalny 1 131 104 A				Nr. porz. w tomie 1	
Przedsięwzięcie	Symbol P-0174	Nr WOI	Branża	Tom 7	Zeszyt	Edycja		
INDUSTRIAL DEMONSTRATION PLANT OF ELECTRON-BEAM PROCESS FOR FLUE GAS TREATMENT OF THE ELECTRIC POWER STATION "POMORZANY" – SZCZECIN POLAND	Data 06.95.		Podziałka —	Faza	Format A3	Przesłano RK	Czas przech.	
FLUE GAS DIAGRAM	Zastępuje rys. / Zastąpiony przez rys. Nr							
	Projektował	J. Rostkowski		Sprawdził	Z. Rotowski			
	Wykonał			Kier. prac.	Z. Rotowski			
	Kreślił	POM1.DWG		Gł. proj.				

See 2

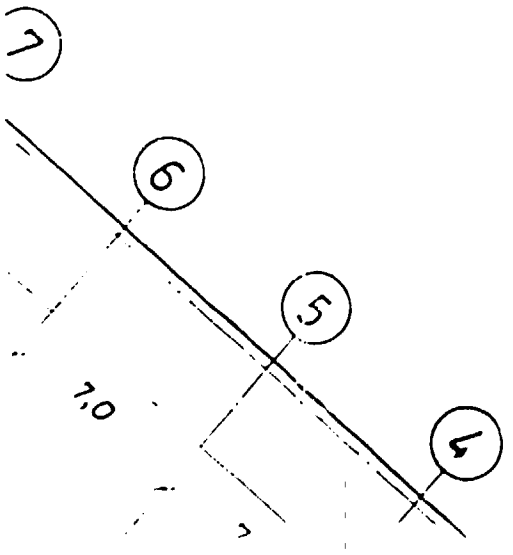


Sec 2

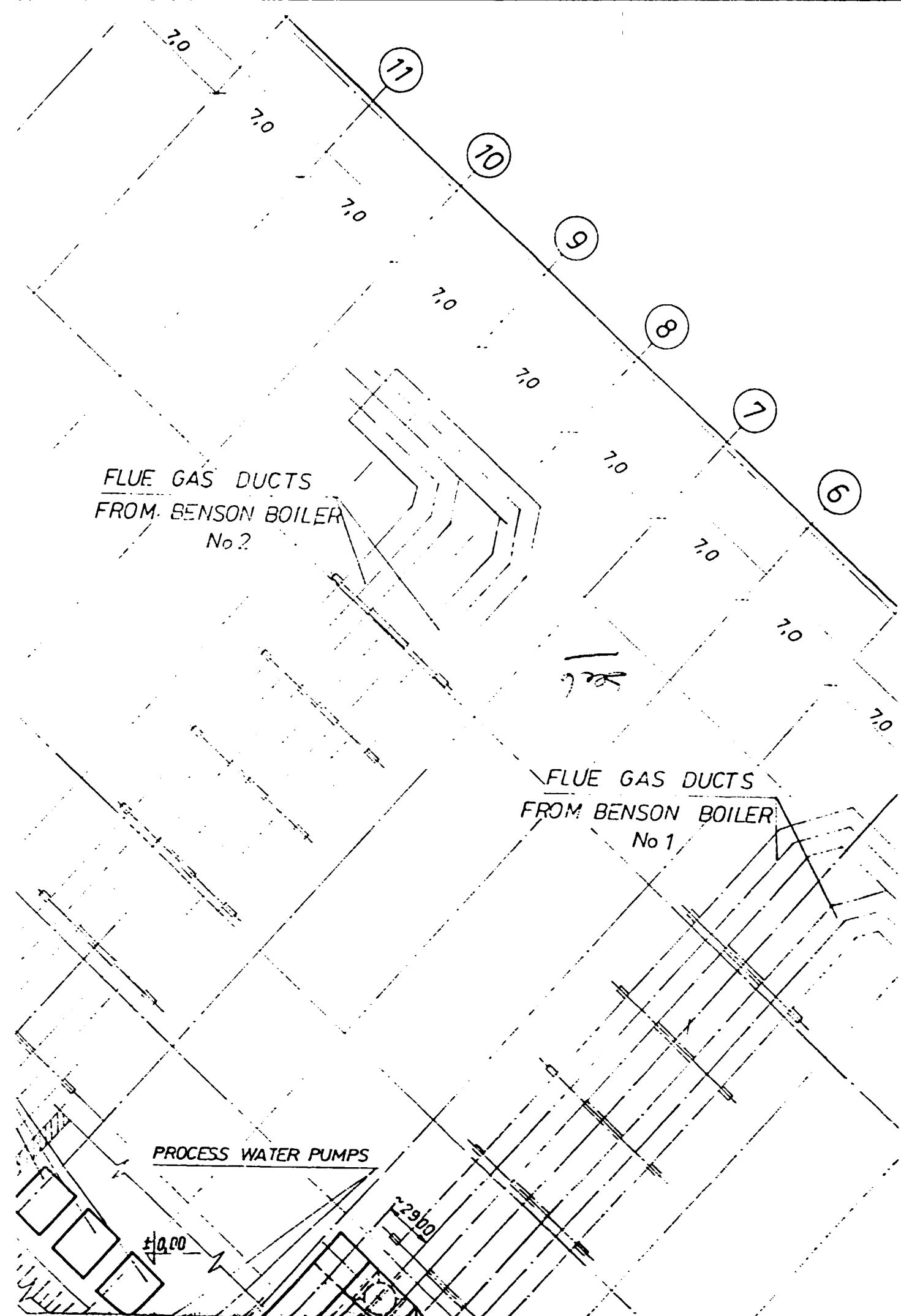


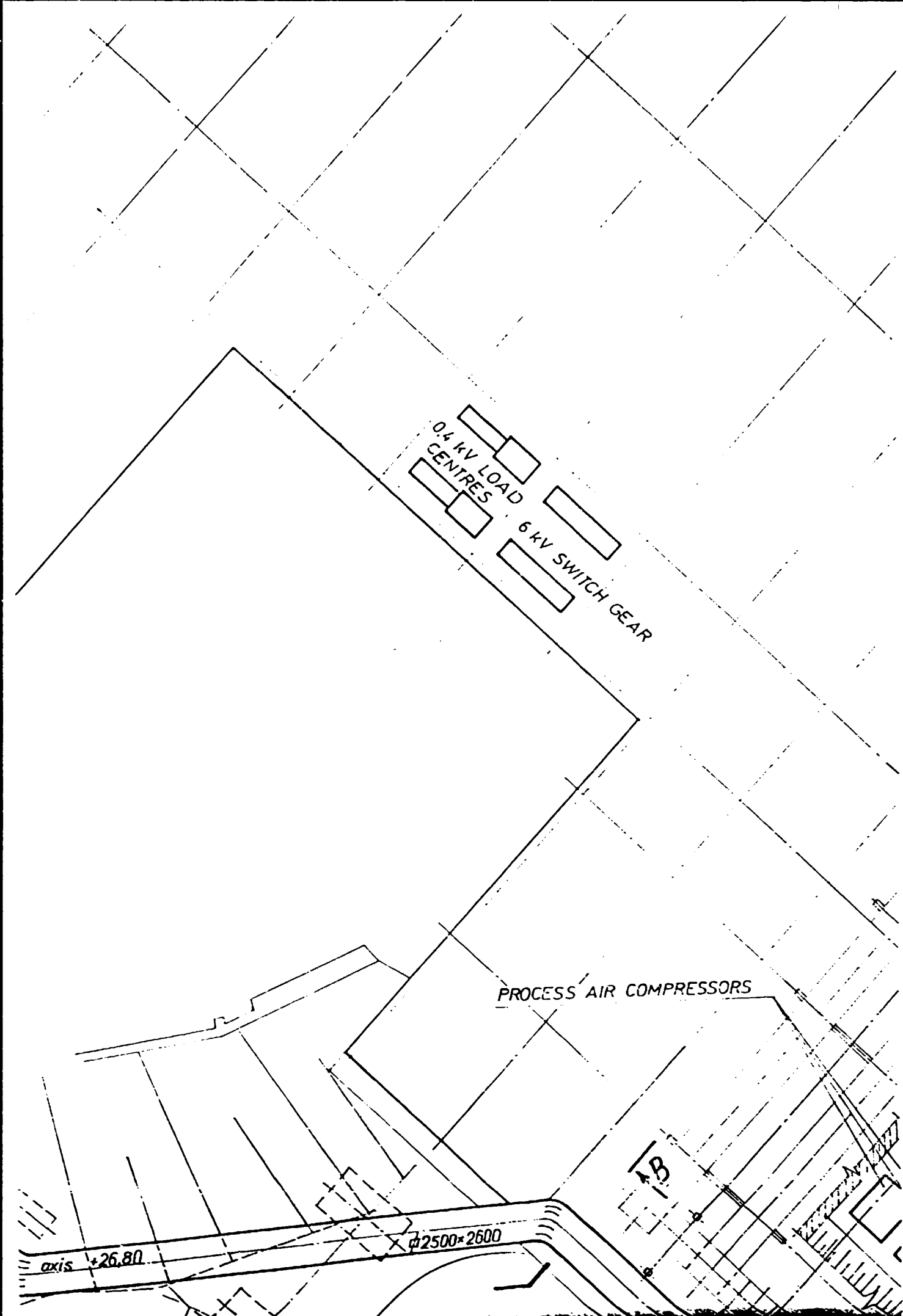
Sec 3


13
12
11
10
9
8
7
6
5
7,0
7,0
7,0
7,0
7,0
7,0
7,0
JE GAS DUCTS
M. BENSON BOILER
No 2

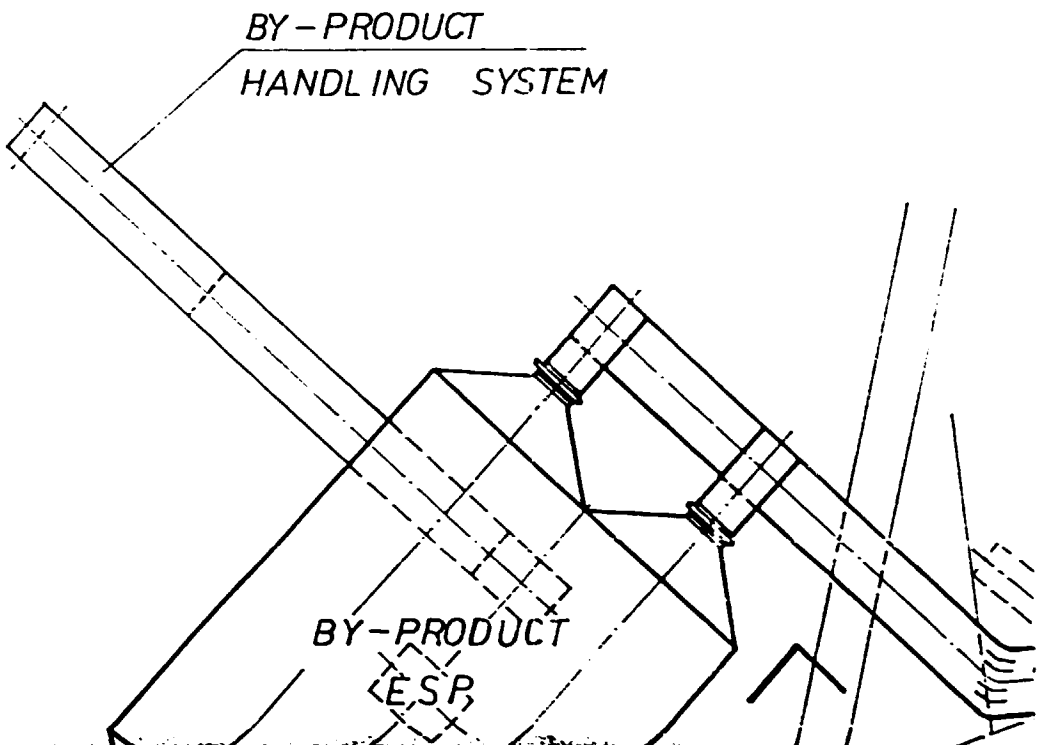

7
6
5
4
7,0

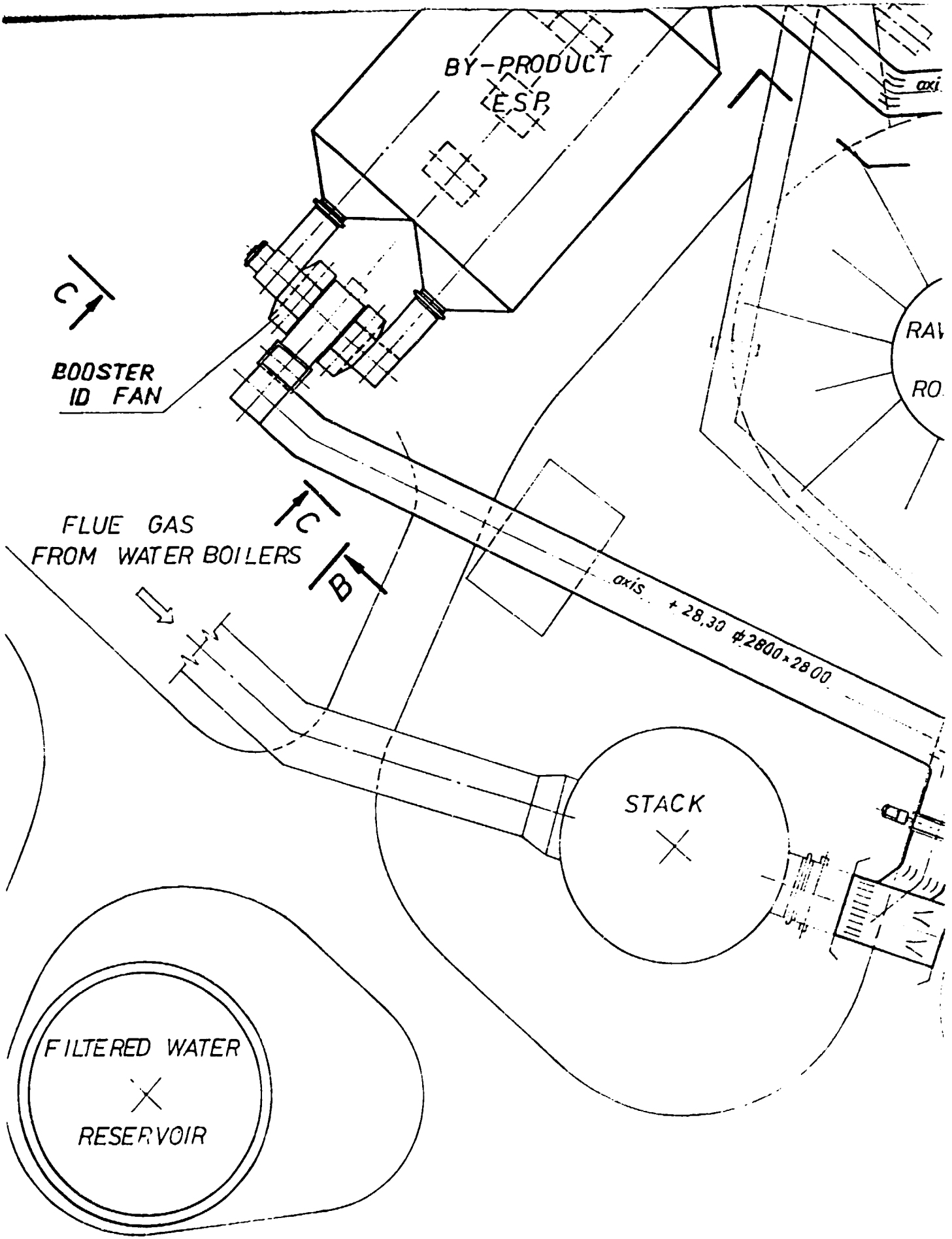
See 5


11
10
9
8
7
6
7,0
7,0
7,0
7,0
7,0
7,0
7,0
FLUE GAS DUCTS
FROM BENSON BOILER
No 2
FLUE GAS DUCTS
FROM BENSON BOILER
No 1
PROCESS WATER PUMPS
±0.00
~2900

