THE EFFECT OF THE PLANT SPECIFICATION ON THE DESIGN, INSTALLATION AND COMMISSIONING OF REFINERY PROCESS HEATERS

by

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A thesis submitted for the degree of
Doctor of Philosophy in Chemical Engineering

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SUMMARY

This is a study of the effect of the Plant Specification on the design, installation and commissioning of a large scale test facility for evaluating burners used in petroleum refinery process heaters. The objective is to examine the project life of a process heater plant so as to draw recommendations which can be applied to a similar project involving a medium sized process plant.

This work is based on a case study which takes as an example a million pound process heater plant (Burner Test Rig, BTR) built at the BP laboratories, Sunbury on Thames. The BTR project life was divided into three stages: Process Development, Project Engineering and Operation. During the examination of these stages it was decided to carry out an operability study using cause and symptom equations to record the results. These equations may be used in a computer program, to be developed by other workers, to generate fault trees as an aid to fault finding.

Instrumentation, control and safety circuits are an important feature of the BTR. A detailed examination is included and presented as tables summarising the location and function of these instruments.

The practical part of this work was carried out on site. During this time a close examination was made of the late BTR. In order to carry out the operability study, engineering line diagrams were drawn showing precisely the equipment and instrumentation as installed. These drawings are appended; plus a block diagram of the overall process.

Information about the BTR, prior to the site study, was obtained from early proposals, specification and tenders. This thesis contains an analysis of these documents as they relate to the overall project and to the equipment finally installed. The proposed and actual schedules are shown as bar charts; reasons for discrepancies in these schedules are discussed.

Five chapters of this thesis deal with specific phases of the project, BTR instruments and the BTR operability study. The analysis of the information is presented in separate lists of findings or conclusions with the exception of the operability study. This has a list of actions which aim to reduce hazardous situations in the BTR.

The stated findings and actions are the basis of the general conclusions and recommendations relating to medium sized projects and to process heater installation. The complete set of conclusions and recommendations are given at the end of this thesis while the most important are given below.

- The client must not be responsible for any items of equipment which form part of a Lump Sum contract.

- An instrumentation schedule describing all the instrument loops should be finalised at the time of issuing the plant specification for a Lump Sum contract.

- An operability study should be carried out on the Engineering Line Diagrams during the project engineering phase.

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Primero que todo dedicó este trabajó a la Sra. María Inéz Bolívar cuya TENACIDAD, GENEROSIDAD e INTEGRIDAD ha sido el ejemplo que he tratado de emular en la realizacion de este trabajo.

First of all, I dedicate this work to Mrs. María I. Bolivar whose TENACITY, GENEROSITY and INTEGRITY is the example I have imitated in the execution of this work.

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ACTUAL FLOW DIAGRAMS

The modified Flow Diagrams based on the contractor P & I Diagram and with the required numbering for the operability study are presented on this appendix as follows:

D.1A	Furnace System.
D.1B	Cooling Water System.
D.2	Combustion Air System.
D.3A & B	Natural Gas System.
D.3A	Natural Gas System - Natural Gas Expansion and Compression.
D.3B	Main and Pilot Natural Gas pipelines to Furnace and Dosing Gases pipelines.
D.4A & B	LPG System.
D.4A	LPG Tanks and Pumps.
D.4B	LPG Evaporators.
D.5A & B	Fuel Oil System.
D.5B	Fuel Oil Pipe Line to Furnace .
D.6A & B	Atomising Steam System.
D.6A	Softener and Boiler Unit.
D.6B	Superheated Steam Generator and Pipeline.

CHAPTER ONE

INTRODUCTION

INTRODUCTION

1.1 Fired Process Heater

A fired process heater (Comprising of a number of operational units or systems) aims to efficiently release heat by firing a fuel in order to increase the temperature and/or change the chemical or physical nature of a material.

Fired process heaters are characterised according to the type of industrial installation (ceramic, steel, refineries, etc) in which it is being used. This thesis studies the effect of the plant specification on the design, installation and commissioning of refinery process heaters by taking as an example a million pound sterling process heater plant (Burner Test Rig, BTR) built at the BP Laboratories Sunbury on Thames.

Also, a computer aid for operability studies (CAFOS), conceived by Dr D A Lihou (43 to 46) has been applied to the BTR; this represents the first industrial application of CAFOS.

1.2 Literature Survey

1.2.1 System Engineering

It is characteristic of the engineering world that principles should be learnt from experience and grasped intuitively long before they are mathematically formulated and expounded. This is specially true of system engineers, who may be Chemical Engineers concerned with the engineering not of components but of system (both physical and organisational) which involve the mutual interation of many components.

Table 1.2.1 Hall's Problem-Solving Sequence - Phases of the BTR Project

BTR PROJECT	Hall's Problem-Solving Sequence	
Process Feasibility	Problem Definition	Essential Definition of a need
Client Specification	Choice of Objectives	A definition of physical needs and of the value system within which they must be met.
Tenders	System Synthesis	Creation of possible alternative systems.
Tendering	Systems Analysis	Analysis of hypothetical systems in the light of objectives.
Tender Selection	System Selection	Selection of the most promising alternative.
Final Tender	System Development	Up to the prototype stage.
PROJECT ENGINEERING	Current Engineering	System realization beyond prototype stage and including monitoring, modifying and feeding back information to design.

iii) The 'cost' or resources required by each system.

iv) A mathematical model, ie. the mathematical or logical framework or set of equations showing the interdependence of the objectives, the techniques and instrumentalities, the enviroment, and the resources.

v) A criterion, relating objectives and costs or resources for choosing the preferred or optimal alternative.

Although the above system analysis (system engineering) concept comes from a managerial organisation, chemical engineering owes its emergence as a separate discipline to the application of precisely this philosophy to analyse complex chemical processes(4).

It is a normal tendecy for the participants during the Design, Erection and Commissioning of a complex chemical process to visualise the process (like the BTR) in terms of a separate operational units (systems).

In practice these operational units do not work as separate systems; but interact so that overlapping occurs which leads to a far more complex operation than that visualised by the participants.

The evolution in the definition of the systems (operational Units) during the BTR project is studied in this thesis so that a clear picture of them is described and areas of overlap are identified.

This permits general recommendations to be made in the preparation of fired process heater specifications by better definition of the operational units to reduce the problem of interaction.

The prediction of the consequences arising from the interaction between the system and the component parts, is one of the every day problems in an engineering project, which is best tackled by the expertise earned in previous experiences.

Part of this thesis is a case study of the BTR project which as an engineering project can be visualised as the total tasks of conceiving, designing, evaluating and implementing the BTR, (4). These tasks can be regrouped and extended so that the BTR stages can be analysed as follows:

Process Development (Complete definition of the Process)

Project Engineering (Project Implemention)

Operation (Start up and Early Operation)

In an ideal situation the process development phase would be frozen and the project engineering phase would follow, leading to the operational phase. The latter is recommended to start as soon as any operational unit from the previous phase becomes available.

The above description shows that the system engineer would have overlapping of activities only during the last two phases which will increase the complexity of the engineer's tasks.

On the other hand in practice, the project engineering phase produces problems that require a feedback of information to the process development phase as proposed by Hall's problem-solving sequence (resulted from empirical experience of many different case studies rather than any theoretical consideration, table 1.1.2) which further increases the complexity of the project.

The overlapping and feedback processes described are a typical occurence in the engineering of a project and specially for those which are "first of a kind" as is the case of the BTR.

This argument is further developed by Chestnut (10) who discusses "The systematic process of performing the engineering and associated work in producing the operating system".

The "operating system" of Chestnut can be defined in this thesis as the Design, Erection and Operation phase.

In this thesis a study is made of the actual overlapping and feedback processes (Bar graphs, appendix 7) occuring during the BTR Engineering and Operation stages. This has enabled the delays to the BTR project to be identified in the project engineering and operation chapters and corresponding recommendations are made with the conclusions of this thesis.

1.2.2 System Analysis

System analysis is the systematic appraisal of the cost and other requirements in various ways(4)

The formal methodology of Smith(12) which is still being practiced and developed by the International Institute of Applied System Analysis (IIASA) consists of the following aspects:

i) An objective or objectives we desire to accomplish.

ii) Alternative techniques or instrumentalities (or 'Systems') by which the objective may be accomplished.

iii) The 'cost' or resources required by each system.

iv) A mathematical model; i.e. the mathematical or logical framework or set of equations showing the interdependence of the objectives, the techniques and instrumentalities, the environment, and the resources.

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It is a normal tendency for the participants during the Design, Erection and Commissioning of a complex chemical process to visualise the process (like the BTR) in terms of a separate operational unit (system). In practice these operational units do not work as separate systems; but interact so that overlapping occurs which leads to a far more complex operation than that visualised by the participants.

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1.2.3 Furnace Design

In a full-fixed furnace, the process of energy transfer, from the mixture of fuel and air entering the combustion zone to the heat-sink surface disposed near the walls entails a series of complex processes (28). This series involves a combination of the following problems (28).

Fluid Mechanics
Molecular and Tubular Diffusion (Burner)
Kinetics of Chemical Reaction
Radiation from Gas and Solid Particles
Absorption of Radiation by Solid and Gases
Reradiation from Refractory Surfaces
Natural and Forced Convection
Wall Conduction, etc.

All the above processes are not susceptible to vigorous mathematical representation. However, simplified calculation methods based on key process conditions can be used to predict the furnace design parameters.

Vendors and Hottel calculation Methods (See 2.4.4.1 & Appendix 5)

The calculation methods used by the tendering firms and client to evaluate the BTR furnace design parameters are a direct derivation of Lobo's Method published in 1939 (17). These methods included McAdam Proposal, Babcock & Wilcox, Perry (3rd Ed.) and Wimpress.

The Lobo's Method is basically a theoretical one (18) which is simple to use while it takes into account such factors as:

Shape of the Box
Amount of Cold Surface and Refractory
Fuel Properties
Excess Air
Temperature and Properties of the Cold Heat-Receiving Surface.

This method assumes that the mean radiant temperature could be taken as the temperature of the flue gases leaving the radiant section, obtained by heat balance, i.e. that the furnaces were essentially well stirred boxes.

This method used an extended Stephan-Boltzman type of equation (including convection /13/) by adding:

- Overall Exchange Factor (Feo/12/).
- Cold Surface Area (α.Acp /4/).

  The latter is the area of a plane which will absorb the same as the actual cold surface in the furnace, while the Overall Exchange Factor correct for:

  - Arrangement of Refractory (Frc /5,6 & 7/).
  - Volume of Combustion Chamber (P.L/8&9/)
  - Flame (furnace) Emmissivity (Ef /11/).

This method's main disadvantage is that the furnace mean radiant temperature is not homogeneous as it is assumed so the selection of one representative furnace temperature (Flue Gases Temperature) is the main cause of uncertainty in this method application.

In relation to selecting the stirred-furnace temperature, McAdams (22) proposed that,

(t flue gases) - (t stirred furnace) = 167°C

while, Lobo in 1977 (18) proposed that,

(t_g, for heat transfer) -
(t_g, for energy balance) = 120 ± 30°C

and Hottel (30) in the Melcher lecture 1960 mentioned his rule-of-thumb approximation for furnace enclosures which were not well-stirred boxes, that of assuming the radiation gas temperature and the leaving enthalpy gas temperature to differ by 120 ± 30°C.

Other calculation methods used by the BTR tenderers involved the assignment of a particular value to the Overall Exchange Factor when the furnace is firing oil, i.e. 0.75 and 0.85 for Perry (3rd Ed.) and simplified B & W Method, respectively.

Wimpress method (20) follows the Lobo and Evans pattern with simplifications through elimination of minor variables and inclusion of general correlations.

TheWimpress' figures (20) substitution of Lobo's equations (Appendix 5) are shown as follows:

The Stephan-Boltzman type of equation /13/ is equivalent to Fig. 6.

The Overall Exchange Factor /12/ is evaluated by Fig.5.

The Arrangement of Refractory /5,6 & 7/ is only considered by the Factor F/α Figure (Fig.2).

The Combustion Volume chamber /3/ is considered by Fig. 3.

The Flame (Gas) Emmissivity /11/ is considered by Fig.4.

This thesis uses two of the Furnace Methods used by the tenderers firm to evaluate the furnace design parameters as well as Hottel's Method whose development is described below.

Hottel's paper (15) in 1931 described the calculation of the factor Fa/α which is part of an empirical equation described in the Wilson, Lobo and Hottel paper (14).

Then, the Lobo method was issued in (18) which included the Hottel Boltzman type of equation (including convection /13/) which presents an interchange factor comprised by Cold Surface Area and Overall Exchange Ratio (α Acp Feo). Later, in 1952, the Hottel's Shape Factors (new approach to evaluate the interchange factor) appears in (13) but this did not consider the gradient temperature, so in 1958, Hottel and Cohen (31) presented their zone method for radiant heat exchange, making allowance for non-uniformity of gas temperatures.

In 1967 Hottel published a book (24) which revised all his previous papers and fully developed the zone method. This is summarised in his contribution to the 6th Edition of the Perry's Handbook where he states that the argument leading to the development of the interchange factor used in his zone method can be applied to the case of absorption within the gas volume if in the evaluation of the direct-exchange areas allowance is made for attenuation in the gas. The necessary (allowance) correction to the Hottel's interchange factor described in Perry, leads to an expression to evaluate the "Total Exchange Area between the Gas Zone and Surface Zone 1 (tubes) in Presence of Refractories" [$(G\bar{S}_1)_r$/33/].

This expression consideres two surface zones, a sink of area A_1 and a radiactively adiabatic zone of area A_r, which enclosed an isothermal gray gas in such shape (Box) and size (PL) that its emmissivity is E_g/30/.

Also, $(G\bar{S}_1)_r$ is corrected by a weighting gray factor, a_1/31 & 32/ which is evaluated in Lobo & Cohen's paper and considered as an allowance for real gases.

The calculation of the weighting gray factor in this thesis used Hadvig (29) approach. This correlates the gas emmissivity as a polynomal in Pc.L over a wide temperature range, with a maximum error of 4%; the above correlation is represented as a table (18) in Appendix 5, so that all the data required for the application of Hadvig Corrected Emmissivity /30/ is available.

The interchange factor $(GS_1)_r$ also includes the Refractory-Tube View Factor (F_{r1}) which is evaluated by the application of:

Crossed String Method	/16/
Conservation $\sum$ Fij = 1	/17/
Reciprocity Aij Fij = AjFji	/18/

1.2.4 Operability Study

The Institution of Chemical Engineers defines an Operability Study as one of the techniques to evaluate loss prevention(57). This covers a wide range of design activities and all the safety aspects of the approved plant.

The first appearance of an Operability Study Technique related to process plant was during the sixties when I.C.I. Limited pioneered a procedure (65) which examined the process model systematically, section by section or line by line (57). The technique has since been developed so that the Chemical Industry Association Limited published "A Guide to Hazard and Operability Studies" (55) which is the basis of the different approaches to carrying out an "Operability Study". This includes the CAFOS operability study conceived by Dr. D. Lihou whose application to the BTR is described in Chapter Six. Also, during the Sixties it was required that Nuclear Power Stations at Oldbury and Wilfa were to be equipped with aids for alarm handling. This was done by the use of "Alarm Trees" which show the sequence of alarms following a particular disturbance (53). The development of the above "Alarm Trees" formally established the use of gates 'AND' and 'OR' which are used by Taylor (48,50) and Andow (53) in the drawing of fault trees including Lihou's computerised technique (CAFOS).

Lihou's technique was the main advantages that its alpha-numeric notation is easy to apply in the examination of process plant. Data from the above examination is easily handled when entered in the computer and a fault tree can be drawn. The resulting tree is to aid the operator in the identification of faults. The author uses CAFOS to examine the BTR and this is the first industrial application of the technique.

CAFOS is also used to enter the data on the computer in order to draw a fault tree and evaluate its real life application.

1.3 BTR System Analysis

In the early stages of the BTR project only the Furnace, Cooling Water, Combustion Air and Fuel Systems were considered.

As the project progressed, better definition of the "Systems" was achieved so that the tendering documents, client specification and final tender became progressively more comprehensive by adding addition "System(s)" to the previous documents.

It is the belief of the author that an improvement to normal practice can be made by considering the instrumentation and safety circuits as two additional separate "Systems" and not as part of the sectional engineering (2.3.2.5) of the tendering document. This is proposed because:

i) The control and electrical panel, as well as the field instruments, are major equipment of the BTR whose functional aims are not adequately described in the system description of the tendering documents, where they are considered as accessories.

ii) Although most of the BTR can work without control loops and with very few monitoring instruments, the full commissioning (equipment acceptance criteria) of part/all of the plant could not be effected until the instrumentation and safety circuits were functioning correctly.

Considering the Instrumentation and Safety Circuits as additional BTR 'Systems', the final BTR description resulting from the work of this thesis can be expressed under the following headings:

Furnace System
Cooling Water System
Combustion Air System
Natural Gas and Dosing Gases System
LPG System
Fuel Oil System
Atomising Steam System
Safety System
Instrumentation (Instrument System)

Although the systems are defined differently by the project participants, i.e. Client (Client Specification), Tenderers (Tenders), Contractor (Final Tender) and Author (Operability Study), the intended operational functions were the same for all the participants.

1.4 Thesis Layout

This thesis is divided into five text chapters, of which three of them described different stages of the BTR project.

PROCESS DEVELOPMENT
PROJECT ENGINEERING
OPERATION

while the other two -

INSTRUMENTATION & CONTROL AND SAFETY SYSTEM
OPERATION

result from a more detailed description of the Instrumentation and Control and Safety Circuits and the application of the Operability Study 'CAFOS', respectively.

Also, this thesis contains a chapter for

INTRODUCTION
CONCLUSIONS

as well as eight appendices which contain complementary information to the text chapter. The last three appendices are contained in a separate file box enclosed to the thesis, these are:

Appendix 6. PLANNING DOCUMENTS
Appendix 7. ACTUAL WORK PROGRAMME - COMPARISON
Appendix 8. ACTUAL FLOW DIAGRAM

CHAPTER TWO

PROCESS DEVELOPMENT

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CHAPTER TWO

PROCESS DEVELOPMENT

2.1 Feasibility Study

This study started during the latter part of the erection phase. Therefore, the study of the initial stages of the project, tendering and most of the erection has been based upon correspondence, written specifications, minutes of business meeting and discussions with the participants.

2.1.1 Original Proposal and Funding

The initial proposal of a Burner Test Rig B.T.R. were made in 1973, when the advantages of large force draught burners fired in the upshot mode were recognised. A number of burner designs were available for testing; but the burner manufacturers did not have the facilities to demonstrate the thermal performance of their designs. Installation of the B.T.R. at the B.P. refinery in Kent was shown to offer no cost benefit over the Research Centre, Sunbury on Thames. In 1974, financial support from the B.P. Company was doubtful, and approaches were made to organisations with test facilities which might have been suitable for the proposed Tests. These included the Gas Council, Hamworthy Engineering Ltd., International Flame Research Foundation at Ijmuiden and Shell; the latter two facilities are in Holland. Only the Shell facilities were suitable for B.P.'s tests; but Shell were not prepared to release their facilities.

In September 1975, a budget proposal of £393,000 was returned in April 1976 for two actions.

> More detailed consideration of modifying redundant refinery heaters, to accomodate the test burners.
>
> Seeking 50% funding from U.K. Department of Energy.

