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PRELIMINARY ENERGY AUDIT FOR HUNGALU MOTIM ALUMINA PLANT MOSOMAGYAROVA, HUNGARY

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QUALITY ASSURANCE

The contents of this report include recommendations based on data provided by the client plant, measurements made on site, calculations, and engineering judgment. The conclusions reached were based on a limited engagement of only about one week's duration in the plant, and not an exhaustive engineering analysis. RCG/Hagler, Bailly, Inc. certifies that this report conforms to the level of best commercial practice for industrial energy audits of similar level of effort, as conducted in the United States. This report has been prepared under the guidance of a registered Professional Engineer, licensed to practice in the United States.

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ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

This report results from a preliminary energy audit carried out by a team of engineers from RCG/Hagler,Bailly and EGI - Institute for Energetics - between March 20 and March 26, 1991 at the Hungarun Motim Plant (MOTIM).

In addition to the team, RCG/Hagler, Bailly provided a complete set of portable instruments to conduct on site measurements; EGI provided all facilities for logistic support, including meeting arrangement and translation services.

Given the scope of the assignment and resources available, it was decided to focus the audit on sectors and subjects considered priorities by the plant management. This means that extensive and deepthrough efforts were developed by the audit team to reach visible and short-term implementable results related to the points on focus. Beyond the focus points, all activities and analysis as part of a preliminary energy audit were covered by the audit team. In addition, the approach and methodology were adapted to provide a continuous training to counterparts of the audit team in the plant.

The areas of focus for the energy audit were (1) the energy efficiency of the power plant and (2) energy management improvement.

In 1990, MOTIM purchased an amount of energy equivalent to 91,000 tons of oil equivalent, expressed in primary energy. Forty three percent of that primary energy demand consists of fuel, the rest, i.e., 57%, consists of electricity.

If that energy had been imported to Hungary at the international market price ($20 per barel of oil), the cost would have been about 12 million US$ in hard currency. Using the current price of energy (March 1991), the actual energy bill paid by MOTIM is worth 878 million Forints.

The potential for energy savings is at least 5 to 10% of the fuel-oil energy use in the steam and power plant, and 5% in the process area and associated buildings. This is equivalent to an annual saving of 30 million Forint, worth US$430,000.

List of candidate equipment which could be procured by USAID as part of the Emergency Efficiency Program

Action ID	Equipment	cost in US$	cost in 000FT	total cost 000FT	energy savings 000FT/Y
B.1	steam valve	10,000	350		
B.2	opacitymeter	20,000	2,100		
A.1	gas analyser	3,000	210		

CHAPTER 1. INTRODUCTION TO THE PLANT

1.1 Description of the Plant and activities

Motim is an alumina plant, processing bauxite as a raw material and producing high value added commercial products such as refractories, sanding materials, and other chemicals (aluminium sulfate,...). The plant capacity (75,000 t/year) would be too small to produce alumina only in the production of aluminium. The plant was built in 1937.

Motim hosts a cogeneration station which supplies heat not only to the process but also to nearby industries and local district heating board.

The plant employs about 1500 workers.

Process areas

o Production of alumina

Bauxite is processed at MOTIM using the Bayer method to extract aluminum for the production of a variety of finished materials. Aluminum is extracted from Bauxite by digestion with an alkaline solution at high temperature, about 240 C, and then precipitated as AL(OH)3 by cooling and separating the precipitate from the alkaline solution. The alkaline solution is returned to the process and the Al(OH)3 is washed and further processed. Some of the Al(OH)3 is sold or processed further to produce Al2(SO)4 for sale. Most of the AL(OH)3 is calcined to form high quality gamma-alumina for manufacturing refractory brick and a lower quality (containing about 50% gamma-alumina) used to produce sanding papers. The Bayer process and calcining operations are both energy intensive using large quantities of high temperature steam and electricity and fuel oil.

The production of these materials is divided into several different areas; The Bayer extraction process takes place in the so called "Alumina Plant" through the first stage separation of Al(OH)3 and alkaline extracting solution from residual Bauxite mud. Separation of the alkaline solution from precipitated Al(OH)3 occurs in the "Calcining Plant" after which most of the Al(OH)3 is vacuum dried and then calcined to alumina, although some of the Al(OH)3 is sent to produce Al2(SO)4 and a small amount sold. Gamma-alumina, used to produce refractory brick, and a lower quality alumina used for sanding grit, is processed in separate facilities as is the Al2(SO)4.

o Production of refractory products

Refractory products are manufactured in electric arc furnaces. There are 6 electric arc furnaces.

o Production of sanding material

This plant is a joint-venture between Motim and a foreign company and is based on a proprietary process. For this reason access to the plant is restricted.

o Production of chemicals

Utility section

MOTIM is provided with a large steam and power station which consists of three residual oil fired high pressure boilers (40 t/h each) and one 10 MW turbogenerator. This installation is oversized given the in-plant energy demand, but was also designed to supply heat in the form of steam to nearby industrial facilities and hot water to the district heating company.

Thermal equipment in the boilerhouse is well engineered, well instrumented and of good technology. However it is operated at a low efficiency: only 83 to 84%. An 89% efficiency or above would be expected in an efficient plant. Although two of the boilers were designed for coal firing, they were converted to oil firing in 1989/1990.

The turbogenerator has proven to be reliable, but the performance of the steam turbine is very poor compared to the original design. Isentropic efficiency is only 60% for the first stage and 40% for the last stage where an average efficiency of 80% would be expected in an efficient plant. The maximum output of the turbogenerator is now 7 MW versus 10 MW in the original design.

Given the fact that steam is generated at both a high pressure and high temperature level (65 b and 505 C), and that there is a large demand of heat at a low level (e.g. 100 C for district heating), the ratio of power output to heat output of this power plant is far below what would be reached in a well designed and efficient plant. Taking this into account, the management has made increasing the power output of this power plant one of its priority objectives.

Energy selling represents an important share of activities of the company, accounting for 22% of the revenue. It considers the power plant an indivual profit center with two key factors affecting its profitability.

- first: the selling prices for thermal energy are kept low, as a result of negotiation with the district heating company.
- second: the maintenance costs are increasing along with the age of the plant.

1.2 Plant Management and Staff

The plant is managed by a general director in charge of two main directorates -- the technical/production division and Economic division.

The Technical/production division is divided into the following departments:

- Alumina
- Corund (sanding material)
- Chemicals
- Utility/Energy
- Shop machining and construction
- Research and Development

1.3 Energy usage and historical data analysis

Energy use consists principally of residual fuel oil and electricity. Fuel oil is used primarily in the power plant but also in the alumina calcining kilns. Electricity is purchased from the grid at 120 kV and is transformed down to 5250 V and 420 V for in-plant use.

According to plant management, energy cost at current price represents -- % of the production cost. This situation is enough to establish energy conservation as a priority in the plant.

Total primary energy use of MOTIM was 91,000 tons of oil equivalent in 1990. This primary energy use has been computed by RCG/Hagler,Bailly using the following conversion factors. These conversion factors represent the average efficiency of energy conversion equipment in Hungary. For example, the electricity conversion factor includes the efficiency of fuel fired power plant plus auxiliary, transportation and distribution losses.

Energy	unit	kg of oil equivalent
electricity	kWh	0.426
Fuel oil	GJ	40.00
steam/hot water	GJ	28.15

The following table shows the breakdown of primary energy use:

	tons of oil equivalent	percent of total energy
Total primary energy use		
Fuel	39,500	43%
Electricity	51,500	57%

Findings are the followings:

- Electricity is the largest energy used in MOTIM with 57% of the primary energy use.
- The above primary energy use accounts for both activity of MOTIM plant, i.e. Alumina based production on one side, and heat supply activity on the other side. The following table gives a breakdown of heat use:

	TJ/year	percent
Total steam generated	1545	100%
Self consumption of powerplant	250	16%
Process energy use	895	58%
Sale of steam	400	26%

Based on the year 1990 energy consumption record and current energy price (March 1991), the energy bill including electricity and fuel oil is evaluated at 878 million Forint. This breaks down into the following items:

	million FT/year	in % of total cost
Purchased energy cost		
Electricity demand charge	109	
Energy charge (variable cost)		
electricity	455	
fuel oil	413	
Sale of steam revenue		
Demand charge	52	
Energy charge	129	
Gross energy cost	878	
Net energy cost	697	

CHAPTER 2. RECOMMENDATIONS FOR ENERGY EFFICIENCY IMPROVEMENT

Recommendations developed by RCG/Hagler, Bailly for energy efficiency improvement are conveniently broken down into three categories of action:

- Energy management improvement actions have been emphasized by MOTIM as a priority in a fast changing economic environment. Actions which fall in this category are coded by "A" preceeding the list number. MOTIM should be able to implement these measures in the next six months, with assistance from the USAID Emergency Energy Program.

- Low cost and short term implementable actions are emphasized as action to which U.S.A.I.D. might be able to further contribute under its program. Actions of this category are indicated with a "B" preceeding a list number.

- High cost or long term actions consist principally of technology improvement projects. Actions of this group are shown by a "C" followed by a list number.

2.1. Energy Management Improvement

2.1.1 Assessment of the existing Energy Managament System

The system of management information and control in place at MOTIM is typical of most factories in Hungary. Production is based on plans, and management exercises control over the process to see that the plan is carried out. These plans set performance targets, which are based on input and output quantities.

A vast amount of data is collected by hand every day, in the form of logs and other records from many different steam, electric and other meters. The data are used to assemble daily reports. The main purpose of these daily reports is to develop monthly cumulative values, so that the monthly reports can be prepared more quickly. The daily reports are internal, and in most cases only the monthly reports are submitted to management. The types of
information included in the reports are basically raw data, such as total fuel consumption, total steam generation, total electric consumption, total electric generation, total steam sales, etc. Ratios or performance indicators are generally not included in the daily or monthly reports.

The Energy Department of MOTIM is essentially in charge of supplying information and justifying energy expenses and usage in the plant. This department keeps a precise record of the input/output energy and mass balance of the power plant. The energy output is delivered to two kinds of "client": one is located outside the plant and pays its energy use in Forint; the other consists of MOTIM process divisions which are not subject to direct invoicing but are rather charged by the Accounting Dept.

RCG/Hagler, Bailly thinks that these process divisions may not be committed to energy management, since this function is left to the energy department. Therefore, the process divisions do not keep detailed records of their energy use.

However, there is a need, at the level of the cost monitoring department, for an allocation of the energy expenses to the various process department.

RCG/Hagler, Bailly's assessment of energy management at MOTIM is summarized below:

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A. Energy Demand Management

Energy demand management focuses on the energy use in process departments as a function of production throughput, status of operation, various operating parameters, and other parameters not related to process operations.

Data on energy used for production are rigorously gathered and entered into computer programs for the purpose of assembling information important to energy management throughout the plant. However, monthly energy reports do not appear to report energy consumption data in a form useful for energy conservation. Instead, the assembled data appear to be a management tool for determining the share and cost of energy used to produce various products. For example, monthly reports show steam and electricity used for producing calcined alumina although these data have to be assembled from two different process areas. Energy used to produce Al(OH)3 is reported but only for the amount of this material that is further processed to Al2(SO)4 or directly sold. It is possible to determine the energy used in the calcining process area for either vacuum drying or calcining, but only by manipulating the reported data. Energy intensity for producing gamma-alumina, tons of steam/ton alumina, MWh of electricity/ton alumina, and tons of fuel fired for calcining/ton alumina, is reported on the basis of products produced, not processes used to produce these products.

When there is a clear relationship between a product and the process producing it, there is a clear and significant interpretation and usefulness for energy accounting on a product basis. For example, MOTIM reports only electric energy consumption for producing refractories and it is quite clear that the energy consumption so reported is the energy for a process as well as a product. In this case, the energy data reported are equally useful for both costing and the analysis of energy efficiency.

Just the opposite is true for 98% gamma-alumina production, for example. Reported types of energy sources and amounts used for alumina production reflect the production of Al(OH)3 and all subsequent processing including separating, vacuum drying and calcining. The energy required for calcining only must be forceably extracted from prepared energy reports. More important is the lack of tangible information which can be used to determine the energy efficiency of only the calcining or the vacuum drying processes. Instead, energy data for those processes used to make 98% gamma-alumna are tangled together with the production of Al(OH)3, the precursor to gamma-alumina manufacture.

B. Energy Supply Management

Energy supply management focuses on the operations of the steam and power plant in charge of supplying energy in various forms to inside and outside users. Residual fuel oil, electric power and water are purchased for this purpose. RCG/Hagler, Bailly observes that:

- There is a fairly accurate energy and mass balance carried out by the Energy Department: steam & condensate balance, fuel gas purchase, production/purchase of electricity, production/purchase of water.

- Heat and mass balances are provided separately, but with no analysis of interrelationship between these various balances. For example, electricity generated by the turbogenerator depends on the steam flow through the turbine, and demineralized water supply to the power plant depends on the water losses and steam & condensate exchanges.

- No efficiency analysis of critical equipment such as boilers and turbogenerators are performed on a regular basis.

- No cost calculation of utilities supplied by the power plant is

performed on a regular basis.

- Energy Department reports are prepared using a state of the art microcomputer using Lotus 123 spreadsheet.

C. **Consequences**

The consequences of the absence of a real energy management procedure are the following:

- High variability of energy consumption is indicated for a given level of production.

  To provide control of a process operation, energy is usually released in specific equipment provided with on/off valve on the energy flow and a control device which limits the energy flow to the amount necessary to process operations.

  In absence of real pressure to control the quantity of energy used, there are situations where poor state of conditions of the energy using equipment, on/off valve, or control device still permit process operation albeit at a higher energy cost. For example, the fouling of a steam heat exchanger can be overcome by increasing the steam pressure (thereby reducing the efficiency) at the end-use equipment. The poor condition of an on/off steam valve will lead the operator to keep it on (thereby increasing the losses), or the failure of the control device will lead to over consumption of energy.

- Maximization of plant safety and reliability condition occurs to the detriment of the energy consumption.

  In the absence of real pressure to minimize the quantity of energy used for a given operation, there is a natural tendency of plant operators to maximize operation safety and reliability. In other words, plant operators minimize potential hazards and troubles, including operation supervision from management, by tuning up the equipment towards a higher energy intensity condition. The difference between the actual energy use and the minimal theoretical energy use is known as the necessary "safety margin". At Buszesz, there is no real control or limitation of this safety margin. For example, excess combustion air is necessary at the burner to avoid release of unburnt gas (CO) which could cause an explosion and the destruction of the boiler. Therefore, if there is no pressure to reduce the excess air to a minimum safe level, the boiler operator will feel more secure with a level of excess air which is higher than the optimum for energy management, consistent with safe operation.

2.1.2 Management improvement recommendations

Action A.1: Energy Data Management for Product Cost Allocation and Process Efficiency Analysis

2.1.3 Optimization recommendation

At a plant operated below its nominal capacity rate, optimization is critical in order to keep production costs as low as possible. Some of the optimization steps already taken by the plant management include:

- Non-operation of the grinders and electric arc furnaces during peak hours of the day.

- Use of cheaper high sulfur content residual fuel oil (instead of low sulfur quality) depending on market availability.

RCG/Hagler, Bailly recommends the following optimization actions:

Action A.2: Dispatch boilers to operate the most efficient boilers in priority

Action A.3: Transfer steam use as much as possible from night hours to day and peak hours.