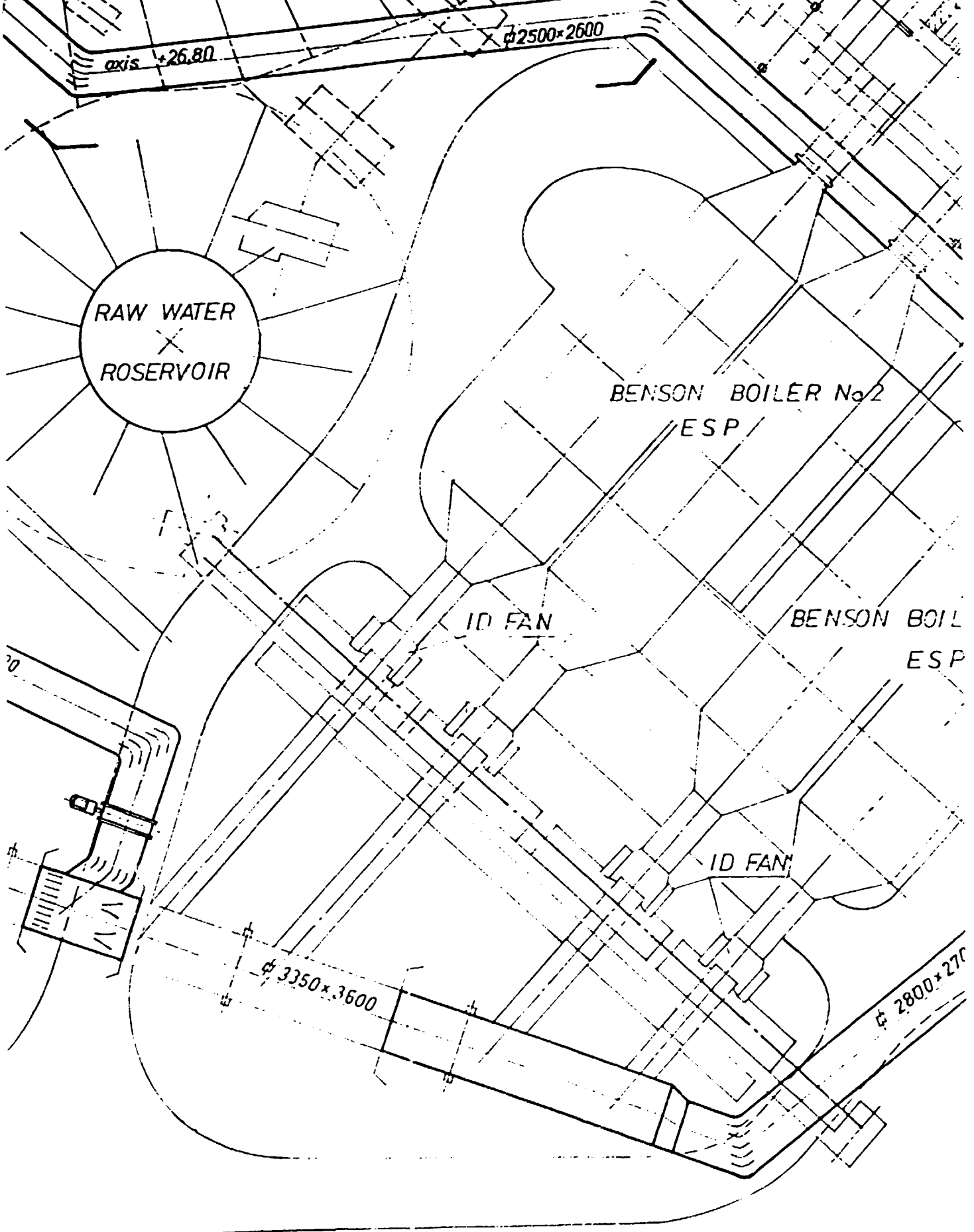

0.4 kV LOAD CENTRES
6 kV SWITCH GEAR
PROCESS AIR COMPRESSORS
axis +26.80
⌀2500×2600

Sec. 8

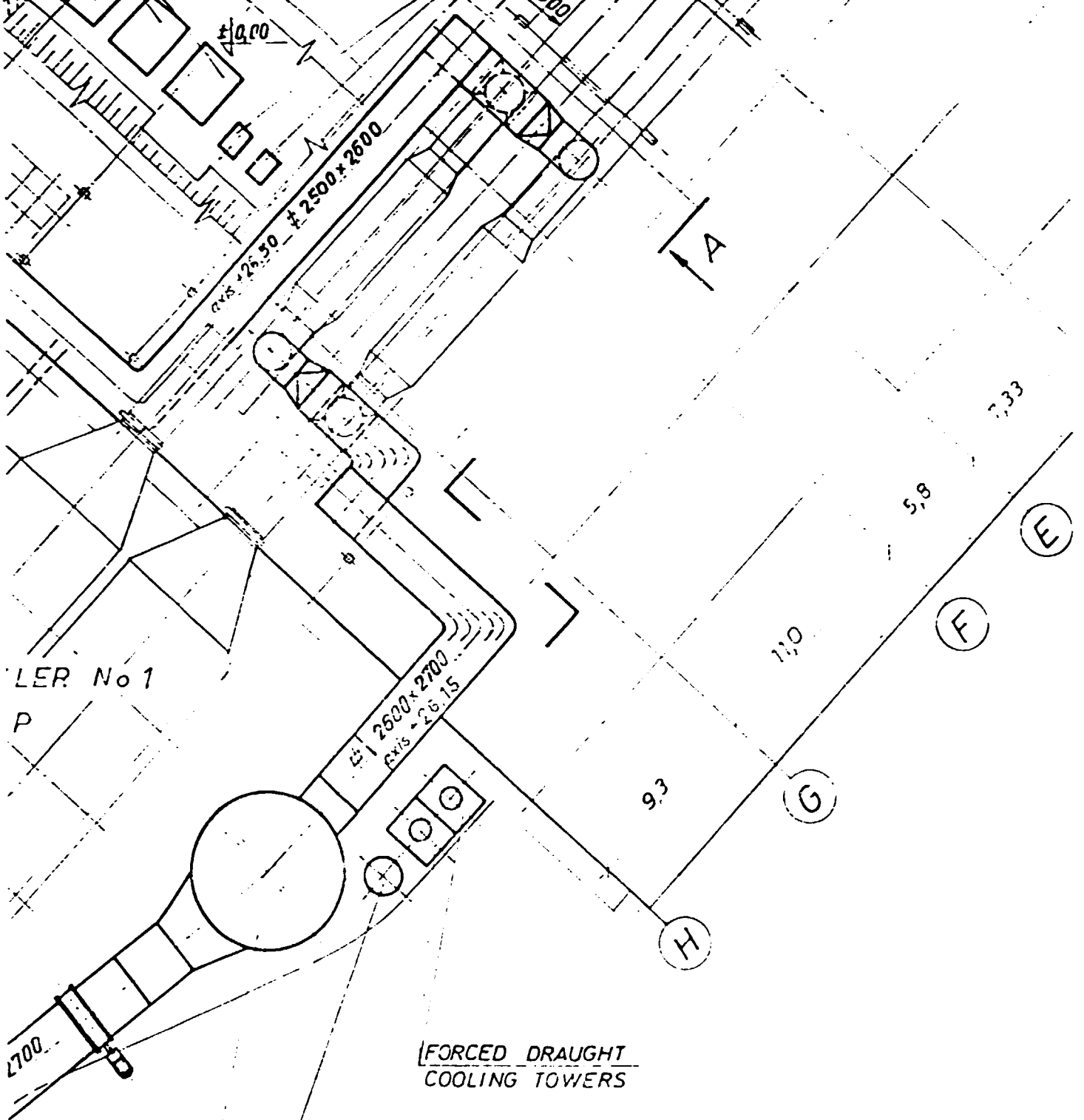


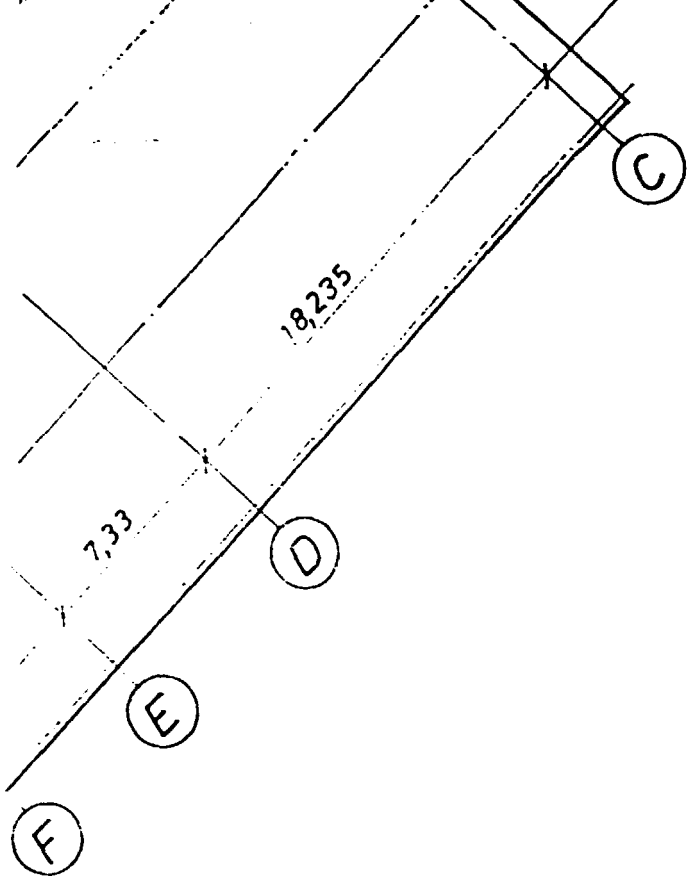

BY-PRODUCT
E.S.P.
axi
C
BOOSTER
ID FAN
RAI
RO
FLUE GAS
FROM WATER BOILERS
C
B
axis + 28,30 ϕ2800×2800
STACK
FILTERED WATER
RESERVOIR

Sec 4


axis +26.80
φ2500×2600
RAW WATER
RESERVOIR
BENSON BOILER No.2
ESP
ID FAN
BENSON BOIL
ESP
ID FAN
φ 3350×3600
φ 2800×270
A

Sec 10


A
E
F
G
H
5,8
9,3
1,0
7,33
LER No 1
P
2600 x 2700
Axis - 26,15
FORCED DRAUGHT
COOLING TOWERS
PROCESS COMPRESSED
AIR EQUALIZING TANK
COOLING HUMIDIFYING TOWER



Sec. 12

"ENERGOPROJEKT®- WARSZAWA" S.A. Warszawa, ul.Krucza 6/14			Nr archiwalny 1 131 105				Nr. porz. w tomie 2	
Przedsięwzięcie	Symbol P-0174	Nr WOI	Branża	Tom 7	Zeszyt	Edycja		
INDUSTRIAL DEMONSTRATION PLANT OF ELECTRON-BEAM PROCESS FOR FLUE GAS TREATMENT OF THE ELECTRIC POWER STATION "POMORZANY"-SZCZECIN POLAND	Data 06.95.		Podziałka 1:250		Faza	Format A1	Pracownia TR	Czas prz
GENERAL LAYOUT	Zastępuje rys. Zastąpiony przez rys.		Nr					
	Projektował	J. Roszkowski			Sprawdził	Z. Radomski		
	Wykonał				Kier. prac.	Z. Radomski		
	Kreślił				Gł. proj.			

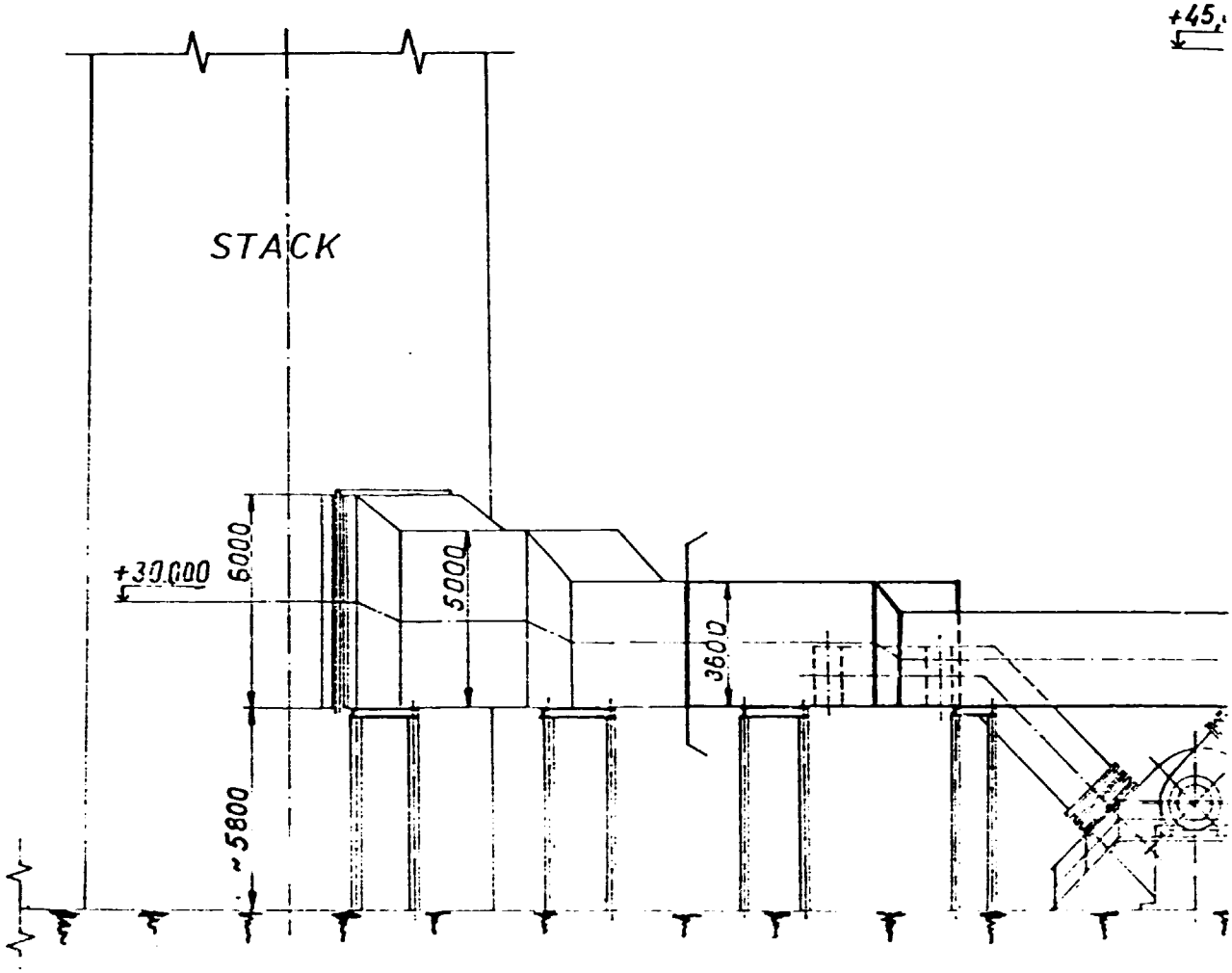
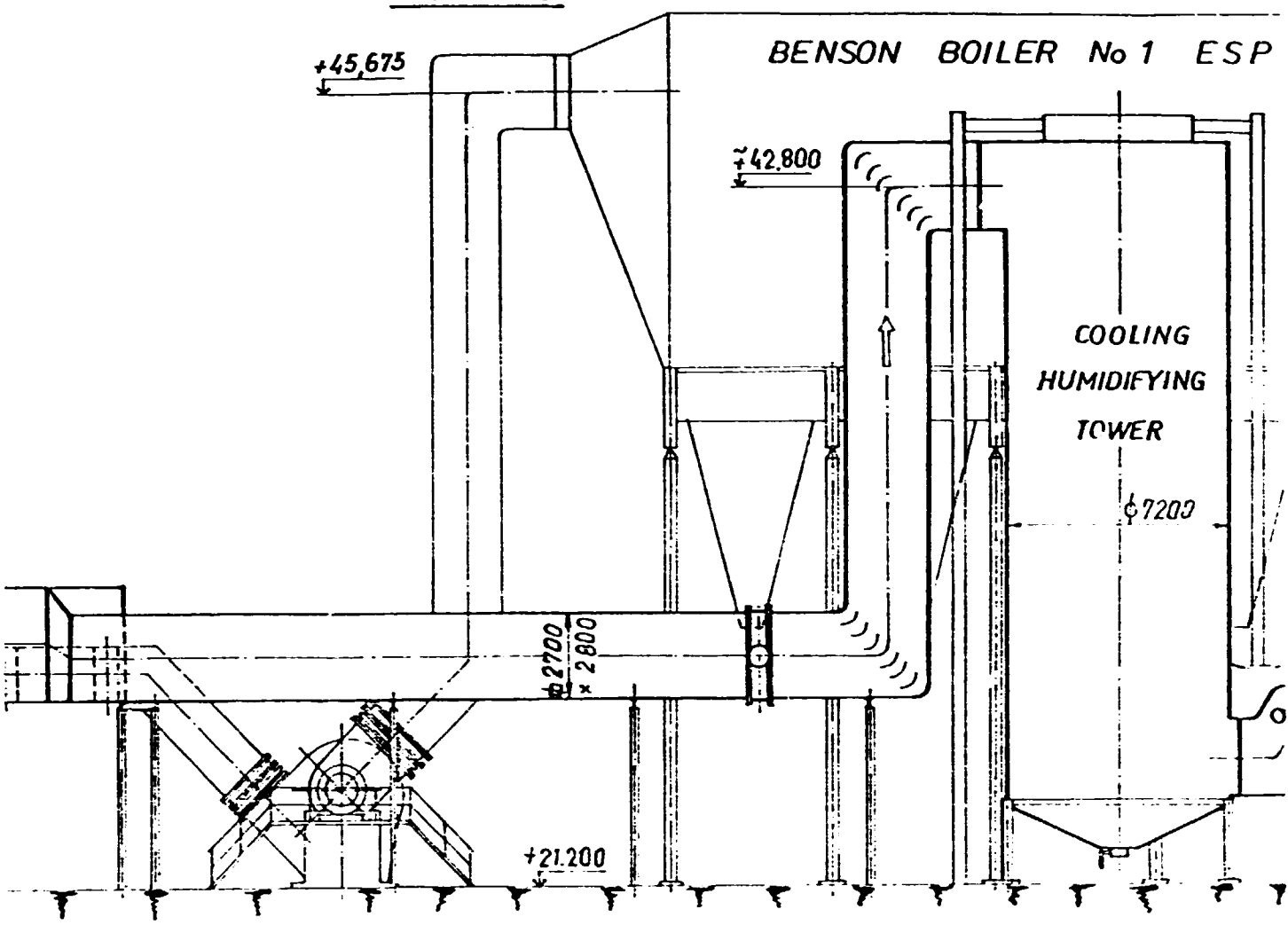
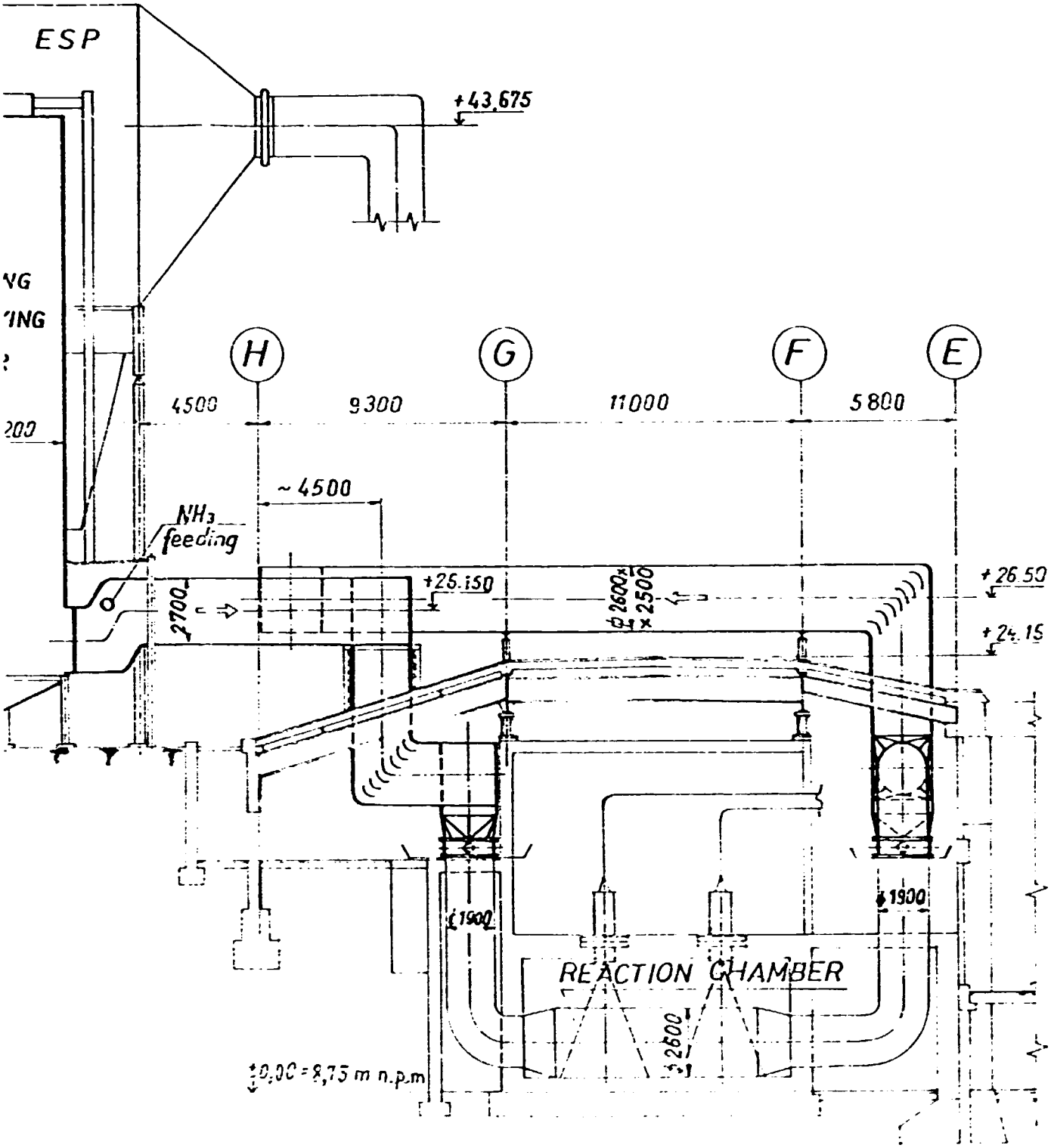