Neither action was fruitful. The only suitable redundant furnace was soon put to use for debottlenecking. The Department of Energy consultant recommended the use of I.F.R.F. Ijmuiden facility, but their's is a horizontal test furnace and unsuitable for upshot firing. Another visit to Shell in Amsterdam, in February 1977, was unfruitful; as was an approach to the E.E.C. for funding under Regulation No. 1303/78.

In April 1977, a revised budget price of £543,000 was estimated. With an estimated construction time of 2 years; taking inflation into account, the total expenditure was calculated as £692,000 for completion in 1979. These budgets were sent to the U.K. Department of Energy, with renewed request for financial aid (£346,000). This application was unsuccessful.

Later in 1977, B.P. decided to proceed with the B.T.R. on the basis of £692,000. The Contract for £786,000 was awarded to Firm C in August 1978; but the total cost of the project, including site facilities was £908,000.

2.1.2 Objectives and Experimental Programme

The principal aim of B.T.R. is to enable B.P. to develop ways of increasing the thermal efficiency of their refinery process heaters. In 1978, B.P.'s oil production, transportation, refining, marketing and chemical operation used energy equivalent to 13 million tonnes of fuel oil. The success of process heater design and operation depends strongly upon the performance of its burners under process operating conditions. It was intended to test large force draught burners from the following manufacturers:

Hamworthy LU 355
Urquhart (R.F.M.)
Gulf Vortomax (Aeroil)
Coppus Fanmix

Burners from other manufacturers may be tested after the initial programme of 18 months duration. It was proposed to recover the expenditure of further testing either by fees paid by burner manufacturers, or by selling the data produced, to users of energy.

In 1976, burner manufacturers expressed an interest in collaborating. The proposal fees were £6,000 for Stage 1 tests, a further £10,000 for Stage 2 tests and a further £20,000 for Stage 3 tests. It was anticipated that only the best two or three burners would proceed to Stage 3.

The burners manufacturers chosen by B.P. for possible collaboration were:

Babcock and Wilcox
Laidlaw Drew
Peabody
Pillard
Shell (Lyunet)
Stordy

The range of performance criteria to be evaluated at each stage is shown later.

A variety of fuels are available to petroleum refiners. Therefore, it was proposed that the most promising burner from Stage 1 should be tested on the following fuels:

Natural gas at 2 barguage

Butane vapour at 2 bargauge

Heavy fuel oil with assisted atomisation

Special liquid fuels from road tankers

Additionally, the gaseous fuels can be mixed with the following gases from cylinders:

Hydrogen

Carbon Monoxide

Hydrogen Sulphide

Hydrogen Chloride

Nitrogen

Ammonia

Also, consideration will be given to dual firing of liquid and gaseous fuels; e.g., Natural gas and Heavy oil, a common mix used in refineries or any possible combination involving the liquids and gaseous fuels already mentioned.
The criteria whereby burner characteristics and operating performance may be quantified are as follows:

Stage I

1. Ignition characteristics

2. Flame stability

3. Gas to oil change-over characteristics

Stage II

4. Radiative Characteristics

5. Heat transfer rate to the water cooled tubes

6. Combustion Emissions

7. Noise Emissions

8. Effect of Air/Fuel ratio on combustion and emission

9. Effect of ratio of Atomising Steam/ Fuel

10. Burner sensitivity of the atomising steam quality

11. Fuel turndown ratio

12. Effect of air and/or liquid-fuel preheat on combustion characteristics and emissions

13. Evaluation of flame failure devices

14. Maintainability-Ease of routine cleaning

Stage III

15. Burner fouling tendencies

16. Long term reliability

In addition to the performance test, the B.T.R. is intended to provide facilities to improve procedures which are equally important for the successful operation of process heaters.

Closed looped control

Maintenance policies

Refractories test

Computer-aided plant operability analysis

2.1.3 Economic Feasibility

The economic feasibility of the project was evaluated by three different methods explained in 2.1.3.2. All these methods required a cash flow for their application which is described as follows

2.1.3.1 Cash Flow

The cash flow for the B.T.R. was evaluated after the calculation of the Income and Expenditure likely to be during the B.T.R. life. This is shown in Table 2.1.3.1.

2.1.3.1.1 Income from fuel saving

In order to estimate the money which could be saved by the use of the B.T.R., the following assumptions were made:

i) For the year 2000 A.D. new furnaces in the B.P. refineries will count for an extra fuel consumption of 10^6 ton.

ii) The above increase of fuel was considered to increase gradually, i.e. 10^5 tonnes every two years.

Table 2.1.3.1 Cash Flow Calculation

Year	Expenditure	Income	Cash Flow
78	133.5		(133.5)
79	831.5		(831.5)
80	150		(150)
81	150	81	(69)
82		281	131
83		291	291
84		379	379
85		379	379
86		467	467
87		467	467
88		555	555
89		555	555
90		643	643
91		643	643
92		731	731
93		731	731
94		819	819
95		819	819
96		907	907
97		907	907
98		995	995
99		995	995
00		1083	1083

iii) Two percent of this fuel can be saved as a result of selecting more efficient burners on the new furnaces.

iv) New burners on old furnaces can produce savings of £81 X 10^3 for 1981; £193 X 10^3 for 1982; and £203 X 10^3 until the year 2000.

The saving due as a result of the assumptions (iii) and (iv) are shown in the table (2.1.3.1.1)

2.1.3.1.2 B.T.R. Expenditures

The expenditure incurred during the B.T.R. project considered:-

i) The Capital Investment.

ii) The Operating Cost.

2.1.3.1.2.1 Capital Investment

The capital investment of the B.T.R. changed considerably since the first estimation was made in 1976 and the last lump sum price which consisted of the main contractor charges plus additional costs due to three other contracts with the consultants, stack manufacturer and natural gas supplier.

In the table 2.1.3.1.2.A is shown that the final capital investment (lump sum) was more than two times the first estimation carried by the client; the tender price was 26% higher than the final estimation by the client; and the final agreed capital investment was 62% and 28% higher than the final estimation by the client and the first contractor's proposal,respectively.

The client carried out two feasability studies which differed only in the capital investment and were done at the time the contractor was selected and later when the final Lump Sum was agreed. The most significant difference between these two feasibility studies was just 2% difference in DCFRR (2.1.3.2.2). Therefore, only one feasibility study is presented and using the final Lump Sum which is shown in the table 2.13.1.2.1.B including the payment schedule.

2.1.3.1.2.2 Operating Cost

The operating cost of the B.T.R. was carried out under the following assumptions:

i) Five burners were to be tested in one year and 80h were to be employed in the evaluation of each of them.

ii) During the time allocated for each burner, the consumption of fuels and electricity was to be maximum.

iii) The time required for the testing of the L.P.G. and Gas Oil was to be half and a quarter of what was assumed in (i).

By the above assumptions an operating cost was evaluated and on this basis £525,000. were allocated for operating expenditure and distributed in four years as the table 2.1.3.1.2.2.B.

Table 2.1.3.2.2 Calculation of the DCFRR and Profitability Index

	At i = 10%		At i = 20%		At i = 30%	
Year 19XX	DISCOUNT FACTOR	CASH FLOW	DISCOUNT FACTOR	CASH FLOW	DISCOUNT FACTOR	CASH FLOW
78	1.000	(133)*	1.000	(133)	1.000	(133)
79	.909	(756)*	.820	(682)	.769	(639)
80	.826	(124)*	.623	(101)	.592	(89)
81	.751	(52)*	.554	(38)	.455	(51)
82	.683	89	.456	60	.350	46
83	.621	181	.377	110	.269	78
84	.564	214	.312	118	.207	78
85	.513	194	.258	98	.159	60
86	.466	218	.214	100	.123	57
87	.424	198	.178	83	.094	44
88	.386	214	.149	83	.073	41
89	.350	194	.124	69	.056	31
90	.319	205	.112	72	.043	28
91	.290	186	.093	60	.033	21
92	.263	192	.078	57	.025	18
93	.239	175	.065	48	.020	15
94	.218	179	.054	44	.015	12
95	.195	162	.045	37	.012	10
96	.180	163	.038	34	.009	8
97	.164	149	.031	28	.007	6
98	.149	148	.026	26	.005	5
99	.135	134	.022	22	.004	4
00	.123	133	.018	19	.003	3
$\sum$ Exp and Inc.		2263		214		(327)

* Capital Investment at 10% = 1065

Table 2.1.3.1.2.1.A Capital Expenditure at different stages of the project and payment in time

Stage	Year	Capital Expenditure £	Increase Related to %		
			First Estimate	Final Estimate	First Lump Sum
First Estimate	1976	393,000	-	-	-
Final Estimate	1977	549,000	140	-	-
Tender Price	1978	692,000	176	126	-
Lump Sum	1978	890,00	226	162	128

Table 2.1.3.1.2.1.4 Variation of the Payment Schedule

	Capital Expenditure £	Payment Schedule % at		
		1977	1978	1979
Tender Price	692,000	5	80	15
Lump Sum	890,000	-	15	85

2.1.3.2 Method to Evaluate the Project Feasability

The economical feasibility of the B.T.R was evaluated by

i) Payback Time

ii) Discount Cash Factor Rate of Return

iii) Profitability Index

2.1.3.2.1 Payback Time

All the incomes and expenditures incurred during a period of time (this case 20 years) are shown in a cash flow manner so that the payback time correspond to time when income cancel the expenditure of the project Fig.2.1.3.1.

Total Expenditure:	1184
Total Income for the eighth year:	1180
PAYBACK TIME	8 years

2.1.3.2.2. Discount Cash Factor Rate of Return

This method finds an interest rate for the period of effectivity of the B.T.R. (t = 20 years) at which the sum of all the incomes and expenditures turn Zero. Table 2.1.3.2.2.

A first interest rate is assumed

$i = 20\%$ $\qquad \sum$ Exp. and Inc. = 214

A second interest rate is assumed

$i = 30\%$ $\sum$ Exp. and Inc. = - 327

The interpolation for $\sum$ Exp. and Inc. of these two values resulted in

$i = 24\%$

So the DCFRR = 24

2.1.3.2.3 Profitability Index

A cash flow for an interest rate of 10% is made. Then, the ratio between:-

$\sum$ Exp. and Inc. (N.P.V of the real net cash flow discount at 10%)

and

$\sum$ Exp. (N.P.V of the real capital investment discount at 10%)

corresponds to the profitability index:

$$\frac{\sum \text{Exp. and Inc.} = 2263}{\sum \text{Exp.} = 1065} = 2.1$$

Profitability Index: 2.1

Table 2.1.3.1.2.2.A Operation Cost

Energy Used	Time[1] h.	Maximum Consumption Therm/h	Cost £/Therm	Cost[2] £
Natural Gas	400	325	.17	34000
Fuel Oil	400	210	.13	11000
Gas Oil	100	210	.14	3000
L.P.G.	200	210	.16	7000
Electricity	400	(Kw) 250	22.2	76000
Total				131000

Table 2.1.3.1.2.2.B Distribution in time of the running cost

	1979	1980	1981	1982
Running Cost X 10^3 (£)	75	150	150	150

1 Assuming five burners per year; allocating 80 h/burner; LPG and Gas Oil were to be burned only half and quarter time of the allocated period.

2 The running cost assigned was £525,000.

Table 2.1.3.1.1 Incomes for fuel saving
due to (iii) Instalation of new furnaces
(iv) Revamp of old furnaces

		New Furnace	Revamping Furnaces
Year 19XX	Fuel Cost (£10^6)	2% Fuel Saving (£10^3)	Fuel Saving (£10^3)
81			81
82	4.4	88	193
83	4.4	88	203
84	8.8	176	203
85	8.8	176	203
86	13.2	264	203
87	13.2	264	203
88	17.6	352	203
89	17.6	352	203
90	22.0	440	203
91	22.0	440	203
92	26.4	528	203
93	26.4	528	203
94	30.8	616	203
95	30.8	616	203
96	35.2	704	203
97	35.2	704	203
98	39.6	792	203
99	39.6	792	203
2000	44.0	880	203

2.2 Contract

Once B.P. decided to carry on with the project a meeting was organised in order to define certain factors which were to characterise the construction of the B.T.R. project. These factors included selection of the tendering contractors (2.4.1) and the tendering conditions which included the type of contract and time schedule of the significant events in the future life of the B.T.R.

2.2.1 Type of Contract

The type of contract affects the time schedule of the significant events in a project and vice-versa. Therefore, the decision to complete the construction of the B.T.R. in one year was to depend on the type of contract chosen.

The B.P. contract division recommended that the contract should be of a lump sum type which gives the contractor real incentive to perform and thus achieve the earliest possible completion date. The contract division recommendation was approved, therefore it required the writing of a sufficiently firm plant specification (excluding the chimney) on which to seek lump sum bids.

The Final Specification (2.3.2) required for a lump sum contract was issued from the Original Proposal (2.3.1) five months later. Therefore, the non-reimbursible B.T.R. contract was committed five months later than if a reimbursible contract would have been used.

The lump sum form of contract imposed the discipline on the B.P. personnel to make firm decisions at an early stage. This avoided variations (Clause 13 of the B.T.R. Contract General Conditions) after contract award.

2.2.2 General Conditions of the Contract

Although "The General Conditions of the B.T.R. Contract" issued by B.P. are referred to the B.T.R. project, the generality of the clauses were maintained. Therefore, the B.T.R. general condition clauses can be compared with those issued by the Institute of Chemical Engineering [I.Che.E.(1)]. This comparison resulted in the classification of the clauses in five sets and finding similar clauses between the B.T.R. and I.Che.E. (Appendix 1) General Contract Conditions. This similarity is shown by the clause numbers respectively.

The first set of clauses refer to the position of the parties in relation to available definition and information.

Definition of Terms	(1)	(1)
Patent, Right, etc.	(7)	(7)
Statutory and other Regulations	(6)	(6)
Arbitration	(34)	(47)
Force Majeure	(35)	(43)
Confidential Information (19)	(41)	(19)
Law (2)	(44)	(2)
Extraordinary Traffic	(38)	-
Metrication	(39)	-
Safety Audit	(40)	-
Taxes, Custom	(42)	-

The second set of clauses describe the responsibilities of the purchaser and defines his rights in relation to the contractor.

Engineer Supervision	(8)	(10)
Engineer Representative	(9)	(10)
Engineer Decision	(11)	(45)
		(16)
. Assignment and Subletting	(6)	(8)
Variations and Omissions	(13)	(16)
Contractor's Default	(14)	(41)
Purchaser to terminate contract	(36)	(42)

The third set of clauses establish general rules in the form of payment to the contractor and the way the contractor could be liable for payment of liquidated or unliquidated damages.

Contract Price Variation	(12)	(18)
Term of Payment	(32)	(39)
Contractor Liability	(31)	(44)
		(36)
Contractor Negligence	(20)	-
Liquidate Damage	(27)	(15)
Bankrupcy	(15)	(1)
Insurance of Works	(30)	(32)

The fourth set of clauses see the proceedures before and during the installation.

Documents	(2)	(12)
Contractor to Inform Himself	(3)	-
Drawings	(4)	(20)
Mistake in Drawings	(5)	(21)
Vesting of Plant	(21)	(25)
Delivery of Materials	(17)	(24)
Inspection and Testing	(16)	(22)
Manner of Execution	(10)	(3)
Erection	(19)	(3)

Delayed Plant	(18)	(14)	
Extension Completion Time	(28)	(14)	
Suspension of Works	(29)	(13)	

The fifth set of clauses define and assign responsibilities before and after the hand over occurs.

Defect prior taken over	(22)	(36)	
Test Completion	(23)	(35)	
Commissioning	(24)	(33)	
		(34)	(37)
Final Certificate	(25)	(38)	
Defect after taken over	(26)	-	

2.3 Client Specifications

The "Final specification" resulted from improvement and addition to the "Original Proposal" (BTR Technical Specification, which was drafted in November 1977. These specifications are described below in a rearranged short version.

2.3.1 Original Proposal

2.3.1.1 Furnace System

i) Chamber to be similar in design to refinery heaters.
ii) Total heat release from test burners.
iii) Internal dimension of the B.T.R. chamber.
iv) Floor Chamber to be removable for burner changes.
v) Chamber not to leak at 5 mbar positive pressure.

2.3.1.2 Cooling Water System

i) Heat absorption rate by cooling coils.
ii) Minimum inlet temperature of cooling water.

2.3.1.3 Combustion Air System

i) Combustion air rate and turn down ratio (10:1).
ii) Combustion air fan discharge pressure and temperature.
iii) Air preheater which supplies air in a range 100/400°C.

2.3.1.4 Fuels System

i) Physical properties of fuels and conditions at the burner.
ii) Natural gas reduction to 0.5 barg.
iii) Recompression of natural gas to 20 barg.
iv) Provision for mixing other gases with natural gas.
v) Liquid fuel storage tank capacities, steam heated.
vi) Atomising steam pressure and flowrate.

2.3.1.5 Instrumentation and Control

2.3.1.5.1 Instruments to be located in the Control Room

i) Flow metering of fuels, air and steam.
ii) Temperature measurement of the following:
Cooling water from cooling town and pressurised water cooler.
Inlets of air into FD fan and burner.
Liquid fuel, steam, flue gases, inlet and outlet of cooling water at the furnace.
iii) Pressure measurement of the following:
Wind box base and furnace arch.
Across the stack damper.
Pilot and main natural gas supply, pressurised cooling water into and out of the furnace.
Liquid fuels at pump and at burner.
Atomising steam at vaporiser and at burner.

iv) Miscellaneous monitoring:
Oxygen analyser and smoke measuring device at the flue duct.
Provision of repeated signals from some instruments for data logging by computer in the future.

2.3.1.5.2 Variable to be controlled

i) Motorised Control Damper.
ii) Water inlet temperature to furnace coils and pond cooling tower temperature.
iii) Combustion air temperature and flow rate
iv) Natural gas pressure to main and pilot burners.
v) Liquid fuel viscosity, pressure and storage temperature.
vi) Atomising steam pressure with respect to the fuel oil pressure.

2.3.1.6 Safety Systems

2.3.1.6.1 Heat Off

This circuit was to shut off to safety all the fuels to the furnace, tripped by the following states:

i) Manual switches; at the control room and at each furnace level.
ii) Flame failure of pilot and main burners.

iii) For the furnace cooling water; low flow, low pressure and high furnace outlet temperature.

iv) For the combustion air; low flow and power failure of F.D. fan.

v) For the fuels supply; low flow or pressure of pilot and main gas and liquid fuels.

2.3.1.6.2 Emergency Shut-Down

This circuit was to be tripped by hand switches which were to be located as those in "Heat Off".

The emergency shut-down was to:

i) Shut off all the fuel supplies.

ii) Stop the compressor, F.D. fan and liquid fuel pumps.

iii) Cause control valve to "fail safe" in the fuel supply lines and cooling water loop.

2.3.1.6.3 Additional Interlocks

Apart of the above systems the following interlocks were to be included:

i) Airpreheater heat off. This circuit was to shut off the natural gas supply to the airpreheater, tripped by the following faulty states:-

Low flow or pressure of main gas supply
Flame failure of pilot or main burners

ii) Fuel Oil shut down. This circuit shut off the fuel oil supply to the furnace if the atomising steam pressure or flow was low.

iii) Oil Tank steam heating off. This circuit shut off the steam heating to a liquid fuel storage tank if the liquid level was low.

2.3.1.6.4 Alarms

All the above events were to be signalled by an audible alarm.