2.2. Low Cost and Short Term Energy Efficiency Improvement Actions

Action B.1: Fuel atomization improvement on boilers

Action B.2: Control optimal excess air and combustion quality with an opacitymeter

Action B.3: Improve the efficiency of the MM boilers

2.3. Investment or Long Range Energy Efficiency Improvement Actions

Action C.1: Refurbishing or replacement of the steam turbine driving the turbogenerator (priority concern).

Action C.2: Create a very low pressure steam level fed with new auxiliary turbines

Action C.3: Heat recovery on boilers flue gases

CHAPTER 3. PRESENTATION OF PROJECT FORMS

Each project discussed above is presented in a stand-alone project form which provides all basic information to qualify the project. The data are provided at the "inventory" level (first order of magnitude approximation), and include the following:

- Description and rationale
- Calculation of savings (energy and others)
- Implementation cost
- Financial analysis limited to the pretax pay-back period
- Planning
- Technical risk and reference
- Back-up data and calculations

ACTION A.1

1. PROCESS AREA

Energy data management for product cost allocation and process efficiency analysis.

2. STATEMENT OF RECOMMENDATION

Redesign the energy data reporting procedure so that energy usage by process and product are available to management and to process area supervisors:

- o Treat the power plant as a separate profit center
- o Institute an energy demand management procedure based on technical efficiency assessment of process operation.
- o Institute an energy supply management procedure based on a simulation model of the power plant
- o Improvement of energy reporting procedure

3. DESCRIPTION/RATIONALE

It is recommended that an energy management procedure be instituted according to the following guidelines:

o Treat the power plant as a separate profit center

Like the other process areas, the power plant should be treated as a separate entity or cost/profit center in the accounts of MOTIM. Therefore, the energy management system of MOTIM should be split into two parts: (1) demand side management which manages the energy use in the process areas and (2) supply side management which manages the efficiency of operation of the power plant.

o Institute an energy demand management procedure based on technical efficiency assessment of process operation:

It is considered important for the assessment of energy efficiency to assemble all types of energy consumed for identifiable processes in each processing area. For example, in the alumina plant, steam and electricity used to produce all $Al(OH)_3$, regardless of its end use, should be reported in a unified manner rather than assigning steam and electricity to final products. The present method, based on accounting energy consumption for products may be suitable for allocating energy costs, but is not suitable for controlling energy used in manufacturing or identifying energy conservation opportunities which of necessity are process oriented.

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This problem of energy reporting for two purposes, cost accounting and energy efficiency, is a data structure problem. The present method of reporting data uses a state-of-the-art spreadsheet, LOTUS 123, for organizing energy and production data. As presently organized, the spreadsheet organization may not be able to serve the two functions of cost and efficiency analysis. It would be more appropriate to develop a database of energy consumption by process area and then to extract and reassemble, by computer, the same data for products to assess costs.

Each process unit should be subjected to a budget procedure specifying standards for energy use according to determining criteria. Such criteria may be:

. particular throughput
. events such as start-up or shut-down procedure
. quality of raw material or finished product
. ambient temperature or seasonal variation
. availability of critical process equipment

Each energy use will be a simple function of the determinant criteria: usually constant (e.g. X tons per day of steam in winter, Y tons per day of steam in summer), proportional (e.g. Energy = A x Production) or linear (e.g. Energy = A x Production + B).

The establishment of such cost functions is one of the primary targets of an energy demand analysis:

(1) The energy cost function must be as close as possible to the reality, therefore a statistical analysis may be useful in first step.

(2) An analysis of the magnitude of each coefficient of the cost functions must be conducted to assess what kind of operating practice they reflect. For instance, in case of poor efficiency and absence of control the constant coefficient will be high.

(3) The final energy cost function must result through discussion with the manager of each production sector in the plant (i.e. Alumina, sanding material, chemicals). The energy intensity must be realistic (i.e., achievable) and at the same time encourage efficient energy pratices. The production managers must agree with the cost function since the production performance of individual sectors will be evaluated by comparing the actual energy consumption with the value calculated using the energy cost function. The production managers will have to explain the differences. The purpose of these explanations is not a "personal justification" but to indicate actions to be taken (usually by the maintenance departement) in order to reduce overconsumptions.

Data logging must be revised to include the key parameters which are listed in the energy cost functions. Energy consumption may be either metered (we consider that there is no need for additional metering) or indirectly evaluated (through heat balance for instance).

The difference between actual and target consumption will be translated into Forint according to marginal costs of utilities calculated by the Energy Department. The summation of all these differences will give an indication of the status of energy savings or over consumption. This can be easily displayed as a trend graph.

- **Institute an energy supply management procedure based on a simulation model of the power plant:**

The steam and power plant should be managed according to a simulation and

optimization model similar to the one elaborated by RCG/Hagler,Bailly during the course of the audit (see appendix 2). This model links together the balance of various forms of energy such as fuel oil, steam, electricity and water. In addition it calculates the efficiency of key equipment (e.g. boilers, turboalternator) and allows comparison with the expected efficiency. In many respects, operating limits, as experienced by plant operators, are as important as efficiency in the search for optimal operation. These actual operating limits must be compared with design operating limits.

Every year, the model can be used as support for negotiating the target performance of the power plant to be written in the next year's budget. For example the boilers' efficiency will be determined by target temperature and excess air of stack gas. As well, the turboalternator efficiency will be determined by target superheat temperature of steam and isentropic efficiency of each stage of the turbine.

The energy supply management model will calculate on a daily basis the marginal cost of steam and condensate and the total operating cost of the power plant as well.

The first basis of energy management is the awareness by any energy user of the true cost of energy. Usually this true cost is defined on a marginal basis. The marginal cost of steam indicates how much energy is saved (or purchased) by the power plant if the end user reduces (or increases) its consumption by 1 unit (tonne/hr or GJ/hr). This marginal cost may vary with the configuration of the power plant; for example, when the turbogenerator is shut-down, steam is more expensive. Also, the marginal cost will vary with the period of the day. Because the steam is expanded through the turbine, it thereby avoids purchase of power from MVMT; and because of MVMT time-of-day tariff structure, the cost of steam will be higher at night than during day or peak time.

A plant manager who knows the true cost of steam is in a better position to anticipate or delay steam use during a period when steam is expensive. For example, it is clearly worthwhile to reduce the steam consumption when the turbogenerator is shut-down because of the higher cost of steam at this time.

The energy model established by the audit team during the course of the audit calculates marginal cost of steam (see appendix 2).

o **Improvement of the reporting procedure**

Report 1: Monthly performance monitoring report

It is recommended that a monthly energy monitoring report be prepared and submitted to the Technical Director which shows in a very simple way the status and trend of energy performance of the plant. This report should have only one page, and would display principally the following graphs:

- Energy demand efficiency graph displaying the ratio of actual process energy demand to budgeted energy demand in process areas.
- Energy supply efficiency graph displaying the ratio of actual energy purchase to expected energy purchase (on a Forint basis).
- Trend of the monthly energy purchase by the plant and net energy cost to the plant (energy purchased minus sales).

Report 2: Daily Energy pricing report

The energy department should distribute to the process department a report indicating the price of utility for the next week. It is expected that the

process managers will modulate their steam demand in function of the price of steam.

o Means for the Energy Management System

It is not recommended to designate a full time energy manager at the level of production departments. Once the energy demand management procedure is shaped, it can be operated by the existing cost control managers in each production department. In case of specific problems related to energy use, it is recommended that the Production departments seek the assistance of the Energy department.

A computer-based management information system (M.I.S.) must be installed to provide the information necessary for energy management. This system must have hardware and software designed to calculate the necessary performance ratios and to present information to management in an easily-understandable form. It was proven during the audit that adequate computer tools and state-of-the-art software permit the design of a valuable information and control system that goes far beyond the capability of the existing in-plant management system.

Lotus 123 used at MOTIM, contains a database capability, although it is not known if this will be sufficient for the purpose suggested here. There are available relational databases which can export data to LOTUS for the assembly of information in a variety of ways.

It is important that the database be made available to production area supervisors whose responsibility it should be to determine energy efficiency opportunities, set targets and goals for process energy improvements, and measure the progress toward these goals.

4. BENEFITS

The separation of energy accounting into two parts, one for determining cost accounting information for allocating costs by product, and another for energy usage. This will ensure that the large amount of data collected will be efficiently used.

5. IMPLEMENTATION COST

6. PAYBACK

7. SCHEDULE

8. TECHNICAL RISK

9. BACK-UP DATA

One of the largest users of process energy at MOTIM is the production of the intermediate material Al(OH)3 from Bauxite by the Bayer method as shown below for 1990.

Bauxite processed	:	180,721 tons
Al(OH)3 produced	:	67,000 tons
Steam consumed	:	226,000 GJ
Electricity consumed	:	34,000 MWh

The Al(OH)3 produced was assumed to be 2% higher than the quantity reported as finished products based on losses assumed for washing, drying and calcining the intermediate. Although the yield of Al(OH)3 is about 36-37% of the weight of input Bauxite, it can pay as much as 25%, and is extremely sensitive to the Bauxite quality -- its extractibility and process conditions.

The steam consumed in this process is about 25% of all steam used; the electricity is about 25% of all electricity used internally at MOTIM for process manufacturing. The specific energy consumption of steam and electricity is computed for this process and reported on periodic energy consumption reports. The variability of energy consumed from period-to-period for this process has been of considerable concern to those responsible for this manufacturing process.

The Bayer extraction process for aluminum from Bauxite in the form of Al(OH)3 is continuous although it is understood that the plant does not always run at maximum capacity. In 1990 the Al(OH)3 produced was about 87% of annual capacity. During five months of the year production rates were from 50 to 80% of capacity. Low production rates have continued into early 1991. The 1990 production by month and the specific energy consumption (steam and electricity) for each period are shown in the accompanying table. In order to examine the variation of energy consumed with operating rate, several graphs were prepared from the data in this table. Although a reasonable pattern to specific energy consumption of both steam and electricity with production rate was expected, this is clearly not the case. The variability of specific energy consumption for steam, and the lack of variability for electricity specific energy consumption is rather clearly shown in the accompanying table and graphs.

It was hopefully assumed that such plots would show decreasing steam and electricity specific energy consumption for production rates that approached the plant capacity. In other words, as equipment such as heat exchangers, pumps and driers operated near their design points, energy efficiency of each device would be maximized. Instead energy consumption is essentially independent of production rate, thus defeating the very purpose of a continuous process.

The reasons for this is known to operating personnel. According to operating personnel, some of the factors contributing to this effect are:

- Bauxite quality (the aluminum content of Bauxite available from different sources and even from the same source).
- The relative amount of silica in Bauxite controls the extent to which the available aluminum content can be extracted.
- Temperature of the extraction system.
- Concentration of the caustic in the extraction solution.
- The temperature of the stored Bauxite affects steam required for heating ground Bauxite and extracting solution to extraction temperature.
- The rate of production.

The effect on energy consumption due to operation at less than plant capacity is particularly troublesome. Equipment modifications that are extremely wasteful of energy (particularly electricity) are required to keep the extraction plant operating when production demands are low. At operating rates less than capacity, pumps and agitators must be run at as high an energy input as that for higher throughput. Operating at less than

design capacity requires modifications in order to maintain good heat transfer rates in exchangers designed for higher flow rates.

Some attempt is made at minimizing steam consumption in the extraction process due to Bauxite quality and extractibility but this is difficult not only because of measuring techniques used, but alos because of the large time difference between the point at which the ground Bauxite enters the process and the time extraction begins. Attempts at producing a uniform Bauxite feed to the process have been unsuccessful because of limited storage space and the apparently extreme variability of the supply.

In summary, there is a strong effort by operating personnel to reduce process energy consumption but the number of variables contributing to energy usage and how the rate at which these variables change during production and affect energy consumption is only generally known. It is extremely important that the process be modeled so that the relationship between energy consumption and the parameters affecting energy use be quantitatively identified for the various stages of this process. Given a minimum of input information, it should then be possible to predict energy consumption for short operating periods. With this capability, energy conservation opportunities can be identified and the technical means and costs of implementing them examined. Targets and goals for reduced energy consumption can be set and the production process monitored for improvements.

ACTION A.2

1. PROCESS AREA

Steam and Power plant

2. STATEMENT OF RECOMMENDATION

Optimization of boilers operation:

- Report flue gas temperature and Oxygen content (at the same point, at the outlet of the air preheater) on the data log sheets and monitor boilers efficiency in the daily report.
- Dispatch boilers to operate the most efficient boiler in priority
- Purchase a portable combustion gas analyser

3. DESCRIPTION/RATIONALE

This project consists of monitoring boilers' efficiency by assessing heat content of flue gas. This requires only oxygen content measurement and temperature measurement at the same point in the flue gas duct after the air preheater. Existing temperature indicator can be used for temperature measurement. Oxygen content must be measured by a portable unit to be procured. This measurement requires a minimum of expertise since oxygen content reading may widely vary with the deepness of the sample point of the gas duct, because of possible air leakage.

Based on this measurement two different actions must be taken to reduce operating cost:

- operate the most efficient boiler in priority
- reduce excess air

For this second action, it is necessary to find out where the excess air comes from: excess air at the burner, air infiltration through boiler's brickwall, or air leakage through the air preheater.

During the course of the audit it was found that the boiler GIB has an efficiency around 89%, while boilers MM1 and MM2 have an efficiency around 85%.

Therefore, boilers MM1 and MM2 use 5% more fuel oil than boiler GIB at the same steam load.
It is recommended to operate boiler GIB as a base load boiler (at 30 t/h of steam) and boiler MM1 to meet the demand. Boiler MM2 would be kept out of operation.

4. BENEFITS

4.1 Energy savings

By running boiler GIB instead of boiler MM1 or MM2, daily savings will be 2.8 tons of fuel oil. Assuming that this situation may occur 180 days per year, annual savings will be 500 tons of fuel oil, equivalent to 5 million Forints per year.

4.2 Other benefits

5. IMPLEMENTATION COST

List of equipment	number	unit cost (Ft)
portable electronic combustion gas analyzer	1	$3,000

6. PAY-BACK

Pay back of the oxygen analyzer is about 2 months.

7. SCHEDULE

This action has been approved by the Head of Energy Department during the 4/25/91 meeting for immediate implementation:

Task 1 - completion date: April 30, 1991

Based on the audit report findings, assign boiler GIB as best efficient boiler for plant base load.

Task 2 - completion date: May 15, 1991

HBI prepares and address to MOTIM specification of a portable gas analyzer.

Task 3 - completion date: May 30, 1991
HBI gets quotations from US manufacturers

Task 4 - Completion date: June 15, 1991
MOTIM reviews offers, finalizes specification and makes recommendation for selection of supplier.

Task 5 - Completion date: June 20, 1991

USAID gives clearance for equipment procurement based on HBI financial and economic study and evaluation of quotation.

Task 6 - Completion date: June 21, 1991

HBI sends purchase orders for equipment.

Task 7 - completion date: August 1, 1991

Shipment of equipment arrives in Hungary.

MOTIM completes an operating procedure for the use of the portable gas analyzer including where should it be stored, who would use it, frequency of use, etc...

Task 8 - completion date: August 15, 1991

Daily readings from portable oxygen analyzer reported on boiler data log sheets and processed in the energy management system.

Task 9 - completion date: September 1, 1991

MOTIM assigns target for boilers efficiency and monitors achievement as part of the energy management system.

8. TECHNICAL RISK AND REFERENCE

Any boilerhouse manager knows that it is never good to keep a boiler out of operation, specially when it has been operated with high sulfur residual oil: At cold temperature, corrosion of tubes may develop quickly. Since boilers MM1 and MM2 have just been revamped at high cost, it is understandable that the boilerhouse management is reluctant to shutdown one of them.