Fig 1

A — A


BENSON BOILER No 1 ESP
+45,675
+42,800
COOLING
HUMIDIFYING
TOWER
ϕ7200
ϕ2700
× 2800
+21.200

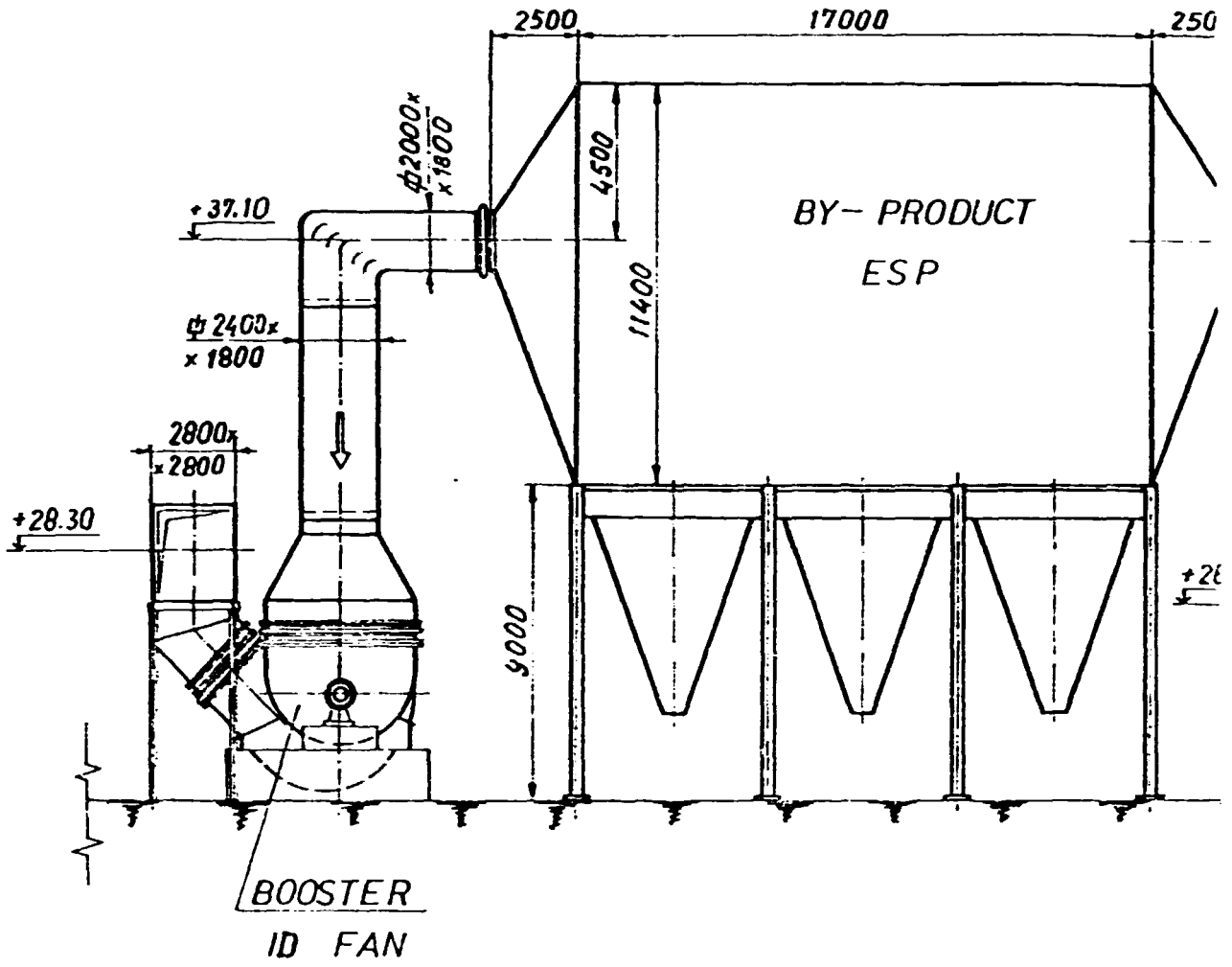
Sec 2



Sec 3

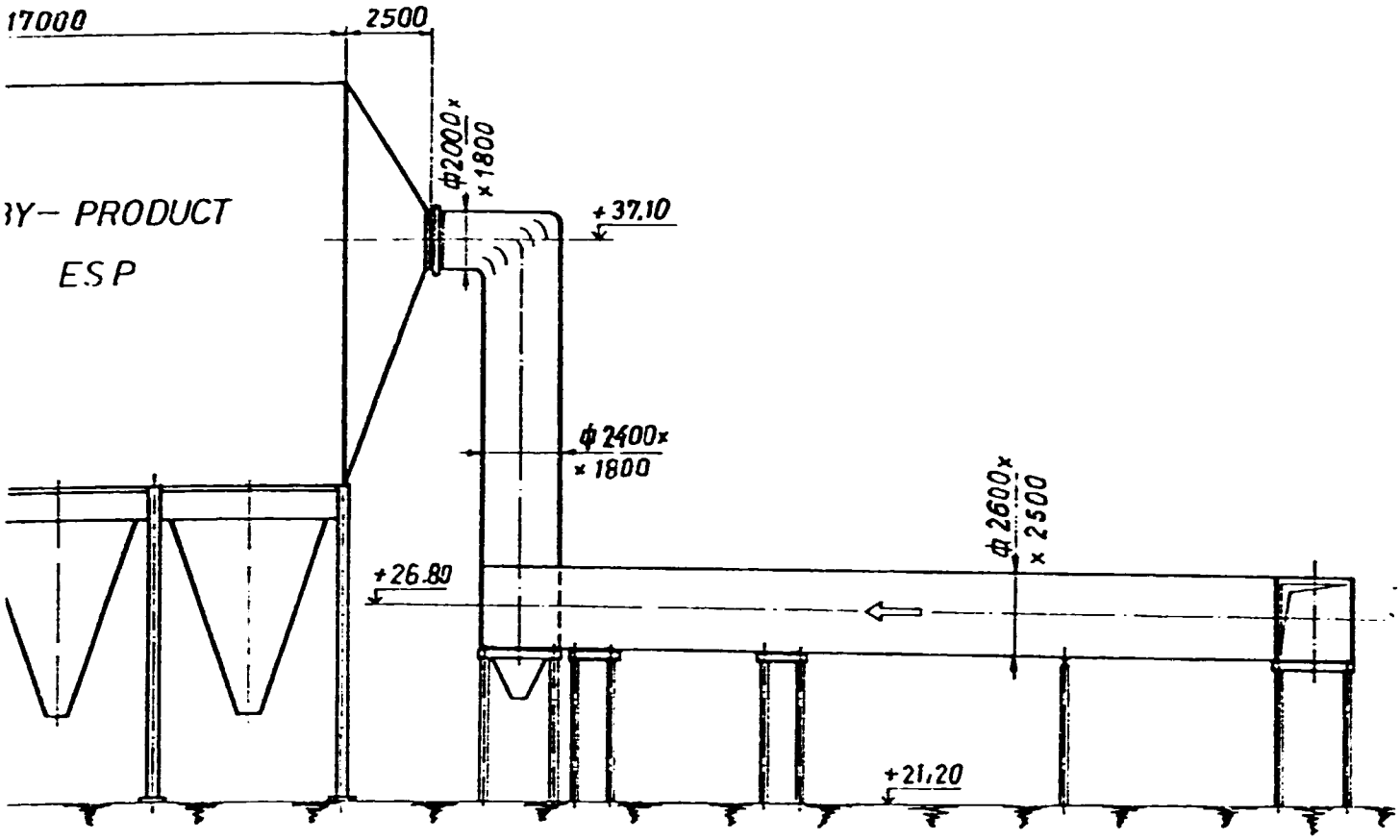
"ENERGOPROJEKT®- WARSZAWA" S.A. Warszawa, ul.Krucza 6/14			Nr archiwalny 1 131 106				Nr. porz. w tomie 3	
Przedsięwzięcie	Symbol P-0174	Nr WOI	Branża	Tom 7	Zeszyt	Edycja		
INDUSTRIAL DEMONSTRATION PLANT OF ELECTRON-BEAM PROCESS FOR FLUE GAS TREATMENT OF THE ELECTRIC POWER STATION "POMORZANY"-SZCZECIN POLAND **FLUE GAS SYSTEM LAYOUT CROSS-SECTION A-A**	Data 06.95.		Podziałka 1:200		Faza	Format A2	Pracownia TR	Czas prz
	Zastępuje rys. Zastąpiony przez rys.		Nr					
	Projektował	J. Roszkowski			Sprawdził	Z. Radomski		
	Wykonał				Kier. proc.	Z. Radomski		
	Kreślił				Gł. proj.			

B — B


2500
17000
250
φ2000x
x1800
4500
11400
+37.10
BY- PRODUCT
ESP
φ2400x
x1800
2800x
x2800
+28.30
9000
BOOSTER
ID FAN