2.3.1.7 Miscellaneous Provisions

General

i) Control Room, boiler house, compressor house, etc.

ii) Acoustic shielding of all equipment.

iii) Communication system between B.T.R. and control room.

iv) Oil water separator.

Furnace

v) Multiflue chimney stack (subject to separate tender).

vi) Burner transporter-lift.

vii) Close circuit television camera with monitor in the control room.

viii) Support and cooling water supplies for sampling probes.

ix) Access platforms with stairways around the furnace.

x) Drained concrete surface below the furnace.

2.3.2 Final Specification

The second and final B.P. specification for the B.T.R. was issued in March 1978. This specification together with the latest version of B.P. Engineering Practice and U.K. and local laws related to this installation, were issued to the contractors as the basic documents on which to tender. In case of conflict, the General Engineering specification set the following priorities:

i) Statutory Requirements
ii) The Final Specification
iii) B.P. Engineering Practice
iv) Special Engineering Codes

The final specification was much more comprehensive than the original proposal and was divided into five main parts:

1. General
2. Site Information
3. Technical Specifications
4. General Engineering Specifications
5. Sectional Engineering Specifications

2.3.2.1 General

This consists of eight sections which establish the scope of the specification and give the general policies to be followed by the contractor, i.e.

Scope.

Design Policy (Operation, overhaul, pollution, electrical drives, water as a main cooling medium, control instrument housed in a building and battery limits).

Design Practice (B.P. Engineering Practices, Standards and Drawings).

Guarantees.

Alternatives; and Departure from Specification.

Commissioning.

2.3.2.2 Site Information

This describes the site and provides soil, meteorogical and utilities data; In addition, conditions of site contracts are listed as follows:-

Require visit to site prior to tendering.

Use of path and road.

Damage.

Security.

Safety.and care of work.

Working hours and overtime.

Welfare.

Lavatories.

Water and Electricity and Clear away.

2.3.2.3 Technical Specification

This third and most important part of the final specification contains the description of the plant required by the client. It consists of ten sections which are rearranged and summarised below in eight sections.

1. General
2. Furnace System
3. Cooling Water System
4. Combustion Air System
5. Fuel Supply System
6. Atomising Steam System
7. Control and Instrumentation
8. Safety Circuits

2.3.2.3.1 General

The general technical requirements were:

i) Simulated fire box of typical refinery process heater fitter with upshot fired burners.
ii) Test work to be on forced burners; but the furnace and stack shall be suitable for natural draught burners.
iii) A range of gaseous and liquid fuel are to be burnt.

iv) The furnace fuel and combustion air system to meet the requirements of the B.P. fired heater engineering practice.

2.3.2.3.2 Furnace System

2.3.2.3.2.1 Process Design

This section establishes the data to be met by the contractors in the design of the furnace, flue duct and damper.

i) The firebox was to be square (3 X 3) m X m and with a minimum height of 9 m. The exact measures were to be determined by the contractor using the process data shown below.

ii) When the heat release of a single burner with 10% excess air, is 5860 KW, the operating and design temperature at the furnace arch was due to be 760°C (1400°F) and 1100°C (2032°F) respectively.

iii) When natural draught burners are being tested, at the heat release of 110 per cent of 5860 KW with 50% excess air, the draught at the floor of the firebox was not to be less than 1.25 mbar.

iv) When firing with forced draught at the maximum firebox outlet temperature, the draught at the furnace arch was to be not less than 0.25 mbar.

2.3.2.3.2.2 Mechanical Design

The firebox (3M X 3M X 9M) with horizontal cooling tubes and two different type of refractories as described below under the following heading:

1. Firebox and Structure
2. Refractories and Installation
3. Cooling Tubes
4. Ducting and Damper

2.3.2.3.2.2.1 Firebox and Structure

i) Floor
   a) Able to support a 2 tonne burner.
   b) Be 3 M above the ground.
   c) Removable section of (1.22M X 1.22M).

ii) Observation, Measurement and Maintenance
   a) Hermetically sealed part and sampling points of location to be agreed.
   b) Access to all viewing parts by a platform interconnected by stairways.
   c) Access door to firebox.

iii) Furnace Structure
   a) Stiff enough to prevent vibration.
   b) Furnace and ducting up to the control damper to withstand the maximum force of the fan when the damper is fully closed.
   c) Fireproofing of the furnace supporting structure up to but not including the floor beams.

d) Leak test of the firebox by smoke release at 5 mbar.

e) Weather protection for personnel working on the furnace platforms.

2.3.2.3.2.2.2 Refractories and Installations

i) Insulation of furnace walls and roof with special ceramic fibre, Pyroblock.

ii) Wear resistance refractory brick for the floor.

iii) Lining up of the exit flue duct up to the stack flange.

iv) External or internal insulation of the preheated combustion air ducts.

v) External maximum temperature of the insulated surfaces to be 65°C ambient temperature.

2.3.2.3.2.2.3 Cooling Tubes

i) Minimum diameter of the horizontal cooling tubes, 100 NB.

ii) Distance between centre tubes, 2 X D.

iii) Distance between centre tubes and surface of refractory wall, 1.5 X D.

iv) Cooling tubes material according to B.P. Fired Heater Engineering Practice.

v) Cooling tubes to be easily replaced, unsupported in the firebox and connected to external header boxes.

vi) Header boxes, flanges and covers must be stiff enough to resist warping in use.

2.3.2.3.2.2.4 Ducting and Damper

i) The furnace pressure to be controlled by a damper, whose movement can be altered by means of a cable winch operated from grade level.

ii) The damper to be easily removed and a ladder to be provided to facilitate the operation. For flue gas temperature greater than 980°C the damper is to be removed.

2.3.2.3.3 Cooling Water System - Process Design

i) A closed cooling water with a maximum heat removal of 4400 KW.

ii) The system was to be pressurised by nitrogen and the minimum water temperature at the inlet of the furnace coil is 140°C.

iii) Adequate provision for operation in freezing conditions.

2.3.2.3.4 Combustion Air System - Process Design

i) Air to be supplied by natural or forced draught.

ii) When the condition of the air supply at the burners are 60 mbarg and 400°C, the flowrate of air was to be 200 S C M M (max) when ambient temperature at 20°C.

iii) An air preheater to be provided to raise the temperature of air from 15°C to a range of 100-400°C. This preheater can be directly or indirectly fired, using natural gas as fuel.

iv) Air flow was to be controlled pneumatically by a flow control damper at the forced draught fan inlet or outlet (according to fan characteristics).

2.3.2.3.5 Fuel Supply System - Process Design

i) Natural gas was to be supplied from the Local Gas Board. The pressure of the natural gas was to be reboosted from 0.03 mbarg at the plant limit to 2 barg at the burner.

ii) A blending drum of 35 L (approx.) capacity was to be provided, having six inlets, four of which were to have flow indication.

iii) The pilot burner was to be supplied with natural gas only and its pressure was to be controlled at 0.375 barg having a heat input of 20 KW (approx.).

iv) The L.P.G. was to be provided from a tank whose capacity was not to be less than one tonne.
Also a steam vapouriser unit was to be installed.

v) Liquid fuels were to be provided from one of three horizontal storage tanks as detailed.
Two heated tanks of 6,000 gall.
One unheated tank of 3,000 gall.

vi) Fuels properties shown in tables 2.3.2.3.5 A & B.

2.3.2.3.6 Atomising Steam System - Process Design

Table 2.3.2.3.5A Liquid Fuels Properties

PROPERTY		HEAVY FUEL OIL	GAS OIL
Specific Gravity at 15°C/15°C		0.95-0.98	0.84
Viscosity at 50°C	cSt	120-600	say 2
Sulphur	% Wt	up to 6	up to 1.5
Flow (L/hour)	min	68	10
	max	545	545
Pressure at burner (barg)	min	1.5	1.5
	max	10.3	10.3
Viscosity at burner (cSt)	min	10	-
	max	80	-
Storage Temperature (°C)	min	50	-
	max	80	-
Calorific Value (MJ/Kg)	gross	42.9	45.6

Table 2.3.2.3.5B Gaseous Fuel Properties

PROPERTY		NAT.GAS	BUTANE
Relative density (air=1)		0.59	2
Calorific value (MJ/m^3)	(gross)	38.62	117.75
Heat Input (Kw)	(max)	5860	5860
Pressure at burner (barg)	(max)	2.0	2.0

i) Atomising steam with 50°C of superheat to be provided from an onsite gas fire steam generator.

ii) Steam required at 10 barg is 295 Kg/h (max). However, if the incremental cost for the steam generator rated at 21 barg is small, this was to be provided.

2.3.2.3.7 Control and Instrumentation

i) Instrumentation and Control was described in the 2.3.1.5 and complemented by 4.2.1.1.

ii) The exact physical location was to be agreed.

iii) Flame monitoring by close circuit T.V.

2.3.2.3.8 Safety Circuits

2.3.2.3.8.1 Heat Off

This circuit was to shut-off all main fuels supplies to the furnace and the air preheater, and was to be initiated by:-

i) Manual switches at the control panel and at every access level on the furnace.

ii) Failure of main burner flame.

iii) Extra high temperature at outlet of furnace coil.

iv) No rotation of the F.D. fan.

v) Extra low pressure on the natural gas main supply to test burner.

vi) Extra low pressure in the fuel oil supply to the test burner.

2.3.2.3.8.2 Emergency Shut Down

This circuit was to:

- i) Activate the Heat Off.
- ii) Shut down all rotating machinery.
- iii) Shut down all the pilots.
- iv) Fail safe all control valves and it will be initiated by:
  - a) Manual switches located as the Heat Off switches
  - b) Failure of the Unit Power Supply.

2.3.2.3.8.3 Additional Interlocks

In addition to the "Heat Off" and "Emergency Shut Down" the following safety circuit systems were to be provided:-

1. Pilot Heat Off. All fuels to test burner were to be shut-off on extra low pressure of the burner pilot gas gas supply system.

2. Fuel Oil Shutdown. Liquid fuels supply to the main test burner was to be shut off on extra low pressure of the atomising steam.

3. Air Preheater Heat Off. The main and pilot gas supply to the air preheater was to be shut off on:-
   - i) Extra low gas supply pressure
   - ii) Flame failure of either main preheater burner or its pilot

2.3.2.3.8.4 Alarm and Annunciator

The above safety systems Heat Off, Emergency Shut Down and Additional Interlocks were to activate an annunciator in the control room and an 'Emergency Alarm'; while the conditions below were to activate also an annunciator but an "Urgent Alarm".

Furnace System

i) Excessive smoke.
ii) Pilot flame failure only.

Cooling System

i) High water temperature at inlet to the furnace water cooling tower.
ii) High water temperature at the outlet from the furnace cooling coils.
iii) Low flow in closed cooling water system.

Combustion Air System

i) Low combustion air flow.

Natural Gas System

i) Low natural gas pressure in furnace main.
ii) Low natural gas pressure in furnace pilot and/or
iii) Low natural gas pressure in air preheater main.
iv) Low natural gas pressure in air preheater pilot

Fuel Oil - Atomising Steam System

i) Low Fuel oil and atomising steam pressure in the pipelines to the furnace.

2.3.2.3.9 Miscellaneous Provisions

i) The connection of lines to the burner was to be by means of flexible tubing to C.E.G.B. Standard 2391.

ii) A mobile burner transporter and lifter was to be provided for the installation and removal of test burners.

iii) Site compressed air was to be supplied to each platform.

iv) Socket (110V AC, 5Hz, 20A) was to be provided adjacent to each sampling point.

2.3.2.4 General Engineering Specification

In this part is given general requirement and mechanical specification which shall be met by contractor during the tendering and after the contract has been awarded. It covers Standards, Codes of Practice, Language Nomenclature, Units, Safety and Welding.

The section on codes and standards reiterates the order of priorities, in the event of conflict between B.P. Standards and National or Statutory Standards. It gives a comprehensive list of all relevant B.P. Standard Codes and Standard Drawings. The rest of the mentioned sections refer to the appropriate B.P. standard. In this part is also included, Document Required with Technical Proposal, Works Inspection Procedures and Building for Control and Steam Generator Plant.

2.3.2.5 Sectional Engineering Specification

This part describes specific requirements and mechanical details of the additional equipment, accessories and the equipment already described in Part 3 of the specification. It includes the following sections:-

1. Utilities Available
2. Noise Level Permitted
3. Civil Engineering Work
4. Structural Steel Work
5. Drainage Systems
6. Unfired Pressure Vessels
7. Heat Exchanger Equipment
8. Rotating Machinery
9. Piping Systems
10. Thermal Insulation
11. Pressure Relieving System
12. Firefighting
13. Electrical Work
14. Instrumentation
15. Tankage
16. Painting

The B.P. specification, in addition to the five main parts already described, includes figures, drawings and appendices.

Figures

In this specification is included a figure of a typical panel layout and a typical alarm panel module.

Drawings

It also included the following four drawings:-

General layout of the B.P. Research Centre.

Plot plant of the site.

Flow Diagram - Refinery Burner Test Rig.

Approximate Major Parameters - Refinery Burner Test Rig.

Appendix

The appendices are as follows:-

Standard for Positive Displacement Pumps.

Specification for Painting.

Report on Soil Conditions.

2.4 Tendering

This section describes the main events during the tendering period as well as the relevant features of the tenders presented.

A review of the "Technical Specification" of the Client, an d participating Firms is described in table 2.4.4. This is followed by a sub-section "Furnace Detail Process Design" section which aims to the evaluation of the design parameters of the furnace and it is based on the theory descibed in the "Literature Survey" (1.2.3) and the calculations presented in Appendix 5.

2.4.1 Description of Tendering Period

Before the issue of the final specification, BP had alread investigated the possible contractors, and the following list of companies in order of preference was produced:

Firm Z

Firm C

Firm A

Firm X

Firm Y

Firm U

They were contacted and invited to tender on a lump sum basis, but two of them wished to tender for the plant solely on their terms. This was unacceptable to BP and only four contractors remained.

The conditions of contract and instructions for tendering together with the BP Plant Specification for the rig and all relevant documents were sent on the 20th March 1978 to those contractors who had confirmed their interest in tendering on a comprehensive lump sum basis; namely Firms C, A, X and U. Subsequently, Firm U requested to be excused from presenting a bid as they were committed with other obligations, and Firm X redirected the documents to their sister company, Firm W. These changes were accepted by BP.

A dead-line date for submission of tenders was set at a month later, but this was extended at the contractors' request for an extra month. The financial section was allowed still an extra week to be handed in.

2.4.2 General Description of the Tenders

The general layout and content of the tenders presented is explained below in order to facilitate the description of the comparison between tenders (2.4.3).

Also this subsection can be considered as a recommended layout and content of a tender.

The content of the tender can be divided into three parts:

- Financial
- Constructional
- Technical Specification

2.4.2.1 Finance

This part includes the final agreement by which the parties will be bound into a contract. This agreement, the "Form of Tender" includes the scope of the work, contract documents, contract price, analysis of tender, completion time, etc. According to the degree of changes in "The General Conditions of the Contract" introduced by the contractor. It will be necessary to add or not an extra part which explains the recommended conditions of the contract.

The part will include an "Analysis of the Tender" which shows how the total contract price is allocated to the following works: Design; Drawings and Specification; Procurement and manufacture of plant and all the accessories with all the services (including precommissioning); civil works (building, drains, paving, etc.); and Commissioning of the plant and all accessories. The variations recommended by the client or the contractor are listed after the analysis of the tender. They will be accompanied by a Lump Sum price which is the contractor's estimated cost to carry out the variation.

Finally, it is added some extra information of general features; for example, Insurance, Project Management Organization, etc.

2.4.2.2 Construction

This part explains, firstly the resources required in the construction and installation of the plant; secondly, the distribution of human resources during work; and thirdly the methods for planning and recording of progress.

The resources required are listed under the following categories:

Labour Force, Supervision Staff, Contractor's Heavy Equipment and Material for use in the civil work.

These lists also show the corresponding rate prices for each participant item involved, so that by a formula to be agreed (e.g., Beama) can be possible to determine the escalation of cost regarding the construction and installation of the plant.

The numbers comprising the Labour Force and Supervision Staff available or required at any time during the works are shown in histograms. They are commonly known as Supervision Staff and Labour Force Schedules.

The planning of the progress of the project is based on the critical path program concept, which should be prepared and updated manually throughout the Project Engineering Phase.

A bar diagram should be prepared covering all aspects of the project including design, procurement, construction and commissioning. These are set on the vertical co-ordinate and the horizontal co-ordinate is usually shown in weeks. Then, a time and a date of completion is assigned to each activity and placed on the diagram, which, after applying the same procedure for the rest of the activities, will eventually display the planned progress of the project. The constructional part may include also lists of subcontractors proposed by the contractor, possible equipment manufacturers, etc.

2.4.2.3 Technical Specification

This part of the tender is the equivalent to the client's technical specification. It describes the plant to be installed but with the difference that the tender will develop the preliminary information supplied by the client's specification; consequently the description of the plant in the tender is likely to complement that already given in the Specification.

In general, the technical part of the tender evolves as explained above; but there are cases where evaluation of alternatives is neceesary or the design philosophy of a system is inadequate. For the latter, the contractor has to consider the system from its conception up to the details necessary to define it.

As in the client specification, this part has a section for each of the systems that form the plant. Also it includes sections which consider specific activities such as Civil Work, Electrical Works, Instrumentation, Piping Work, Effluents, Noise, Utilities, Spare parts, etc.

Drawings were not physically included in the technical part because of their bulk. However, they are absolutely essential in presenting an unambiguous contractor's technical proposal.

Appendices were used to include parameter calculations for the design of the equipment and the assembling of the systems.

2.4.3 Particularities of the Different Tenders

It is described below the main features of the financial and technical parts of each one of the tenders presented.

2.4.3.1 Firm A Tender

The Firm A tender was presented in three separate volumes classified as Financial, Technical and Constructional.

2.4.3.1.1 Financial Volume

The first volume contains the analysis of the tender which is broken down as follows:

21.37% for Design, Drawings and Specifications, 53.85% for Procurement and Manufacture of Plant and all accessories, 21.76% for Erection of Plant and all accessories with all services, and 0.0967% for Civil Works and Commissioning. These percentages are of a total contract price of £1,109,000. The completion time quoted was seventy-five weeks. This is explained by the contractor as follows. Six extra weeks are required for redevelopment Heat and Mass Balance, the Engineering Line Diagram and further considerations of noise, health and safety, etc. In this schedule the definition of the Natural Gas Compressor and Combustion Air Blower were at the end of the process development stage and their deliveries take ten or nine months respectively; so they were to be finally installed at the 12th and 13th month of the project.

The financial volume also includes corrections and different interpretations of "The General Conditions of the Contract" given by BP and this extends to an extra set of conditions.

2.4.3.1.2 Technical Volume

The technical volume contains description of the BTR systems but their description is that described in the client technical specification, with minor extensions. Details like nominating subcontractors and equipment is not stated and, although a very detailed policy for the engineering of the instrumentation is described in the technical volume, no reference is made to any system in particular.

2.4.3.1.3 Firm C Tender Review

The overall strategy of this contractor was to concentrate his effort on the design of the furnace and to set a general background for the rest of the plant, upon which to base further redevelopment. The long completion time (72 weeks) was to accommodate the development of details of the ancillary equipment and their delivery and to carry a complete study of the noise level.

2.4.3.2 Firm W

This tender was presented in four volumes: Financial, Constructional, Technical and Drawings.