During the audit, it was found that three boilers were found shutdown:

- boiler GIB (40 t/h, 65b steam)
- boiler MHO (20t/h, 12b steam)
- boiler PTVM 30 (spare hot water boiler)

For boilers which are kept shut down for a long period, it is recommended that specific conservation steps be implemented, such as washing externally the tubes with a neutralizing solution and blowing warmed-up dry air inside the tube to avoid oxygen corrosion on wet surfaces.

9. BACK-UP DATA AND CALCULATION

10. SPECIFICATION OF EQUIPMENT

ELECTROCHEMICAL PORTABLE GAS ANALYZER

o **Physical description:**

case	insure protection against choc and dust
probe	high temperature probe

o **Electrical:**

battery	6V, rechargeable, quick recharge
AC	220V 50Hz

o **Display:** LCD with backlight

o **Measured Parameters**

Ambiant temperature	0-150 C
Stack temperature	0-1100 C
Oxygen sensor	0-25%, electrochemical cell, life > 1 year
Nitrogen oxide	0-2000ppm, electrochemical cell, life > 2 years

Sulfure oxide	0-2000ppm, electrochemical cell, life > 2 years
Carbon monoxide	0-2000ppm, electrochemical cell, life > 2 years
Combustion gases	0-2.5%, semiconductor sensor, life > 5 years
Draft	piezoresistive sensor

o **Computed parameters:**

Excess air
Combustion efficiency
Carbon dioxyde
Emissions (CO, NOx, SO2)

o **Printer:**	built-in thermal printer with form feed and line feed buttons

o **Miscellaneous:**

Fuels	3 or more fuel in memory + custom fuel
Messages	diagnostic and help messages in english
Calibration	Optional autozero on start-up

o **Parts**
Oxygen cell
CO cell
paper for printer

ACTION A.3

1. PROCESS AREA

Steam management

2. STATEMENT OF RECOMMENDATION

Transfer as much as steam use as possible from night hours to day and peak hours.

3. DESCRIPTION/RATIONALE

Because of the turboalternator and the time of the day electric tariff structure, steam has a different cost for each day time period. The energy model provided in appendix 2 of this report shows the cost of steam on a marginal basis:

	daily average Ft/GJ	peak hours Ft/GJ	day hours Ft/GJ	night hours Ft/GJ
65b steam	268	256	268	274
12b steam	272	217	270	297
3b steam	250	169	246	285
hours/day	24	3	13	8

Because of the low price of electricity at night, steam is more expensive at night than during the other periods. Therefore, it is recommended to postpone steam demand which can be delayed from night time to day time.

For example, steam heating in residual fuel oil tanks should be shutdown at night, at least during the non freezing season.

4. BENEFITS

4.1 Energy savings

Assuming that 0.5 t/h of 3b steam could be displaced from night time to day time period, savings would be:

0.5 t/h x 2.94 GJ/t x 8 h/d x (285 - 246) Ft/GJ = 460 Ft/d
Total savings on a period of 200 days par year woul be 92,000 Ft/year.

4.2 Other benefits

5. IMPLEMENTATION COST

This project does not require any specific equipment.

6. PAY-BACK

Pay-back is immediate.

7. PLANNING

8. TECHNICAL RISK AND REFERENCE

9. BACK-UP DATA AND CALCULATION

ACTION B.1

1. PROCESS AREA

Steam and Power plant

2. STATEMENT OF RECOMMENDATION

Fuel atomization improvement on boilers MM1 and MM2:

- o install a line to feed atomizing steam to burners straight from the 65b steam level
- o install a pressure reducer valve 65b/13b

3. DESCRIPTION/RATIONALE

Currently, atomizing steam is supplied to the burners using 12b steam extracted from the turbogenerator.

Fuel oil burners were procured by Babcock. The tip of the burner is equiped with a Y shape steam atomizing device. This technology is up-to-date and usually efficient (i.e. good atomization and low steam consumption) but requires a constant pressure of steam, and a minimum of 2 bar of pressure difference between steam and fuel oil at the burner.

Findings:

- o Carbon monoxide content in flue gas of boiler MM1 was found swinging between 0 ppm and over 1500 ppm within a few minutes.

- MP steam at the extraction of the turbogenerator was found swinging around 10.5 b with a maximum amplitude of 1 bar.
- Fuel-oil temperature at burners was measured at 141 C

Action:

Currently, the boiler operators y to overcome this problem by:

- increasing the excess air level at 3% O2 in the firebox, although these burners could be operated with an excess air level less than 1% O2 in good conditions (0.6% O2 would be a good target in optimal conditions with this type of burner).
- opening the 65b/11b by-pass valve of the tubogenerator in an attempt to stabilize the pressure of 11 bar steam. The by-pass valve was found to be open up to 30%. The aftermath is a loss of power generation through the turbogenerator.

Both actions taken by the operators are effective in overcoming the problem, but reduce the efficiency of the power plant and therefore are costful to the company.

Recommendation:

Based on our experience in western countries, it is not acceptable that the variation of MP steam demand in process area compromises the atomization of fuel oil at the boilers. At best, it is costful to the company, and at worst, it compromises the safety of operation.

Therefore, it is recommended to supply atomizing straight from the 65b level using a new and dedicated 65b/13b letdown valve.

4. BENEFITS

4.1 Energy savings

Energy savings result from an improved excess air in the boiler (from 20% down to 10% excess air at the burner) and a reduction of steam flowrate through the by-pass of turbogenerator (from 5 t/h down to 1 t/h).

Using the model of the power plant established during the audit, savings are:

Fuel oil	:	-0.01 t/h
Electricity	:	+273 kW

equivalent to an hourly saving of Ft 700.

Considering that these savings would apply 8,000 h/y, annual savings are 5,600,000 Forints.

4.2 Other benefits

5. IMPLEMENTATION COST

List of equipment	number	unit cost (Ft)
steam control valve	1	$10,000

Total cost is estimated at 2,000,000 Forints

6. PAY-BACK

The pay-back is about 6 months

7. SCHEDULE

This action has been agreed by the Head of Energy department during the 4/25/91 meeting for immediate implementation.

Task 1 - completion date: May 10, 1991

MOTIM prepares and address to EGI specification of steam valve.

Task 2 - completion date: May 30, 1991

MOTIM gets quotations from local suppliers.
HBI gets quotations from US manufacturers.

Task 3 - Completion date: June 7, 1991

MOTIM reviews offers, finalizes specification and makes recommendation for selection of supplier.

Task 4 - Completion date: June 15, 1991

USAID gives clearance for equipment procurement based on HBI financial and economic study and evaluation of quotation.

Task 5 - Completion date: June 16, 1991

HBI sends purchase orders for equipment.

Task 6 - completion date: August 1, 1991

Shipment of equipment arrives in Hungary
MOTIM prepares installation drawings of steam valve including drip pot, purge valve, block valves, and links.

Task 7 - completion date:August 30, 1991

Installation works by MOTIM

Task 8 - completion date: September 1, 1991

Operation of the new steam valves. Conduction of tests to reduce the Oxygen content in combustion gas. Turbogenerator by-pass valve is kept closed.

8. TECHNICAL RISK AND REFERENCE

9. BACK-UP DATA AND CALCULATION

10. SPECIFICATION OF EQUIPMENT

10.1 STEAM CONTROL VALVE

Line
Nominal diameter
Internal diameter
Standart reference
Design pressure
Design temperature

Fluid characteristics

Type			superheated steam		
			mini	normal	maxi
Temperature	C	450	505	520	
Inlet Pressure	bar g	65	67	70	
Pressure drop	bar	52	54	57	
Outlet pressure	bar g	13	13	13	
required flowrate	kg/h	100	500	600	

Mechanical characteristics

body
- diameter
- shape
- material
- serial
- connection

seat
- diameter
- Number of seats
- material

plug
- shape
- law
- material

shaft
- material

guide
gasket
etancheity
failed position open
action fluid compressed air 6b

Positioner
type
signal 4-20 mA
air pressure
action law
connection

Options
manual drive
fins
expansion joint
letdown air filter
end of course contacts

ACTION B.2

1. PROCESS AREA:

Steam and Power Plant

2. STATEMENT OF RECOMMENDATION:

Control optimal combustion level using an opacitymeter.

3. DESCRIPTION/RATIONALE:

Compared to the other boilerhouses that the RCG/Hagler,Bailly team visited in Hungary as part of this USAID funded Energy Efficiency Emergency Program, MOTIM's boilerhouse is well instrumented and operated mostly on an automatic control mode.

MM1 and MM2 boilers have an open loop excess air control system where the position of inclinators at the suction of air fan is determined by the fuel flow measurement corrected by a function. This function has been carefully identified for variou loads in order to keep a constant oxygen level in the firebox. This function can be manually corrected by the operator in the control room in case of low oxygen level or black smoke at the oulet of the stack.

This scheme relies on two sensors (fuel oil flowmeter, Oxygenmeter) and two actuators (inclinators at the aspiration of air fan, fuel oil control valve).

However several problems on the boilers do not permit to operate the automatic air fuel trim control loop as efficiently and as safely as expected:

- First, heavy and variable air leakages in the boilers' air preheaters make the air flow at the burners unpredictable for a given position of air fan inclinators.

- Second, unstable atomizing steam conditions makes impossible to operate the boilers with a low oxygen level in the furnace.

As a result, operators are operating the boilers from the control room almost blindly, since they have no information on the quality of combustion: regularly, an operator goes outside the boilerhouse's control room (which has no window) to look at the top of the concrete stack and check whether there is black smoke or not. Of course, this is impossible at night.

Therefore it is recommended to install on each boiler MM1 and MM2 a new sensor to inform boilers' operator on the quality of combustion (presence of unburns in flue gas) and possibly to adjust automatically the air/fuel ratio in function of the measurement. This sensor can be either a carbon monoxyde meter or an opacity meter. Both instruments are based on optical principle: absorption of a light beam either visible for an opacitymeter or infrared for a COmeter.

COmeters are fairly recent and rather sophisticated. Opacitymeters have been used for a long time in western fuel-fired boilers, and have proven to be robust, reliable, easy to maintain, and effective. This is why we recommend opacitymeters.

Note that an opacitymeter would not apply for a fuel-gas fired boiler, COmeter would be the only solution. Note also that an additional advantage of opacitymeter for fuel-oil fired boiler is that it gives an information on the presence of particles (which might be requested sooner or later by the environmental legislation). Our experience is that an opacitymeter detects the presence of unburns and particules far before the human eye can see it at the outlet of the stack.

We leave to MOTIM the final decision to use opacitymeters signal as an indication in the control room (with a high level alarm) or to trim the air/fuel ratio. We have seen both cases in western countries. Our preference would be to trim the air/fuel ratio within a limited percentage such as [-10%, +30%].

4. BENEFITS

4.1 Energy savings

The opacitymeter installed as a air/fuel ratio trim control device, will permit to assign a target of 1.5 %O2 in the boilers (instead of 3% currently), equivalent to 8% excess air. In case of perturbation and lack

of air, it will automatically increase the excess air. Therefore, savings will be 1% of fuel consumption in boiler MM1 and MM2.

The annual savings is 400 tons of fuel, worth 4 million Forints.

4.2 Other benefits

This project has a significant impact on the emissions level to the environment:

o first, the emission of particulates will be reduced
o second, the reduction of excess air will reduce the conversion of SO2 into SO3 in the boiler and limit local fall of acid drops.

This impact doesn't really translate into savings of money to MOTIM (at least on the short term).

5. IMPLEMENTATION COST

List of equipment	number	unit cost (Ft)
Opacitymeters	2	$10,000

Total cost is estimated at 3 million Forints.

6. PAY-BACK

Pay-back is about 9 months.

7. SCHEDULE

This action has been approved by the Plant's Energy Manager during the 4/25/91 meeting for immediate implementation:

Task 1 - completion date: May 15, 1991

HBI prepares and address to MOTIM specification of opacitymeter.

Task 2 - completion date: May 25, 1991

HBI gets quotations from US manufacturers.

Task 3 - Completion date: June 15, 1991

MOTIM reviews offers, finalizes specification and makes recommendation for selection of manufacturer.

Task 4 - Completion date: June 25, 1991

USAID gives clearance for equipment procurement based on HBI financial and economic study and evaluation of quotation.

Task 5 - Completion date: June 26, 1991

HBI sends purchase orders for equipment.

Task 6 - completion date: August 15, 1991

Shipment of equipment arrives in Hungary.

MOTIM completes studies for the installation of opacitymeters.

Task 7 - completion date: September 15, 1991

MOTIM completes installation works of opacitymeters.

Task 8 - completion date: September 30, 1991

MOTIM assigns target for boilers efficiency and combustion excess air and monitors achievement as part of the energy management system.

8. TECHNICAL RISK AND REFERENCE

9. BACK-UP DATA AND CALCULATION

10. SPECIFICATION OF THE EQUIPMENT

OPACITYMETERS

Number of items: 2

o **Physical description:**

casing	Weatherproof (outdoor installation)
probe	high temperature probe

o **Electrical:**

Power	AC, 220V 50Hz
Instrument signal	DC, 24 V

o **Signal:**

	4-20 mA
display of signal	in control room

o **Measured Parameter**

Opacity

o **Miscellaneous:**

cleaning sequence	automatic
cleaning fluid	compressed air

o **Installation**

case location	outdoor
ambiant temperature	-30 C to +50 C
probe location	between economizer and air preheater
maximum flue gas temperature	350 C
inside length of gas duct	
outside length of gas duct	

o **Parts**

ACTION B.3

1. PROCESS AREA:

Steam and Power house

2. STATEMENT OF RECOMMENDATION:

Improve the thermal efficiency of the boilers MM1 and MM2:

o install sootblowers

o refurbish air preheaters

3. **DESCRIPTION/RATIONALE:**

Boilers MM1 and MM2 were found being operated at low efficiency compared to Western standard. Efficiency is currently 83 to 84% where a minimum efficiency of 89% would be requested by Western countries' Public Administrations to permit the operation of such boilers.

Detailed information and calculation of efficiency are provided in Appendix 2 of the report, as part of the energy model of the boilerhouse.

Several problem were identified which account for the low efficiency of boilers:

o absence of sootblowers

It was reported that the stack gas temperature increases from 180 C up to 240 C in two weeks after a shutdown cleaning of tubes.

During the audit, temperature of stack gas was found at the level of 185 C, which, at first view, seems correct. Unfortunately, this temperature results of a mixture of fresh air and combustion gas in the air preheater, because of heavy leakage. We calculated that in absence of air leakage in the air preheater, the temperature of stack gas would raise up to 220 C for boiler MM1 and 206 C for boiler MM2. It is expected that adequate sootblowers would keep stack gas temperature between 190 C and 200 C.

o Refurbish air preheaters (boilers MM1 and MM2)

As mentioned above, stack gas temperature is already quite low as a result of mixing fresh air and combustion gas inside the air preheater. As long as this situation pevails, it might be hazardous to implement above recommendations since the temperature of stack gas would decrease below the acid dew point, potentially causing hazards on down stream equipment (F.D. fan, gas duct). Therefore the condition for improving the efficiency of boiler is the reduction of air leakage in the air preheaters.