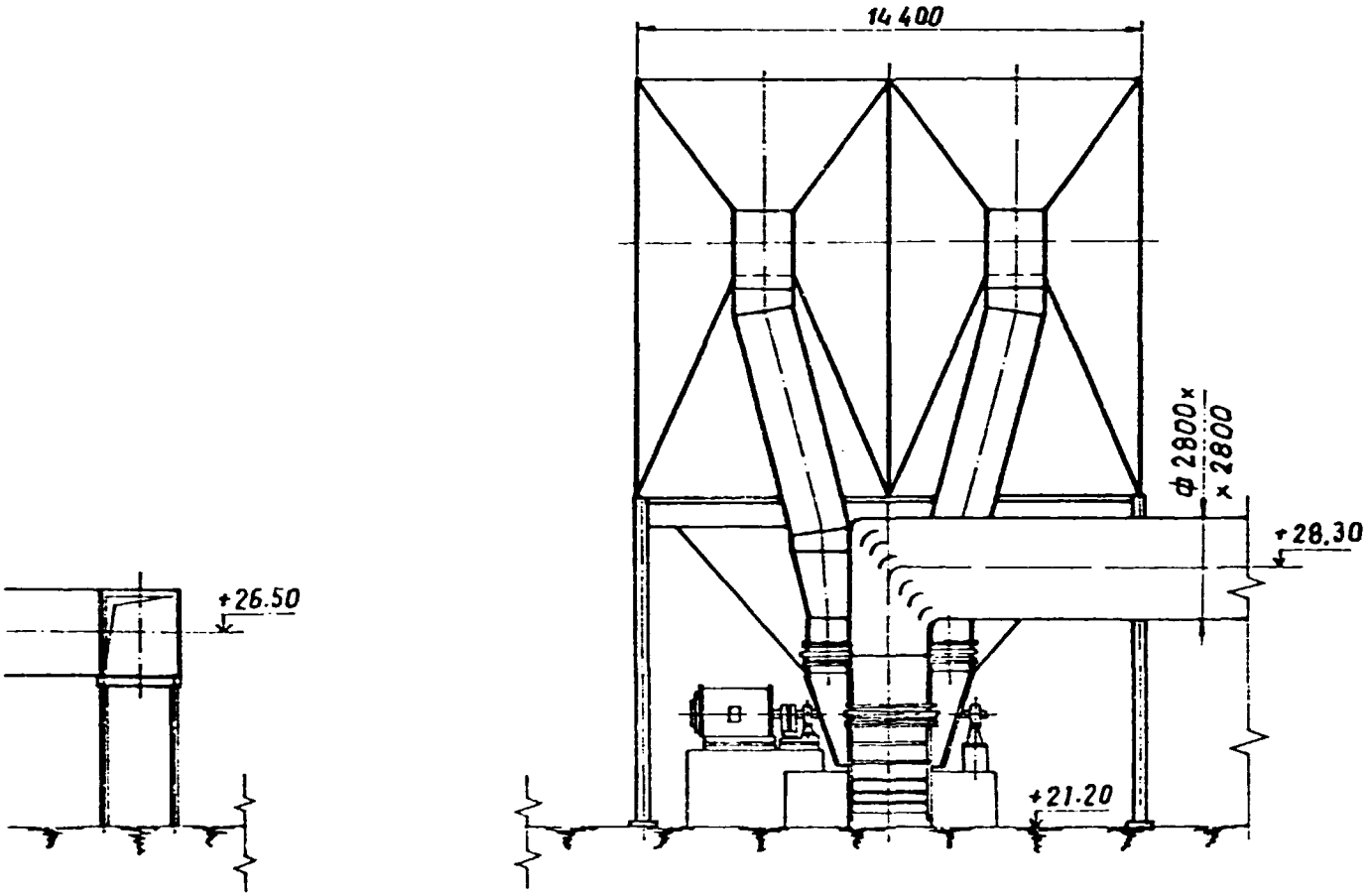
See 11

B — B


17000
2500
Φ2000×
×1800
+37.10
Y– PRODUCT
ESP
Φ2400×
×1800
Φ2600×
×2500
+26.80
+21.20

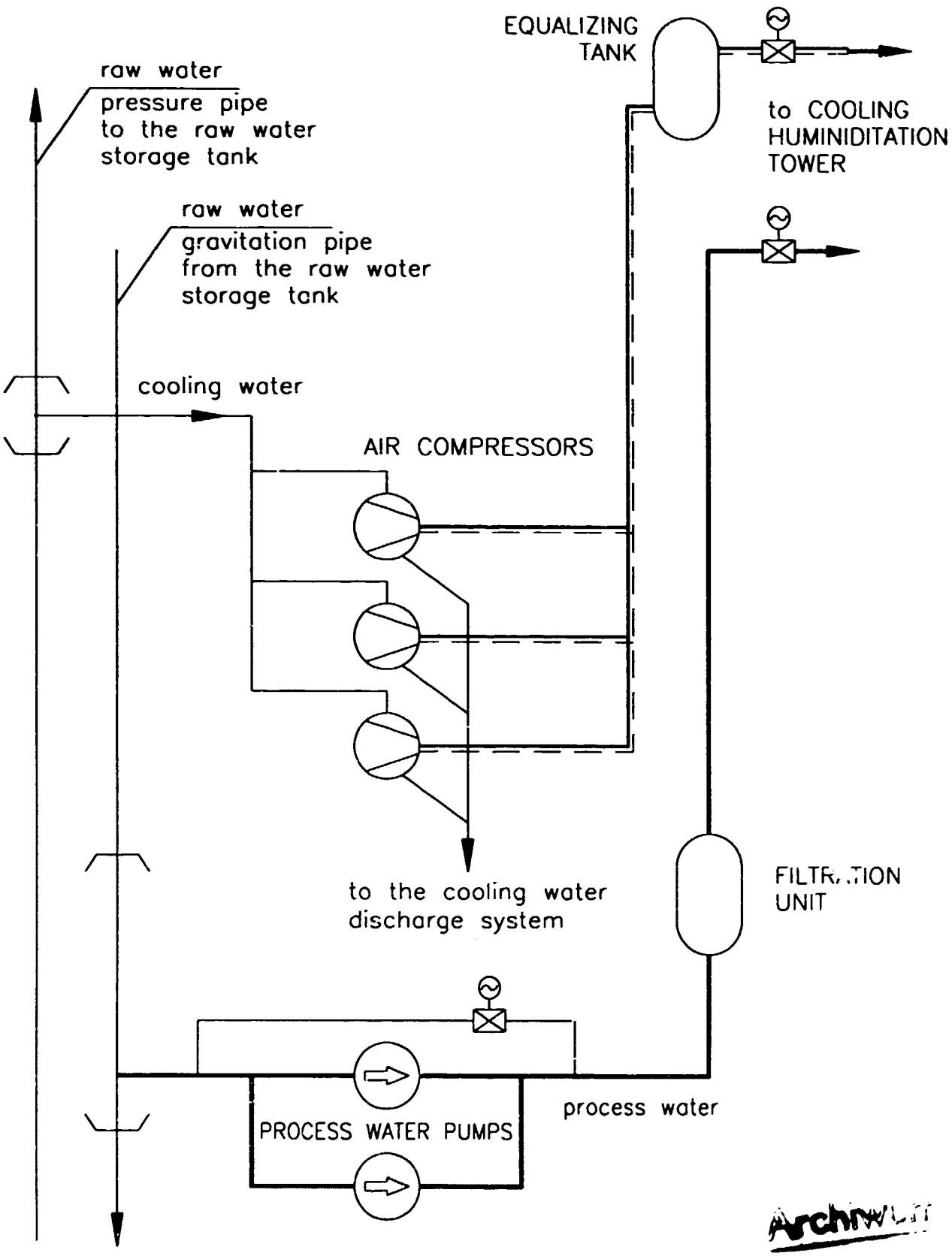
Sia 2

C — C



Sec 3

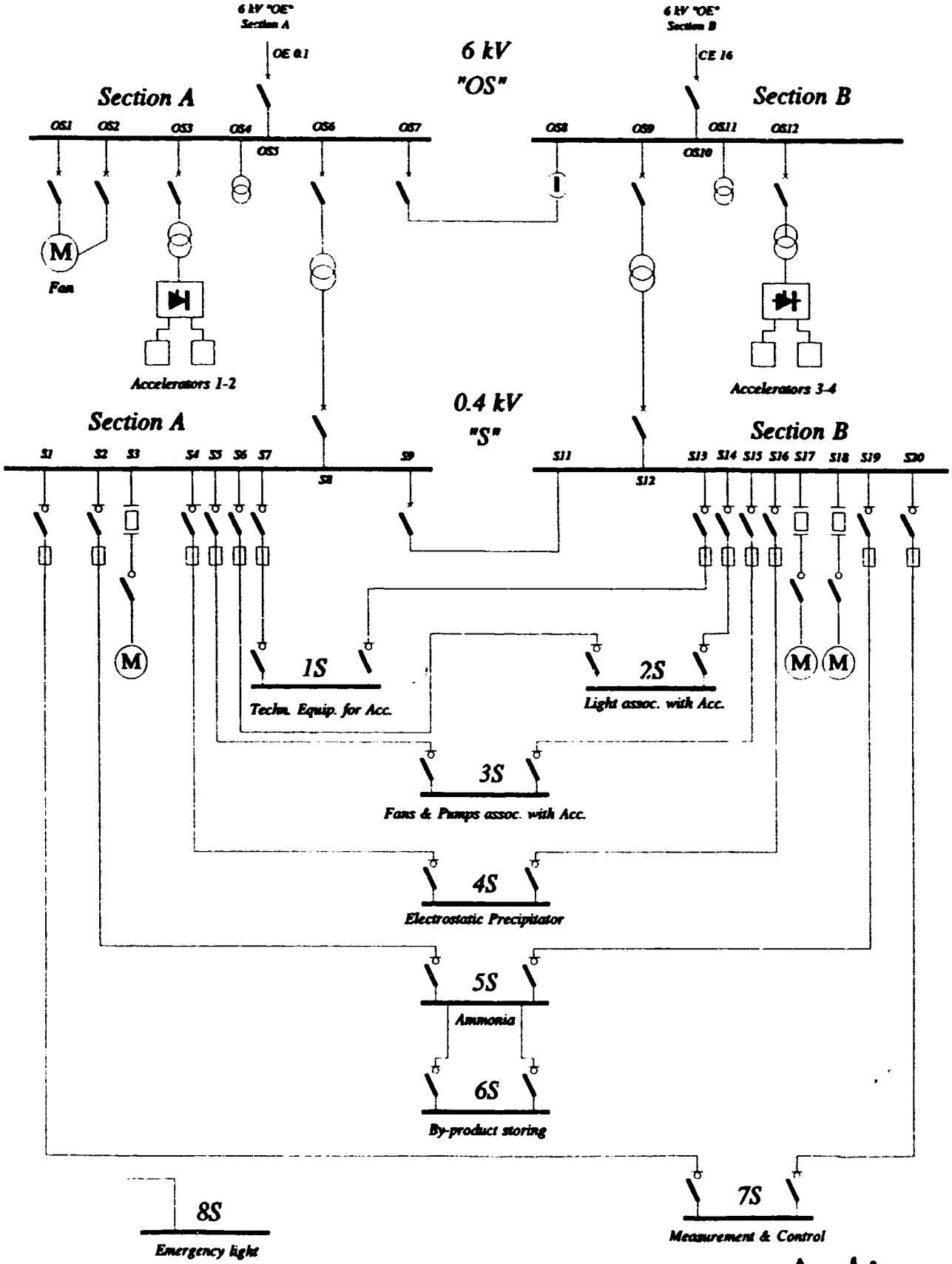
"ENERGOPROJEKT®- WARSZAWA" S.A. Warszawa, ul.Krucza 6/14			Nr archiwalny 1 131 107				Nr. porz. w tomie 4
Przedsięwzięcie	Symbol P-0174	Nr WOI	Branża	Tom 7	Zeszyt	Edycja	
INDUSTRIAL DEMONSTRATION PLANT OF ELECTRON-BEAM PROCESS FOR FLUE GAS TREATMENT OF THE ELECTRIC POWER STATION "POMORZANY"-SZCZECIN POLAND **FLUE GAS SYSTEM** **LAYOUT CROSS-SECTION B-B, C-C**	Data 06.95.		Podziałka 1:200		Faza	Format A3	Pracownia TR	Czas przech.
	Zastępuje rys. Zastąpiony przez rys.	Nr						
	Projektował	J. Roszkowski			Sprawdził	Z. Radomski		
	Wykonał				Kier. proc.	Z. Radomski		
	Kreślił				Gł. proj.			



Archiwalny

Faz.	Nazwa czesci	Ilosc	Material	Nr normy lub rysunku	Jedn.	Ciez. Masa w kg	Uwagi
"ENERGOPROJEKT®- WARSZAWA" S.A. Warszawa, ul.Krucza 6/14				Nr archiwalny 1 131 120			Nr. porz. w tomie
Przedsięwzięcie	Symbol P-0174	Nr WOI		Branża	Tom 7	Zeszyt	Edycja

INDUSTRY DEMONSTRATION PLANT ... STEAM PROCESS ... TREATMENT ... POWER STATION CZECIN POLAND	Data 09.95.	Podziałka —	Faza	Format A4	Przesmie RK	Czas przech.	
PRO... ER & COMPRESSED AIR . LOW DIAGRAM	Zastępuje rys. Zastąpiony przez rys.		Nr				
	Projektował	M. Cyron		Sprawdził	Z. Radomski		
	Wykonał			Kier. proc.	Z. Radomski		
	Kreślił	POM4.DWG		Gł. proj.			



"ENERGOPROJEKT"® - WARSZAWA" S.A.
Warszawa, ul.Krucza 6/14

Przedsięwzięcie	Symbol	Nr WOI
	P-0174	

Nr archiwalny	Branża	Tom	Zeszyt	Edycja
1 131 122		9		

Nr. poz. w tomie: 1

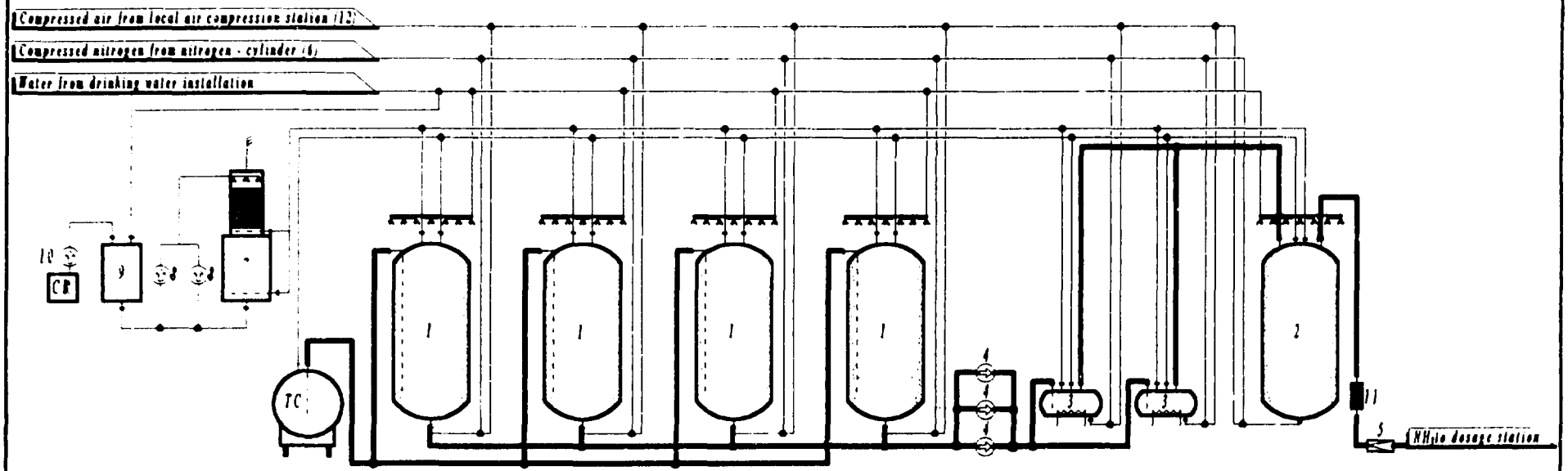
INDUSTRIAL DEMONSTRATION PLANT OF ELECTRON-BEAM PROCESS FOR FLUE GAS TREATMENT OF THE ELECTRIC POWER STATION "POMORZANY"-SZCZECIN POLAND

ELECTRICAL POWER SUPPLY UNIT
SINGLE LINE DIAGRAM

Data	Podziałka	Faza	Format	Przesunięcie	Czas przech.
06.95.			A4	RK	

Zastępuje rys. Nr
Zastępiony przez rys.

Projektował	G.Błajszczak		Sprawdził	Z. Radomski
Wykonał			Kier. proc.	Z. Radomski
Kreślił	POM7.DWG, POM8.DRP		Gł. proj.	



PERMANENT INSTALLATION

1. Liquid ammonia storage tank
2. Gaseous ammonia equalizing tank
3. Ammonia gasificator
4. Liquid ammonia pump
5. Gaseous ammonia decompression station
6. Compressed nitrogen cylinder
7. Absorption tower
8. Sulphuric acid solution pump
9. Preparation tank (sulphuric acid solution)
10. Reloding pump (concentrated sulphuric acid)
11. Gaseous ammonia filter
12. Air compressor

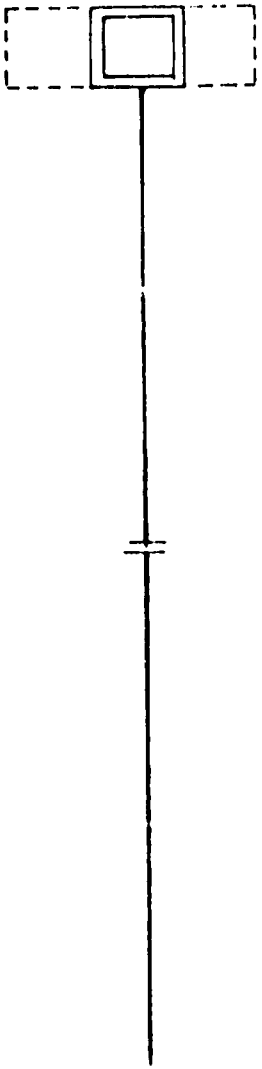
SUPLIED ACCORDING TO DEMAND

TC - Tank car (liquid ammonia)
CB - Carboy (concentrated sulphuric acid)

ENERGOPROJEKT Warszawa SA Biuro Studiów i Projektów Energetycznych Warszawa ul. Ernesta 6/10			Nr archiwalny 1131110				Nr part. w tomie 1
Przedsięwzięcie	Symbol P - 0174	Nr wOl	Branża	Tom 3	Zeszyt	Edycja	
INDUSTRIAL DEMONSTRATION PLANT OF ELEKTRON-BEAM PROCESS FOR FLUE GAS TREATMENT OF THE ELECTRIC POWER STATION "POMORZANY" - SZCZECIN, POLAND **AMMONIUM STORAGE AND DOSING UNIT FLOW DIAGRAM**	Data czerwiec 1995r		Podziałka		Faza	Format	Proc H2 / Czas przech
	Zastępuje rys						
	Projekt	mgr inż L [illegible]			Sprawdził	mgr inż [illegible]	
	Wykonał	mgr inż A [illegible]			Kier prac		
	Kreślił	POM 6 PRI			Gł proj		

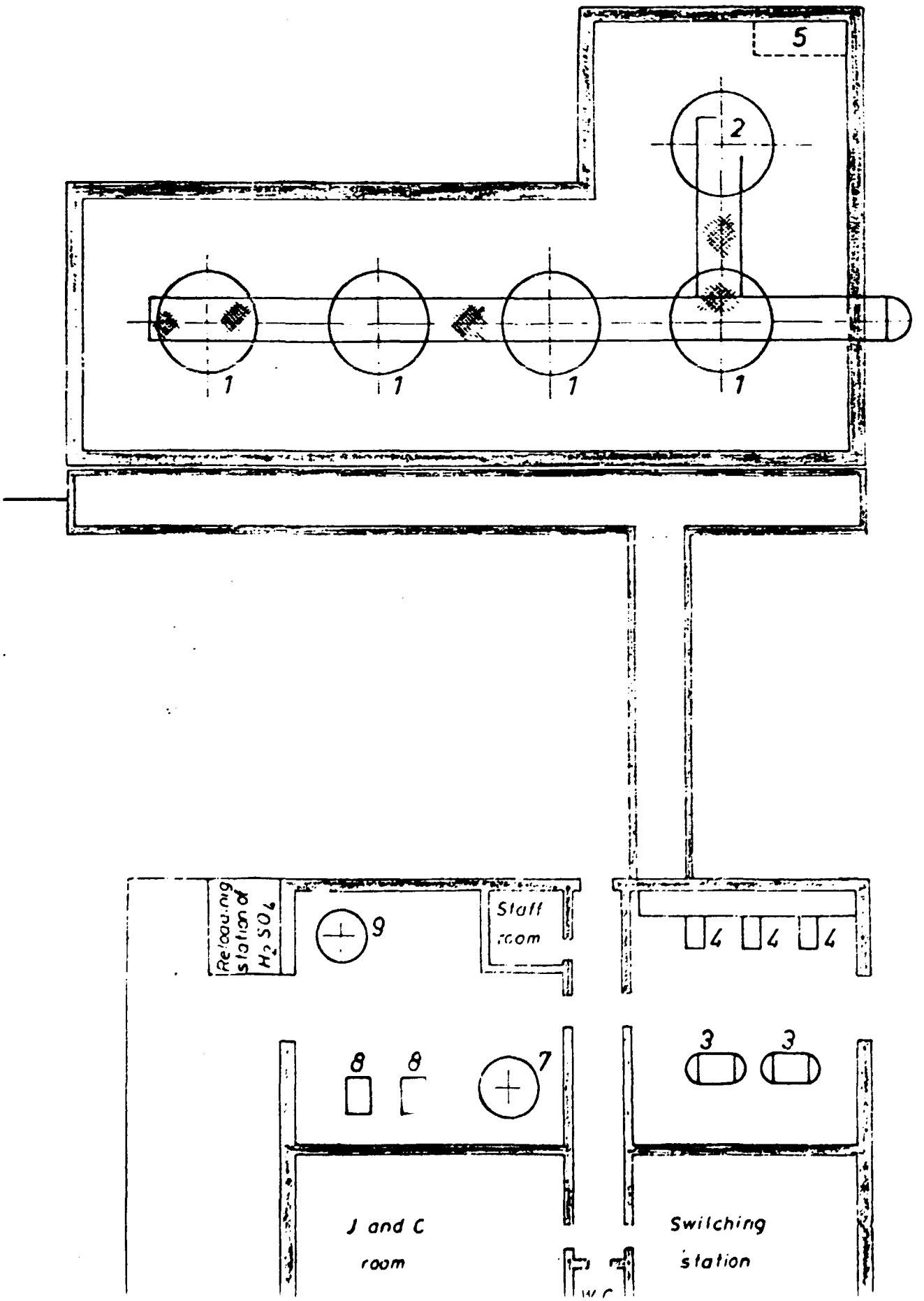
Railway track

Unloading station of liquid ammonia



Sec 1

Sec 2


5
2
1
1
1
1
Relaxing station of H_2SO_4
9
Staff room
4
4
4
8
8
7
3
3
J and C room
Switching station
W.C