2.4.3.2.1 Financial Volume

The financial part contains the contract price (£1.3 x 10^6) and the completion time, 52 weeks. Also, it proposed six ways to reduce the contract price which are listed below:

i) Reduction of the furnace size with a drop of 20% in its cost.

ii) The coil to be preassembled before being installed in the furnace.

iii) Change the refractories proposed to a cheaper one which can equally match the operating conditions.

iv) Higher temperature at the furnace cold face.

v) Forced draught air cooling instead of water cooling for the process fluid which comes out of the furnace coil.

vi) Direct air preheater instead of the indirect air preheater.

2.4.3.2.2 Technical Volume

The technical volume of this tender is well structured and complete. It is divided into sections which may be classified as follows:

Design Philosophy, Technical Performance, Technical Description, Data Sheet, Calculations and Specification.

Design Philosophy

This is an introduction section which summarizes the main consideration in the design of the different parts of the systems.

Furnace
Discussion of the method used in the calculation of the furnace size.

Stack
Refractory ring which reduces the chimney to 900mm may be installed to reduce the possibility of temperature inversion or down wash.

Cooling System

Consideration to the possibility of subcooling.

Steam overpressure rather than N_2 overpressure using an electric heater immersed in the pressuriser. This would eliminate the possibility of pump cavitation and the chance of N_2 coming out of solution in the furnace tubes, which could result in the onset of accelerated fire-side corrosion.

Blowdown cooling system.

LPG Storage

Considers the maximum consumption of LPG for the testing of a burner. Thus testing a burner in two weeks will consume LPG equivalent to approx.3 tonnes.

In order to allow for maintenance of a tank and considering the safety requirement and the area available, the storage system proposed is 4 tanks, each of 1 tonne capacity separated by 1.5m and 7.5m from any equipment and ignition source by 1.5m and 7.5m, respectively.

Plant Performance

This section presents a schematic review of all the conditions stated in the BP Specification.

Technical Description - Data Sheet - Calculations.

This information is located in different sections of the technical volume of the ---Firm W----- tender. The first describes the systems, emphasizing the most relevant features while the second presents the data sheet for almost all the equipment of the different systems, and the third contains a series of calculations which include detailed calculation for the following equipment or systems:

Furnace
The furnace size by five different methods, namely, Basic and Modified Lobo, McAdams Proposal, Babcock & Wilcox and Perry.

Stack and Flue duct.

Air Preheater.

Cooling System.

2.4.3.2.3 Firm W Tender Review

The elaboration and extension of details by Woodall-Duckham in their tender and their high contract price were signs of the type of plant they envisaged; that is, engineered with considerable attention to detail. This assessment was communicated to ---Firm W------, who proposed as a solution to change the contract from Lump Sum to Turn Key. Although this gives the client better control over the contract price, it is not very efficient in checking the tendency to over engineering and besides BP had decided that a lump sum contract would be most appropriate in order to ensure a fast and efficient erection of the BTR. Therefore, after looking at all the above, consideration of the ----Firm W----- proposal was discarded.

2.4.3.3 Firm C Tender

The content of this tender is presented in one volume with attached drawings. The text is divided into the typical sections; Financial, Constructional and Technical.

2.4.3.3.1 Financial

In the financial section a contract price of £711,012 is quoted and analyse as follows: Design, Drawing and Specifications 6.31%; Procurement and manufacture of the plant and all the accessories (ex Works) 61.91%, Delivery to site on erection of the plant and eleven accessories with all services including precommissioning 19.76%; Commissioning of plant and all accessories based on five days attendance of GKN Birwelco Commissioning Engineer and subcontractors' specialist and civil work including building, paving, drains, etc. 8.24%; Spare parts recommended for 2 years operation as itemised on an separate list 3.77%.

The completion time proposed by ---Firm C--- was that required by BP, 52 weeks.

2.4.3.3.2 Technical Specification

The technical part of this tender is not as detailed and extensive as the ---Firm W----- tender, but it covers all the different systems forming the BTR and describes them all in sufficient detail. The following recommendations were included:

Furnace
The furnace box is bigger than that recommended by the BP Specification; also, the coil surface area was enlarged by 80%. These features are provided without incurring additional cost to the basic Firm C ---- contract price.

Air Cooler
An air cooler rather than cooling tower is proposed as a better alternative on space and economy reasons.

Air Preheater

Indirect fired preheater, despite the installation requiring more space and costing more than a direct fired preheater. Firm C ---. pointed out that these penalties are compensated by the fact that this alternative is more compatible with the objectives of the BTR.

Storage Tanks

Vertical storage tanks for Oil and LPG were recommended subsequently, including:

- A new layout for the storage facilities and alterations for the rest of the plot diagram.
- Bigger capacity of LPG: two 5 tonne tanks of 2000 gallon capacity.

Fuel Oil System

The fuel oil system described in the BP specification was recommended to be modified by adding a ring main system in order to have more stable conditions of the oil at the burner and improving the oil burning efficiency.

2.4.3.3.3 Firm C Tender Review

The ---Firm C--- tender complies with all the requirements of the BP Specification; it shows good understanding of the objectives of the BTR and its recommendations were very reasonable. These features of the Firm C tender, and the fact that it was the lowest contract price quoted, resulted in BP awarding the contract to Firm C (Table 2.4.3.3.3).

Table 2.4.3.3 Relevant Factors in the Selection of the BTR Tender

	BP	A	B	C
Furnace Internal Dimension m X m X m	3x3x9	3x3x8.8	3.2x3.2x9.6	3x3.66x10
Completion Time (weeks)	52	76	52	52
Contract Price ($X£10^6$)	0.69	1.10	1.30	0.70

The system detailed process design is considered as the compilation of the following concepts.

i) Operation Data as the complementary operating conditions to the system parameter defined above.

ii) Partial Mechanical Data as key mechanical data in the definition of the system.

iii) Accessories as important secondary equipment of the system.

Finally, the detailed engineering of the system is considered as:

i) Plant layout which considers the physical location of the major equipment in the system.

ii) Detailed drawings which considers the detail drawings of the major equipment in the system.

iii) Detailed mechanical data of the equipment of the systems.

2.4.4 Technical Specifications Presented During the Tendering Period.

The client specification and tenders "Technical Specification of the BTR Systems" were tabulated (Table 2.4.4) in a way that their completeness can be evaluated and compared.

The BTR System Technical Specification was divided as the generally accepted format use to define major equipment specifications.

Process Design

Detailed Process Design

Detailed Engineering

The process design specification is considered as a compilation of the following concepts.

i) Design Philosophy as the general approach in the design of the systems.

ii) System Synthesis as the proposal of a feasible alternative system/major equipment.

iii) System Parameter as the completeness of the operating key conditions which defined the system/major equipment.

iv) Technical Description as the completeness in system description.

v) Flow Diagram as the completeness of the system in being represented in the flow diagram.

TECHNICAL SPECIFICATION		FURNACE SYSTEM				COOLING WATER SYSTEM								COMBUSTION AIR SYSTEM								NATURAL GAS SYSTEM				DOSING GASES SYSTEM (H_2,Cl_2,CO,H_2S)			
		A	B	C	BP	A		B		C		BP		A		B		C		BP		A	B	C	BP	A	B	C	BP
						Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Indirect	Direct	Indirect	Direct	Indirect	Direct	Indirect	Direct								
PROCESS	Design Philosophy																												
DESIGN	(Problem Definition)	/	/	/	/	/	/		/		/	/	? ?					/		?		/	/	/	/ ?	/	/	/	/
	(Alternative Process)																												
	System Synthesis	/	/	/	/																	/	/	/	/	/	/	/	/
	System Selection Parameter of the system	/	/	/	/	/	/	/	/	/	/	/	?	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
	Technical Description	/	/	/	/	/	/	/	/	/	/	/		/	/	/	/	/	/			/	/	/		/	/	/	/
	Flow Diagram	/	/	/	/		/	/	/	/	/	/		/	/	/	/	/	/			/	/	/ /			/	/	
DETAILED PROCESS	Operation Data	/	/	/	/		/	/ /	/ /	/ /	/ /					/	/	/		/	/		/				/	/	
DESIGN	Partial Mechanical Data	/ /	/ /	/ /	? ?						/																		
	Accessories	/	/	/	/																								
DETAILED	Plant Layout																											/	
ENGINEERING	Detailed Drws	/ /	/	/						/				/	/														
	Detailed Mechanical Data		/						/																				

Table 2.4.4 Vendors & Client Technical Specification (continue)

Special Contribution / /; Adequate/ ; Inadequate ?; Questionable ? ?; Missing;

TECHNICAL SPECIFICATION		LPG SYSTEM				FUEL OIL SYSTEM				ATOMISING STEAM SYSTEM				INSTRUMENTATION			
		A	B	C	BP	A	B	C	BP	A	B	C	BP	A	B	C	BP
PROCESS DESIGN	Design Philosophy (Problem Definition)	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/	/
	System Synthesis (Alternative Process)	/	/	/	/	/	/	/	/	/	/	/	/				
	Parameter of the Systems	/	/	/	/	/	/	/	?	/	/	/	/				/
	Technical Description	/	/	/		/	/	/		/	/	/		/	/	(-)/	/
	Flow Diagram	/	/	/				/	/	/	/	/		/	/	/	/
DETAILED PROCESS DESIGN	Data Operation		/	/				/									
	Partial Mech. Data		/	/													
	Accessories		/	/													
DETAILED ENGINEERING	Plant Layout		/	/ /													

Table 2.4.4 Vendors & Client Technical Specification (continuation)

Special Contribution / ; Adequate / ; Inadequate ?; Questionable ??; Missing;

2.4.4.1 Furnace Detailed Process Design

The furnace system technical specification presented during the tendering table 2.4.4 was the most complete in comparison to the rest of the BTR systems. This particularly good with respect to the furnace design parameter calculations by "-B-" and the presentation of the parameter design (Detail drawings) by "-A-".

This subsection is only to deal with the "Furnace Detailed Process Design" and in particular with the 'Furnace Partial Mechanical Data' which involved the Furnace Dimension and its Heat Transfer Area, expressed as a Cold Plane and Tube Area (Table 2.4.4.1).

The Furnace Partial Mechanical Data shown in Table 2.4.4.1 resulted from the application by the different vendors of furnace calculation methods which are described in 1.1.4. by referring to the author's calculations, shown in Appendix 5.

The Table 2.4.4.1 also shows the deviation in area from the tenderers' proposals in relation to the actual furnace size.

Table 2.4.4.1 Comparison of Furnace Dimension

Responsible	FURNACE				
	Dimension Internal m x m x m	Tube Number	AREA		
			Cold Plane M^2	Tubes[4] M^2	Heat Transfer Deviation %
BP	3X3X9	89[3]	54	96[3]	-22
B	3.2X3.2X9.6	92	61	115	-12
A	3X3X8.8	88	53	95	-24
C[1]	3X3.66X10	96	72	126	3
C[2]	3X3.66X9.6	84	70	110	0

1 Original Tender

2 Final Tender (Actual Furnace Size)

3 Calculated by extrapolating A data

4 External tube diameter 11.43 cm.

2.4.4.1.1 Reliability of Furnace Calculation Methods.

The Table 2.4.4.1.1 shows the result of the author's calculations in the final form, i.e. using the actual process conditions and mechanical data, (Appendix 5); the cold plane/area tube of the furnace was calculated by the Lobo, Wimpress and Hottel Methods so that the results were compared with the actual data. This resulted in a deviation of about 5% for Lobo and Wimpress Methods, while the diviation for the Hottel Stirred-Furnace was of about 15% which accounts for the worse selection of local convective coefficient that in this case can increase/decrease the deviation by (say) 10%.

Also, exploratory calculations were made with Lobo and Wimpress;

Firstly, smaller size furnace is assumed to calculate the furnace actual size but this shows a negative deviation (-10%) in the table, which indicates that these methods led to a bigger furnace size if the smaller furnace size is assumed.

Secondly, colder flue gases temperature (t = 760°C) as expected, resulted in a bigger furnace (18%) or hotter flue gases results in smaller furnace (-16%).

Table 2.4.4.1.1 Furnace Calculation Method Reliability
Calculations and Symbols in Appendix 5

METHOD		Heat Transfer Area Deviation Furnace Dimension (mXmXm) 3X3X9	3X3.66X9.6
Lobo (Cold Plane)		-9	6*
Wimpress (Cold Plane)	Actual Temp. 1073°K	-16	-4*
	Lower Temp. 913°K	18	33
Hottel Stirred-Furnace * (Tube Area)			
Corrected by a_1=0.4	Calculated h_1=0.013	-	16
	Estimated[1] h_1=0.017	-	4
Uncorrected by a_1(=1)	Calculated h_1=0.013	-	-6
	Estimated[1] h_1=0.017	-	-15

1 Maximum Estimation by Lobo (17)

* Using Actual Data

2.4.4.1.2 Deviation of Vendor Furnace Specification

The furnace process design specification required to evaluate the furnace heat transfer area Cold Plane/Tube Area is very much interrelated so that a set of key process conditions can corresponde with only one furnace dimension (within a maximum deviation, 15%) and vice versa when the appropriate assumptions are made as shown by the author's exploratory calculations.

If the tendering process participants would have strictly followed the Final Client Specification of 15MBTU/h of heat removal (30% smaller than the actual value) and 760°C, the final furnace size would have been at least 30% bigger than the proposed, by any vendor. The furnace heat transfer area deviation of the unselected tenders is even bigger (50%) when the actual furnace size is taken as a reference.

These furnace client/vendors deviations were caused by the relaxation in the flue furnace gases temperature 800 ± 100°C and the smaller size furnace (3X3X9) originally proposed by the client as a guide.

2.5.1 Technical Modifications to the Original Tender

The final tender resulted from agreed modifications between BP and ---Firm C--- to the original tender. The discussions which led to such modifications were carried out in minuted meetings where a full analysis of the original tender took place.

The observations made by BP engineers during the first two of these meetings about the original tender are briefly answered in the first section of the final tender. These comments are the basis for the selection of the equipment to be finally used and the alterations to the original tender.

Next, it is listed all those matters pointed out during the minuted meetings which are either the basis of alterations to the original tender or those which did not fully satisfy either BP or Firm C.

Also, a further list "Analysis of Reductions and Increases" is presented in this section which describes all the agreed alterations of the original tender and the estimated costs for carrying them out.

i) The furnace box was oversized and the arch planned by the contractor was likely to produce mal-distribution; therefore the contractor was asked to quote for the reduction of the furnace size and a flat arch for the furnace. £17,200 reduction

ii) The foundations of the furnace were to be checked.

iii) The stack damper materials were to be changed from 18/8 to 25/10 stainless steel. £1,000 addition

iv) Assurance that the furnace floor were to be finished with a top surface of fire brick.

v) The facilitate the removal of the damper.

vi) Widen the walkways where sampling was to take place.

vii) Solid checker plate with toe board was to be used in the walkways and open mesh on the stairs. £2,400 addition

viii) Better protection against unfavourable weather conditions by roof extension.

ix) Removable davit and manual hoise to lift 1.5 cwt.

x) Two cameras were to be used (one at the top, looking down at the flame and the other at the first floor, looking across the flame. £2,000 addition

xi) Observation windows and camera view ports would be glazed with internal SS shutter for protection.

xii) Sampling slot of 15 inches, for which BP assumed the responsibility of sealing.

xiii) The contractor was asked to study the possibility of substituting:
 Header boxed by tube hanger.
 Pyroblock which is attacked by
 Sodium and Vanadium ashes.

Cooling Water System

i) Excessive heat removal by the coil originally designed by FirmC to be reduced by decreasing the number of tubes from 2 x 48 to 2 x 42.

ii) Minimise the furnace water inlet temperature to 140°C and restrict the water temperature rise through the exchanger in order to keep the N_2 pressure down to 5 barg.

iii) No make up pump required; Because the system volume should remain constant if the cooler is correctly sized. The primary drum is needed only to take the volume change from cold to operating temperature plus a capacity to take the run back when circulation is stopped.

£400 reduction

iv) Single valves rather than double valves.

v) Automatic air vent (no blowdown). A reduction of accumulator size should be investigated, possibly associated with blow down.

vi) Temperature recorder after air cooler
HH & LL alarm on expansion drum (B105)
H & L alarm on expansion drum (B105)
controlling make up pump (J105).
Step wise control for the three fan motors
on the air cooled exchange.

vii) The relief line from the make up pumps discharging to the expansion tank is unnecessary. A system 'floats' on the make up drum which is itself fitted with a relief valve.

Combustion Air System

i) Selection of the indirect air preheater that proposed by Firm C seemed oversized:

£40,553 addition

ii) After some discussion, it was decided to keep an automatic inlet vane on the air blower rather than relying on manual control in view of manpower restrictions during testing.

iii) Combustion air measured by turbine meters.

iv) To check flue gases in balance and inversion. would not be a problem should a test situation exist of high air preheat temperature with low burner firing.

v) Direction of the air preheater stack. An alternative route for the flue gas ducting between the air preheater and the stack. Instead of it rising vertically to the furnace/stack cross over duct, it could go horizontally into the stack at a lower level.

Fuel Oil System

i) To check and revamp the hot oil return line for the furnace to prevent the possibility of pressurising the filter or alternative oil tanks.

ii) Oil separator is intended to deal with spillage and small amount of flushing only.

iii) In the oil tank, steam coils are preferred rather than external heat exchangers.

iv) Viscometer EVT by -T- is preferred over other manufacturers.

v) Three way valves to be avoided where practicable.

vi) Manual valves are required. BP would substitute them by motorised if it is necessary.

LPG System

i) BP have a fire main available and will not require the LPG drench storage tank option.

Instrumentation

Panel to have interchangeable parts
Pressure transducer mounted directly on the lines.

Electrical

i) Motor starters conformed to the following section rules:
Motor less than 10 HP : on line start
Motor between 11 & 20HP: Star delta starters
Motor exceeding 20HP: Cito autostart.
£4100 addition

ii) No objection to the use of copper strand type earthing and test points at the control room and the tank form area.

Miscellaneous

i)	At the sampling position is required cooling water, electrical power and compressed air.	
ii)	Electric traction burner transporter	£2400 addition
iii)	Commissioning	£2500 addition
iv)	Bigger boiler by different manufacturer	£3125 addition

Analysis of Reduction and Increases

Reductions

Furnace	£17,200
Make up Pump J105	£ 420
Cooling Tower	£ 7,345
	£24,905

Increases

Air Preheater (Indirect)	£40,553
Cameras	£ 2,000
Transporter	£ 2,400
Commissioning	£ 2,500
Damper	£ 1,000
Starters	£ 4,100
Civils	£ 3,649
Boiler	£3,125
Furnace Steelwork	£ 2,400
Instrumentation	£ 450
	£62,177

Total Increase : £37,212

2.5.2 Final Tender

The contractor, with the consent of BP, issued a final tender which defines most of the plant, the method of construction and the responsibilities of the parties involved regarding financial matters.

The final tender resulted from the technical modifications to the initial tender.

2.5.2.1 Analysis of the Final Contract Price.

The reduction and increases due to these modifications described in the previous section changed the final contract price for the ---Firm C--- contract to £785,110. This contract price was based on the following main components: Test furnace; Indirect air preheater; Closed circuit air-cooled furnace cooling system based on air cooled heat exchangers; Package steam boiler and ancillaries generating the specific amounts of atomising and heating steam with 50° super heat; Fuel oil viscosity control system based on "T---------- EVT"; Burner transporter/hydraulic with weatherproof electric traction.All associated civil engineering works comprising separate compressor building, foundation slab, fence and gate for gas let-down station.