MM1 and MM2 boilers' air preheaters are of an advanced technology using heat pipes. This technology is patented in Hungary, and MOTIM's installation is one of the first installations made under this patent. Heat pipe technology is well known in Western countries. For example, in the USA, it was developped by Q-Dot and marketed worldwide by Foster Wheeler with limited success. The basic rationale of this technology is that heat transfer coefficient is much higher than with conventional surface exchanger, thus permitting smaller and cheaper equipment. This technology never broke through the western market (at least for industrial heat recovery application).

Each air preheater consists of about 5000 heat pipes. Obviously, heat pipes are working, but there is probably a mechanical engineering misconception in the supporting of tubes at the tubular plate, which do not guarantee airtightness.

It is recommended that MOTIM solve this misconception problem with the help of local engineering companies or envisage to replace the air preheaters.

4. **BENEFITS**

4.1 **Energy savings**

4.2 Other benefits

5. IMPLEMENTATION COST

List of equipment number unit cost (Ft)

Total cost is estimated at

6. PAY-BACK

7. PLANNING

ACTION C.1

1. PROCESS AREA:

Steam and Power plant

2. STATEMENT OF RECOMMENDATION:

Refurbish the turbogenerator

3. DESCRIPTION/RATIONALE:

It was found during the audit that the isentropic efficiency of the steam turbine is 61% for the high pressure stage and 45% for the low pressure stage versus an average efficiency of 74% in the design condition and an efficiency of 77% to 80% for modern technology turbines.

4. BENEFITS

4.1 Energy savings

4.2 Other benefits

5. IMPLEMENTATION COST

List of equipment number unit cost (Ft)

Total cost is estimated at

6. PAY-BACK

7. PLANNING

8. TECHNICAL RISK AND REFERENCE

9. BACK-UP DATA AND CALCULATION

ACTION C.2

1. PROCESS AREA:

Steam and Power plant

2. STATEMENT OF RECOMMENDATION:

Improve the power to heat ratio of the cogeneration plant:

- o Operate the boiler feedwater preheater using 12b steam
- o Create a very low pressure steam level at the power plant (1.2b) by installing an auxiliary turbine in replacement of an electric motor

3. DESCRIPTION/RATIONALE:

4. BENEFITS

4.1 Energy savings

4.2 Other benefits

5. IMPLEMENTATION COST

List of equipment	number	unit cost (Ft)

Total cost is estimated at

6. PAY-BACK

7. PLANNING

8. TECHNICAL RISK AND REFERENCE

9. BACK-UP DATA AND CALCULATION

ACTION C.3

1. PROCESS AREA

Steam and Power Plant

2. STATEMENT OF RECOMMENDATION

Heat recovery on Boiler Flue gas

- o reduce the acid dew point of flue gas
- o reduce the temperature of boiler feedwater

3. DESCRIPTION/RATIONALE

It was found that the boiler feedwater enters the economizer at the temperature of 142 C at a point where the temperature of combustion gas is over 315 C. To avoid any corrosion problem, it is essential that the flue gas side skin temperature of tubes at the entrance of the economizers be over the acid dew point, (i.e. around 160 C) plus a safety margin of say 10 C to 20 C. The skin tube temperature is intermediate between flue gas and water temperature, and closer to water temperature because of higher heat transfer coefficient. Assuming that skin temperature is equal to water temperature plus 1/3 of temperature difference between water and flue gas, water temperature could be reduced from 142 C down to 115 C. This

short calculation shows that there is enough of a safety margin in decreasing feedwater temperature from 142 C down to 132 C. In any case, a detailed calculation of skin temperature should be conducted in function of the mecanical design of the first tubes of the economizer.

Temperature of boiler feedwater should be controled using a steam pressure control valve at the deaerator (to be installed).

4. BENEFITS

4.1 Energy savings

4.2 Other benefits

5. IMPLEMENTATION COST

List of equipment	number	unit cost (Ft)

Total cost is estimated at

6. PAY-BACK

7. PLANNING

8. TECHNICAL RISK AND REFERENCE

9. BACK-UP DATA AND CALCULATION

APPENDIX 1: List of data provided by the plant

As part of the preliminary energy audit (PEA), RCG/Hagler, Bailly reviewed a number of standard MOTIM reports. because of the limitations on time and level of effort for the PEA, only selected data were used. In this section, we summarize the types of reports used at MOTIM.

o **Daily Steam production and fuel consumption report**

For each day of the month
  for each boiler: MM1, MM2, GIB, MHO
    steam meter reading, production in t
  total of steam generated
  for each boiler: MM1, MM2, GIB, MHO, PTVM (hot water)
    fuel meter reading, consumption in t (density .9)
  total fuel in t
  specific consumption per boiler MM1, MM2 and GIB in tFO/tsteam

summary for 10 days period and for the whole month

o **Daily fuel storage status**

For each day of the month
  tank holding
    measured (not indicated)
    from books
  Power station
    daily delivery
    daily consumption
  Calcining plant
    daily delivery
Quantity purchased
  by rail
  by truck
  modification in purchased order during the month
  total
For power plant, calcining
  quantity requested
  quantity received
  quantity to be delivered next month

o **Monthly energy report**

Energy input (in tons, GJ/t, GJ)
  fuel oil
  used lubricant
    subtotal fuel
    pure concentrate
  alkaline condensate from process
  raw water
    subtotal water
  HP feedwater preheater
  deaerator
    subtotal self consumed steam
  self-consumption electricity
    generated
    purchased

Energy produced
  70b steam to process
  70b steam admission turbogenerator
  extraction turbogenerator
  exhaust
  letdown 67b/13b

letdown 67b/3b
saturated 13b steam from stand-by boiler
hot water from stand-by boiler

Energy supplied
70 b
13 b
4 b
hot water
electricity

Electric power
production
self consumption for power generation
self consumption for steam generation minus steam supplied
self consumption for steam supplied

Operation of boilers
for MM1+2, GIB, MHO, PTVM
steam production t or GJ
hours of operation
average load (t/h)

Efficiency (gross efficiency, power station, net efficiency)

This report is signed by the head of energy department, and given to the technical manager and the accounting department.

o Energy specific consumption report

Process/product
production in tons
type of energy
monthly consumption
specific consumption in unit/ton

various types of energy are:
electricity
steam 70b
13b
4b
compressed air in m3
water
fuel oil and light oil
non process steam
non process electricity

Various Process/products are:
bauxite preparation
extraction
mixing
evaporation
wet plant
calcining
wet plant alumina
vanadium pentoxide
alumina sulfate
sanding powder
grain
mullit
refractory
korvisit
zirk s
zirk y

refractory+sanding
compressed air 0.111 kWh/m3
well water 0.384 kWh/m3

o **Monthly report from energy department to sale department**

water consumption of outside consumers:

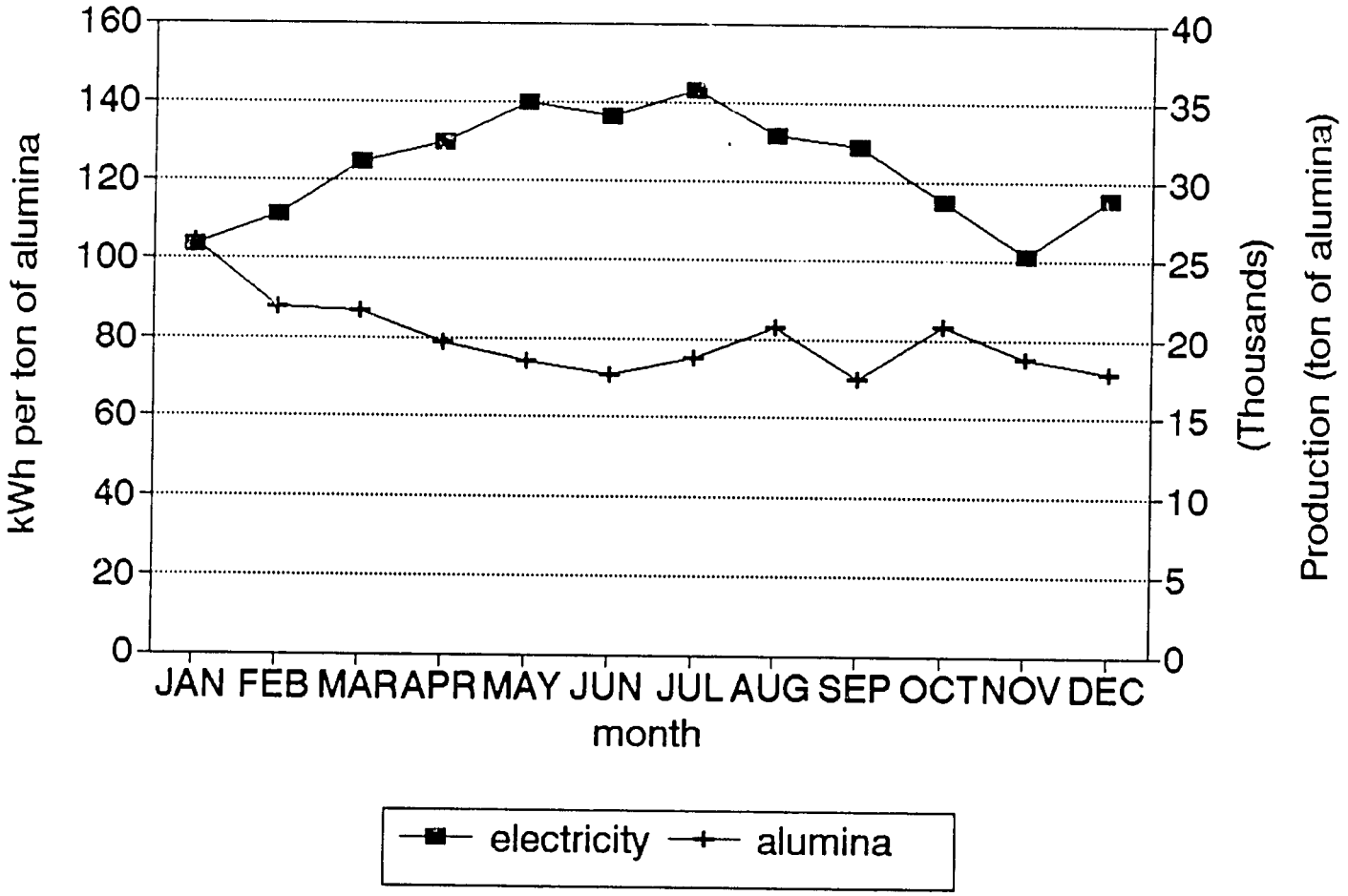
toothbrush fact
canned food fact

industrial water
drinking water

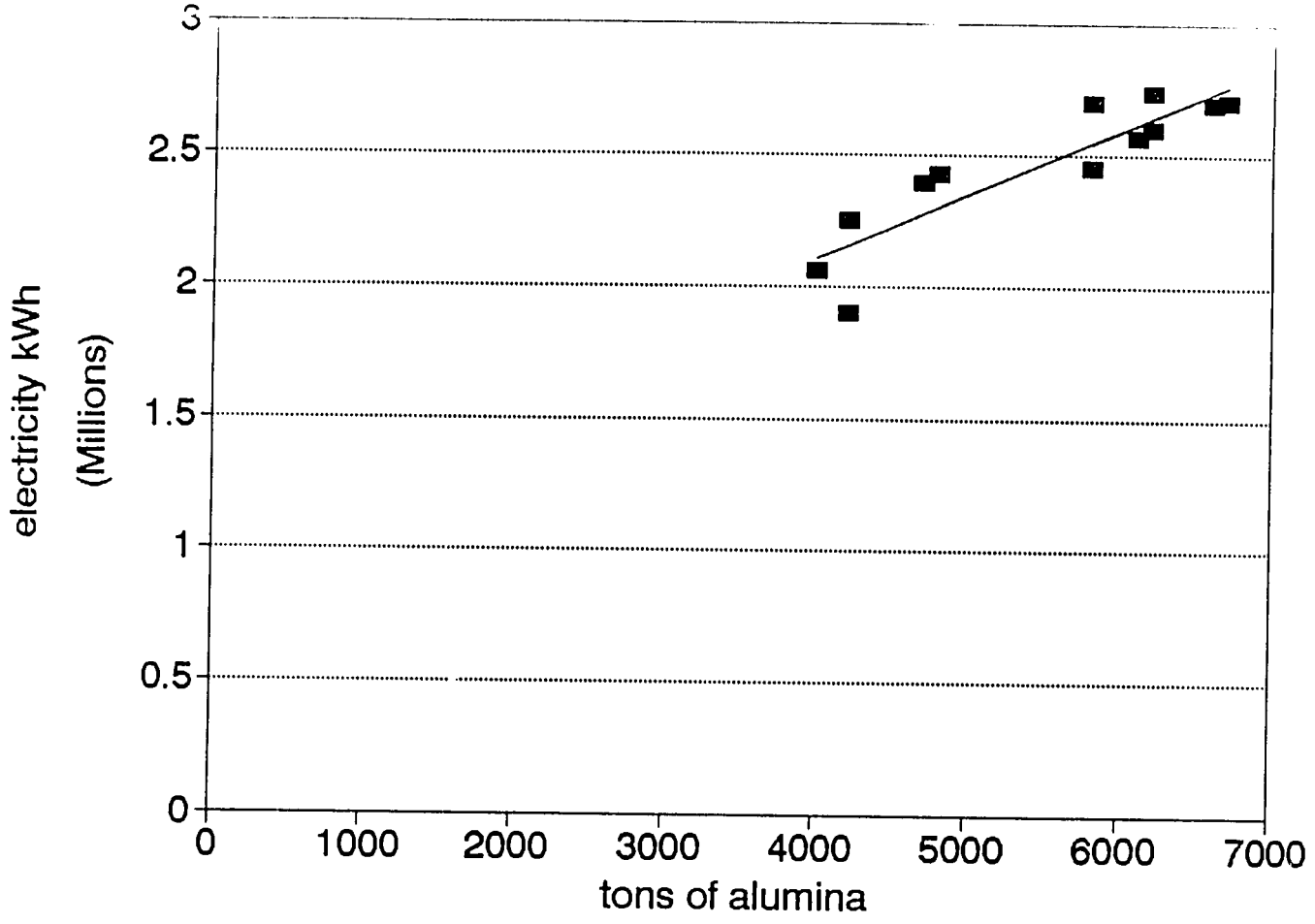
utility consumption of in-plant services
ambulance building (3b steam, electricity)