See 3

Specification :

1 Storage tank of liquid ammonia D 4000 H 7500

2 Equalizing tank of gaseovs ammonia D 4000 H 7500

3 Gasification pressure tank with heating unit D1200 L 1500

4 Liquid ammonia pump type of 4NH2 $Q = 3 m^3/h$ $H = 20 m\ H_2O$

5 Decompression station of gaseovs nitrogen

6 Decompression station of nitrogen

7 Absorption tower of outlet ammonia D1400 H 3000 I D 2400 H 7500

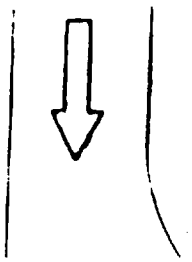
8 Pump of sulphuric acid solution type of 50KCZ 30 $Q = 30 m^3/h$ $H = 13 m\ H2$

9 Tank of 10 20 % sulphuric acid solution D 2000 H 3000

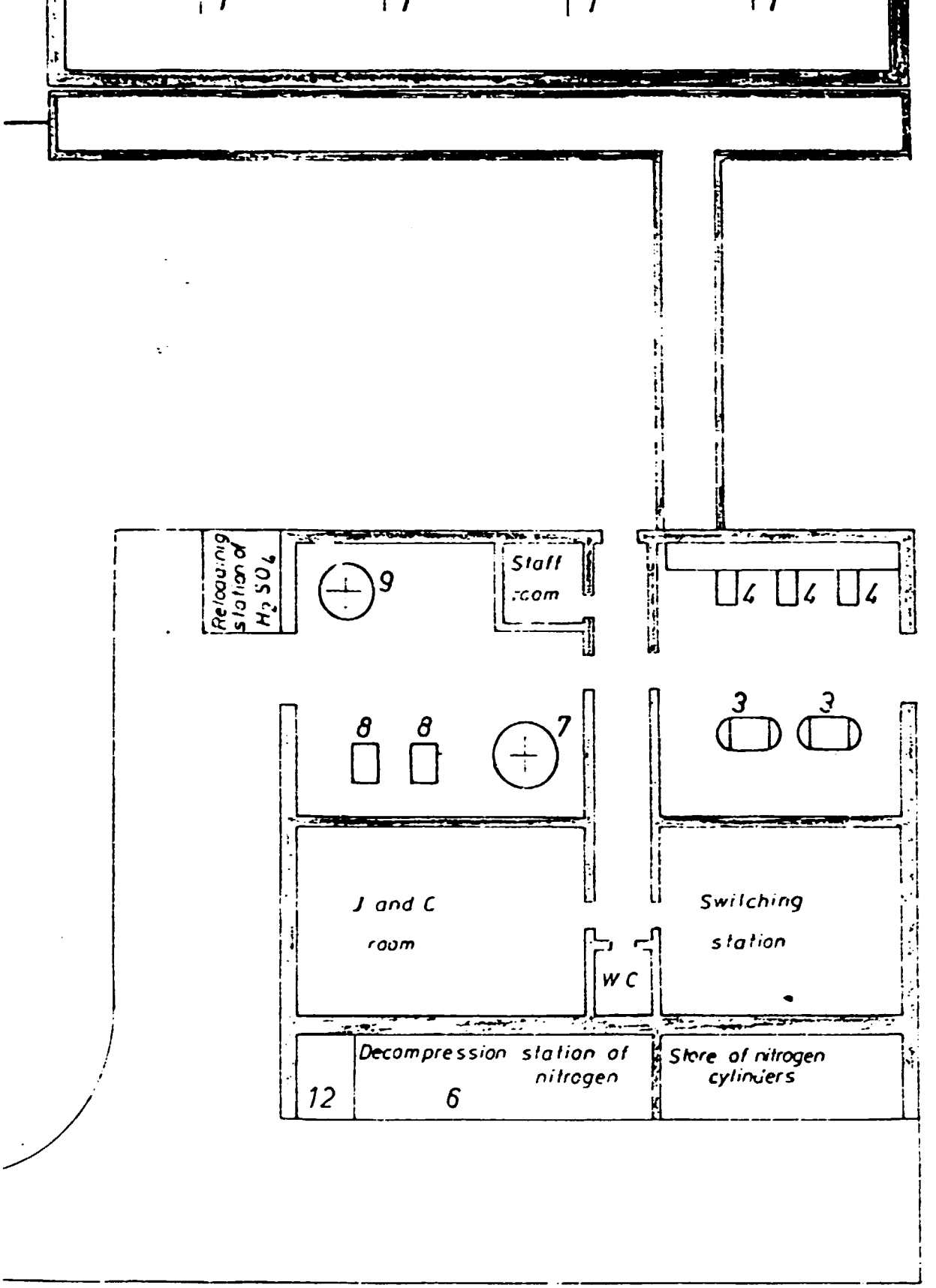
12 Low pressure air compression station

Railway track

Unloading station of l
ammonia



See 4


Relaxing station of H_2SO_4
9
Staff room
4
4
4
8
8
7
3
3
J and C room
Switching station
W C
12
Decompression station of nitrogen
6
Store of nitrogen cylinders

See 5

2 Equalizing tank of gaseovs ammonia D4000 H7500

3 Gasification pressure tank with heating unit D1200 L1500

4 Liquid ammonia pump type of 4NH2 Q= 3m^3/h H=20 m H_2O

5 Decompression station of gaseovs nitrogen

6 Decompression station of nitrogen

7 Absorption tower of outlet ammonia D1400 H 3000 i D2400 H7500

8 Pump of sulphuric acid solution type of 50KCZ 30 Q = 30m^3/h H= 13 m H_2O

9 Tank of 10 20 % sulphuric acid solution D 2000 H 3000

12 Low pressure air compression station

do 6

„ENERGOPROJEKT - WARSZAWA" S.A.
Biuro Studiów i Projektów Energetycznych
Warszawa, ul. Krucza 6/14

Nr arch. wytw. 1131111

Nr przy. w tomie 2

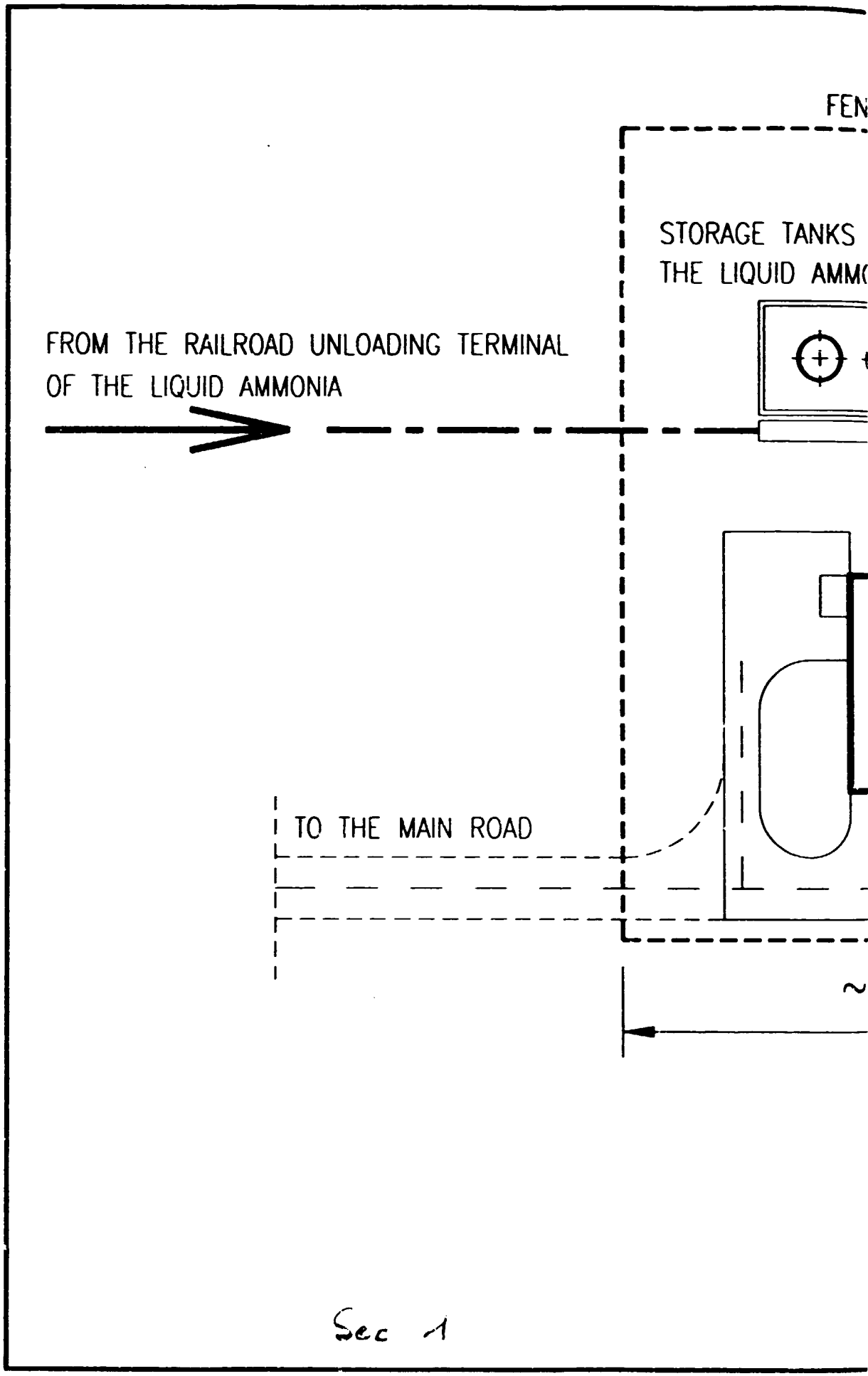
Przedsięwzięcie: EL Pomorzany P-0176 | Symbol | Nr arch. | Branża | Tom | Zeszyt | Edycja

Industrial demonstration plant of electron - Beam process for flue gas treatment of the electric power station „Pomorzany" Szczecin, Poland

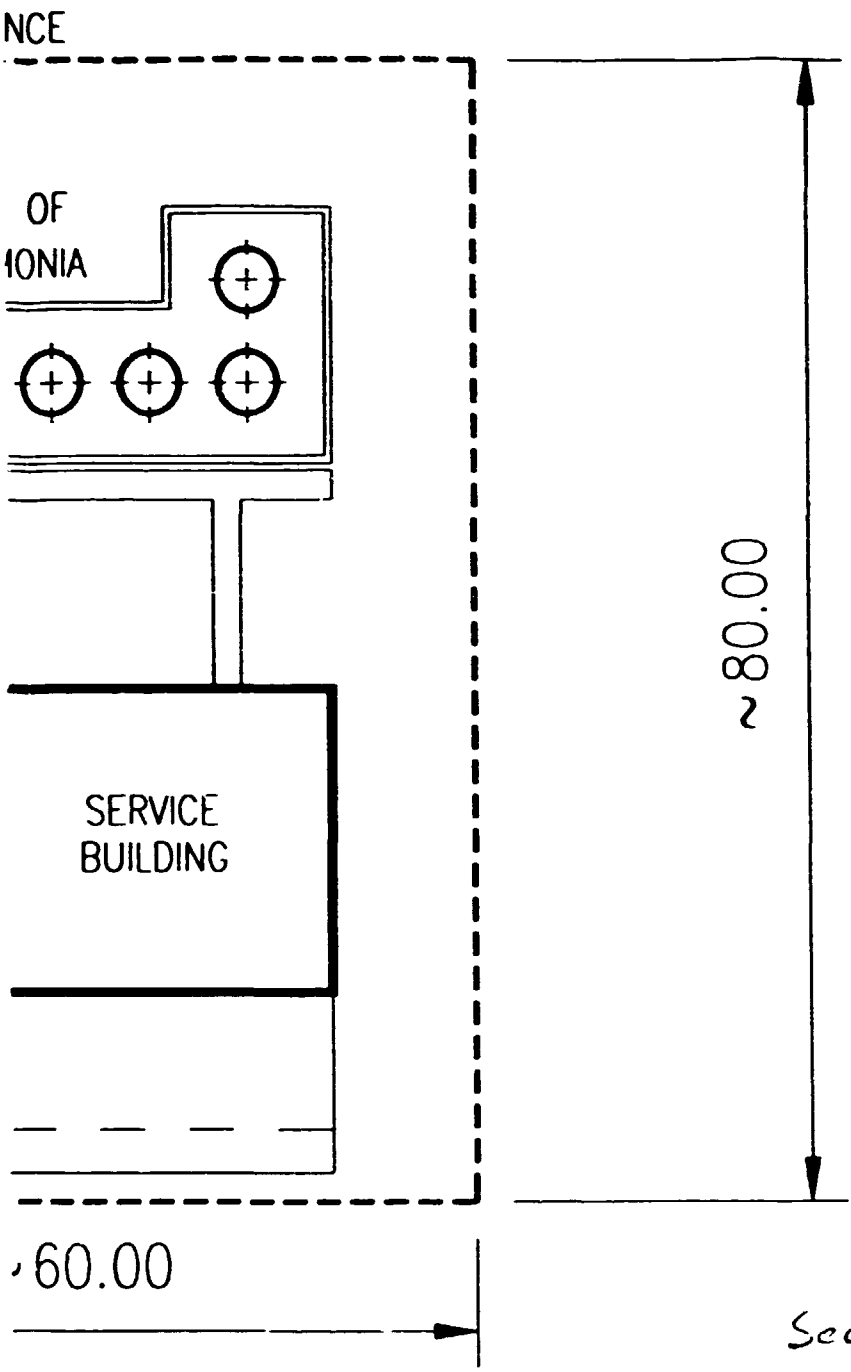
Ammonium storage and dosing unit layout

Data: 95 06 | Podpis | Skala | Format: A1 | Proc: H2 | Czas przech.