The final contract price was broken down into the following items:

i) Design drawings and specifications 6.31%

ii) Procurement and manufacture of plant and all accessories 61.9%

iii) Delivery to site and erection of plant and all accessories with all services, including precommissioning 19.76%

iv) Commissioning of plant and all accessories, based on 5 days attendance of Firm C's Commissioning Engineer and subcontractor's specialists — 0.32%

v) Civil works including buildings, drains, etc. — 7.93%

vi) Spare parts recommended for two years operation — 3.77%

This tender analysis excluded the following items:

i) The supply of any plant, equipment or service not specifically mentioned in the tender.

ii) Any consumable such as fuels, chemicals unless specifically included.

iii) Fees and expenses of Inspection Authorities other than those operating for Firm C.

iv) The main stack.

v) The test furnace flue gas ductwork which is downstream of the final expansion joint.

vi) The consequences of any errors or delays by third parties.

2.5.2.1.1 Total Cost Incurred by the BTR.

Using the service of consultants, BP determined the possible escalation of the BTR to be £62,500. Additional costs incurred by BP apart from those with the main

contractor, Firm C , included; Contract of Consultancy for £5,000;
Contract with Gas Board (Gas Supply) £16,300;
Contract with Firm G (Main Stack) £28,300.

Therefore, the overall cost of the project amounted to £897,210. In the calculation of the cash flow, the spare parts were considered as a revenue (£28,700) and a contingency part was added, bringing the total capital investment to £890,000.

2.5.2.2 Final General Contract Conditions.

1) Payment Schedule

After some discussion about the method of payment to the contractor, it was decided to adopt payment by events or date, whichever was the latest.

Percentage of the contract price %	Date due for payment Week after contract is awarded	Events
5	4	Submission of the plant lay-out and foundation drawings.
10	10	Submission of drawings for test furnace, aircooler and tankage.
10	18	Receipt in shops of major materials for test furnace and aircooler.
15	24	Site delivery of first major plant items.
25	32	Shop completion of test furnace steelwork.
25	42	Site delivery of test furnace.
10	52	Completion of erection.

2) Bank Guarantee

The proposal by Firm C that the Bank Guarantor was to retain 5% instead of 10% of all the payment due, was accepted by BP. This has a validity of 6 months and was worded in accordance with the "Form of Guarantee" per I.Mech.Eng./I.E.E. Form General Conditions "A/1976".

3) Insurance

The tender included an Insurance Policy which covers BP, in connection with Firm C's works, against accidental personal injuries and accidental loss or accidental damage to property caused by subsidence, vibration, or by removal or weakening of support or by fire or explosion.

4) Liquidated Damages

It was proposed by BP that a payment by the contractor of £5000 per week for the default produced by delay in the completion time predicted by Firm C.. These payments were to be up to a total maximum of 2½% of the contract price (£785,110) given by Firm C.

5) Period of Maintenance

Firm C assumes responsibility for 2 years for any possible inconvenience arising from defective design, materials, plant or workmanship or from any act or omission of the contractor that may develop or become apparent under the conditions provided by the contract.

6) Performance Guarantee

Firm C guarantee that the plant will meet and maintain the specified performance for a period of 6 months following the completion of the erection.

2.5.3 Contractor Technical Specification

The technical part of the Firm C tender, which was approved by BP, is described below. This description highlights the characteristics of the most important systems of the BTR. The information in this subsection is complementary to the BP specification which is given in 2.3.2.3.

2.5.3.1 General Specification

2.5.3.1.1 Design Philosophy

Firm C ---- adhered to the performance criteria for the Test Rig as laid down in the BP enquiry specification; but Firm C ----- considered that, the specification could be improved if the following modifications were implemented.

Test Furnace

Postpone details of TV camera location and the sealing of the furnace apertures.

Cooling System

Extension of the coil, and use of non-evaporative cooling closed circuit.

Combustion Air

Indirect air preheating, and measurement and control of combustion air.

Fuel Oil

Extra recirculation

Plant Layout

Consider safety, economy and operability factors.

The above modifications are described in more detail in the appropriate sections below.

2.5.3.1.2 System Flow Sheet

Some additions and modifications were made to the Flow Diagram supplied by BP. They were incorporated into the following -- Firm C -- drawings.

Furnace and Associated Control

Closed Circuit Air-Cooled System

Natural Gas

LPG Supply

Fuel Oil Supply

2.5.3.1.3 Layout

The plant has been accomodated within a plan area measuring 35584 mm by 17221 mm. The proposed arrangement was arrived at subject to the following constraints within the available space.

Fixed position of furnace stack (by Firm G)

Safe Location of Oil Storage in relation to LPG plants.

Trenches, drains and other excavations to be positioned with due regard to possible LPG spillage.

Firm C ----- having these considerations in mind has proposed a layout which is amenable to easy plant access for operation and maintenance whilst being economical in terms of duct and pipe routing.

2.5.3.2 Furnace System

2.5.3.2.1 General

The test furnace has been designed to conform with the enquiry requirements given in part 3 - Technical Specification.

The tube surface area and the firebox dimensions of the heater, when compared to the preliminary BP specification, have been increased.

2.5.3.2.2 Mechanical Design

The mechanical design of the furnace complies with the Enquiry Specification. The key parameters are described on Furnace Data Sheets and Drawings, which were supplied later, at the appropriate time.

2.5.3.2.2.1 Sealed Furnace Box

One of the essential design features of this furnace must be tightness against air leakage. Therefore the following features were incorporated in the ---Firm C--- design:

i) Fully welded construction of furnace casing. With the exception of the burner floor construction which is bolted and sealed with asbestos tape.

ii) Main cooling water inlet and outlet connections (4 total) have fully welded bellows seals.

iii) A fully sealed welded construction for the header box.

iv) Unavoidable bolted opening to fire box such as the burner mounting and the access manually have accurately finished flanges and gaskets and were sealed after bolting in position.

v) Other openings such as sampling slots have leak proof covers ensured by ground seating surfaces, gasket and positively tight clamping devices for opening and closing.

2.5.3.2.2.2 Structure and Accessories

i) Adequate cross bracing to eliminate vibration due to the burner operation.

ii) Access platforms, walkways, stairways and ladders were widened.

iii) Location of observation doors, TV viewing points, sampling parts were to be discussed later with the engineer nominated by BP.

iv) The flue gas damper is a two leak segmental type operating with a 25 mm circumferential clearance inside the insulation.

2.5.3.2.2.3 Refractories

i) Internal wall insulation of the furnace was to be ceramic fibre modular block material (Firm K Pyro Block AB).

ii) The internal walls to which the self-adhesive blocks will be applied will after cleaning and descaling receive an acid-resistance coating of a silicone based adhesive.

iii) The structural design allows for the alternative future loads which can result from future installation of different insulation.

iv) The flue gas duct, in the region accessible to personnel from the top access platform is insulated by a layer of ceramic fibre plus an inside layer of anchored castable refractory. Beyond this region is insulated with anchored castable material.

2.5.3.2.2.4 Instrumentation related to the Furnace

The test facilities, instrumentation, etc conform to the extent described in the BP enquiry specification and the flow diagram. The following observations are relevant:

i) Control and Measurement Instrument for furnace firing.

The preferred detail grouping and location of burner controls were to be finalised with the engineer at a later stage.

Measurement of fuel condition would be taken as close to the burner as possible.

Monitoring instruments were to be sited after consultation with the engineer.

ii) Visual and Monitoring Flame

A single view point, irrespective of its location is quite inadequate to convey a meaningful picture of spiralling flames therefore two cameras are located as follows:-

Lower portion of the combustion chamber and receiving at right angles to the burner.

Flue gas hood locking vertically downwards onto the flame.

The tender includes two camera mountings, glazed viewing ports with stainless steel shutters with the necessary cooling water and weather protection.

The extent of sampling slots, both in number and individual dimension are restricted to a minimum.

The positioning of viewing ports and sampling slots were to be made in conjunction with accessability and obstruction considerations.

2.5.3.2.2.5 Burner Transporter and Lifter

i) The lifting mechanism is powered hydraulically.

ii) The complete lifted unit is mounted on a trolley with manual steering and hand control to give precise movement.

iii) The traction is electric and the motors are totally enclosed and weather proof.

2.5.3.3 Cooling Water System

2.5.3.3.1 Process Design

i) The proposal was to take water from the furnace cooling coils at 195°C and 19 barg and pass this directly to three forced-draught finned tube coolers, fitted with low noise fans. The water is arranged in series through the coolers and the air path in parallel. The water is cooled to 165°C and flows into the suction of a pressure booster pump (with a standby) which returns the cooled water at 457 igpm and 22.8barg to the inlet of the furnace cooling coils.

ii) System Pressurisation is by nitrogen bottles with automatic pressure govenors.

2.5.3.3.2 Mechanical Design

i) The forced-draught coolers are arranged as the roof to a modular steel structure covering the booster pumps and water make up facilities and pressurised water expansion drum.

ii) For quick start-up and to prevent under cooling of the plant the fan motors are provided with thermostatic controls working on the water temperature leaving the cooler.

iii) The air cooler and furnace coils are not winterised, therefore the system is operated without antifreeze addition and drained when not in use during severe winter conditions.

2.5.3.4 Combustion Air System

2.5.3.4.1 Air Preheater

A natural gas fired indirect heater is provided. The design allows a 4:1 turndown of exit temperature, by varying the burner excess air and gas rate independently, to produce varying quantities of flue gases at varying temperatures. The flue gases so produced then flow over chrome steel tubes through which the combustion air passes.

2.5.3.4.2 Fan

A turn down of 10:1 in a ---Firm A--- fan supplying combustion air flow is achieved by automatic angular positioning of valves placed across the fan inlet.

Silencing of the fan is by inlet and outlet in-line silencers with an acoustic enclosure cover the fan and motor to reduce casing transmitted noise. The silencers are weather proof and totally removable for maintenance access.

2.5.3.4.3 Ducts

i) All ducting in the combustion air system was to be constructed of mild steel fabrications. For hot duty the ducts were to be lined with a light castable.

ii) The external surface of ducting was to be grit blasted to BS 4232 and painted with one coat of zinc silicate primer followed by two coats of aluminium silicone.

iii) The flue from the indirect preheater was to be connected to the main furnace flue (Between the furnace damper and the stack connection).

iv) The air preheater was to be equipped with its own damper and can thus be operated independently of the furnace controls.

2.5.3.5 Gas Supply System

2.5.3.5.1 Natural Gas System

i) Natural gas is received at the pilot limit by a Gas Board/BP installed gas govenor and metering station.

ii) Gas for the steam generator is passed directly to the unit.

iii) Gas for the other applications is passed to the suction of a reciprocating oil free compressor, compressed, cooled in and after-cooler passed onto a main filter to remove particles greater than two micron in size.

iv) Pilot Gas is removed before the filter and piped to the pilot burners via a pressure control valve.

v) Filtered gas is piped to the burners via pressure control valves.

vi) All control valves are of the block and by pass type.

2.5.3.5.2 Dosing Gases System

i) The bottled gas supply system has been designed to allow from 0.3 to 30% V/V of the main gas feed to be added in the form of a supply from a bottled gas station.

ii) Six inlet branches are fitted to the inlet manifold of the gas mixing drum. These branches are fitted with the following flow monitoring equipment.

Branches	B101-1	None
	B101-2	None
	" -3	10-100 ft^3/min (STP)
	" -4	10-100 ft^3/min (STP)
	" -5	1-10 ft^3/min (STP)
	" -6	1-10 ft^3/min (STP)

iii) Metering equipment was to be of -----FB------- type.

iv) The gas mixing drum is constructed from 316 stainless steel to allow versatility in the type of gases to be mixed and is fitted with the instrumentation shown in the drawings including local temperature and pressure measurement.

2.5.3.6 LPG System

2.5.3.6.1 General

The LPG is intended for short term operation of the test rig. Therefore, a necessary prerequisite was, that liquid butane is stored on the site in adequate quantities for efficient, safe and stable operation. The LPG storage installation was to meet the standard of practice set out by the Health and Safety Executive and LPGITA. In an informal presentation an HSE's expert had favourably received the proposed layout.

2.5.3.6.2 Tanks

i) Two vertical butane storage tanks designed to the BS 5500 code, with a design working pressure of 70 psig.

ii) Included are internal and external ladders together with suitable platforms at the top of the tanks in order to have accessability to the transfer valves.

iii) The tanks are finished to BP standard.

iv) For a LPG capacity of 2000 gallons the required separating distances is 25 ft to all the main sources of ignition.

2.5.3.6.3 Vaporisers

i) Two vaporisers of 500 lb/h at a pressure of 4 barg were supplied .

ii) The vaporisers of the steam heated type requiring a site steam supply pressure of 6 barg at 165°C.

iii) The construction is to BS 1500 class II, both mounted on a common fabricated steel base frame, each complete with vapour stack, pressure gauge safety relief valves, drains, level switches and all interconnecting valves and pipework.

iv) Selection of two half capacity vaporisers instead of a single unit resulted from discussions with the HSE and LPGITA.

v) There is 6 ft clearance between the vaporisers and either LPG storage tanks and 40 ft from the boiler and control building.

2.5.3.6.4 Pumps

i) The pumps selected are of centrifugal type.

ii) The pump has self priming lateral channels with the optimum suction performance of a centrifugal impeller; thus allowing the pump to operate at a low NPSH with complete reliability.

iii) The pumps are sited in the LPG compound 8 ft from the centre of either of the storage tanks.

iv) Two pumps are supplied (one running, one standby) with delivery pressure of 85 psig and at flow rate of 3 igpm.

2.5.3.6 Miscellaneous Equipment

i) All pipework is seamless of carbon steel material cooled API5L grade 'B' with welded joints.

ii) Electrical heat tracing is provided from vaporisers to the furnace burner to prevent condensation in the pipe. To commence '9' from vaporisers.

iii) Installation of all electrical equipment within the LPG compound will be zone 1 classification.

iv) Fixed water drenching system, activated by increased pressure vapour in the tank is supplied. The tanker layby adjacent to the LPG compound will also be provided with a drenching system manually operated. Both drenching systems will be designed to be frost protected.

2.5.3.7 Fuel Oil System

2.5.3.7.1 General

i) The most critical plant requiring the maximum separation would be the fuel oil storage tank whose contents have a flash point below 150°F and the boiler control building which was an unclassified electric area.

ii) Heating of the oil to a steady temperature to secure a constant viscosity will improve the efficiency of the burner. This can be achieved by an oil recirculation. System described below.

2.5.3.7.2 Storage Tanks

i) Three vertical tanks are supplied.

ii) Each tank is constructed to British standard 799 type 'G' supplied with man holes, internal and external ladder with safety cages and all necessary nozzles and gauges.

iii) The two heavy fuel oil tanks are fitted with finned tube steam heating coils of all-welded construction to ASME VIII DIVI and BP standard. Both tanks are thermally insulated with 3 inches of mineral wool as per BP Engineering Practice section 13.

iv) The tanks are positioned on concrete foundations housed in a bunded compound with drain facilities to an oil separator.

2.5.3.7.3 Pumps

i) The pumps are of positive displacement gear type.

ii) The capacities of the pumps are sized at three times the rated oil requirement of the burner 360 gl/h. This allows a recirculation rate of twice the burner consumption.

iii) The pumps have been located as near as possible to the oil supply tanks in order to provide maximum NPSH.

iv) Gate valves are installed on the suction side of the pumps to assure minimum friction losses.

v) The suction oil piping from the tank to the pump has been amply sized and designed to eliminate leakage.

vi) The pump packing glands are of the mechanical type and designed to prevent air ingress.

2.5.3.7.4 Filters

i) These are of the duplex type with filtered mesh of 0.5 mm aperture.

ii) The filter body construction is cast carbon steel pressure tested to 225 psig.

iii) The filter element is arranged to permit cleaning without interruption of the flow of oil.

iv) They are positioned just upstream of the pumps.

2.5.3.7.5 Oil Preheater

i) The oil preheater uses steam to heat the equivalent of 120 gall/h of heavy fuel oil from 180°F to 270°F for the test burner requirement.

ii) The oil preheater is installed as near as possible to the test burner furnace in order to reduce heat loss of oil in transit, to assure constant oil temperature at the burner and to permit quicker start.

iii) At the preheater outlet a pressure relief valve is installed for protection against accidental closing of both isolation valves and excessive internal pressure due to thermal expansion of oil.

iv) Relief discharge flows back to the exit line from heavy oil storage tanks(before tank isolation valves) via a lockable 3 way valve.

The return of this small quantity of hot relieved oil will not infringe any safety flash point consideration of the tank contents, due to the small quantity 10.5 gallon compared to the diluting bulk of the tank contents.

2.5.3.7.6 Piping

The pipeline was to be installed, where possible, as a return or recirculating system with the oil supply and oil, return running parallel, steam traced, all wrapped and insulated together.

The steam tracer line is supplied with low pressure site steam and fitted with condensate traps installed at a low point to secure proper drainage.

The thermal expansion of the pipework has been catered for in the flexibility of pipe runs.

the air through a double jacket surrounding the external combustion chamber.

ii) The gas burner incorporates a perforated cone to give flame stability.

2.5.3.8.2.2 Feed Water

i) Water preheating is provided by a thermostatically controlled steam injection nozzle.

ii) A double-acting positive displacement piston pump is provided.

iii) Pressure relief valve fitted after the water pump will relieve on any increase in pressure drop through the coil.

iv) A safety valve at the outlet of the coil relieves at 2 barg above the operating pressure.

2.5.3.8.2.3 Boiler Instrumentation

i) A sinchronous programming unit controls the start up and shut down sequence.

ii) A differential pressurestat, fitted to the steam outlet, controls burner firing rate according to steam demand.

iii) The burner can be locked out by:-

Pipe anchors will be fixed where required to protect equipment.

2.5.3.8 Atomising Steam System

This plant comprises a softener, steam generator (boiler) and a superheater. The mechanical design is for the higher pressure (21 barg) requested in the BP specification.

2.5.3.8.1 Water Softener

i) The unit is duplex constructed, operating on an automatic water meter change over. Whilst one resin bed is softening incoming water the second bed is undergoing automatic regeneration with brine.

ii) The capacity between regeneration and self requirement for regeneration varies as a function of the water solid contents and the flow rate. The salt is added to a brine saturator which holds sufficient brine for a regeneration before recharging.

iii) The softener package includes all automatic controls and water metering equipment to provide service, regeneration and back wash automatically.

2.5.3.8.2 Steam Boiler

2.5.3.8.2.1 Chamber

i) This is a gas-fired, vertical coil steam generator. The coiled tubes form a combustion chamber and secondary convention surfaces, with insulation and combustion air preheating being achieved by circulating

Ionisation system of flame detection
Flame failure detection system (ionisation)
Thermostatic switch at the walls of the coil (High temperature).
Thermostat located at the steam outlet (very high temperature).

2.5.3.8.3 Superheater

i) The unit supplied should be capable of 4:1 turndown and handling of 800 lb/h giving a final steam temperature of 50°C superheat when working at 21barg.

ii) This unit and the boiler were to be tested in accordance with BP standard (section 20) where applicable.

2.6 Findings About the BTR Process Development

1. The initial BTR proposal was made in 1973 when the advantages of upshots draught burner modes were recognised

2. During the process of finding the required funds for the BTR outside of BP the objective and experimental programme were clearly defined.

3. The advantage of the upshot draught burner mode over natural draught burner, and the lack of facilities for manufacturers to test such burners, justified the BTR project which started in 1977.