MOTIM - ALUMINA PLANT - YEAR 1990

electricity consumption

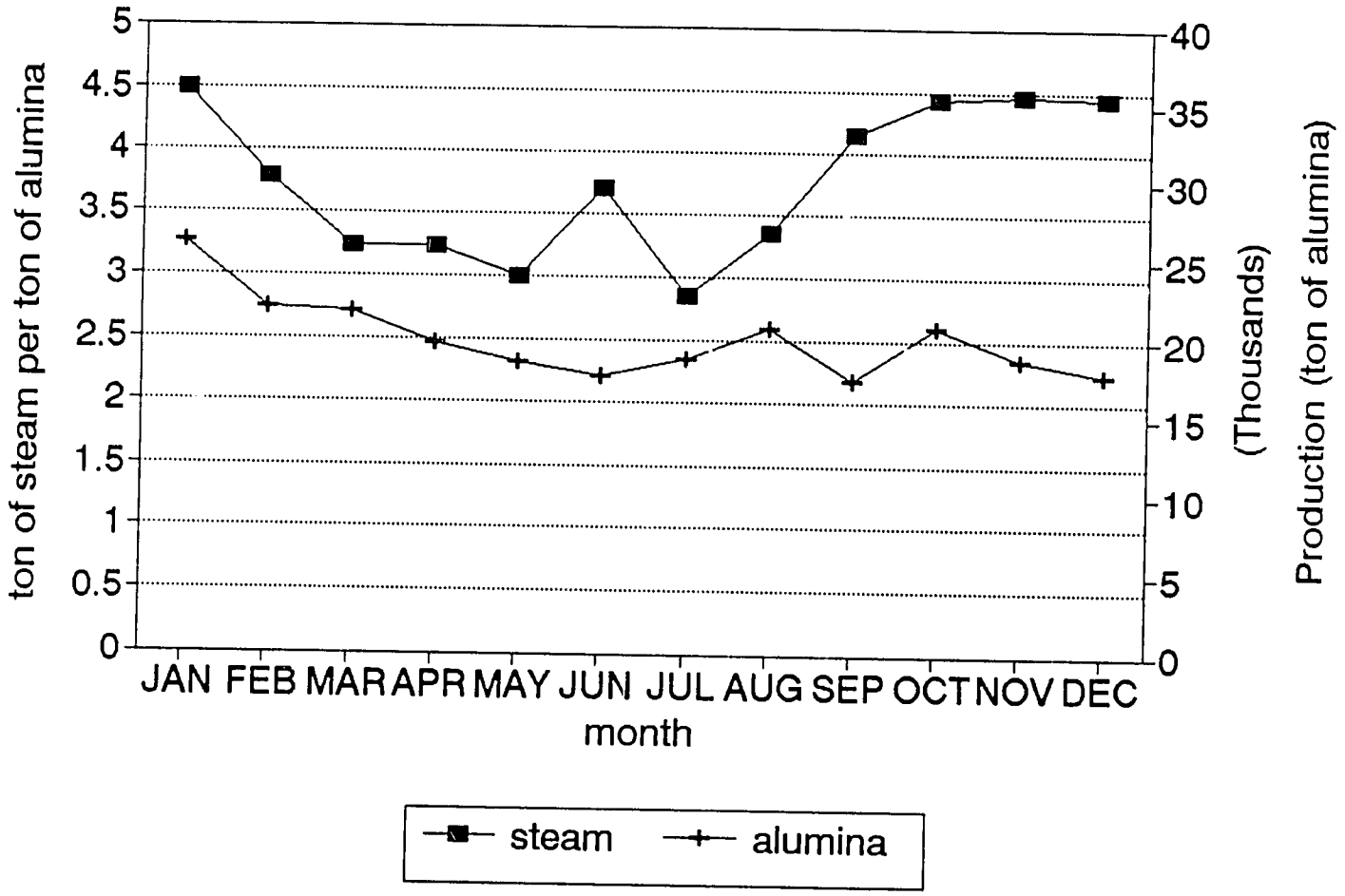


MOTIM - ALUMINA PLANT - YEAR 1990

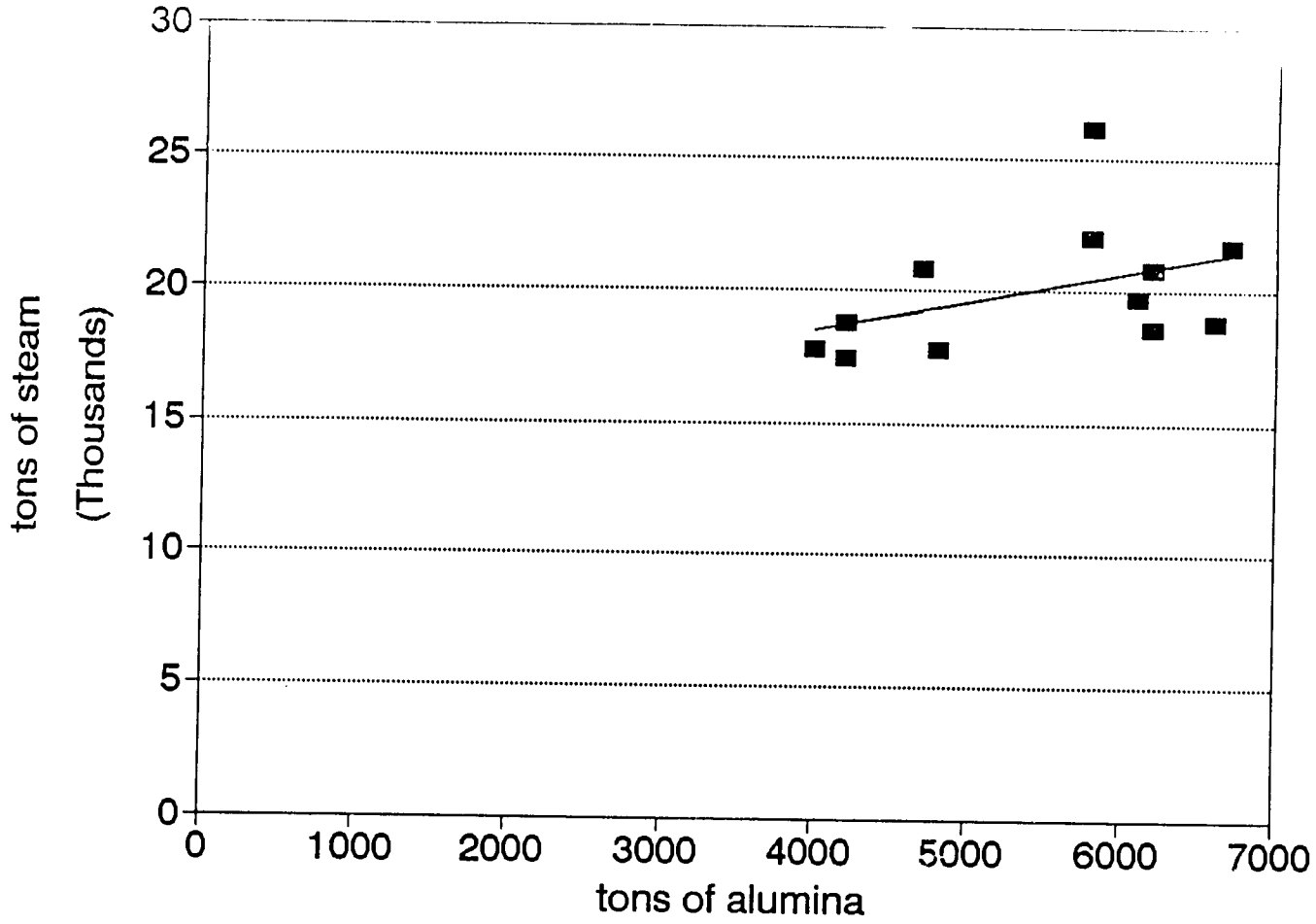


MOTIM - ALUMINA PLANT - YEAR 1990

steam consumption

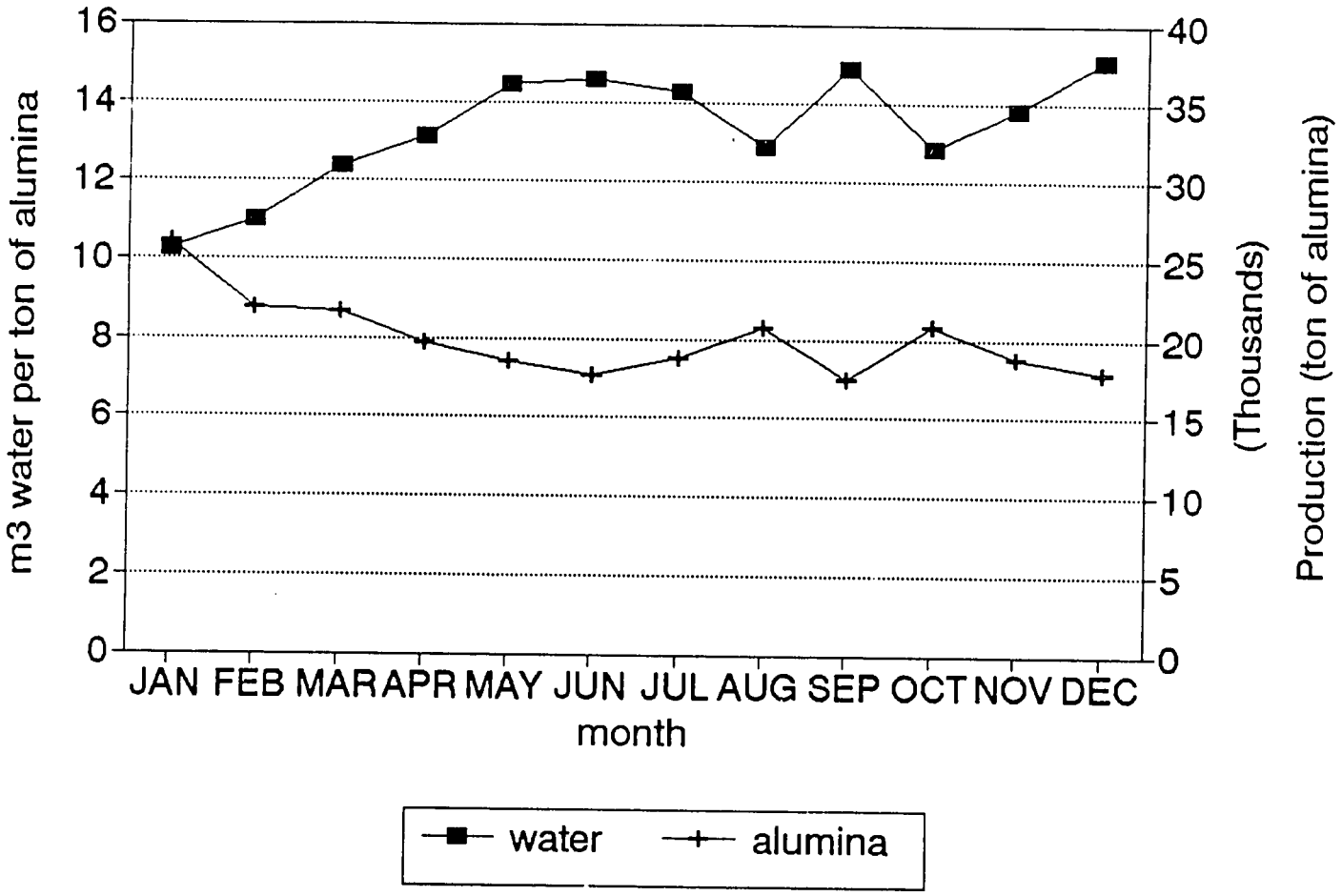


MOTIM - ALUMINA PLANT - YEAR 1990

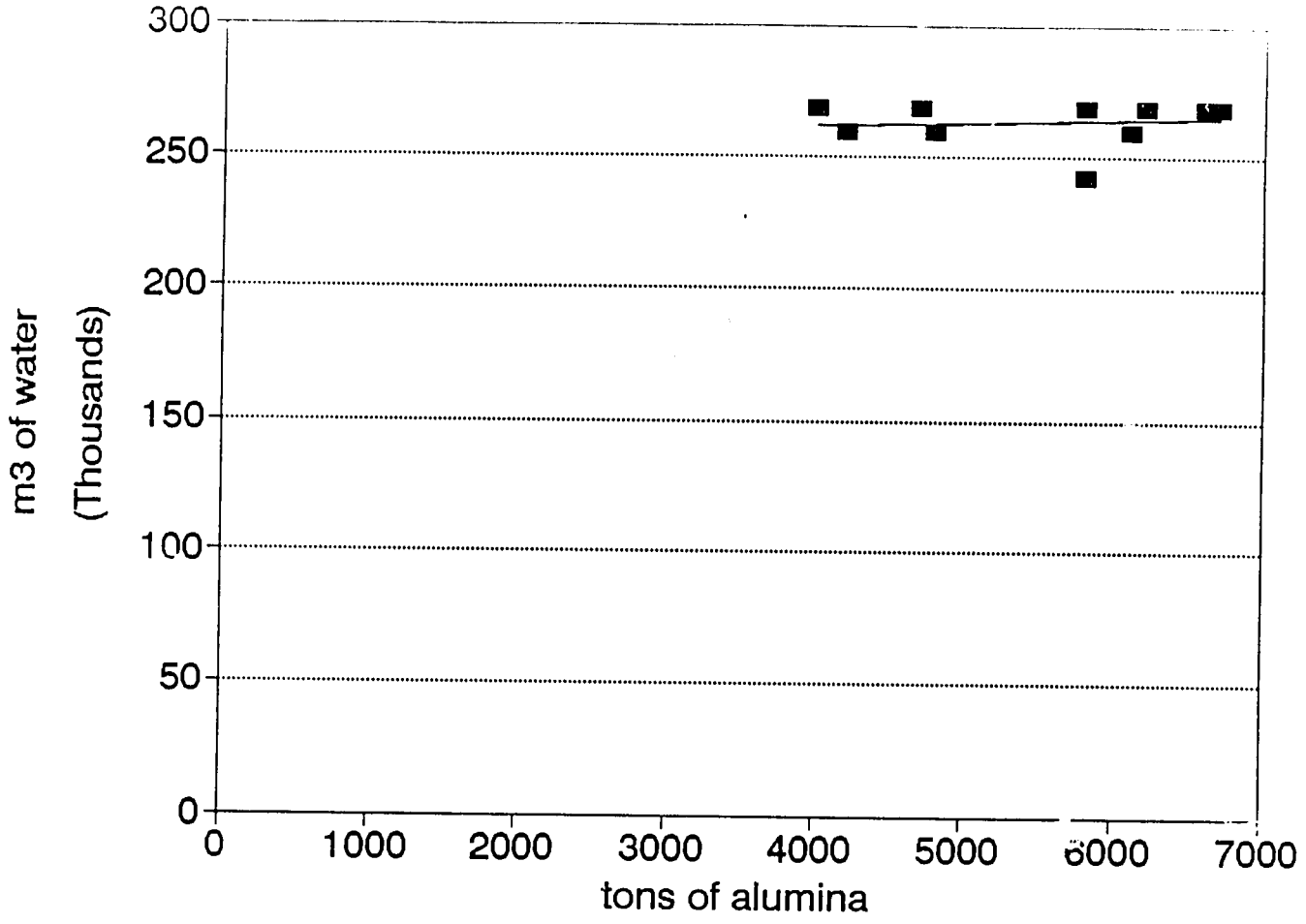


MOTIM - ALUMINA PLANT - YEAR 1990

water consumption

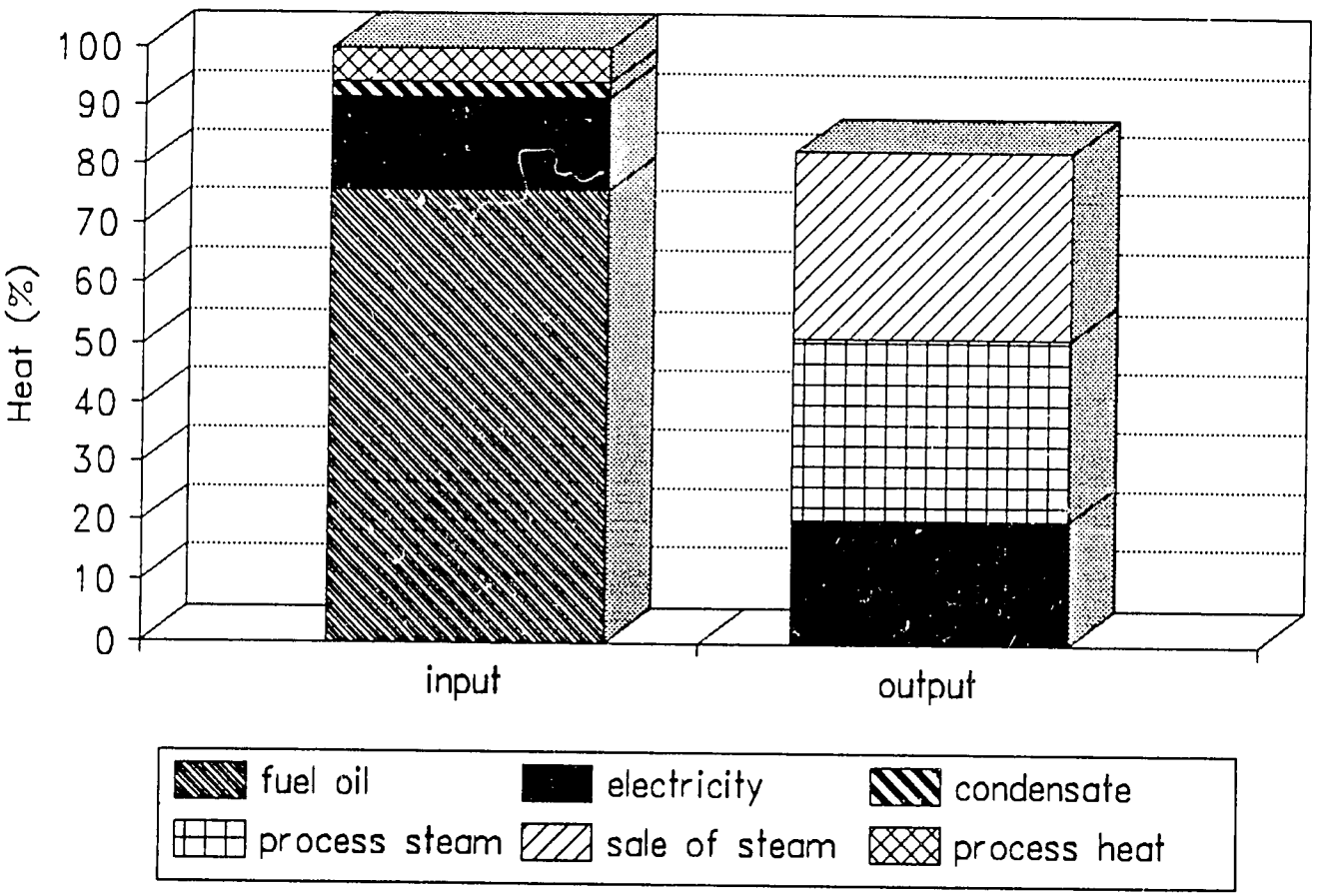


MOTIM - ALUMINA PLANT - YEAR 1990



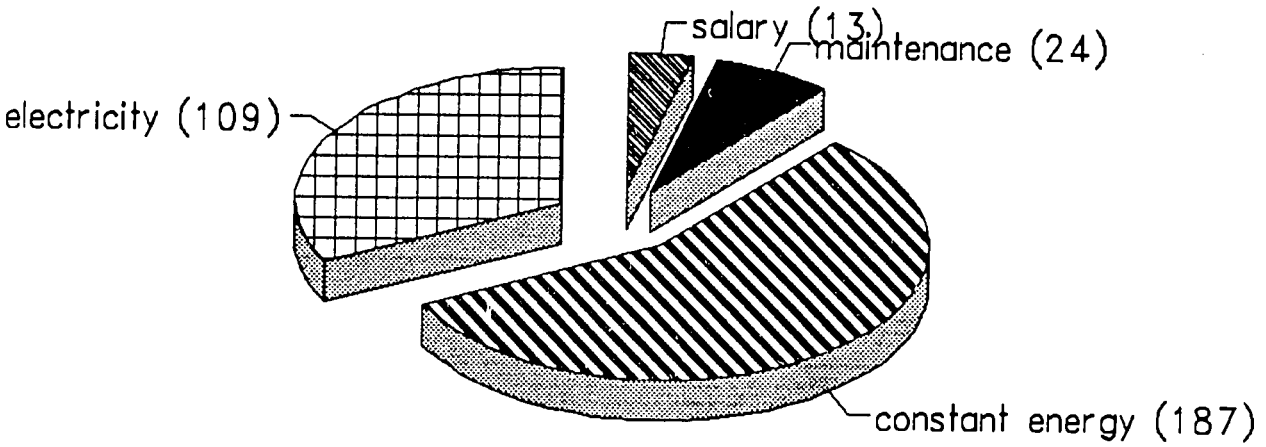
MOTIM – POWER PLANT

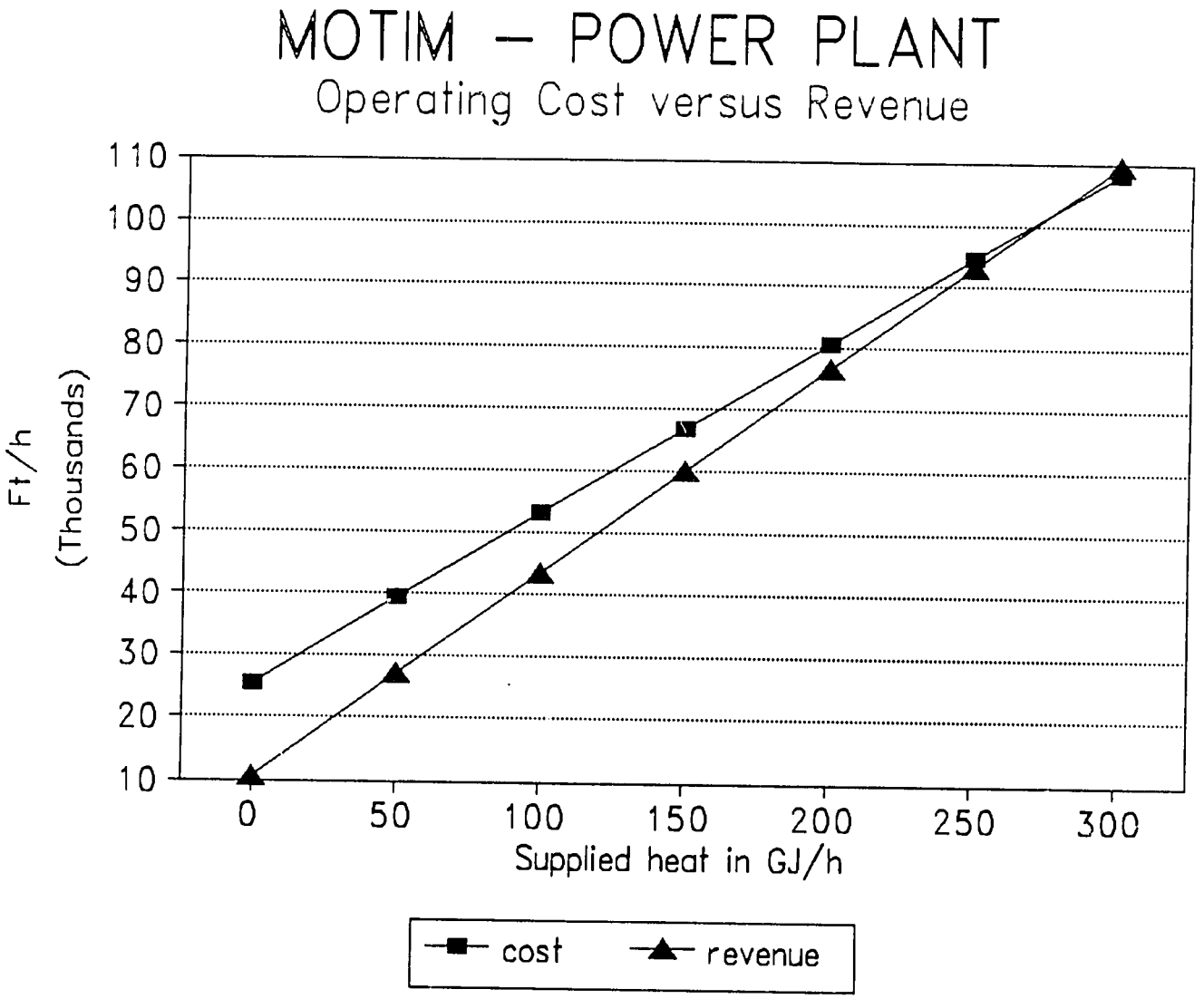
Overall Thermal Efficiency



MOTIM – POWER PLANT

Fixed cost structure (MFt/year)




MOTIM – POWER PLANT
Operating Cost versus Revenue
Ft/h
(Thousands)
110
100
90
80
70
60
50
40
30
20
10
0
50
100
150
200
250
300
Supplied heat in GJ/h
cost
revenue

macro alt-n

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MOTIM POWER PLANT

CASE STUDY

				t/h mini	t/h max	MWth max
OUTSIDE CUSTOMER DEMAND FOR HEAT AND UTILITY		T/H	MWth			
12B STEAM						
KNITWARE FACTORY		2	1.64	0	5	4.10
TOOTHBRUSH FACTORY		3	2.46	0	3	2.46
FOOD CANING FACTORY		3	2.46	0	3	2.46
3B STEAM						
FOOD CANING FACTORY		3	2.45	0	2	1.63
KNITWARE FACTORY		2	1.63	0	6	4.90
CONDENSATE RETURN		5.7	-0.40			
RAW WATER		20.0				
						15.54
DISTRICT HEATING						
WATER FLOWRATE	M3/H	420.0				
TEMP. IN/OUT	C	50	80			
HEAT SUPPLIED	GJ/H	52.7	14.63			24.66
MOTIM PROCESS HEAT AND POWER DEMAND						
65B STEAM PROCES	T/H	12.0	9.51	9	15	11.89
12B STEAM	T/H	3.0	2.46	1	4	3.28
3B STEAM	T/H	12.0	9.80	9	18	14.70
CONDENSATE RETU	T/H	19.4	-1.80			
PROCESS HEAT REC	TH/H	4000	-3.53			
ELECTRICITY	KW	16600				29.86
OVERALL COS PHI		0.993				
MOTIM BUILDING HEATING						
WATER FLOWRATE	M3/H	250.0				
TEMP. IN/OUT	C	65	75			
HEAT SUPPLIED	GJ/H	10.5	2.90			5.81
						75.88
PLANT EQUIPMENT IN OPERATION		#	max			
# BOILER MM1		1	1			
# BOILER MM2		1	1			
# FEEDWATER 12B STEAM PREHEA		0	1			
# BOILER GIB		0	1			
# TURBOGENERATOR		1	1			
# FEEDWATER MOTORPUMPS MM 4		1	2			
# FEEDWATER MOTORPUMPS MM 2		0	2			
# FEEDWATER TURBOPUMP MM		0	0			
# FEEDWATER MOTORPUMPS GIB		0	2			
# DISTRICT HEATING CIRC PUMPS		1	0			
# IN-PLANT HEATING CIRC PUMPS		1	0			
ATOMIZING STEAM (65B=0, 12B=1)		1				

RESULTS – FUEL/HEAT USE

		measured	calculated
Purchased fuel oil	t/h		5.34
	GJ/h		219
	Ft/h		62318
Sale of heat	GJ/h		91.0
	Ft/h		29475
Non return condensat	t/h		7.3
20% steam exp	t/h		2.6
	Ft/h		240
NET FUEL/HEAT COST	Ft/h		32603

RESULTS – ELECTRIC POWER BALANCE

		measured	calculated
Purchased power	kW		12697
	Ft/h		37297
Cos phi penalty/bonus	in %		-5
	Ft/h		-1865
Sold power	kW		0
	Ft/h		0
NET POWER COST	Ft/h		35432