Projekt: mgr inż. | Sprawdził: mgr inż.
Wykonał: L. Olmielewski | Kier. zesp.: Z. Gorałczyk
Kreślił: Zimowska


FEN
STORAGE TANKS
THE LIQUID AMM
FROM THE RAILROAD UNLOADING TERMINAL
OF THE LIQUID AMMONIA
TO THE MAIN ROAD

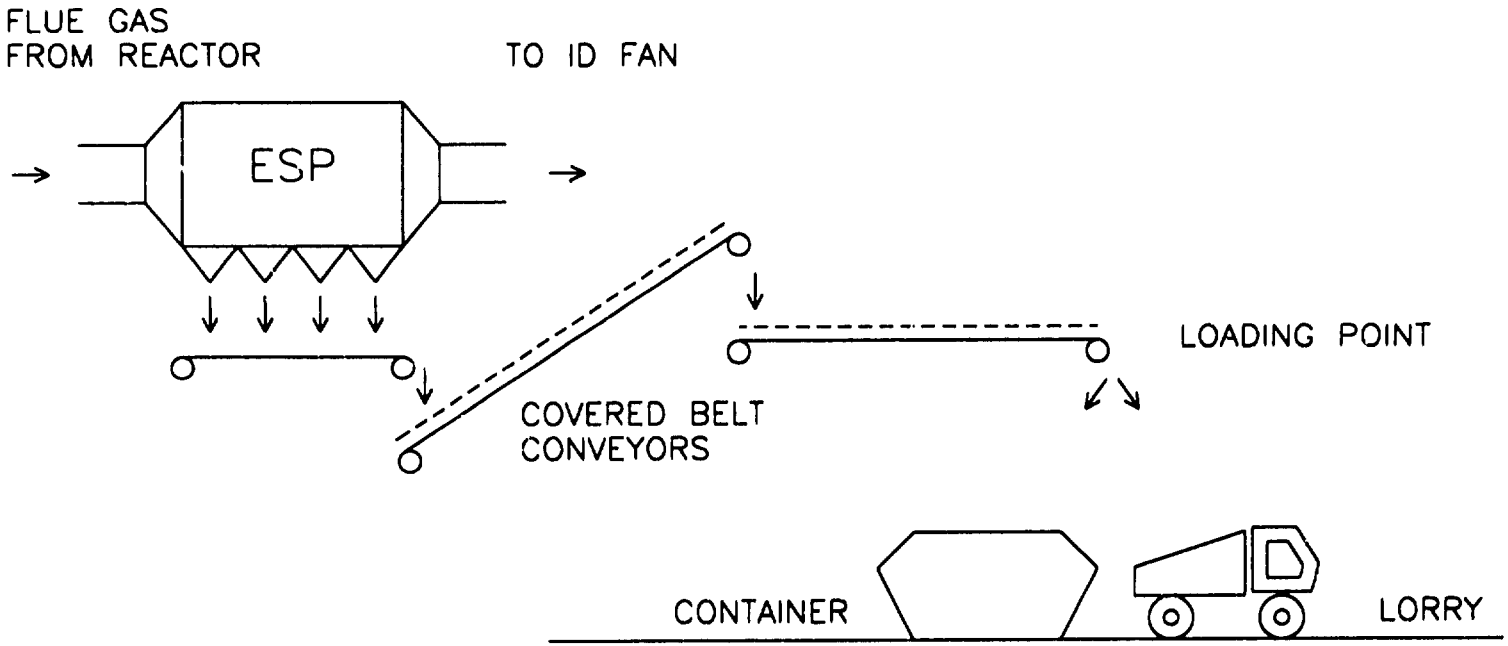
Sec 1



Sec 2

"ENERGOPROJEKT®- WARSZAWA" S.A. Biuro Studiów i Projektów Energetycznych 00-950 Warszawa, ul. Krucza 6/14			Nr archiwalny 958 673				Nr porz. w tomie 1
Przedsięwzięcie	Symbol P-0174	W.O.I.	Branża BP	Tom	Zeszyt	Edycja	

INDUSTRIAL DEMONSTRATION PLANT OF ELECTRON-BEAM PROCESS FOR FLUE GAS TREATMENT OF THE ELECTRIC POWER STATION "POMORZANY" -SZCZECIN, POLAND	Data IX.1995 r	Podziałka 1:500	Faza	Format A3	Proc. B-1D	Czas prz
	Zastępuje rys. Zastąpiony przez rys. Nr					
	Projekt. mgr inż. Z. Warakomski		Sprawdził mgr inż. J. Drabczyk			
LAYOUT OF THE AREA OF AMMONIA STORAGE AND DOSING UNIT	Wykonał		Kier. proc. mgr inż. R. Kołakowski			
	Kreślił		Gł.proj.			



Poz.	Nazwa części	Ilość	Materiał	Nr normy lub rysunku	Jedn. / Masa w kg	Ceła.	Uwagi

"ENERGOPROJEKT"® - WARSZAWA" S.A.
Warszawa, ul.Krucza 6/14

Nr archiwalny 1 131 116

Przedsięwzięcie	Symbol	Nr WOI	Branża	Tom	Zeszyt	Edycja	Nr. porz. w tomie
	P-0174			6			

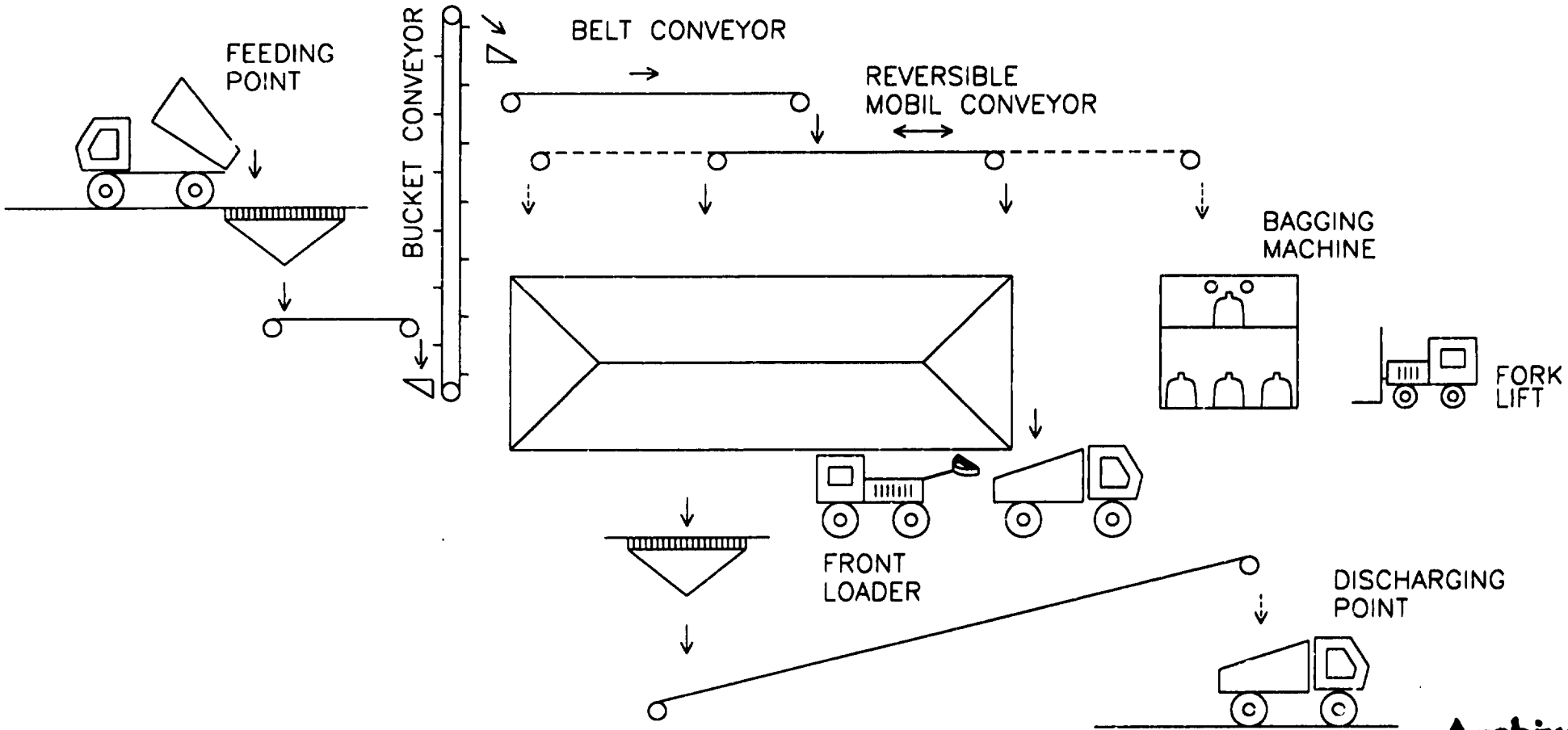
INDUSTRIAL DEMONSTRATION PLANT OF ELECTRON-BEAM PROCESS FOR FLUE GAS TREATMENT OF THE ELECTRIC POWER STATION "POMORZANY" - SZCZECIN POLAND

SCHEME OF BY-PRODUCT HANDLING SYSTEM -OF POWER PLANTS AREA-

Data	Podziałka	Faza	Format	Przewim	Czas przech.
06.95.			A4	RK	

Zastępuje rys. Nr
Zastąpiony przez rys.

Projektował	L.Kosiński		Sprawdził	Z. Rademski	
Wykonał			Kier. proc.	Z. Rademski	
Kreślił	POM3.DWG		Gł. proj.		



Archiwum

Poz.	Nazwa części	Ilość	Materiał	Nr normy lub rysunku	Jedn. miary	Ciężar w kg	Uwagi

"ENERGOPROJEKT" - WARSZAWA" S.A.
Warszawa, ul.Krucza 6/14

Nr archiwalny: 1 131 117

Nr. porz. w tomie

Przedsięwzięcie	Symbol	Nr WOI	Branża	Tom	Zeszyt	Edycja
	P-0174			6		

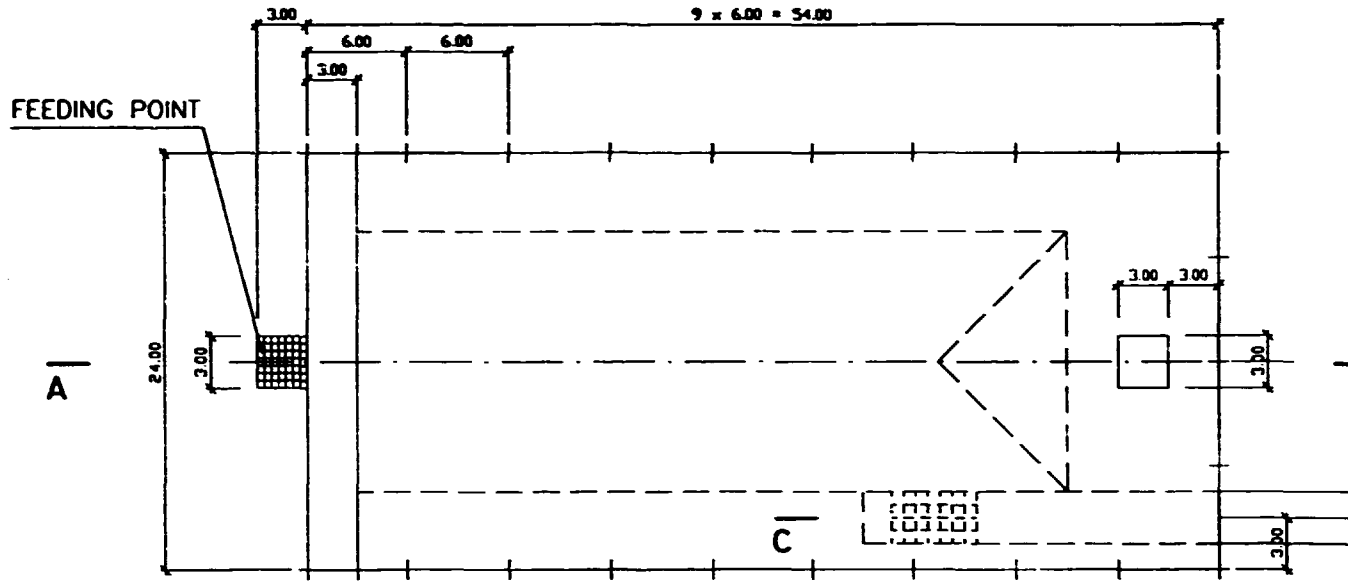
INDUSTRIAL DEMONSTRATION PLANT OF ELECTRON-BEAM PROCESS FOR FLUE GAS TREATMENT OF THE ELECTRIC POWER STATION "POMORZANY" - SZCZECIN POLAND

BUFFER STOCK YARD
-SCHEME-

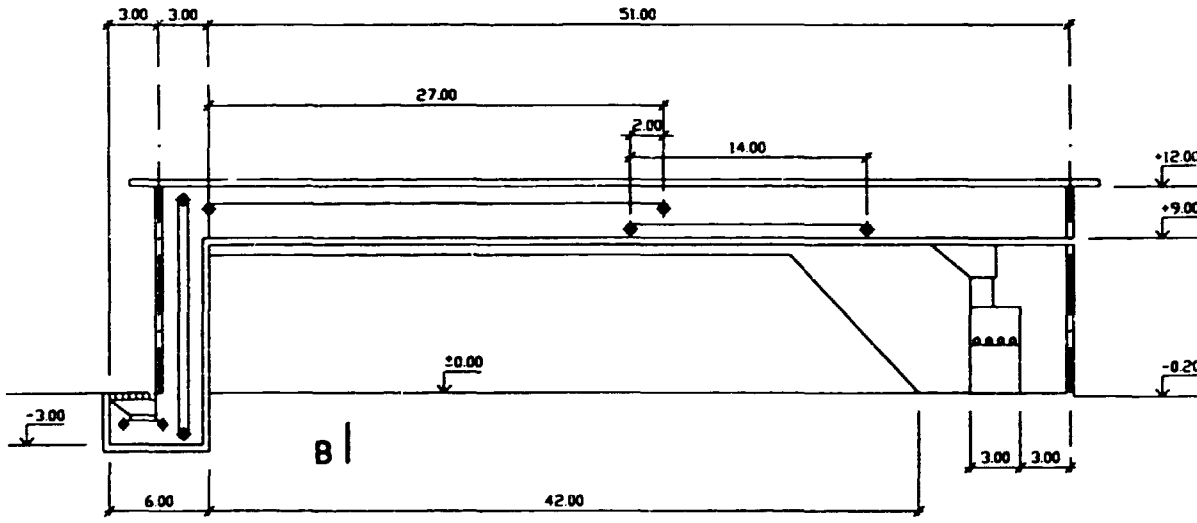
Data	Podziałka	Faza	Format	Przewodnik	Czas przech.
09.95.			A4	RK	

Zastępuje rys. Nr
Zastąpiony przez rys.

Projektował	L.Kosiński		Sprawdził	Z. Radomski
Wykonał			Kier. proc.	Z. Radomski
Kreślił	POM2.DWG		Gł. proj.	


3.00
9 x 6.00 = 54.00
6.00
6.00
3.00
FEEDING POINT
A
24.00
3.00
3.00
3.00
3.00
C
3.00

B | A - A


3.00
3.00
51.00
27.00
2.00
14.00
+12.00
+9.00
±0.00
-3.00
-0.20
B |
3.00
3.00
6.00
42.00

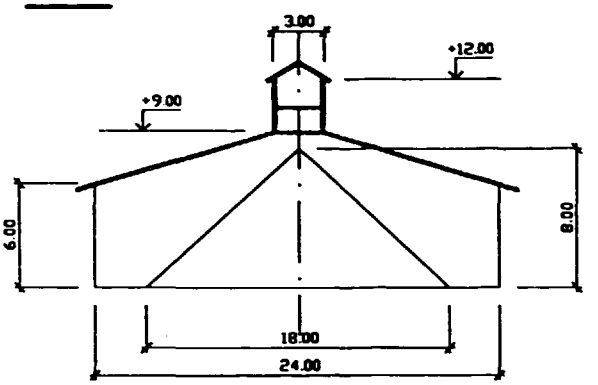
Sec A

DISCHARGING POINT

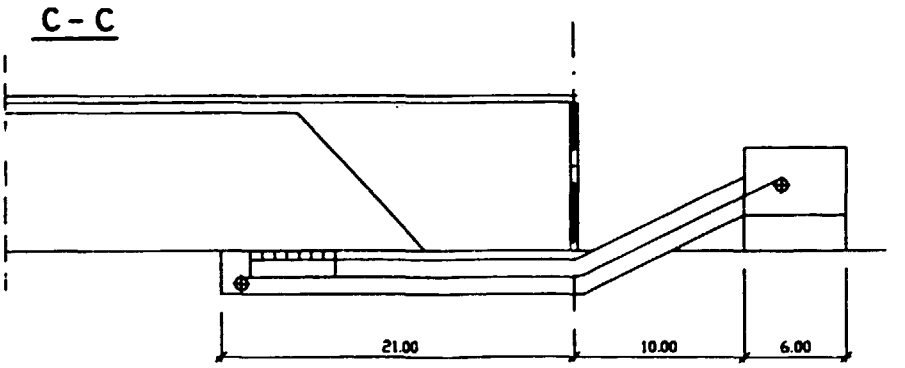
A

C

B - B



C - C

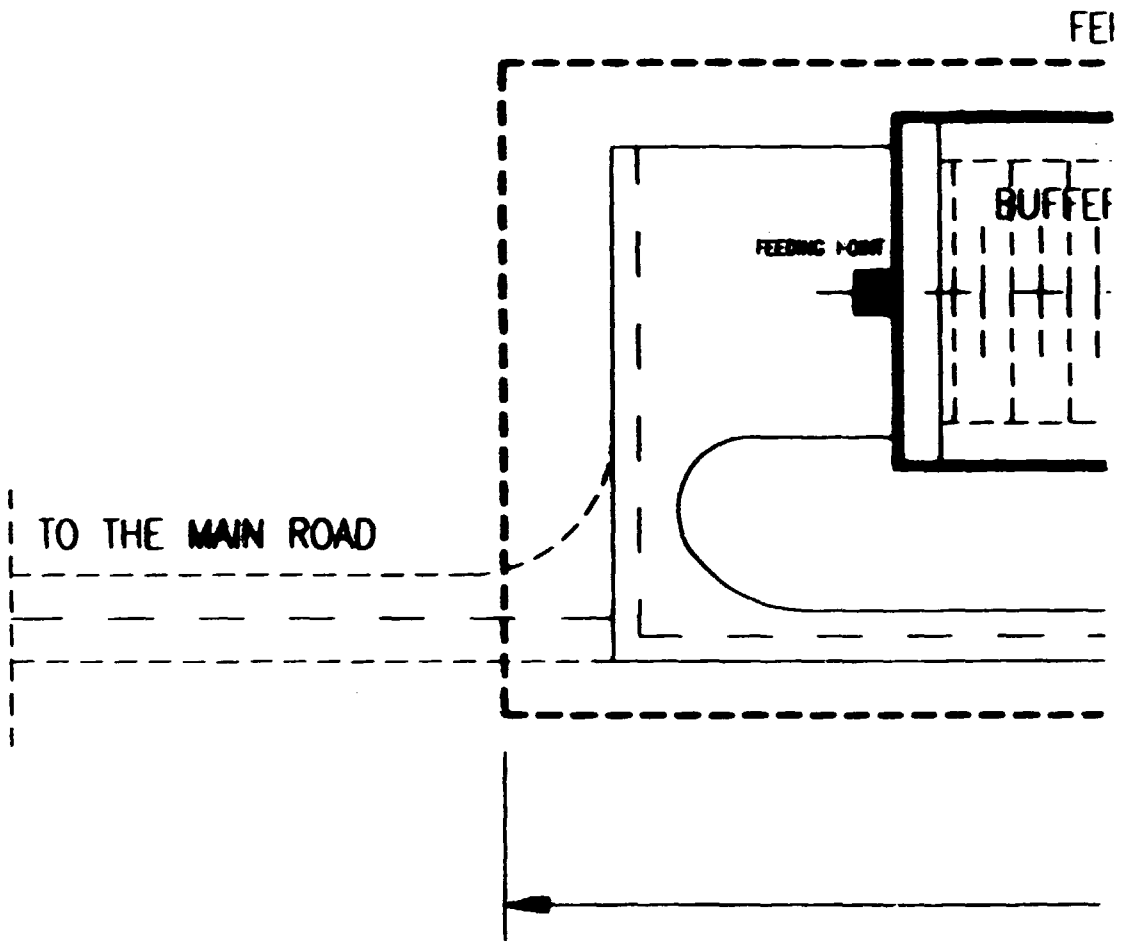


Archiwum

Poz.	Nazwa części	Ilość	Materiał	Nr normy lub rysunku	Jedn. / Masa w kg	Ciężar	Uwagi
"ENERGOPROJEKT® - WARSZAWA" S.A. Warszawa, ul.Krucza 6/14				Nr archiwalny 1 131 118			Nr. poz. w tomie
Przedsięwzięcie: Symbol 7-0174	Nr WOI			Branża	Tom 6	Zeszyt	Edycja