4. A lump sum-contract was chosen instead of another contract type because it set the conditions most likely to result in fast and efficient completion of the BTR.

5. A sufficiently firm "BTR Specification" was required to enable the client to fully utilise a lump sum type contract.

6. The "BTR General Contract Conditions" did not deviate significantly from the typical "General Contract Conditions" given by the Institute of Chemical Engineering.

7. The "General Contract Conditions" which were particularly discussed between client and contractor were the Form of Payment, Percentage of Bank Guarantee, Liquidated Damage, Period of Maintenance and Period Guarantee.

8. Once the BTR funds were approved, an original proposal (2.3.1) was issued by the client. This proposal described only the technical hardware of the Plant.

9. The client's original proposal was a technical hardware description of the BTR generically called a "Technical Specification". This proposal can be considered as the "First Technical Specification" which was folllowed by the "Client Technical Specification" (2.5.3.).

10. The BTR hardware of a "System" can be divided into the format shown below which represents the successive stages of detailed description of the "System" hardware.

Process Design Specification
Detailed Process Design
Detailed Engineering

If the stage of "Detailed Process Design" is incomplete it is generally referred to as the "Final Process Design" or "Partial Detail Engineering".

11. The Final Client Specification was complete in so far as defining the "Process Design Conditions" of all the systems which comprise the BTR.

12. In the Final Client Specification the Operating conditions of the Cooling Water System, Atomising Steam System, Oil and LPG Storages were defined in terms of minimum requirements, i.e. maximum furnace inlet water temperature, minimum superheated steam temperature and a minimum storage capacity for the Oil and LPG. In contrast, the Furnace System, Air Preheater and Fuels at the burner were more precisely defined.

13. The air preheater and cooling water system are defined in the Final Client Specification. Two alternatives are proposed (System Synthesis) but no additional data is mentioned of the second alternative.

14. The Final Client Specification differs from the original proposal in that, additional to the description of the technical hardware, it also contains Chapters for the:

Site Description
General Engineering Specification
Sectional Engineering

15. The Sectional Engineering Specification and the Client Flow Diagram defined in detail all the Instrumentation & Control and Safety Circuits considered in the Client Specification.

16. Six firms were selected by the client for tendering prior to the tendering period. This number was later reduced to three which was desirable for the project.

17. The "Tendering Period" was scheduled to last two months but was later extended to three months and in practice it took a further two months to carry out the "Selected Tender Modification".

18. The general format of the tender contains:

- The Finance part which answers the conditions (Cost, Time, Contract) under which the project is to be carried out.

- The construction part deals with the BTR installation and describes the procedures (Planning Documents) to be followed by the contractor in the execution of the project.

- The technical specification describes the BTR by complementing (Full definition of major equipment; Final Process Design and Detailed Engineering) the Client Specification.

19. The tender selected was both cheaper and more technically complete than the others, as can be seen from Table 2.4.3 and 2.4.4. It can also be judged to be the most innovative.

20. The attention paid to the Instrumentation and Control and Safety Circuits was very small in comparison to that paid to other systems during the tendering period.

21. The core of the process design of the BTR system was firmly established (Final Process Design) while the Detailed Process Design was added by the "Tender's Technical Specifications".

22. During the "Tender Modification Period" the best alternative to the Air Preheater and Cooling System was chosen. The most relevant reasons for choosing the Indirect air preheater and non-evaporative cooling system were better compatibility with the BTR objectives and space reason, respectively.

23. Also during the "Tender Modification" agreement was reached on all (2.6.3) "GeneralContract Conditions" particularly applied to the BTR, during the execution of the Project by the Contractor.

CHAPTER THREE

PROJECT ENGINEERING

3.1 Civil Works

The civil works involved in the construction of the BTR is summarised below and can be divided in three stages, as follows:

Subsurface Works

Surface Works

Compounds, Structures and Buildings

3.1.1 General Description of Subsurface Work

i) Levelling and Grading

The top soil, to 350 mm deep over the working area of the site was removed and replaced with 40 mm single size stone BS 882 to a depth of 300 mm. The BTR structure, including all peripheral equipment was built on this foundation.

ii) Electrical Cable and Trench Ducts

Concrete ducts of internal dimensions 584 mm wide and 300 mm deep were used to carry electrical cables. Removable trench topping is water tight and able to support pedestrian.

iii) Petrol Interceptor

The interceptor complies with the Public Health Act 1936. Section 27. It consists of a cast iron pot with a class C, UPVC vent pipe, up to the level of the bund wall.

The cast iron cover is double-sealed and can be lifted with a special key.

iv) Drainage For Oily Water

This is provided by 225 mm wide gullies covered with Broad 41 heavy duty grating and frame complete with stop end to the tanker lay-by. A channel type of drainage around the inside of the bunds is piped through the walls into a gully via trap door. Both outflow are directed into the interceptor and later to the existing soakaway system.

3.1.2 General Description of Surface Work

i) Tanker Lay-by

This was constructed from a reinforced concrete slab, complete with two layers of steel mesh reinforcement to BS4483, laid over 300 mm depth of type 2 material laid to MOT specifications for road and bridge works, clause 802 and 804. Precast concrete kerb to BS340.

ii) Foundations

These are constructed from a reinforced ground slabs and concrete plinths designed to the principle of CP110. These have an allowable loading stress of 25 N/mm^2.

This type of foundation is used in the following installation Oil Storage Compound, (Oil-impervious additive was used in the concrete), LPG Storage Compound (with 1:60 Slope), Control Building, Compressor House, Furnace Base (included, holding down bolt pockets), Air Preheater, Air Blower and Pressure Reducing Station.

Pipeline and support bases consist of 1/2 cubic yard of 21 N/mm^2 concrete as thrust blocks.

iii) Foot Path

The 25 yards of pathway originally proposed was extended to provide foot paths between all the major equipment and the control room.

3.1.3 General Description of Compounds and Buildings

i) Oil Storage Compound

The compound is enclosed by an unbroken bund wall 1524 mm high built from engineering bricks as BS 3921 class B with an oil-proof rendering coat applied internally.

ii) LPG Storage Compound

The ground is surrounded by three low brick (610 mm) walls. The fourth side adjacent to the road tanker lay-by, is fronted by a gravel filled catching area in case of LPG spillage or over flow from the equipment.

iii) Control Building and Compressor House

Building are of traditional brick and block construction consisting of 114 mm facing brick, 50 mm cavity, 100 mm block work.

The outside walls are constructed to the 1976 Building Regulations Schedule 8 Part 1 giving four hours fire protection. The roof is 150 mm thick precast concrete planks.

The control building has the following features:

A ceiling consisting of 12.7 mm asbetolux panels supported by aluminium trim and suspended with wire. (Headroom of 10 feet)

A division wall between the boiler and the control room of 140 mm thick concrete block containing a fire check single door with 1/2 hour protection.

Seven modular steel frame windows, another 1/2 hour fire check single door, a pair of louvred doors, electrical light, fan heater and plug.

3.1.4. Execution of Civil Work

3.1.4.1. Delay in Site Clearance and Document Approval

The civil engineering works described above was subcontracted to ------ Firm H ----------. They were to start the site clearing two weeks after the main contract was awarded, see fig 3.1.4.1; but there was a 5 weeks delay caused partly by the contractor wishing to have a final comment from the local authorities before proceeding, and partly due to uncertainty about the location of the natural gas pressure reducing station.

Furthermore, BP stated that excavation around 600 mm depth considered by the subcontractor, might damage certain services. Later was convened to remove up to 300 mm deep.

Before the start of the works, a site plan and an electrical zoning drawing was submitted for approval to the BP Safety Officer (Sunbury), the Area Health Safety Executive and the Surrey Petroleum Office. Also, after the start, sketches of the buildings were prepared and submitted to the Local Council Building Department for interpretation regarding building regulations. This vetting by various authorities caused an additional delay of 5 weeks.

3.1.4.2 Plan Schedule and Promised Completion Dates

The civil engineering works schedule is shown in fig 3.1.4.1. as supplied by the contractor in their tender it established a completion time of 12 weeks where:

Layout and foundation drawings were to take 4 weeks
Site Clearance and Drawings (including separator) were to take 6 weeks
Foundations, Lay-by and ducting were to take 4 weeks
Storage Compounds
Control Compressor Building, and foot path were to take 4 weeks

According to the above schedule, which incorporates parallel activities, civil work was to be finished in the 20th week. But this was postponed to the 25th week and again to the 28th week. The actual schedule on fig 3.1.4.1 shows that by the 31st week, the civil engineering work was about 98% complete; but key items such as the roofs of the buildings were not completed until the 40th week.

3.1.4.3. Civil Works Progress from the First Promised Completion Date

Although the civil works was not finished on the 25th week (First promised completion date) priority had been given to complete the works works which would permit to proceed with the equipment erection. Thus, at the 25th week, the oil storage bund and bases for the air and oil preheaters were completed and the control/boiler building was well in advance.

Table 3.1.4.2 shows the degree of completion of the items of the three principal parts of the civil work.

Most of the remaining jobs from the 25th week were carried out and completed in the 28th week. The jobs unfinished at this time were completed or in progress in the 31st week. Those jobs completed were the tank bund and air blower base.

The job in progress was the building roofs, whose final completion date in the 40th week disrupted the erection works of the compressor which was on site since the 37th week.

Other minor civil works were done at the appropriate time. This included roof finish, building doors, grouting equipment, extension of viscometer and pressure reducer bases, sealing cable ducts and paths.

Table 3.1.4.3 Progress on Civil Work at the 25th week.

Stage	Activity	Percentage of Completion %
Subsurface	Site Clearance	100
	Drainage (Petrol Interceptor)	100
	Cable Ducts	20
Surface	Tanker Lay-by	100
	Foundations for Buildings	100
	Storage Compounds	100
	Furnace (Ladder Base)	90
	Pumps	100
	Preheaters	80
	Air Blower	80
	Expansion Drum	80
Compound and Buildings	Oil Storage Compound	98
	LPG Storage Compound	65
	Control Building	70
	Compressor House	35

3.1.5.1 Findings about the Civil Work Programme

i) The civil work took nearly twice as long as the 12 weeks quoted by the contractor. Assuming completion in the 31st week.

ii) An important factor in this delay was the time taken to receive approval of drawings from the different local authorities and the client; for which the civil engineering contractor was not made responsible.

iii) The client and the main contractor agreed a revised completion date, week 25; but this was exceeded by a further 6 weeks.

iv) Owing to the delay in the completion date, the civil work was in a discontinuous and uneconomical order.

v) Despite the late completion date, the civil engineering work did not significantly delay the erection of equipment because most of their delivery dates were not met. This is explained in the next section.

3.2 Ordering and Delivery of Equipment

The BTR is comprised of a variety of equipment which can be classified according to how they are manufactured. That is, if they are specially fabricated (first of a kind) or batch manufactured (duplication), or continuously manufacturered (standard). Each of these classifications have peculiarities regarding specification and availability.

Normally, the degree of complexity in preparing an equipment specification and the availability of an equipment will be simpler for standard manufactured than for duplication or special fabrications. The ordering and delivery of an equipment depends on its classification, requiring different amounts of time to draft a specification and secure delivery.

The requisition of equipment and their delivery in the BTR project is described below.

3.2.1 Requisition Orders and Progress Order List

In the 6th week, requisition orders were prepared. They included most of the major equipment with the following exceptions:

i) Compressor, Boiler Unit, and Air Preheater which are packaged duplicate-type equipment and were still in the bidding stage;

ii) Some parts and equipment for the cooling water system, which were still unspecified;

iii) Furnace which was still being designed by GKN-Birwelco

iv) Instrumentation, Electrical supplies and piping whose specification were in progress.

Items listed under (ii), (iii) and (iv) above fall into the "first of a kind" category, requiring unique specification and design for the BTR.

Three lists showing the progress of ordering and promised delivery of equipment were prepared by the project management. These are summarised below and displayed on the figure 3.2.1.

3.2.1.1 First Progress Order List

At the 19th week, a list of subcontractors and ordered equipment with their respective promised delivery dates was issued by the contractor. It contained all the major equipment with the exclusion of the pressurising expansion drum and the make up water pump (cooling water system) and some parts of the air cooled heat exchanger and the furnace bolts. The promised dates of the equipment deliveries spans between the 12th and 38th weeks. The late bidding equipment, boiler, compressor and air preheater were due to be delivered around the 38th week while the other equipment were to be delivered between the 13th and 31st week.

3.2.1.2 Second Order List

A second list of ordered equipment was issued on the 32nd week. In view of the few equipment delivered up to this date, a revision of expected delivery dates was obtained from the equipment suppliers.

These involved extension of between 4 and 6 weeks. Also the first list was extended to place order for the remaining equipment and the service of subcontractors.

These additional orders included: the Pressure expansion Drum, the Make up Water Pumps, the Refractories for chimney and furnace, Other equipment parts and Accessories, and the full supply and installation of Instrumentation and Electrical Equipment.

3.2.1.3 Third Order List

Two weeks after the second order list, a final one was issued and showed further postponements in the expected delivery dates of up to 5 weeks.

Additionally, in the third list was the ordering of an equipment part and the engagement of two subcontractors. The latters were to be responsible for the installation of the equipment on arrival and the erection of the pipework, respectively.

3.2.2 Findings about Ordering and Delivery of Equipment

i) The sequence of placing orders and sub-contracts is seen in relation to four milestone dates: the 6th, 19th, 32nd and 34th week. In each of the last three dates was issued an order list.

ii) During the period required for design of special equipment and for tendering on duplicate (package) equipment, all the standard equipment had been ordered.

iii) By the 19th week the majority of orders had been placed. However, there was decisions to be taken on the detailed engineering of the expansion and make up equipment for the cooling system,the furnace lining and the flue ducts. These all relate to specially designed equipment for the BTR.

iv) The originally promised deliveries, if kept would have allowed a gradual economical erection of plant items; starting with the Oil and LPG major equipment installation and followed by piping and instrument installation in these systems. This should have made time for the consecutive arrival of the combustion air, natural gas and atomising steam equipment and their sequential installation.

v) The package units were delivered on schedule between the weeks 37 and 41. By contrast the standard items of equipment, which were promised for earlier delivery, arrived simultaneously with the package equipment after two postponements in their delivery dates.

vi) The order for the natural gas pressure reducing station was placed by BP during the tendering phase of the BTR. British Gas promised delivery of this package unit in the 35th week; but it did not arrive until the 63rd week. Therefore, all the delays in the delivery and consequently in erection of equipment were not as critical as they would have been; because precommissioning tests could not be started.

3.3 Furnace System

The furnace is the main equipment of the BTR therefore since the earliest stages the achievement of the whole project was measured as a function of the state of advance reached by the furnace. This is reflected by the payment schedule, which sets the payment in seven parts and five of which were fixed according to events partially or fully related to the furnace.

The furnace system consisted of the furnace box and accessories (Table 3.3). The latter included the refractories, coils, burner as well as platforms, stairs, ducts, chimney and instrumentation.

Because of the special specifications of the linings and the different problems found in the chimney completion. These two accessories have separate sections which explain their progress in detail.

3.3.1 Furnace Box and Accessories

3.3.1.1 Detail Engineering Stage

This section explains the modifications that the furnace and accessories were subjected to as well as some final details which were left from the tendering stage, to be discussed during the engineering of the project.

3.3.1.1.1 Modifications

The modifications of the furnace and duct included one discussed in the tendering stage (flat arch) and another two which occurred during the detail engineering. These two could be classified as "an improved alternative" (supported floor) and the second one as a "remedy of a problem" (sweeping flue duct).

Table 3.3 Furnace System

Actual Project Engineering Schedule

	Furnace Box	Burner	Lining	Walk-ways Stair etc.	Coil	Duct	Chimney
PLACE ORDER	0	20th	29th	0	6th	0	0
DETAIL DESIGN	6th (Structural design) 25th (Drawings)		-	20th	20th	20th	36th
FABRI-CATION	35th	-	-	-	30th	35th	39th
DELIVERY	36th	48th	45th	35th	35th	38th	46th
ERECTION	47th	50th	48th	40th	50th	60th	53rd
INSTRU-MENTATION	58th	-	-	-	-	-	-
PIPING/ DUCTING	60th	52nd	-	-	-	-	60th

Note: This table shows the date when the different activites (Ordering, Fabrication, Delivery etc.) had been carried out for the main equipment which comprised the Furnace System. The dates are expressed in relation to the week when the contract was awarded, i.e. the nth week after the award of contract.

Furnace Arch

The original arch proposed by the contractor produced, in the flow pattern of the flue gases, a turn of 90° just before leaving the furnace. This feature was likely to generate turbulence, which would impair the intended stable operation of the test furnace. The modification implemented was to keep the same direction of the flue gases along the furnace and duct until after the damper, when the duct turns 90°.

Support Floor

The constructed supported floor has as a disadvantage that the immediate removable floor area was restricted to 1.6 X 1.1 m^2 instead to accommodate a burner of diameter of 1.2 m^2 as specified. But in compensation, the two supporting girders offer a safer alternative to a floor suspended only by bolts.

The girders decrease the ability for dismantling the floor because they present extra obstacles for enlarging the removable area of the floor further than 1.6 X 1.9 m^2. It was suggested that the girders could be easily cut; but then doubts arise about the soundness of the structure if any girder is cut.

Sweeping Duct

The third modification was due to lack of understanding between the parties involved: chimney subcontractor, client and main contractor. This led to the installation of a chimney whose theoretical induced draught at the furnace arch was smaller than that expected by the contractor. In order to increase the draught, it was decided to reduce the friction losses at the connections of the air preheater flue duct to furnace duct to chimney. The above connections with an angle of 90° were swept in 15° and 6o° respectively so that the friction losses were reduced (3.3.3.1.2).

3.3.1.1.2 Final Details

Among the pending details to be agreed and included in the final drawings were the positions of the following; Viewing ports, Sampling ports, Access Door, Compensator Joint and T.V.cameras.

Viewing bolts

The original location of the viewing ports was on the middle of the shielded walls. Then in week 25 in order to increase visibility of the lining a proposal to stagger the windows was discussed but the original idea prevailed and the viewing ports are at the middle of the shielded walls and at each level of the furnace.

The sampling ports location above or below the viewing ports was discussed. Also four sampling ports to be situated on the duct, i.e. two pairs diametrically opposite.

Access Door and Platform

The access door on the first level was slightly moved from the original position in order to improve access. The platform and stairs were wider than the original proposal.
Two compensator joints of stainless steel with extra thickness for resisting Vanadium attack were added to the burner and duct connections to the furnace.

T.V.Cameras As described in the tender, two T.V.cameras were installed on the furnace. One was on the first floor and the other at the top of the furnace looking downward. The former was slightly tilted in order to see the furnace floor.

T.V.Cooling System The cooling of the cameras is carried out by an extra cooling water system which has a pump with a capacity of 10 gallons per minute and able to generate a pressure head of 30 psig at the top of the furnace. This pump is started locally, has a bypass and a pressure gauge at the outlet.

This extra cooling system is used also for the sample probes.

3.3.1.2 Work Progress

3.3.1.2.1 Furnace Box Fabrication, Delivery and Related Payment.

Second payment The details and modifications delayed the handing over of the furnace drawings, which were nominally accepted before their full completion, in order to proceed with the corresponding payment. The valuation was passed to ---Firm C--- in week 24.