RESULTS – WATER BALANCE

		measured	calculated
Water treatment	m3/h		17.1
	Ft/h		684
Raw water sale	m3/h		20
	Ft/h		120
NET WATER COST	Ft/h		564

OVERALL THERMAL EFFICIENCY

Heat input	unit	unit/h	GJ/h
fuel oil	t	5.34	219.2
electricity	kWh	12697	45.6
condensate	t	25	7.9
process heat	th	4000	16.7
	subtotal		289.5
Heat output			
sale of steam	t	13	38.3
district heating			52.7
in-plant building heating			10.5
process steam	t	27	78.4
electricity	kWh	16600	59.7
	subtotal		239.5
Overall cogeneration efficiency	y %		83

RESULTS - INTERNAL VARIABLES

		measured	calculated
steam to district heat.	t/h		18.4
steam to process	t/h		27.0
steam export	t/h		13.0
steam raised	t/h		67.6
steam supplied	t/h		58.4
steam raised/steam supplied ratio			1.158
TG steam admission	t/h		53.4
TG by-pass	t/h		4.2
extraction steam	t/h		7.3
LP steam to deaer.	t/h		10.5
TG power	kW		5053

CONVERGENCE

		Guess	Calculated
steam to deaerator	t/h	10.54	10.54
boilers flow	t/h	67.64	67.64

CONSTRAINTS

CONTRACTUAL LIMI		value	maxi	mini	ACTION	
demand						
Export steam MWth		25.3				
Elec power MWe		12.7	21.0			
Elec. power factor		0.993		0.9		
ENVIRONMENTAL LIMITS		value	maxi			
SO2	kg/h	131	1800			
NOx	kg/h		1290			
Dust	kg/h		310			
TECHNICAL LIMITS		value	maxi	mini	ACTION	
TG exhaust		45.6	50.0			
TG extraction		7.9	15.0			
TG inlet		53.4	66.0		letdown 65/12 ===>>	5
Boilers steam flow		67.6	80.0			

INCREMENTAL COSTS

	fuel kg/t	purchased elec kWh/t	sold elec kWh/t	demine water t/t	marginal cost Ft/t	marginal cost Ft/GJ
65b steam process	81.76	-27.13	0	1.018	914	268
12b steam	91.72	-104.29	0	1.021	804	272
3b steam	97.68	-151.77	0	1.022	734	250
condensate ret	-6.19	9.10	0	-1.00	-85.5	-341

	dayly average Ft/GJ	peak hours Ft/GJ	day hours Ft/GJ	night hours Ft/GJ
65b steam process	268	256	268	274
12b steam	272	217	270	297
3b steam	250	169	246	285
condensate ret	-341	-284	-338	-366

COST STRUCTURE EQUATION

	fuel t/h	elec kWh/h	demine water m3/h	total Ft/h
Variable Heat cost	3.5	-3824	15.7	30149
Variable Elec cost		16600		48762
Constant cost	1.8	-79	1.4	21387
Total cost	5.34	12697	17.1	1E+05

Total variable heat cost	Ft/h	30149	26%
Total heat supplied	GJ/h	109 5	
Unit cost	Ft/GJ	275	
Total variable elec cost	Ft/h	48763	42%
Total elec supplied	kWh/h	16600	
Unit cost	Ft/kWh	2.94	
Power demand charge	Ft/h	12493	
Constant heat cost	Ft/h	21388	18%
Maximum heat demand	MWth	75.9	
Unit cost	Ft/MWth/h	282	
	kFt/MWth/month	206	
Total fixed cost for heat supply			
salary	MFt/year	12.5	
maintenance	MFt/year	24	
thermal energy	MFt/year	187	
total	MFt/year	224	
	Ft/h	25554	22%
Unit cost	Ft/MWth/h	337	
	kFt/MWth/month	246	
Total fixed + variable operating cost	Ft/h	116959	100%