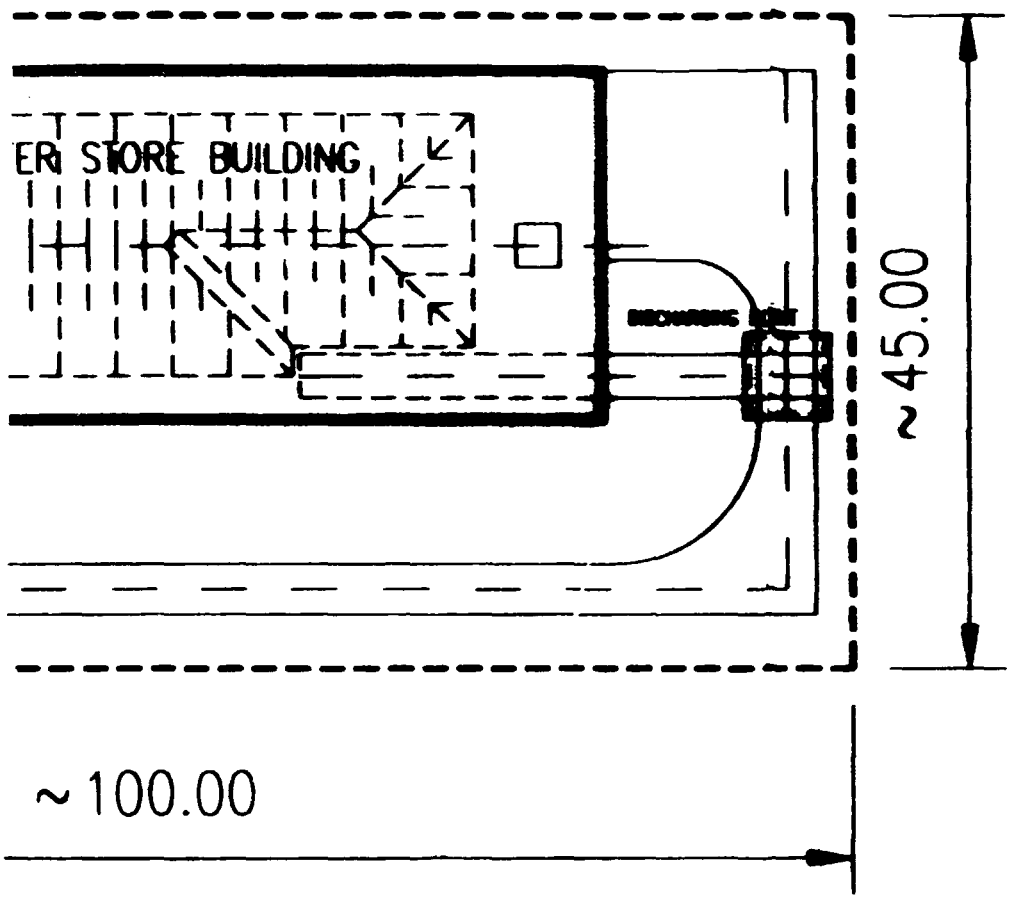
INDUSTRIAL DEMONSTRATION PLANT OF ELECTRON-BEAM PROCESS FOR FLUE GAS TREATMENT OF THE ELECTRIC POWER STATION "POMORZANY"-SZCZECIN POLAND	Data 09.95.	Podziałka –	Faza	Format A3	Przesłał RK	Czas przech.	
BUFFER STORE BUILDING LAYOUT	Zastępuje rys. / Zastąpiony przez rys. Nr 0045						
	Projektował: L.Kosiński			Sprawdził: Z. Radomski			
	Wykonał:			Kier. proc.: Z. Radomski			
	Kreślił: POM7.DWG			Cł. proj.:			

Sac 2



Sec 1

ENCE



Sec 2

Sec 2

"ENERGOPROJEKT" – WARSZAWA" S.A. Biuro Studiów i Projektów Energetycznych 00-650 Warszawa, ul. Krucza 6/14			Nr archiwalny 958 674				Nr parz. w tomie 2
Przedsięwzięcie	Symbol P-0174	W.O.I.	Branża BP	Tom	Zeszyt	Edycja	
INDUSTRIAL DEMONSTRATION PLANT OF ELECTRON-BEAM FLUE GAS TREATMENT OF THE [illegible] POWER STATION "POMORZANY" – SWIECIE, POLAND	Data IX.1995 r		Podziałka 1:500	Faza	Format A3	Proc. B-10	Czas przech.
	Projekt.				Sprawdził		
LAYOUT OF THE AREA OF THE BUFFER STORE BUILDING	Rysował				Kier. proc.		
					Kier. proj.		

This volume has been prepared by:

Consulting Engineers - Power Engineering Study and Design Company, „Energoprojekt - Warszawa SA"

Engineering Design Of An Electron Beam (EB) Flue Gas Purification Industrial DemonstrationPlant

Basic Engineering.

Volume 11

Balances.

Warsaw, January 1996

No of Volume	List of Volumes	Author
Volume 0	Executive Summary	
Volume I	Process Technology	INCT
Volume II	Gas Conditioning Unit	INCT
Volume III	Ammonia storage and dosing unit	Energoprojekt-Warszawa
Volume IV	Reaction chamber	Proatom
Volume V	By-product filtration (ESP)	Energoprojekt-Warszawa
Volume VI	By-product removal from filter, its transportation and conditioning	Energoprojekt-Warszawa
Volume VII	Flue gas ducts. Emission of flue gases to atmosphere	Energoprojekt-Warszawa
Volume VIII	Measuring, monitoring and control system	SINS
Volume IX	Electrical power supply units	Energoprojekt-Warszawa
Volume X	Composite documentation	Energoprojekt-Warszawa
Volume XI	Balances	Energoprojekt-Warszawa

Authors of this volume:

1. M.Cyran	Energoprojekt W-wa
2. Z.Radomski	Energoprojekt W-wa
3. J.Roszkowski	Energoprojekt W-wa

Volume 11

Balances

Contents

1. Introduction

This volume collect the basic input and output data, investment cost specification and results of economic analysis.

2. Power Station "Pomorzany" basic data

Gross electricity output	120 MWe
Net electricity output	112 MWe
Steam generators output	285 MW
Water boilers output	279 MW
Gross electricity production	584 444 MWh (year 1994)
Net electricity production	538 978 MWh (year 1994)
Heat production	3 313 668 GJ (year 1994)
Consumption of hard coal (basic fuel)	384 729 ton (year 1994) (8 822 557 GJ)

Coal basic data.

Heating value	22,8 MJ/kg
Ash content	21,8 %
Sulphur content	0,72 ÷ 0,8 %
Humidity	7,8 %

3. Basic data of flue gas treatment plant

3.1. Operation mode

Industrial demonstration plant of electron beam process for flue gas treatment at the Electric Power station "Pomorzany" will purify 50 - 60 % of flue gas from two existing 142,5 MWt Benson steam boilers.
Continuous operation of the plant is foreseen with annual operating time equivalent to 6500 full load hours.
Flue gas flow by Electron Beam Purification Plant will be mainly constant, however it will be controlled to maintain stack inlet temperature of mixed raw and purified flue gas above 110 ^{o}C to avoid acid attack in the existing concrete stack.

3.2. Inlet flue gas data

Nominal flue gas inlet flow	270 000 Nm^3/h
Min. flue gas inlet flow	150 000 Nm^3/h
Flue gas inlet temperature	145 - 170 ^oC

Flue gas inlet composition:

- SO_2	1,1 g/Nm^3
- NO_x	0,6 g/Nm^3
- CO	0 % vol.
- CO_2	8 % vol.
- O_2	7 ÷ 8 % vol.
- N_2	to the balance
- fly ash	0,08 g/Nm^3
- moisture	5 ÷ 6,9 % vol.

3.3. Basic process data

SO removal efficiency	70 %
NO removal efficiency	80 %
Solid particle emission	≤ 20 mg/Nm^3
Flue gas process temperature	80 ^oC
Flue gas process humidity	10 - 12 % volume
Electrons energy	0,8 MeV
Average electron beam accelerators output	4 × 300 kW
Nominal by-product output	700 kg/h (4550 t/a)

By-product composition

- $(NH_4)_2SO_4$	70 %
- NH_4NO_3	26 %
- fly ash	2 %
- moisture	2 %

4. Annual consumption of media

4.1. Basic media consumption

Ammonia	1 300 t/a
Process water (raw water)	87 750 m^3/a
Cooling water (raw water)	78 000 m^3/a
Electrical energy	13,2 GWh/a

4.2. Auxiliary media

Auxiliary media with negligible yearly consumption are specified below.
- Demineralized water - make up water for accelerators primary closed cooling system.
- Washing up water.
- Drinking water.
- Sulphuric acid.

5. Investment cost specification

Results of preliminary cost calculation are presented in the table

Ordinal number	Specification of objects, work and expenditures	Total cost in thousand USD	Portion %
1	2	3	4
1.	Accelerators	2 900	14,57
2.	Flue gas humidification tower	600	3,02
3.	Reaction chambers - reaction units	500	2,51
4.	Electrostatic precipitator *)	4 110	20,65
5.	Booster fan	190	0,95
6.	By-product handling system	840	4,22
7.	Ammonia storage and dosing unit	830	4,17
8.	Measuring, monitoring, and control system	1 500	7,53
9.	Refurbishment of accelerator building	1 100	5,53
10.	Radiation shield walls of accelerators and of reaction chambers	400	2,01
11.	Ventilation system for accelerator building	200	1,01
12.	Accelerator cooling system	150	0,76
13.	Sygnalling system of accelerator operation	100	0,50

1	2	3	4
14.	Lighting system of accelerators building	80	0,40
15.	Electrical power supply	710	3,56
16.	Flue gas ducts, complete with connections and support structures	1 200	6,03
17.	Process water pumping system	10	0,05
18.	Compressed air system	230	1,16
19.	Documentation, supervision	1 350	6,78
20.	Training	200	1,01
21.	Commisioning	200	1,01
22.	General civil engineering contracting; supervision on site	700	3,52
23.	Total	18 100	90,95
24.	Reserve	1 800	9,05
25.	Total	19 900	100,0

*) Cost of ESP has been estimated on the basis of the quotation submitted by ABB FLAKT.

6. Economic analysis

6.1. Basic assumption

The purpose of economic analysis is to calculate the unit cost of SO_2 & NO_x reduction in power generation process and to estimate the increase of cost of electricity production involved by implementation of electron - beam flue gas tratment plant.
Economic analysis was carried out according to UNIDO standards with application of discount method of economic efficiency evaluation. Analysis was done on the basis of constant price level that of second quarter 1995, regardless of inflation, increase of prices and VAT taxes.
The analysis spans the extend 1996 up to 2010 i.e. resulting period of erection and depreciation expiry of equipment. Analysis takes into account the investment costs, operation costs, financing costs, returns from by-product sale and reduction of environmental fees.
The investment and operation cost estimation takes into consideration the expences associated with EB FGT only. Additional costs necessary for rehabilitation of Pomorzany PS to ensure its future uninterrupted operation have not been considered in this elaboration.
The above said assumption and the brake down of investment costs should be considered the most realistic.
It should be pointed out that the most probable way to cover the expences of installation and operation of EB FGT is signing of the long term contract agreement between the Pomorzany PS and Polish Power Gird Co for power kWhrs delivered to the grid.

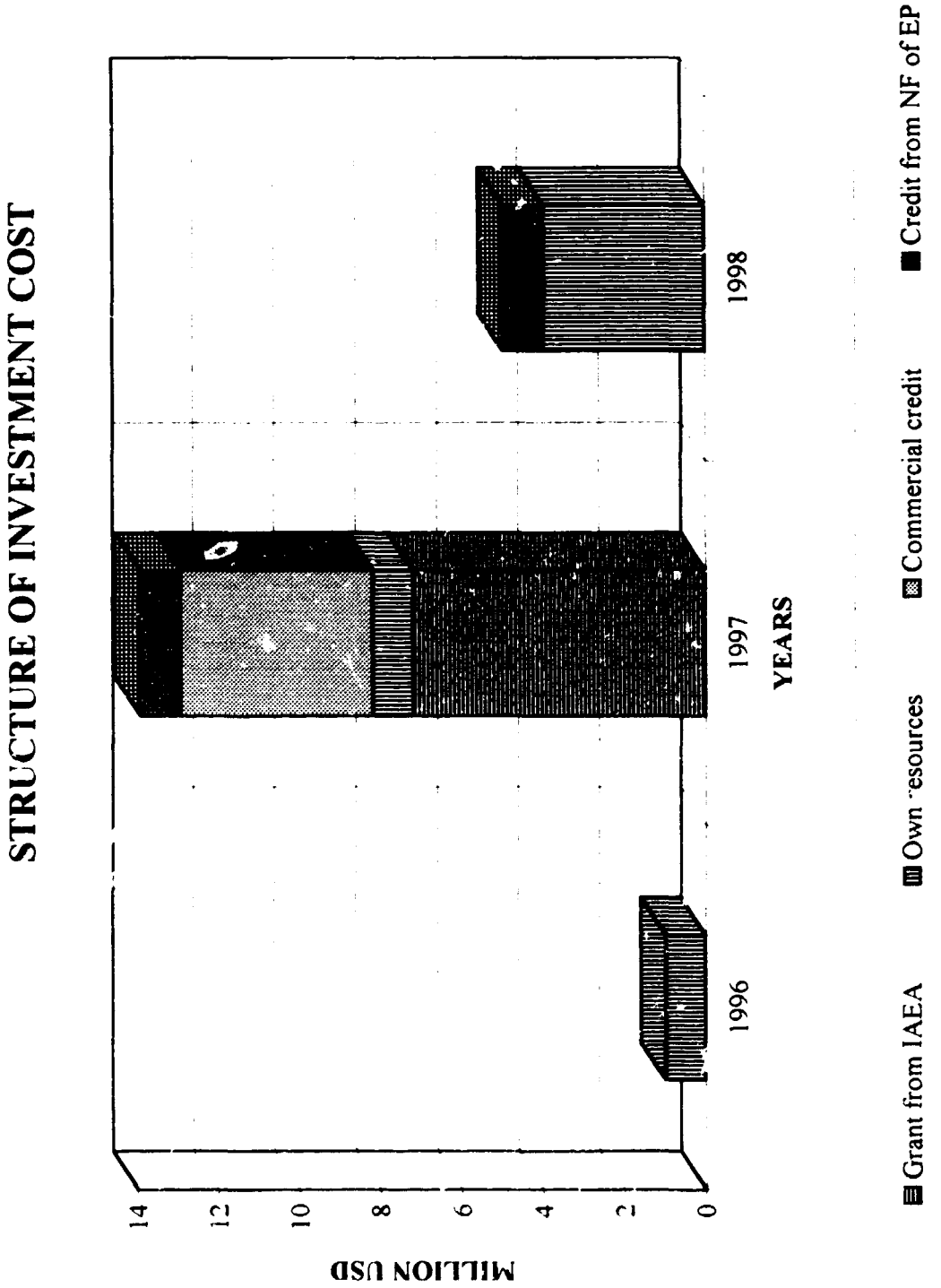
6.2. Sources and timeschedule of financing

Since there are not any recognized financing procedure for this project, the following assumption have been taken for economic analysis:
Sources of financing:
- 36 % of investment cost: grant from IAEA,
- 30 % of investment cost: own resources of investor,
- 24 % of investment cost: commercial credit, intrest rate 14 %, 5 years,
- 10 % of investment cost: credit from National Foundation of Enviroument Protection (Poland), intrest rate 6 %, 5 years.