Furnace & Duct Fabrication and Delivery The furnace and ducts fabrication in the shop started after the payment for the furnace drawings and was completed in the 36th week; this was four weeks later than was originally planned; but the delivery was expedited so that the furnace and ducts were on the site in the 38th week, which corresponds to four weeks before the planned date.

Fourth Fifth Sixth Payment	After the fabrication and delivery of the furnace and the ducts, the 4th and 5th invoices were issued. However, the agreed payment schedule considered the above events for 5th and 6th payments. At this time, it was agreed to tie payment number six, or the penultimate invoice, to the lining of the furnace. This was accomplished in the 46th week, four weeks later than planned.

3.3.1.2.2. Furnace Box Erection and Accessories Installation.

The actual erection of the furnace which lasted two weeks, was the starting point for installation of the lining and completion of the erection (walkways, stairs, etc). Two weeks after the completion of the lining which lasted four weeks, the coil bundle arrived. The installation of the coil lasted three weeks and was followed by a hydraulic test which the coil passed successfully.

Lining Header Boxes and Floor Cooling System Completion	After this event, three activities started simultaneously:- Completion of the coil, bellows, lining of the header boxes, and covering the furnace floor with special refractory bricks. These activities were completed in the weeks 55th, 53rd and 52nd, respectively.

3.3.1.2.3. Burner Delivery, Installation and Operation.

Two weeks after the lining of the floor, the burner was received. This burner was different to the one originally ordered during the tendering stage. The manufacturer on the basis of the wide range of temperature to be used on the BTR, proposed to change the original burner for a smaller type which could cope better with the variation of temperature. The smaller burner model was approved and ordered in the 20th week, with the manufacturer's promised delivery in the 46th week, but the delay of the project allowed the delivery date to be in Week 54.

Burner Installation

The burner was installed and connected with flexible pipes instead of rigid pipes. The latter were preferred on the ground of being more reliable; but because different burners are to be tested and they come in a wide range of sizes and arrangements, the connection is greatly eased by the use of flexible pipes.

Two Filters

The burner proposed by the manufacturer is quite versatile, can burn liquid and gaseous fuels either individually or in combination. During a test run with oil the burner jet was blocked; therefore two filters were mounted: One in the oil line and the other in the atomising steam line (3.8.1.2.1).

3.3.2. Lining.

3.3.2.1. Pyroblock Proposal.

Introduction	In addition to burner testing in the BTR, BP was interested also in testing a new lining, which although commercially available no application in refineries was known.
Advantage	This new pyroblock has the advantage that an adhesive is used to hold the lining instead of studs which are likely to be attacked by sulphuric acid condensation when burning sulphur bearing fuel oils. Thus, in the final tender, Firm C proposed to line the furnace with modules of pyroblock insulation and adhesive acid resisting backing (no stud fixing) on the exposed and shielded walls and flat arch of the firebox.
Lining Bidding and Problems Found	Three companies were contacted, among them ---Firm J--, which is the sole representative in the UK of --- Firm K --- (U.S.A.) manufacturer of the pyroblock. In obtaining the performance guarantee from Firm J under the conditions set by BP, some conflict arose.
Chemical Properties	This was particularly evident with regard to the chemical resistance of the synthetic fibre which they recommended instead of the china clay. However, the former is a more resistant type of pyroblock. Firm K only gave one year guarantee and recommended a limit be set on the vanadium content of the fuel oil at 60 ppm. This value is approximately 15% of Vanadium content in the fuel originally proposed by BP.

Physical Properties

Another problem was the fact that due to the high temperature used in the furnace, 850°C normal running and 1100°C as the design temperature, there was a possibility of shrinkage at the surface of the pyroblock with subsequent exposure of the adhesive resin whose design temperature is only 250°C. Firm K accepted that the adhesive could crack not before the lining would have to be changed. This was by reference to the steel industry where the average life of linings is shorter than in the oil industry.

3.3.2.2. Final Lining Proposal, Delivery and Installation.

In view of the above uncertainties, BP agreed with the main contractor to use pyroblock only on one unshielded wall and on the arch and castable refractory on the remaining walls.

Contract Conditions

Agreement was reached with the lining sub-contractors, one for the pyroblock and another for the castable refractory, that they would share the responsibility of assuring a proper finish for the interface of the two different lining systems.

Delivery and Installation

The orders for the lining were placed in the 32nd week and the delivery was promised for ten weeks later. This delivery date was met and the installation was carried out without delay in spite of a temporary unavailability of electrical supply. The latter was required to weld the stud which hold the castable lining.

After the installation of the lining, the connection between the chimney furnace was to be completed but an unexpected delay occurred.

Lining Damage

During this delay the lining was exposed to the weather. This was of concern for the client because they were liable for the chimney furnace connection delay and therefore the main contractor and lining subcontractors did not have any contractual responsibility for any damage which could occur to the refractory.

3.3.3. Chimney

3.3.3.1. Detail Engineering

Order of the Chimney

BP awarded the contract for erecting the chimney to the subcontractor Firm G before the tendering process started. At the tendering stage a detailed drawing was supplied by the --Firm G-- which outlined the main dimensions supplied by BP and the characteristics of the chimney.

3.3.3.1.1. First Evidence of Incorrect Draught and Misalignment

Tendering

One of the tendering companies for the BTR contract, ----- Firm D -------, advised that the dimensions of the chimney were not compatible with the draught specification at the furnace. This contention was referred to ---Firm G--- who stated that their responsibility was "limited to the structural design of the chimney". Then, the problem was referred to BP who asked

---Firm D---- to proceed with their design using the conditions described and report their findings.

Independent Opinion about the Chimney

The conclusion to which Firm D arrived was that at low flowrates, the efflux velocities are too low for effective dispersion of the combustion products and the stack may suffer from temperature inversions or down wash.
Also, in view of the small pressure drop margin available, particularly under natural draught conditions, the diameter for both duct and stack should be the biggest possible 4'6" (1.3 M).

Bolt Orientation

Also, early in the project, Week 6, it was discovered accidentally that the hold down bolts were shifted 12 mm in the clock-wise direction. This problem was solved by rotating in the opposite direction the bolt holes on the chimney base.

3.3.3.1.2. Draught Problem and Solution

Design Engineering Chimney

At the 15th week, the main contractor supplied engineering data of the chimney to Firm G -----, and this included arrangement of the duct draught specification and loads. Four weeks later, Firm C enquired of the chimney subcontractor the following data:

i) Deflection of the chimney
ii) Draught at the duct-chimney connection.
iii) Acceptance of a drawing showing the ducts arrangement.

iv) The approval of the connection flange design by Firm C.

Responsibility of Chimney Subcontractor (define by themselves)	Firm G's reply was delayed for a month and reaffirmed that their responsibility is exclusively with the structural design of the chimney; Therefore they questioned the fact that their opinion was being asked about configuration of the duct and draughts. They argued that the dimensions of the chimney were provided for them by BP and the connection of furnace chimney is the responsibility of Firm C., consequently they made no attempt to answer questions outside of their control.
Draught Problem Problem in inducing the proper draught	However, --Firm G ---. also said, that in order to be of assistance, they would answer the main contractor's queries. All the queries were answered satisfactorily, with the exception of the draught at the flange connection. The draught given by Firm G was evaluated by a Shell Publication, "Chimneys for Industrial Oil-Fired Plant". The result of this calculation was 0.1 inch wg, well below the expected minimum draught 0.28 inch wg by Firm C. . Apparently, the reason or part of the reason that the draught was so far out of specification was due to misunderstanding by Firm G and miswording of Firm C. who wrote that "the worst operating condition was to be found in the chimney when the furnace is working at full load on its own" instead of the furnace and air preheater working together at full load.

Possible Solution (sweeping the chimney)

BP stated that alterations to the dimentions of the stack could not be accommodated because of the limited design load of the base block which had been constructed under BP supervision. However, in order to decrease the pressure loss, it was proposed by BP to sweep the preheater flue duct into the chimney, as well as the furnace flue duct. These alterations were accepted by all parties involved.

Drawings

In week 26 a new set of drawings were approved by BP but including the requirement for the duct connection and flue preheater sweeping.

3.3.3.2. Work Progress - Misalignment Correction and Cost

Furnace Position Error

At this time Firm C. recognised liability for an error of the furnace position which was detected by the comparison of the chimney drawings with the equipment installed on the site. Although, the furnace base was moved in order to correct the distance to the chimney, nothing was done regarding an orientation error between the chimney and the furnace.

3.3.3.2.1. Misalignment

Therefore, later in the 49th week when the chimney was erected a misalignment was discovered. Although this did not stop the concrete lining and Combustion Air Ductworks connection, the furnace chimney connection had to wait for modification works in the chimney. After some discussion and correspondence - interchange, it was clear that neither client nor subcontractor accepted liability for the discrepancy in the alignment. Hence, it was decided that discussions for finding the liable party could be postponed until after the due correction was effected.

Correcting the alignment

The modification started with the rotation of the liner as much as could be done without recourse to cutting or any alteration which could weaken the design structure of the chimney. Although, the chimney subcontractor rotated the liner by 1° 5', the chimney still did not align and it was necessary to alter the flange duct. This involved making a wooden template of the flange in order to determine the exact remaining offset of the liner (0° 31'). Then the flange duct was modified and the connection between chimney and furnace was carried out.

3.3.3.2.2. Misalignment Correction Cost

The cost of the variation, in addition to materials and labour cost, included charges for the uneconomical work incurred by the subcontractor who amended the duct, and the management cost (associated cost) incurred by Firm C. to normalise the situation.

Part of the payment due to Firm G was stopped by BP but, the former explained that they had continued the contract (making the necessary modification) despite the circumstances, therefore they expected BP also to honour the contract and to discharge the full payment; thereafter the question of liability was to be discussed. BP proceeded with the full payment and no further claim was made.

Table 3.3.3 A Chimney Main Events

Reason	Problem	Solution
Communication		Action Firm G
Site Management-Drw.Office	Holdown Bolt Orientation	Rotation of Bolts hole on the chimney base.
Communication		Action Firm G/BP/ Firm C
Process Management Design Office	0.1" wg draught instead of 0.3"wg	Sweeping the air preheater duct and the furnace duct at their connection.
Communication		Action Firm C.
Site Management-Drw.Office	Wrong distance between Furnace/ Chimney	Moving the hold-down bolts of the furnace.
		Action Firm G
Site Management	Unplumbing	Grouting
Communication		Action Firm G Rotation of the Liner and
Site Management-Drw.Office	No alignment between Furnace/ Chimney	Action Firm C Modification of the Duct flange.
	Liability	Action BP-Firm G
Contract	Firm G claim that their responsibility is limited to the sound structural design of the chimney. (No responsibility for site checking or visits.)	Wider definition of responsi-bility in the contract.

TABLE 3.3.3 B

CHIMNEY PROJECT ENGINEERING

Activity	Year	Month	Event
Detailed Eng Design Drawings		-	<- Detail Drw. of Chimney
		-	<- --Firm G--- established his "Solely structural Design responsibility"
		6 -	
			<- Main Contract is awarded
		-	
Detail Engineer-ing Discussion		9 -	
			<- Main Contract is awarded
		-	
		10 -	
			<- Wrong Orientation of the hold down bolt
		-	
		11 -	
		-	<- FirmC's Data Design pass to Firm G.
		12 -	
Detail Engineering	1979	-	Flange Connection Draught 0.1" wg instead of 0.30" wg.
		3 -	<- Chimney Drawing to include sweeping.
		-	
			<- Firm C accept furnace position but the wrong alignment was not noted.
Shop Fabrication		4 -	
		-	
		5 -	<- Final Approval of Drw.
		-	
		6 -	
		-	
			<- Chimney Delivery to Site
Chimney erection and Concrete lining		7 -	
		-	<- Discovery of the Chimney being unplumbed and wrongly aligned
		8 -	
		-	
Modification to Chimney and duct flange		9 -	
		-	
			<- Modification Cost (Variation Cost Clause)
		10 -	
		-	
		-	

3.4 Cooling Water System

3.4.1 Detailed Engineering Description

The cooling water system is a closed-loop circuit in which high pressure water circulates concurrently to the flame through two parallel serpentine coils of 46 tubes each, and the designed heat absorption was 15 millions BTU/h.

This heat is later removed by an air-cooled heat exchanger consisting of a four row finned-tube bundle (Aluminium fin; Carbon Steel tube of O.D. 1 inch) of 24 feet long and 8 feet wide, three fans (6 foot Aluminium Blades) and electric motors (1450 R.P.M; 3 Kw).

After the air cooled heat exchanger, the loop has a connection to a pressurising expansion vessel and a make up pump and tank. The former vessel is about 0.9 m^3 and contains enough water to compensate a shrinkage of water volume in the circuit following a drastic drop of temperature. The pressure of the system is maintained by a governor which regulates the nitrogen flow rate (from nitrogen cylinders) into the expansion pressure vessel until the set pressure is reached.

The 4.5 Kw make up water pump with a discharge pressure of 18 barg, is of centrifugal multistage type, able to pump soft water from a heated (electric immersed resistance, 2 Kw) 0.4 m^3 atmospheric tank into the loop. The pump is activated by level switches positioned in the pressurising expansion drum.

A pair of circulating pumps (one on stand by) supply the furnace coils with enough flow rate and heat of water to ensure an adequate temperature difference below the boiling point (inlet 53°C; outlet 14°C) to guarantee the non-formation of vapour. These 30 Kw circulating pumps with a discharge pressure of 21 barg, are of centrifugal type with a jacketed cooling water system.

3.4.2 Work Progress

As has been described, this system interacts with the furnace through the cooling coils. These have been discussed as a part of the furnace, therefore in this system only the following four units of equipment will be considered: Air Cooler, Water Circulating Pumps, Expansion Pressure Drum and Make Up Water System (Table 3.4.2). These units were delivered around week 38, erection followed and completion was achieved for the 41st week.

Subsequently pipework and instrumentation started and a recorded progress shows 20%, 65% and 85% completion for the weeks 43, 52 and 56, respectively. Finally, the pipework successfully passed the hydraulic test in the week 57. But commissioning extended up to the time when the B.T.R. was handed over in the 77th week, due to a number of modifications needed to correct faults in the system.

Project engineering details of each equipment are described below, including the necessary modifications.

3.4.2.1 Air Cooler Heat Exchanger

The air cooler was built on the site with the contractor taking responsibility for the design. The design of this equipment was done at a very early stage followed by the structural design and the issue of a set of drawings which showed two different views of the system. These were presented on the 20th week.

Table 3.4.2 Water Cooling System
Actual Project Engineering Schedule

	AIR COOLER		WATER CIRCULATING PUMPS	EXPANSION PRESSURE DRUM	MAKE-UP WATER SYSTEM
PLACE ORDER		20	20	25	25
DELIVERY	Ave:	34	40	38	37
	Last item:	37			
ERECTION		38	31	40	39
PIPING & INSTRU-MENTATION	20%	-	43	-	-
	65%	-	52	-	-
	85%	-	56	-	-
				(39th to be computed)	
PIPEWORK TESTING		-	57	-	-
MODIFI-CATIONS or FAULTS	Split tapper (57th) Guard belt lowered 42nd Fan Chamber 51st Angle clear-ance of fan checked 59th Fan shut off control (wrong) 67th		Flange thickness 42nd Bearing Water Cooling pumps 9th. Remove and replaced 60th Lubricating oil loss 7th Gland leaks i) Tightened up ii) Water cooling jacket	Possible Drum leak 77th HL Alarm switch 80th Liquid level switch 80th	New Make-up Control Unit 67th

Orders for the equipment from which the cooling system was to be fabricated, were all placed in week 20; but delivery was promised for different dates starting at the 20th week.

The parts were delivered in a very discontinuous manner which affected the fabrication. However, in relation to other equipment, the completion of the Air Cooler in the 38th week, would have permitted commissioning of the whole rig in the 52nd week.

The completeness of the air cooler and other equipment in the cooling system allowed the start of the firing commissioning; but this was affected by some faults which required modifications.

3.4.2.1.1 Modification and Addition to the Air Cooler H.E.

In the case of the air cooler several modifications were carried out:

i) Firstly, the fan guard was lowered to provide additional protection for personnel.

ii) Then a modification to the plenum chamber was carried out in order to increase the air circulation in the bundle assembly and consequently the fan efficiency.

iii) The latter was further increased by setting the optimum angle of the fan blades and their clearance to each other.

iv) Additionally, the client was permitted to fabricate split taper bushes to secure the fan motor to the drive shafts.

v) Once the air cooler was installed, it was decided to add a shut off control unit. This control unit was not installed until after the handover of the plant; even then it took time to get it to work satisfactorily.

3.4.2.2 Water Circulating Pumps

These were ordered in the 20th week and delivered without any delay to the scheduled delivery in week 38. Their erection was completed in the 40th week when a small modification was introduced and later some problems were encountered.

3.4.2.2.1 Modifications to Water Circulating Pumps

i) During the pump installation in the 40th week the thickness of the flanges were reduced, with the client approval, by 1/4" to 1 1/8" thick. This change was accepted by the client on the basis that the duty of the pumps was not severe enough to require flanges to the BS1560.

ii) A bearing fracture in one of the circulating pumps was detected in the hydraulic test. This pump was removed to carry out repairs.

iii) Another problem encountered was a leaking gland in one of the pumps. The leak was temporarily stopped by tightening up the glands but soon afterwards the leak recurred. Then the glands were changed without solving the leak problem. Finally, the manufacturer recommended a cooling water jacket around the pump which solved the problem.

iv) Also a recurring lubricating oil leak was solved by tightening the respective glands.

3.4.2.3 Pressure Expansion Drum and Make-up Water System.

Despite the late ordering of these equipments they were delivered in the 38th week at the same time as the delivered B.T.R. equipment bulk. The erection followed the deliveries; but final connections and instrumentation had not been completed in the 59th week, that is, two weeks after the hydraulic test of the pipework and the complete installation of other major equipment in the system. Eventually, the works were completed for the 60th week and the precommissioning started. During this time some problems described below were found.

3.4.2.3.1 Modifications to the Pressuring and Make-Up System.

In the 67th week erratic operation in the control unit of the make up water pump was noticed. The contractor agreed to change the whole unit which was damaged by ineffective water proofing.

Instrumentation faults requiring repairs were detected also in the pressure expansion drum whose liquid level switches and high level alarm were either erratically operating or not operating at all.

3.5 Combustion Air System

3.5.1 Project Engineering

This system consisted of the ducts and two major items (Table 3.5).

The Combustion Air Blower (J102) and Combustion Air Preheater (H109) were ordered in the 6th and 29th weeks, respectively; and their complete deliveries were by weeks 38 and 47, respectively.

These items were erected on arrival, therefore by week 49 they were ready to be connected.

The ductworks connection could not start until the 50th week because the ductworks were being lined. The delay caused by the late duct lining 10 weeks after delivery resulted, as explained below, from the installation used by the subcontractor encharged.

The installation of the combustion air system ductworks was subcontracted to its fabricator, "-M-", who also were to install the furnace and its flue ductworks. The Firm M ductwork installation procedure was to carry all the related works in a continuous manner. Therefore, the ductwork lining was to start at the chimney erection so that the subcontractor was sure that all the ductworks could be carried out, including the flue ducts.

Despite problems found with the erected chimney, the ductworks started; but only the ductwork connections between F.D. Fan-Air Preheater-Furnace were carried out during weeks 51-53.