BREAK-EVEN POINT

		actual cost	selling price
Energy charge	Ft/GJ	275	330
Fixed cost	Ft/MWth/h	337	139
Maximum demand	MWth	76	
Break-even point	GJ/h	275	
Current demand	GJ/h	110	
Profit margin	Ft/h	-9025	
	Ft/GJ	-82	

ENERGY PURCHASE PRICES

	F.O. High S Ft/t	F.O. Low S Ft/t	boiler feedwater Ft/t	elec. energy Ft/kWh 1/
Peak hours 18h-21h	10010	11660	40.0	4.5
Day 6h-18h 18h-22h	10010	11660	40.0	3
Night 22h-6h	10010	11660	40.0	2.25
daily average	10010	11660	40.0	2.94
	kFt/MWth	MWth	kFT/MWe	MWe
monthly demand charge				
peak			370	15
day			170	21

note 1: penalty/bonus table for power factor

cos phi	penalty/bonus in %
0.98	-5
0.96	-4
0.94	-3
0.92	-2
0.9	0
0.88	2
0.86	4
0.84	6
0.82	8
0.8	10

ENERGY SELLING PRICES

	hours/day 2/	Hot water Ft/GJ	12b steam Ft/GJ	3b steam Ft/GJ	elec. energy Ft/kWh	non retur condens Ft/m3 1/	raw water Ft/m3
Peak hours 18h-21h	3	324	344	323		40	
Day 6h-18h 18h-22h	13	324	344	323		40	
Night 22h-6h	8	324	344	323		40	
average energy price		324	344	323	0.00	40.00	6
		kFt/MWth	kFt/MWth	kFt/MWth			
monthly demand charge		108	121	92			

note 1: 20 Ft/m3 for the first 20% non returned condensates, then 40 Ft/m3
note 2: From March to September, peak hours from 18h to 21h
From October to February, peak hours from 16h30 to 21h

DATA BASE

CHARACTERISTICS OF FLUIDS

Equip ID No	LIBELLE DES PARAMETRES	unite	No instrum.	actual value	saturated condition vapor	saturated condition liquid	isentropic letdown 1	isentropic letdown 2	
	65B STEAM AT BOILER PLANT								
	pressure	bar g		67			12		67
	temperature	C		500	281.2	281.2	259.6		T
	enthalpy	th/t		814.9	662.7	296.9	705.4		520
	heat content 1/	GJ/t		3.407					500
	65B STEAM AT THE USER POINT								480
	pressure	bar g		65					450
	temperature	C		300	281.2	281.2			
	enthalpy	th/t		682.4	662.7	296.9			
	heat content 1/	GJ/t		2.853					
	12B STEAM AT BOILER PLANT								
	pressure	bar g		12					
	temperature	C		260	191.2	191.2			
	enthalpy	th/t		705.6	665.0	194			
	12B STEAM AT THE USER POINT								
	pressure	bar g		12					
	temperature	C		260	191.2	191.2			
	enthalpy	th/t		705.6	665.0	194			
	heat content 1/	GJ/t		2.950					
	3B STEAM AT THE BOILER PLANT								
	pressure	bar g		3					
	temperature	C		240	143.2	143.2			
	enthalpy	th/t		703.0	653.6	144.1			
	3B STEAM AT THE USER POINT								
	pressure	bar g		3					
	temperature	C		240	143.2	143.2			
	enthalpy	th/t		703.0	653.6	144.1			
	heat content 1/	GJ/t		2.939					
	1.8B STEAM								
	pressure	bar g		1.8					
	temperature	C		150	130.9	130.9			
	enthalpy	th/t		659.8	649.8	131.4			
	heat content 1/	GJ/t		2.759					
	BOILERS STEAM DRUM								
	pressure	bar g		70					
	temperature	C		283.2	283.2	283.2			
	enthalpy	th/t		662.1	662.1	299.4			
	DEAERATED FEEDWATER								
	pressure	bar g		3					
	temperature	C		143.2	143.2	143.2			
	enthalpy	th/t		144.1	653.6	144.1			
	total dissolved solid	ppm		0					
	CONDENSATE RETURN FORM OUTSIDE								
	pressure	bar g		0					
	temperature	C		60					
	enthalpy	th/t		60					
	heat content 1/	GJ/t		0.250					

note 1: heat content of steam in GJ is based on the total enthalpy of steam

CHARACTERISTICS OF FLUIDS

Equip ID No	LIBELLE DES PARAMETRES	unite	No instrum.	actual value	saturated condition vapor	saturated condition liquid	isentropic letdown 1	isentropic letdown 2
	DEMINERALISED WATER							
	pressure	bar g						
	temperature	C		20				
	enthalpy	th/t		20.03				
	AMBIANT AIR							
	pressure	bar g						
	temperature	C		25				
	enthalpy	th/t						

FUEL OIL

Equip ID No	PARAMETERS	unite	No instrum.	current fuel	Value	Value
	type			LS	HS	LS
	chemical composition					
	C	% wt		88.3	86.5	88.3
	H	% wt		10.7	10.5	10.7
	S	% wt		1.2	3	1.2
		g/10th		24.99	64.17	24.99
	specific gravity	t/m3		0.9	0.95	0.9
	viscosity @ 100øC	mm2/s		40	40	40
	viscosity @ 150øC	mm2/s		12	12	12
	LHV calorific value	th/t		9808.	9569.	9808.
		MJ/Nm3		41000	40000	41000
	HHV calorific value	th/t		10397	10143	10397
		MJ/Nm3		43460	42400	43460
	neutral air/fuel ratio	kg/10th		14.47	14.66	14.47
	atomizing steam rate	g/kgFO		85	85	85
	neutral flue gas/fuel ratio	kg/10th		15.52	15.74	15.52
	flue gas specific gravity	kg/Nm3		1.32	1.32	1.32
	flue gas specific heat	kcal/kg.C		0.260	0.259	0.260

BOILER HEAT BALANCE

Equip ID No	LIBELLE DES PARAMETRES	unite	No instrum.	in	out	in	out	in	out
	CHARACTERISTICS			BOILER MM1		BOILER MM2		BOILER GIB	
	Maximum steam raised	t/h			40		40		40
	Steam pressure	bar g			67		67		67
	Superheat temperature	C			505		512		505
	HP steam enthalpy	th/t			817.7		821.8		817.7
	Pressure relief valves	bar g			71		71		71
	Minimum steam raised	t/h			15		15		15
	BASIC DATA - TEST								
	Steam flow	t/h	meter		19.2		28		40
	Fuel gas flow	th/h	meter	14860		22032			
	Superheater 3								
	Steam side								
	temperature	C		283.2	380	283.2	380		
	heat exchanged	th/h		1070.		1560.			
		kcal/10th		720.0		708.2			
	Flue gas side								
	temperature	C	thermocou	550		575			
	temperature calc	C		602.5	470.1	646.6	518.3		
	Economiser								
	Feedwater side								
	Temperature	C		144.1	204.1	142.1	222		
	flowrate	t/h	meter	19.29	19.29	28.14	28.14		
	heat exchanged	kcal/10th		779.0		1020.			
	Flue gas side								
	Temperature	C							
	Temp calc	C		470.1	315.9	518.3	319.2		
	flue gas flow	kg/10th			19.42		19.71		
	LMTD	C		215.5		231.6			
	Heat exchanged	th/h		1157.		2248.			
	Heat tranfer coef.	th/h/C		5.371		9.703			
	Air/flue gas preheater								
	Air side								
	Temperature	C		43	170	42	195.5		
	enthalpy	th/t		10.28	41.08	10.04	47.34		
	air flow	kg/10th		22.64	17.36	19.02	16.35		
	heat exchanged	kcal/10th		480.3		582.9			
	Flue gas side								
	Temperature measured	C	Thermoco	265	182	261	185.7		
	Temperature calculated	C	======>	315.9		319.2			
	flue gas enthalpy	kcal/10th		1597.	1170.	1638.	1082.		
	O2 total	% vol	Enerac	4.65	8.4	4.85	7		
	total excess air	%		27	63.5	29	47.5		
	total air flow	kg/10th		18.37	23.65	18.66	21.34		
	air ingress	kg/10th		5.281		2.676			
	% inlet flue gas	%		27.18		13.57			
	temp	C		42		42			
	flue gas flow	kg/10th		19.42	24.70	19.71	22.39		
	flue gas specific heat	kcal/kg.C		0.260	0.260	0.260	0.260		

BOILERS HEAT BALANCE (CONT.)

Equip ID No	LIBELLE DES PARAMETRES	unite	plant instrum.	in	out	in	out	in	out
	O2 in firebox	% vol	Enerac	3		2.5			
	combustion excess air	%	=====>>	20		13			
	CO in firebox	ppm	Enerac	100		50			
	Combustible in firebox	% vol	Enerac	0.13		0.13			
	Down total dissolved solid	ppm	TDS meter						
	Blowdown rate 1/	%			0.5		0.5		
	Other water/steam loss	t/h					0		
	Fixed heat loss	%					3.7		
		th/h			371.5		815.1		
		kcal/10th			250		370		
	Blowdown enthalpy	th/t			299.4		299.4		
	Atomizing steam	g/kgFO		85		85			
	Atomizing steam enthalpy	th/t		705.6		705.6			
	Fuel oil temperature	C		141		141			
	Fuel specific heat	kcal/kg.C		0.48		0.48			

BOILERS HEAT BALANCE (CONT.)

Equip ID No	LIBELLE DES PARAMETRES	unite	plant instrum.	in	out	in	out	in	out
	VARIATION OF TOTAL EXCESS AIR								
	Threshold								
	steam flow	t/h			20		20		25
	excess air	%		70		50		20	
	Low point								
	steam flow	t/h			15		15		20
	excess air	%		80		60		40	
	VARIATION OF STACK GAS TEMPERATURE								
	Upper point								
	steam flow	t/h			40		40		
	temperature	C			205		250		
	Lower point								
	steam flow	t/h			20		20		
	temperature	C			195		240		
	HEAT BALANCE EQUATION								
	C=(X4*Q+X5)/(X0+X1*EA-TF*(X2+X3*EA))								
	X0			1.027		1.027			
	X1			1E-04		1E-04			
	X2			4E-04		4E-04			
	X3			4E-06		4E-06			
	X4			674.4		680.4			
	X5			371.5		815.1			
	EQUATION FUEL OIL/STEAM FLOW								

Steam flow	Q	t/h		37.63		30	
Feedwater flow		t/h	37.82		30.15		
Stack excess air	EA	%	70		50		
Air leakage							
through the air preheater		% of EA	35		20		
through boiler casing		% of EA	15		15		
Combustion excess air		%	20		15		
Air fan excess air		%	55		35		
Air fan flowrate		t/h	64.04		46.62		
		m3/h	57284		41704		
		m3/l F.O.	17.70		15.42		
Stack temperature	TF	C		203.8		245	
Fuel oil	C	10th/h	2855.		2386.		
Fuel oil to steam ratio		th/t	758.6		795.6		
		kg/t	77.34		81.11		
		l/t	85 94		90.12		
Efficiency on LHV		%		85.6		82.7	
Atomizing steam		t/h	0.247		0.206		
Fuel heating steam		t/h	0.221		0.184		

BOILERS BLOWDOWN

Equip ID No	PARAMETRES	unit	No instrum.	in	out
	Liquid				
	flowrate	t/h		0.338	0.338
		% saumur			100
	enthalpy	th/t		299.4	299.4
	Flash steam				
	pressure	bar g			
	total dissolved solid	ppm			
	flowrate	t/h			0
		% flash			0
	enthalpy	th/t			

STEAM LETDOWN

Equip ID No	ITEM	unit	No instrum.	in	out
	67B DESUPERHEATING				
	Steam				
	flowrate	t/h		9.571	12
	temperature	C			
	enthalpy	th/t		819.5	682.4
	Desuperheating water				
	flowrate	t/h		2.428	
		%		25.37	
	enthalpy	th/t		142.1	
	67B/12B				
	Steam				
	flowrate	t/h		4.158	5
	temperature	C			
	enthalpy	th/t		819.5	705.6
	Desuperheating water				
	flowrate	t/h		0.841	
		%		20.22	
	enthalpy	th/t		142.1	
	65B/3B				
	Steam				
	flowrate	t/h		0	0
	temperature	C			
	enthalpy	th/t		819.5	703.0
	Desuperheating water				
	flowrate	t/h		0.000	
		%		ERR	
	enthalpy	th/t		142.1	

STEAM LETDOWN (CONT'D)

Equip ID No	ITEM	unit	No instrum.	in	out
	12B STEAM EXTRACTED				
	Steam				
	flowrate	t/h		7.260	7.855
	temperature	C			
	enthalpy	th/t		751.8	705.6
	Desuperheating water				
	flowrate	t/h		0.595	
		%		8.205	
	enthalpy	th/t		142.1	
	12B/3B				
	Steam				
	flowrate	t/h		0.995	1
	temperature	C			
	enthalpy	th/t		705.6	703.0
	Desuperheating water				
	flowrate	t/h		0.004	
		%		0.456	
	enthalpy	th/t		142.1	

WATER BALANCE

Equip ID No	ITEM	unit	No instrum.	in	out
	Water losses				
	sewed blowdown	t/h			0.338
	atomizing steam	t/h			0.454
	fuel preheating steam	t/h			0.406
	sootblowers	t/h			0
	loss 67b	t/h			0.1
	fuel oil tank heating	t/h			0.2
	other boiler house	t/h			0.5
	deaerator vent	t/h			0.2
	boilers loss				0
	Total loss	t/h			2.198
	Steam to process plant/export				
	67b steam	t/h			12
	12b steam	t/h			11
	3b steam	t/h			17
	condensate return	t/h		25.1	
	Make-up water				
	demineralised water ter R	t/h		17.09	
	Water treatment balance				
	demineralised water	t/h			17.09
	raw water to demine	t/h			20.60
	raw water sale	t/h			20
	total raw water	t/h		40.60	

FEEDWATER PREHEATER USING STEAM

Equip ID No	ITEM	unit	No instrum.	in	out
	Feedwater				
	flowrate	t/h		67.97	67.97
	temperature	C		144.1	144.1
	enthalpy	th/t		144.1	144.1
	12b steam				
	flowrate	t/h		0	0
	enthalpy	th/t		705.6	194

TURBOGENERATOR

Equip ID No	LIBELLE DES PARAMETRES	unite	plant instrum.	in	out	design	
	CHARACTERISTICS						
	Maximum inlet flowrate	t/h		66			
	Maximum extraction flow	t/h			15		
	Maximum exhaust flow	t/h			50		
	Design Maximum power	kW			10000		
	Current Maximum power	kW			10000		
	Minimum power	kW					
	Alternator nominal power	kVA					
	ENERGY BALANCE						
	Source						
	Inlet steam						
	flowrate	t/h		70		70	
	pressure	bar abs		66		65	
	temperature	C		505		485	
	enthalpy	th/t		818.3		809.2	
	entropy	th/t.C		1.634		1.621	
	Extracted steam (HP stage)						
	flowrate	t/h			15	70	
	pressure	bar abs			13	4	
	temperature	C			350	275	
	enthalpy	th/t			750	687	
	entropy	th/t.C			1.713	1.621	
	actual enthalpy drop	th/t			68.39	122.2	
	isentropic letdown	th/t			111.1	165.8	
	isentropic efficiency	%			61.52	73.75	P in KW = 142.6 x Q in t/h -
	electromecanical efficiency	%			93	93	= 142.6 x (Q - 5)
	kWh per ton of steam	kWh/t			73.95	132.2	kWh/t kWh
	HP stage power	kW			5176.	9257.	142.6 -724.
							= 5.083
							no load loss 7.3%

TURBOGENERATOR

Equip ID No	LIBELLE DES PARAMETRES	unite	plant instrum.	in	out
	Exhaust steam (LP stage)				
	flowrate	t/h			55
	pressure	bar abs			4
	temperature	C			275
	enthalpy	th/t			720
	entropy	th/t.C			1.785
	actual enthalpy drop	th/t			30
	isentropic letdown	th/t			66.63
	isentropic efficiency	%			45 02
	electromecanical efficiency	%			93
	kWh per ton of steam	kWh/t			32.44
	LP stage power	kW			1784.