Timeschedule of financing :
(in thousand USD)

Item	Specification	1996	1997	1998	Total
1	Grant from IAEA		7200		7200
2	Own resources	995	995	3980	5970
3	Commercial credit		4740		4740
4	Credit from NFoEP		995	995	1990
5	Total	995	13 930	4 975	19 900

6.3. Results of economic analysis



UNIT COST OF S02 AND NOx REDUCTION AND INCREASE OF ELECTRICITY UNIT COST

No	SPECIFICATION	UNIT	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
1	INVESTMENT COST	1000 USD/Y	995.00	13930.00	4975.00												
2	INTERESTSM DURING CONSTRUCTION	1000 USD/Y		447.75	985.65												
3	CAPITAL COST	1000 USD/Y			906.67	2844.91	2615.70	2386.49	2157.27	1928.00	1813.34	1813.34	1813.34	1813.34	1813.34	1813.34	1813.34
4	DEPRECIATION	1000 USD/Y			906.67	1813.34	1813.34	1813.34	1813.34	1813.34	1813.34	1813.34	1813.34	1813.34	1813.34	1813.34	1813.34
5	FINANCE COST	1000 USD/Y			0.00	1031.57	802.36	573.15	343.93	114.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	OPERATION COST	1000 USD/Y			503.87	1007.75	1007.75	1157.00	1157.00	1157.00	1157.00	1157.00	1157.00	1157.00	1157.00	1157.00	1157.00
7	MAINTENANCE	1000 USD/Y			24.87	49.75	49.75	199.00	199.00	199.00	199.00	199.00	199.00	199.00	199.00	199.00	199.00
8	LABOUR	1000 USD/Y			119.03	238.06	238.06	238.06	238.06	238.06	238.06	238.06	238.06	238.06	238.06	238.06	238.06
9	PROCESS WATER	1000 USD/Y			0.40	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81
10	ELECTICITY	1000 USD/Y			205.75	411.50	411.50	411.50	411.50	411.50	411.50	411.50	411.50	411.50	411.50	411.50	411.50
11	CHEMICALS	1000 USD/Y			128.95	257.89	257.89	257.89	257.89	257.89	257.89	257.89	257.89	257.89	257.89	257.89	257.89
12	OTHER	1000 USD/Y			24.87	49.75	49.75	49.75	49.75	49.75	49.75	49.75	49.75	49.75	49.75	49.75	49.75
13	TOTAL COST	1000 USD/Y			1410.55	3852.67	3623.45	3543.49	3314.28	3085.00	2970.34	2970.34	2970.34	2970.34	2970.34	2970.34	2970.34
14	FEES DIFFERENCE	1000 USD/Y			107.91	215.83	215.83	215.83	215.83	215.83	215.83	215.83	215.83	215.83	215.83	215.83	215.83
15	BY-PRODUCT SALE	1000 USD/Y			198.03	396.05	396.05	396.05	396.05	396.05	396.05	396.05	396.05	396.05	396.05	396.05	396.05
16	REDUCTION SO2	ton/y			405.71	811.42	811.42	811.42	811.42	811.42	811.42	811.42	811.42	811.42	811.42	811.42	811.42
17	REDUCTION NOx	ton/y			162.27	324.53	324.53	324.53	324.53	324.53	324.53	324.53	324.53	324.53	324.53	324.53	324.53
18	UNIT COST OF REDUCTION SO2 i NOx				0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	WITHOUT REGARD TO FEES DIFFERENCE	1000 USD/T			1.00	1.37	1.29	1.26	1.18	1.10	1.06	1.06	1.06	1.06	1.06	1.06	1.06
20	WITH REGARD TO FEES DIFFERENCE	1000 USD/T			0.79	1.15	1.07	1.04	0.96	0.88	0.84	0.84	0.84	0.84	0.84	0.84	0.84
21	INCREASE OF ELECTRICITY UNIT COST				0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	WITHOUT REGARD TO FEES DIFFERENCE	USD/MWh			4.83	6.59	6.20	6.06	5.67	5.28	5.08	5.08	5.08	5.08	5.08	5.08	5.08
23	WITH REGARD TO FEES DIFFERENCE	USD/MWh			3.78	5.55	5.15	5.02	4.62	4.23	4.04	4.04	4.04	4.04	4.04	4.04	4.04

ENERGOPROJEKT - WARSZAWA S.A.

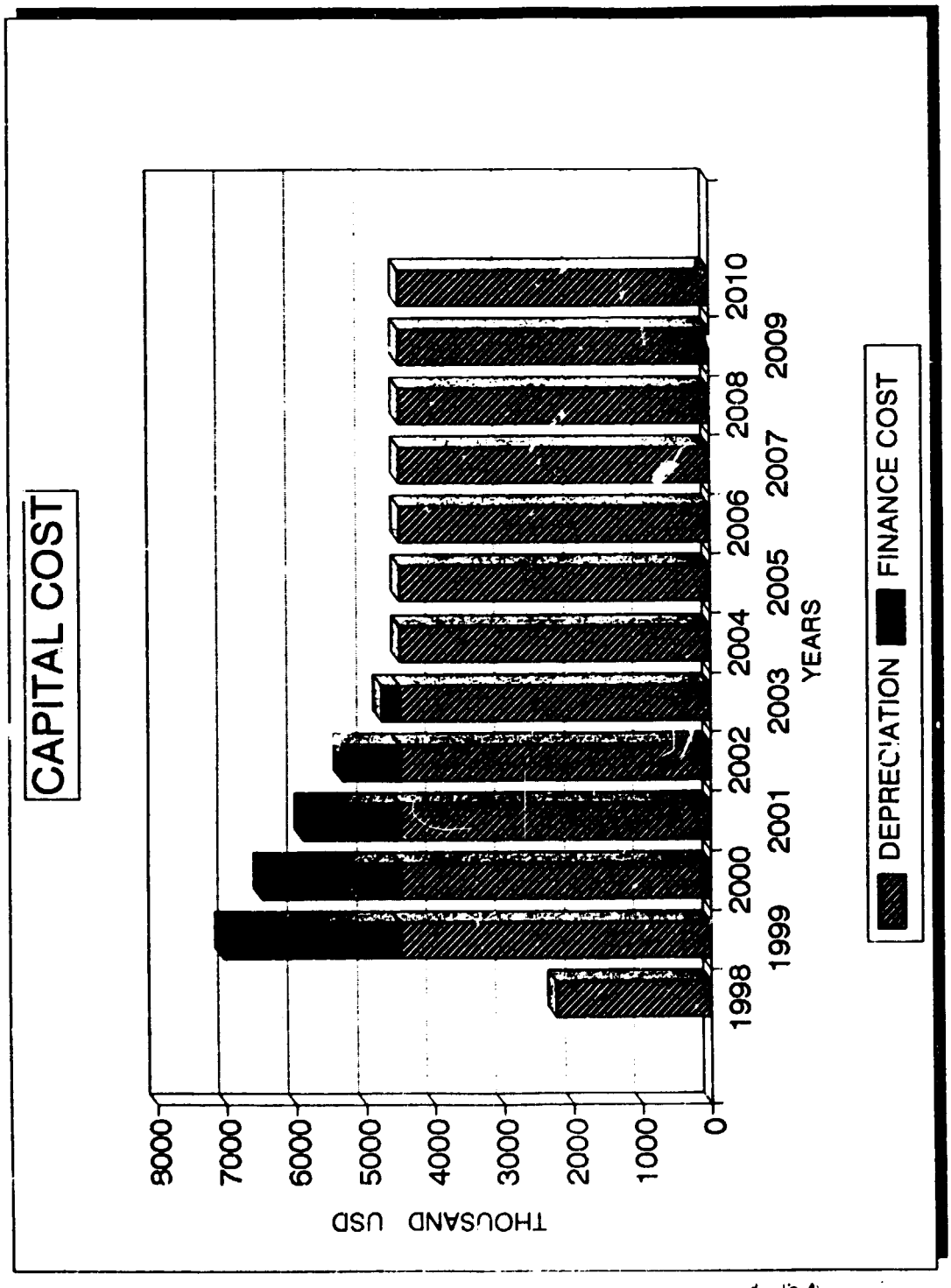
Industrial Demonstration Plant of Electron-Beam Process for Flue Gas Treatment at the Electric Power Station "Pomorzany" Szczecin, Poland

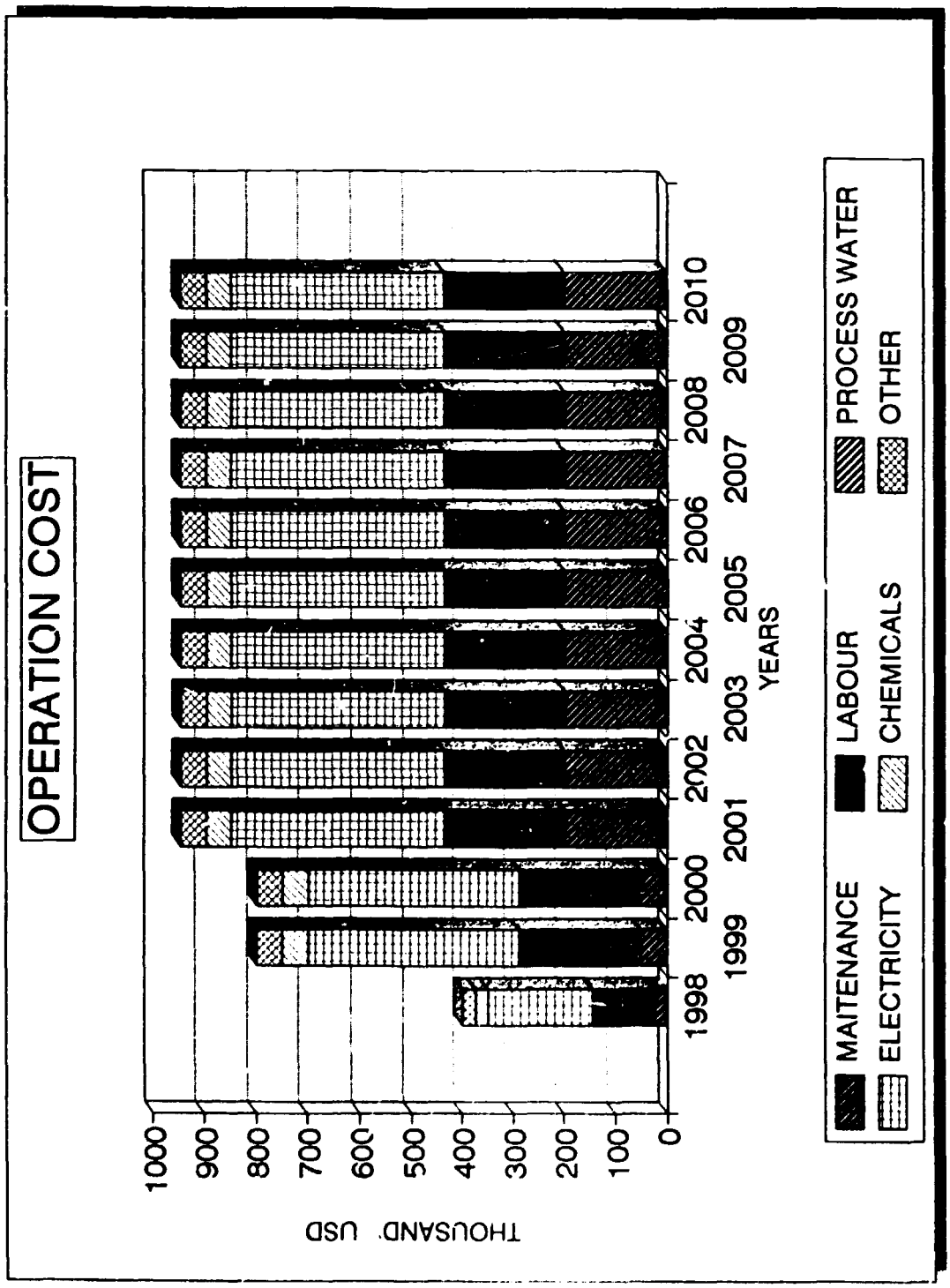
Balances

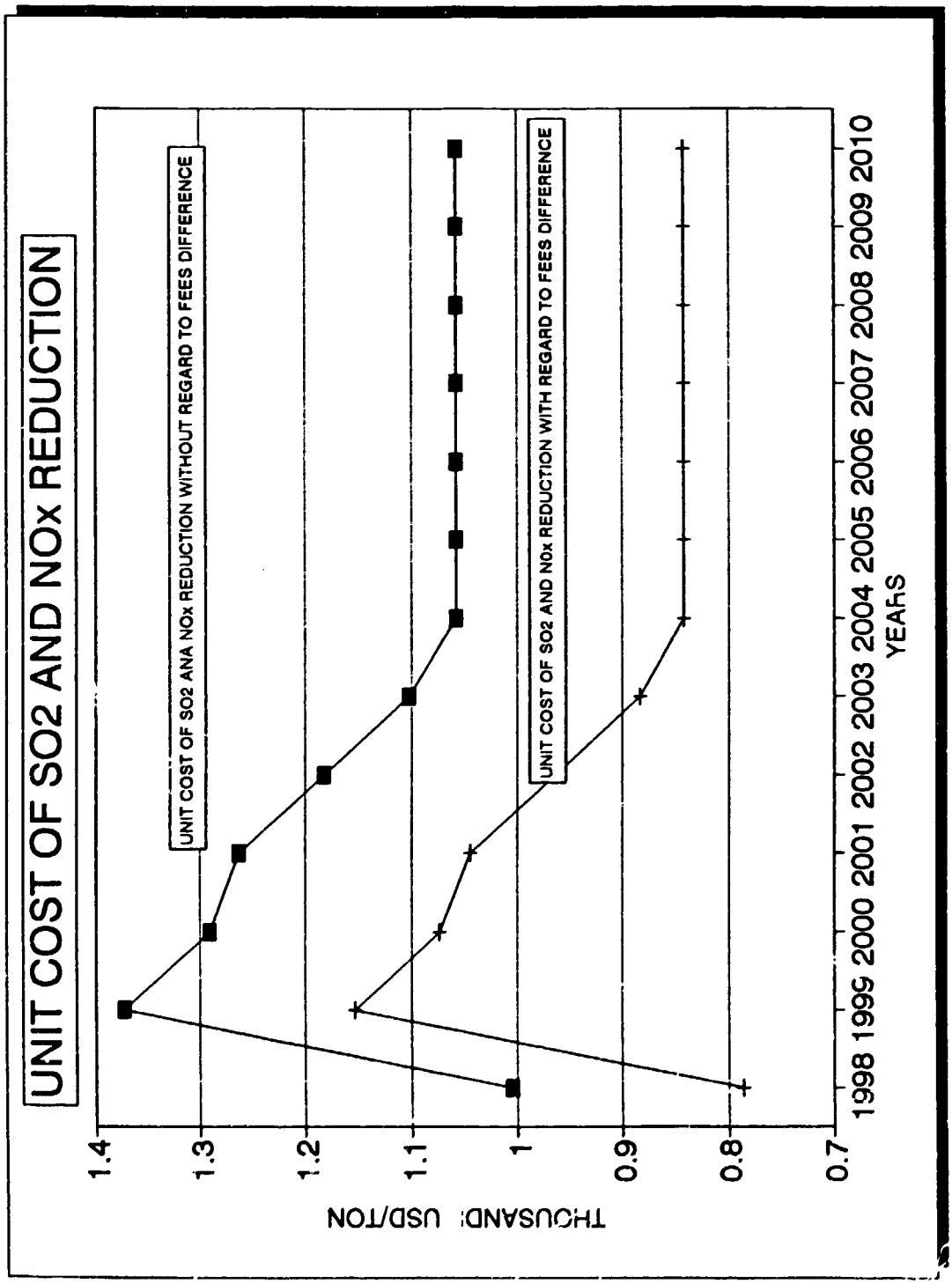
P - 0174 Code

1 131 125 A Archival No.

11 - 10 / 15 Volume - page pages


CAPITAL COST
THOUSAND USD
9000
7000
6000
5000
4000
3000
2000
1000
0
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
YEARS
DEPRECIATION
FINANCE COST


OPERATION COST
THOUSAND USD
1000
900
800
700
600
500
400
300
200
100
0
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
YEARS
MAITENANCE
LABOUR
PROCESS WATER
ELECTRICITY
CHEMICALS
OTHER


UNIT COST OF SO2 AND NOx REDUCTION
UNIT COST OF SO2 ANA NOx REDUCTION WITHOUT REGARD TO FEES DIFFERENCE
UNIT COST OF SO2 AND NOx REDUCTION WITH REGARD TO FEES DIFFERENCE
THOUSAND USD/TON
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010
YEARS

ENERGOPROJEKT - WARSZAWA S.A.	Industrial Demonstration Plant of Electron-Beam Process for Flue Gas Treatment at the Electric Power Station "Pomorzany" Szczecin, Poland	P - 0174 Code	1 131 125 A Archival No
	Balances	11 - 15 / 15 Volume - page / pages	

ENERGOPROJEKT - WARSZAWA S.A.	Industrial Demonstration Plant of Electron-Beam Process for Flue Gas Treatment at the Electric Power Station "Pomorzany" Szczecin, Poland	P - 0174 Code	1 131 125 A Archival No
	Balances	11 - 14 / 15 Volume - page / pages	

96 11 26