TURBOGENERATOR (CONT'D)

Equip ID No	LIBELLE DES PARAMETRES	unite	plant instrum.	in	out
	HP + LP stages				
	actual enthalpy drop	th/t			98.39
	kWh per ton of steam	kWh/t			106.3
	Electromechanical efficiency	%			93
	Power generated	kW			6961.
	STEAM FLOW/POWER EQUATION				
	High pressure stage				
	power/steamflow ratio	kWh/t			73.95
	no load loss	% max.va			14.19
		kWh			800
	incremental power	kWh/t			85.38
	Low pressure stage				
	power/steamflow ratio	kWh/t			32.44
	no load loss	% max.va			18.03
		kWh			350
	incremental power	kWh/t			38.80
	No load loss coefficient	kWh			1150

CORRECTION OF THE EQUATION STEAM FLOW/POWER
IN FUNCTION OF INLET ENTHALPY

Equip ID No	PARAMETERS	unite	plant instrum.	Design	Actual	calc	measured	
	HIGH PRESSURE STAGE							
	pressure	bar abs		66	66			
	temperature	C		505	505			
	specific gravity	kg/m3		12.61				
	enthalpy	th/t		818.3	819.5			
	entropy	th/t.C						
	pressure extraction	bar abs		13	13			
	temperature extraction	C		350	350			
	enthalpy extraction	th/t		750	751.8			
	actual enthalpy drop	th/t		68.39	67.71			
	isentropic letdown	th/t		111.1	111			
	isentropic efficiency	%		61.52	61			
	no load loss	%		14.19	12.5			
	power correction coefficient			1	0.990			
	average power	kWh/t		73.95	73.22			
	marginal power	kWh/t		86.19	83.68			
	no load loss	kWh		807.5	690.3			
	LOW PRESSURE STAGE							
	pressure	bar abs		13	13			
	temperature	C		350	350			
	enthalpy	th/t		750	751.8			
	entropy	th/t.C						
	pressure exhaust	bar abs		4	4			
	temperature exhaust	C		275	275			
	enthalpy exhaust	th/t		720	724.0			
	actual enthalpy drop	th/t		30	27.84			
	isentropic letdown	th/t		66.63	66.3			
	isentropic efficiency	%		45.02	42			
	no load loss	%		18.03	27			
	power correction coefficient			1	0.928			
	average power	kWh/t		32.44	30.11			
	marginal power	kWh/t		39.58	41.25			
	no load loss	kWh		357.0	556.8			
	TG EQUATION							
	HP stage coefficient			86.19	83.68	124.9	125	total drop
	LP stage coefficient			39.58	41.25			
	constant			-1164	-1247	-1257	-1250	
	auxiliary motors	kW		-10	-10			
	Extracted steam	t/h			7.260			
	Exhaust steam	t/h			45.64			
	Generated power	kW			5053.			

AUXILIARY TURBINES

Equip ID No	PARAMETERS	unite	plant instrum.	in	out
	FEEDWATER TURBOPUMP				
	number in operation			0	
	steam quality			15B	1.8B
	maximum flow	t/h		2	
	minimum flow	t/h		0.5	
	power	kW			50
	equation				
	proportional coefficient				50
	constant				-50
	steam flow	t/h		0.5	0.5
	power	kW			0

AUXILIARY MOTORS

Equip ID No	PARAMETERS	unite	plant instrum.	Value	Value	
	FEEDWATER MOTORPUMPS MM BOILERS					
	number of motorpumps			2	2	
	number in operation			1	0	
	nominal flowrate	m3/h		100	60	
	temperature	C		140	140	
	density			0.924	0.924	
	head	m		1000	1000	
	efficiency	%		65	65	
	nominal power pump	kW		387.3	232.4	
	nominal power motor	kW		400	250	
	power/flow equation W= f(QW)					
	constant			302.1	181.2	
	proportionnal coef.			0.852	0.852	
	quadratic coef.			0	0	
	feedwater flowrate					
	feedwater to boilers	t/h		67.97		
	desuperheating water					
	67B to process	t/h		2.428		
	letdown 67B/12B	t/h		0.841		
	letdown 67B/3B	t/h		0		
	extracted 13b steam	t/h		0.595		
	letdown 12B/3B	t/h		0.004		
	total	t/h		71.84		
	feedwater flow per pump	t/h		71.84		
	power per pump	kW		363.3		
	motor load	%		91		
	total electric power	kW		363.3		
	BOILER FANS			OIL 1	OIL 2	OIL 3
	number of fans			2	2	2
	nominal power per boiler	kW		250	250	
	nominal steam flow	t/h		40	30	40
	actual steam flow	t/h		37.63	30	0
	ID fan	kW		114.9	127.3	0
	FD fan	kW		108.6	88.56	0
	total electric power	kW		437.4		

AUXILIARY MOTORS

Equip ID No	PARAMETERS	unite	plant instrum.	Value
	MAKE-UP FEEDWATER			
	number			3
	number in operation			1
	nominal flowrate QV	m3/h		80
	temperature	C		60
	density			1
	head	m WG		60
	efficiency	%		0.6
	nominal power W	kW		21.8
	power/flow equation W = f(QW)			
	constant			17.00
	proportionnal coef.			0.059
	quadratic coef.			0
	make-up water flow	t/h		17.09
	electric power	kW		19.38
	IN-PLANT BUILDING HEATING PUMPS			
	number			2
	number in operation			1
	nominal flowrate QV	m3/h		250
	temperature	C		60
	density			1
	head	m WG		60
	efficiency	%		0.6
	nominal power W	kW		68.12
	motor rating	kW		95
	power/flow equation W = f(QW)			
	constant			53.13
	proportionnal coef.			0.059
	quadratic coef.			0
	district heating water flow	t/h		250
	electric power	kW		73.25
	DISTRICT HEATING CIRCULATING PUMP			
	number			2
	number in operation			1
	nominal flowrate QV	m3/h		420
	temperature	C		60
	density			1
	head	m WG		95
	efficiency	%		0.6
	nominal power W	kW		181.2
	motor rating	kW		250
	power/flow equation W = f(QW)			
	constant			141.3
	proportionnal coef.			0.094
	quadratic coef.			0
	district heating water flow	t/h		420
	electric power	kW		194.8

AUXILIARY MOTORS (CONT'D)

Equip ID No	PARAMETERS	unit	plant instrum.	value
	OTHER AUXILIARIES	kW		61.48
	fuel pumps	kW		20
	raw water pumping	kW		16.48
	deminer. water pumps	kW		15
	miscellaneous	kW		10
	TOTAL AUXILIARIES	kW		1149.

FEEDWATER/DEAERATOR

Equip ID No	PARAMETERS	unite	plant instrum.	in	out
	DEAERATOR				
	Feedwater				
	flowrate	t/h		61.50	71.84
	enthalpy	th/t		57.39	144.1
	Steam (LP/vent)				
	guessed flowrate	=======		10.53	
	calculated flowrate	t/h		10.53	0.2
	enthalpy	th/t		659.8	650

DISTRICT HEATING HEAT BALANCE

Equip ID No	PARAMETERS	unit	plant instrum.	in	out
	HEAT RECOVERY EXCHANGER				
	Water side				
	water flow rate	m3/h		420	420
	temperature	C		50	59.52
	Heat recovery side				
	water flowrate	t/h			
	temperature	C			
	heat exchanged	th/h		4000	
	STEAM HEAT EXCHANGER				
	District heating Water side				
	water flow rate	m3/h		420	420
	temperature	C		59.52	80
	In-plant building heating water side				
	water flow rate	m3/h		250	250
	temperature	C		65	75
	4b steam side				
	water flowrate	t/h		18.40	18.40
	enthalpy	th/t		703.0	100.1

FEEDWATER/DEAERATOR

Equip ID No	PARAMETERS	unit	plant instrum.	in	out	
	FEEDWATER TANK					
	Make-up water	t/h		17.09		
	enthalpy	th/t		20		
	Condensate return from outside	t/h		5.7		
	enthalpy	th/t		60		
	Process condensate	t/h		19.4		
	enthalpy	th/t		80		
	District heating condensate	t/h		18.40		
		th/t		100.1		
	Feedwater tank heat loss	th/h			600	
	Feedwater ex tank	t/h			60.60	
		th/t			57.39	
	FEEDWATER INLET DEAERATOR					
	feedwater ex tank	t/h		60.60		
	enthalpy	th/t		57.39		
	condensate 12b steam/feedwater pre	t/h		0		
	enthalpy	th/t		194		
	Water inlet deaerator					
	flowrate	t/h			60.60	
	enthalpy	th/t			57.39	

3B STEAM BALANCE

Equip ID No	PARAMETERS	unite	plant instrum.	in	out		
	turbogenerator exhaust	t/h	meter	45.64		<<==	50
	12b/3b letdown	t/h		1			
	67b/3b letdown	t/h		0			
	deaerator	t/h			10.53		
	fuel oil tank	t/h			0.2		
	other boiler house	t/h			0.5		
	steam district heating	t/h			18.40		
	steam sale	t/h	meter		5		
	steam process	t/h	meter		12		

12B STEAM BALANCE

Equip ID No	PARAMETERS	unite	plant instrum.	in	out
	TG extraction desuperheated	t/h		7.855	
	65b/12b letdown valve	t/h		5	
	to feedwater preheater	t/h			0
	atomizing steam	t/h			0.454
	fuel heating	t/h			0.406
	to 12b/3b letdown valve	t/h			0.995
	steam export	t/h	meters		8
	steam to process	t/h	meter		3

67B STEAM BALANCE

Equip ID No	PARAMETERS	unite	plant instrum.	in	out
	Steam to TG	t/h			53.40
	of which extraction	t/h	meters		7.260
	exhaust	t/h	meter		45.64
	exha loss	t/h			0.5
	65b/12b letdown valve	t/h			4.158
	65b/3b letdown valve	t/h			0
	65b to process (non desuperheat)	t/h	meter		9.571
	65b to atomization	t/h			0
	losses	t/h			0.5
	Total HP steam	t/h		67.63	
	steam generated	t/h	meter=>>	67.63	

ELECTRICITY BALANCE

Equip ID No	PARAMETERS	unite	plant instrum.	in	out
	TG power generation	kW		5053.	
	auxiliaries consumption	kW			1149.
	Process plant power demand	kW			16600
	Purchased power	kW		12696	
	Sold power	kW			0

MACRO

```
*———— alt b Macro de convergence
*————    et de test des limites
IQ          4
IZ          4

\b        {calcul}


*———— alt m Macro de calcul des couts marginaux
CI        5.366406                          Stockage valeur combustible
WI        12465.20                          Stockage valeur electricite
WJ        0
RI        17.10355                          Stockage valeur eau demine

\m        {let CI,C.value} ~                ] Sauvegarde
          {let WI,WN:value} ~               ] des valeurs
          {let WJ,WX:value} ~
          {let RI,R:value} ~                ] initiales
          {let E,E+1:value} ~                 +1 t/h sur la HP
          {calcul}
          {let HPC,(C-CI)*1000:value} ~     ] Affichage couts
          {let HPW,WN-WI:value} ~           ] marginaux de la
          {let HPX,-WX+WJ:value} ~
          {let HPR,R-RI:value} ~            ] HP
          {let E,E-1:value} ~
          {let F,F+1:value} ~                 +1 t/h sur la MP
          {calcul}
          {let MPC,(C-CI)*1000:value} ~     ] Affichage couts
          {let MPW,WN-WI:value} ~           ] marginaux de la
          {let MPX,-WX+WJ:value} ~
          {let MPR,R-RI:value} ~            ] MP
          {let F,F-1:value} ~
          {let G,G+1:value} ~                 +1 t/h sur la BP
          {calcul}
          {let BPC,(C-CI)*1000:value} ~     ] Affichage couts
          {let BPW,WN-WI:value} ~           ] marginaux de la
          {let BPX,-WX+WJ:value} ~
          {let BPR,R-RI:value} ~            ] BP
          {let G,G-1:value} ~
          {let COND,COND+10:value} ~
          {calcul}                            Retour aux valeurs initiales
          {let CONDC,(C-CI)/10*1000:value} ~
          {let CONDW,(WN-WI)/10:value} ~
          {let CONDX,(-WX+WJ)/10:value} ~
          {let CONDR,(R-RI)/10:value} ~
          {let COND,COND-10:value} ~
          {calcul}
```

```
calcul   {let BPHP,5:value} ~
         {let ECHMAX,ECHAPMAX:value} ~
         {for IQ,1,3,1,BQ}                                   Equilibrage du bilan vapeur
test1    {if adm<admmax+.1} {branch test3} ~                 Test admission GTA
         {let ECHMAX,ECHMAX-(ADM-ADMMAX):value} ~
         {for IQ,1,2,1,BQ} {branch test1} ~                  Reequilibrage du bilan vapeur
test2    {if BPHP<2.1#OR#adm>=admmax-.1} {branch test3} ~        Optimisation bipasse GTA/ admission
         {let BPHP,BPHP-@max((admmax-adm)*.91,.05):value} ~          admission non saturée, détente ouverte
         {let BPHP,@max(BPHP,2):value} ~
         {branch test1} ~
test3    {for IQ,1,3,1,BQ} {RETURN}                          Affinage de la convergence

BQ       {for IZ,1,3,1,BZ}                                   ] Boucles de convergence du bilan vapeur
         {let QE,QC:value} ~                                 ]
                                                             ]
BZ       {let ZE,ZC value} ~                                 ]
```

*——— alt n Macro de gestion du programme par menu
Macro en cellule AA1630

```
{MENUCALL Menup}                                                    Menup
{BRANCH \n}
                                                                          {

                                                                    MAJPA {

                                                                    smenu
                                                                          {
                                                                          {

                                                                    IMP   {

                                                                    smenu
                                                                          |
                                                                          /
```

Initialise	Solve	See result	Marginal c	Print	Save	Quit
Initialisatio	Convergen	Voir les re	Calcul des	Impressio	Sauvegard	Retour en mode READY 123
{HOME}	{GOTO}c	{GOTO}re	{GOTO}c	{IMP}	{HOME}	{QUIT}
{QUIT}	{BRANCH	{QUIT}	{BRANCH \m}		/FS~R	

MENUBRANCH smenu1}

Boilers	Water	Turbogene	Turbines	Motors	Balances	Quit
Caracterist	Water bala	Caracterist	Turbines a	Moteurs a	Bilans vap	Retour au menu principal
{GOTO}c	{GOTO}w	{GOTO}gt	{GOTO}tu	{GOTO}m	{GOTO}bilans~	
{QUIT}	{QUIT}	{QUIT}	{QUIT}	{QUIT}	{QUIT}	

MENUBRANCH smenu2}

All	Quit
Impressio	Retour au menu principal
/ppr	
A1.Y1200~	
gq	