Table 3.5 Combustion Air System

Actual Project Engineering Schedule

	AIR BLOWER	AIR PREHEATER PART A & B	DUCTS
PLACE ORDER	6th	20th	0
DELIVERY	36th	42nd & 46th	38th
ERECTION	38th	49th	Others 54th Flue ducts 60th
DUCT AND INSTRUMEN-TATION	80% 100%	53rd 61st	
	Faulty Motor 38th Acoustic Cabinet 59th Blower Charts to be supplied 61st Valve control damper 77th (Turndown 10:1 is delivered but 25-250 instead of 20-200 scmm) 80th	Control Motor Positioner 67th Governor Diaphragm perforated 67th Ignitor leads 67th Rusty Case 67th Regulator added 77th Fragile control unit case (changed) Control Room - Site Incompatibility of temp.chart.	

Later during week 56-57, the connection of the air pre-heater flue duct was completed but the final duct connection to the chimney was not achieved until week 60.

3.5.1.1 Air Blower

3.5.1.1.1 Project Engineering

The air blower was among the first equipment to be ordered in the 6th week; but the promised delivery date was shifted twice. Firstly from week 25 to week 36 and finally to week 38 when it was delivered. Erection work followed the equipment arrival and was completed by week 40.

The ductworks connection to the furnace through the air pre-heater was achieved by week 53 which in addition to electrical connection and preparation of the air blower permitted its precommissioning.

A final erection work related to the air blower was an acoustic cabinet around it, built at week 61.

3.5.1.1.2 Precommission and modifications.

During the air blower commissioning the following problems were discovered.

i) The full precommissioning of the blower was postponed from the 56th to the 58th week because the electrical motor was faulty and had to be removed for repair.

ii) The first precommissioning tests, showed fluctuating pressure reading in the duct connecting the air preheater to the furnace. This was caused by the turbulence of the combustion air flowing through the ducts. This problem was solved by placing a perforated plate in a duct joint close to the burner. Later a second perforated plate was installed at the expansion joint close to the burner damper.

iii) A modification concerned with the compliance of the air blower 10:1 turndown was required. This was, that the turndown of the original blower installation of 8:1 was improved up to the specified value by changing the air blower damper into vanes. However, the turndown ratio was achieved. The absolute values of the air flow rate 25-250 sm^3/h was higher than the specified value 20-200 sm^3/h. This was acceptable to the client therefore the air blower commissioning was approved.

3.5.1.2 Air Preheater

3.5.1.2.1 Project Engineering

The air preheater was ordered in the 20th week after final details and price were agreed between contractor and manufacturer.

The first two promised deliveries, week 34 and 38, were cancelled and postponed to the weeks 40 and 47 when the air preheater top and bottom section, respectively, were delivered.

The erection of the air preheater was completed two weeks after the delivery of the air preheater bottom section.

A week later, the ductworks started but because of the chimney misalignment the final installation of the air preheater was not until week 60.

3.5.1.2.2 Precommission and modifications.

The precommissioning of the air preheater was delayed due to the unavailability of the natural gas which was finally supplied by week 65. Before the first attempt to precommission the air preheater at week 66 some final piping and wiring connections of this equipment were carried out at the 65th week.

During the airpreheater precommissioning the following faults were discovered. These can be classified as general and those related to the operation of the local control unit.

i) General faults

During the air preheater precommission a contractor visual inspection indicated that the air preheater casing, the support framework and personnel heat protection guards were in very rusty condition and the local control unit case was not robust enough. These contractor observations were confirmed and solved by the manufacturer. Also, a few faulty parts were discovered and replaced. These included the ignitor leads and a perforated diaphragm in the gas supply governor.

Finally, one of the temperature controller TIC4, had a lower temperature range, 0-400°C, than the required 0-1000°C. This was solved by adding an extra resistance in the temperature controller.

ii) Faults related to the operation of the local control unit.

In addition to the above faults, two others were mentioned. These were mal-function of the flue gas high pressure safety interlock and the control motor positioner.

The former mal-function cut out the gas supply to the air preheater and it was supposed to be caused by an uncontrollable rise in the pressure during start up. In relation to this problem the contractor and client agreed to the following modifications.

Place at the air preheater main gas supply a redundant pressure regulator PCV50 from the LPG and reposition at the high pressure switch tapping.

The latter mal-function was attributed to wrong wiring between the control panel and the local control unit. This was checked by the instrument subcontractor but no improvement was achieved.

Then a meeting was organised a week before the final hand over between the manufacturer, client and contractor.

In this meeting the contractor stated firstly that the circuitry of the local control unit was incorrect but the manufacturer explained that the system was a basic control system which had been used successfully in previous contracts.

Then, some discussion took place and the conclusion was reached that the controllers in the control panel were incompatible with the local unit of the air preheater.

Finally, it was proposed to modify the circuitry of the air preheater but this did not solve the problem and the operation of the air preheater is now carried out manually without the local control unit and aided by the controllers in the control panel.

3.6 Natural Gas and Dosing System

3.6.1 Project Engineering

This system is formed by filters, mixing drum, compressor package unit and pressure reducer (Table 3.6). The ordering of this equipment, apart from the pressure reducer, were placed in weeks 6 and 20.

The delivery of the equipment occurred in the 34th and 38th weeks and erection commenced. Despite some problems with the compressor, erection was completed for the 43rd week.

At the completion of the erection, it was estimated that 10% of the pipework and instrumentation was completed and later, the completion achieved was of 85% and 95% by the 49th and 51st week, respectively. This pipework also included gas lines for the boiler and air preheater.

3.6.1.1 Filter and Mixing Drum

This equipment was ordered on the 6th week; the filter delivery was postponed once, arriving on the 34th week, while the mixing drum did not have any delay and arrived on the 24th week.

The installation work of this system started in week 37. The mixing drum was erected then; one of the filters was installed with the compressor unit package and the second during pipework.

3.6.1.2 Compressor Unit Package - Modifications

The compressor unit included a Fan-Cooled Exchanger at the compressor outlet and a Pressure Vessel Receiver afterwards.

Table 3.6 Natural Gas and Dosing System.
Actual Project Engineering Schedule.

		PRESSURE REDUCER	COMPRESSOR HOUSE	MIXING DRUM AND FILTERS
PLACE ORDER		0	20th	6th
DELIVERY		63rd	37th	24th & 34th
ERECTION		65th	43rd	37th
PIPING & INSTRU-MENTATION	10%		43rd	
	85%		49th	
	95%		51st	
		Plastic cone in GESTRA Non Return Valve 63rd Wrong type of meter (unacceptable loss Press.)	Exception list 6th from APl 618 Belt drive guard modi-fied (49th) Relief valve repositioned A pipe section blast cleaning. Diferential Press Range is too wide Trap Valve change Receiver Vessel has working set press lower than the required Removal and replacement of compressor. (Epoxy resin)	Press Relief valve to Nace Spec. No HCl can be used

This package was ordered in the 20th week. The delivery in week 38 was followed by the erection which was completed by the 43rd week. Later, during the 56th week, pre-commisioning had been carried out with air and the installation was found to be in good working order. However, when the natural gas was connected some problems were detected. This, and some incidents during the erection, are explained below.

3.6.1.2.1 Compressor Modifications During Erection

During the erection some modifications or rectifications were required. These are explained below in a chronological order of appearance.

i) At the start of the work the manufacturer's inspector ordered the lifting of the compressor in order to grout the unit with special cement grout mixture and an epoxy grout. The former provides a non-shrinking surface and the latter is oil resistant with high compressive strength and good bonding.

ii) Then, the drive belt guard needed modification in order to fit to the compressor unit.

iii) The positioning of the relief valve onto the inlet pipe to the pressure vessel receiver, instead of at the vessel dome, which would have required an opening in the roof.

iv) Also, during erection precautionary measures were taken. These included blast cleaning of the pipe section between the filter and the compressor inlet and change of the consensate trap valve on the drain line from the pressure vessel receiver for a more reliable one.

3.6.1.2.2

i) Once the unit was precommissioned with the normal supply of gas, it was realised that the pressure vessel receiver was insured to operate at 3.25 barg although operating pressures above this value were required. Then the insurance company was asked to accept a higher operating pressure on the basis that the vessel was designed for a pressure of 8.06 barg and was hydraulically tested to 11.89 barg. This new operating pressure was accepted by the client.

ii) Another inconvenience at this stage was fluctuating pressure of the natural gas at the burner during low demand. The sudden increase of pressure in the system occurred during the compressor discharge of natural gas. A set of four unloading valves are opened and closed by a pressure switch which is activated for a set range of pressure (high and low) detected in the receiver pressure vessel.

a) The first attempt to solve the problem was to reduce the high and low pressure setting from 4.8-4.0 barg to 4.25-3.9 barg. The fluctuation was reduced in absolute value and range but was still significant.

b) A second attempt was to install a pressure regulator at the outlet of the receiver pressure vessel but there was no perceptible change; therefore the regulator was removed.

c) Finally, it was decided to bypass natural gas from the receiver pressure vessel to the suction of the compressor. This bypass included a control valve actuated by the pressure in the vessel; therefore, bypassing more or less gas the pressure is kept constant in the receiver pressure vessel and the system.

3.6.1.3 Pressure Reducer Station - Modifications

On the 10th week a contract between BP and the Gas Board to supply natural gas was issued. This included the Pressure Reducer Station, PRS,delivery and installation.

The PRS was to be on site by the 19th week, but this date was rescheduled for not later than the 35th week. Then, after expediting visits and revised dates for commencement, excavation works started on the 50th week but they were stopped because the delivery of the PRS was not possible as the PRS was not ready, according to the PRS manufacturer. Eventually the PRS arrived in the 63rd week and after its installation gas was available in the 65th week.

Because the Gas Board only was to supply natural gas to the BTR by the Pressure Reducer Station, its unavailability delayed the full precommissioning of the Compressor, Boiler, Air Preheater and Essential Instrument for Dry Out in 11, 6, 6 and 5 weeks, respectively.

3.6.1.3.1 Modifications to the Gas Pressure Reducer Package

During precommissioning the following deviations from expected operation were discovered and corrected.

A low demand of natural gas could not be supplied, because the non-return valve in the pressure reducer package did not open at low flow rate. A replacement for the valve was not available; therefore the steel core of the valve was replaced by a plastic one, with a spring assisted return. This allowed the regulator of the Pressure Reducer Station to be reset to 37 in. wg static pressure and 27 in. wg on load. At these pressures, the boiler, which has a minimum working pressure of 11 in. wg, could operate.

Also, the Gas Board was to install a meter at the pressure reducer outlet; but the particular meter required was not available and instalment of the meter available at the time necessitated considerable alterations to the pipework. This resulted in an unacceptable pressure drop of 5 to 6 in wg at the compressor. Subsequently, the Gas Board agreed to replace the installed meter on arrival of the proper meter and authorised that natural gas could bypass the installed meter.

3.7 L.P.G. System

3.7.1 Project Engineering

In view of the higher flammability of the LPG fuel, in comparison to the other fuels used in the BTR, the LPG system formed by two tanks, pumps and evaporators (Table 3.7.1) was specified in more detail during the tendering stage. Thus, the information was enough to enable the contractor to order all the equipment of the system in the 6th week.

The LPG system equipment promised for about the 28th and 31st weeks arrived with the bulk of the equipment between weeks 37 and 41. This was an overall delay of 6 weeks.

The erection started as soon as the second tank arrived and was completed in the 43rd week.

Then the pipework started; but some client recommendations about the drench system caused the contractor to decrease noticeably the activities in the LPG pipeworks, which only achieved 5% completion in the first 6 weeks. Later, at week 49, the contractor confirmed to carry out some of the client drench system recommendations, and also decided to stop the activities in the LPG System to allow time for the client to fully consider the safety system.

On the other hand, LPG engineering included a modification in the pipework arrangement which consisted of a common bypass around the vaporiser temperature pilot control valves, pressure self control valves, strainers and isolating valves in the vaporiser steam supply lines.

At week 51 the client engineer asked the contractor to proceed with the works. This resulted in the completion of

Table 3.7.1 LPG System

Actual Project Engineering Schedule

	TANKS	VAPORISERS	PUMPS
PLACE ORDER	6th	6th	6th
DELIVERY	43rd	32nd	37th
ERECTION	45th	45th	45th
Start PIPING AND INSTRUMENTATION	5% 5%	48th 41st	
Mechanical Client's Approval of the system		65th	
	Fireproofing at the bottom of the tanks Leak on 2 ball valves. Leak on diaphragm valve Steam control governor was stuck Extension of Drench pipe. Drench tanker operated by a ball valve. Drench tanker valve close to the filling connection valves.	Oper.Manual delay Leak at flange connection Flooding	

the drench system at week 54, although the rest of the pipework did not show much progress at the time.

During the weeks 54 and 59 the contractor concentrated his attention on the precommissioning of the equipment required to carry out the dry out of the furnace refractories, subsequently the LPG works were again slowed down, and furthermore, the extension of the tanker drench pipe, proposed by the client was analysed and approved by the contractor during this period.

During weeks 63 and 64, the drench pipe modification was carried out by the pipework subcontractor, whose charge was qualified as excessively high by the client.

Then, at week 66, after the tanks fireproofing by Firm L ----, the client's expert was called in and a visual inspection was carried out. The system was approved and LPG ordered at week 67, so LPG was available for commissioning around the 71st week.

3.7.1.1 Storage Tanks and Drench System

The delivery of the tanks were originally promised in the 30th week, but after two cancellations, they were delivered, separately. One tank arrived at week 38 while the other arrived together with the accessories equipment at week 41.

The erection took place together with the other equipment and was completed in week 43.

The Drench System to spray the tanks and the lay-by where the oil tanker parks during loading, was engineered by Firm N ---. This subcontractor was encharged to issue the detail drawings which were expected by the contractor and the client since the week 35.

At this time, the contractor's mechanical drawings of the system showed two columns to support the water spray, located in the lay-by area. The client considered that the columns were in a hazardous position, therefore it was recommended that the columns should be moved as far back as practical, on the area between the tanker lay-by and the LPG storage area.

This modification was accepted by the contractor who transmitted it to the subcontractor, Firm N.

Two weeks later the detail drawing of the drench system was received and apart from the recommendation that the drain valve designated WD6 was not required and that a small hole in the pipe was sufficient for drainage purposes, the system was unconditionally approved.

In the 41st week, BP's Fire Officer commented about the system and recommended that the drench valve should be provided with a quick deluge valve and located away from the lay-by area.

The former recommendation was partially implemented by the contractor's decision of changing the existing wedge valve by a ball one.

The latter recommendation was complemented by the BP's expert as follows:

> The drench valve should be as close as possible to the filling connections from where it would be clearly visible at the discharge end of the ullage tubes and pressure gauges at the top of the tanks. Also a hand operated drench switch was to be sited in this area.

3.7.1.2 Vaporisers and Pumps

Although the pumps delivery were promised at week 38, three weeks earlier than the vaporisers. After two postponements they were on site at week 37, five weeks later than the vaporisers.

The erection of the vaporisers and pumps was carried out in two and one week, respectively.

After the pumps were supplied, the contractor confirmed with the client that iron cast casing was acceptable, although this was in any case specified in the tender.

3.7.1.3 LPG System Modifications

The LPG system had three modifications or additions after erection. Two were concerned with safety and included fireproofing on the bottom of the LPG tanks and an extension of the drench pipe at tanker lay-by. This extension was to spray any size of tanker, including the driver's cab.

The third modification was to fuel the furnace pilot line with LPG; therefore a connection between the main gaseous line (NG1004) and the pilot gas line (NG1007) was added. This connecting line included an isolating and non-return valves as well as an orifice plate which was connected to the existing flow transmitter and indicator of the furnace pilot line.

Modification During Commissioning

In the first LPG firing commissioning carried out by the contractor, it was found there was a leak in the vaporiser flange. After tightening up the leak disappeared.

In a second LPG commissioning firing, two leaking ball valves were changed and one of the steam pressure regulators, stuck open, was repaired

3.8 Oil System

3.8.1 Project Engineering

The system is comprised of two pumps, filters, tanks and one steam oil preheater (Table 3.8.1).

As the LPG system, all the oil system equipments were ordered by the 6th week. The equipments were received by week 37, with the only exception of the oil preheater which arrived on the 27th week.

The erection was done on arrival. Thus, by week 42, all the equipment was installed and the pipework connections started. A recorded progress report shows that 85% and 98% completion of the pipework was achieved for the 49th and 51st weeks, respectively. Lagging and a few instrument connections outstanding in week 51 were considered by --Firm C--- to constitute 2% of the oil system. This was satisfactorily completed four weeks before the 57th week, when the client approved the completion of the whole oil system.

3.8.1.1 Oil Storage Tanks

The tank ordered in the 6th week was promised for week 29, but three postponements by the manufacturer changed the delivery from week 29 to 38. The tank erection followed their delivery and was completed at week 40.

A set of pipework layout and mechanical drawings issued around the 20th week showed the majority of the design details of the system comprising the BTR. However, a few details were left to be decided later in the project. These included the level where the tank temperature sensor was to be positioned. The sensor supplies the signal to the controller which manipulates the steam required to warm up the tank at a set temperature.

Table 3.8.1 Fuel Oil System

Actual Project Engineering Schedule

	TANKS	PUMPS & FILTERS	PRE-HEATER
PLACE ORDER	6th	6th	6th
DELIVERY	38th	38th	27th
ERECTION	42nd	40th	40th
TEST APPLIANCE	57th		
PIPING & INSTRUMEN-TATION	10%	49th	
	80%	51st	
	98%	57th	
BP TANK ACCEPTANCE			
	Aluminium (49th) Cladding Extension Ladder & Dip Tube (47th) Temp Sensor(49) 1.220m Delay in issuing approv. cert. (61) Steamtrap leaking Separator. Notification (80) Pipe below level. Plastic vent to be changed.	Adequate Spillage containment Coarse Mesh to be fitted (67th) Filter in the oil line and another in the atomising steam.	

Note: Viscometer on site in week 67 but without chart.

Expert to calibrate viscometer (77)

Temp.range of viscometer incomp.with control room. Taylor E.V.T. (5-150°C) and TIC(0-200°C)(It has been calibrated)

Steam trace leaking 65th

Burner jet blocked 67th

The decision to locate the tank temperature sensor at a level of 1.22 m was taken at week 49 and also to include in the operating instructions an adequate notice which warns that the operation cannot be carried out if the level drops under the 1.22 m.

Additionally, the client recommended the addition of a dip tube to the tank which was a C & E requirement for its clearance.

At week 44, the contractor started preparing the dip tube detail drawing which, contrary to the stipulations of the C & E, shows that the dip tube was not placed in the centre of the tank. The reason for the deviation from the stipulation was because the coil heater was in the way.

Five weeks later, C & E approved the dip tube detail drawing and its installation was completed at week 51.

Also at week 44, C & E recommended an extension of the ladder and the contractor on his part recommended the use of aluminium cladding to cover the insulations, which BP accepted because no extra charge was incurred.

The installation of the storage tank was completed by week 51 once the coil heater was installed and ready for calibration.

A first calibration was carried out by the Customs and Excise with 90 psig steam in the 55th week. Two weeks later, the client approved the system after the coil heaters were re-calibrated at a pressure normally used by the client for testing steam lines. This was 225 psig instead of 90 psig. The former test pressure was to be used by the contractor to test other steam lines.

The C & E clearance was finally issued at week 61. This allowed the client engineer to order the oil, whose delivery was met by week 65, and since then oil was available in the rig.

3.8.1.2 Equipment in the Oil Pipe Line

3.8.1.2.1 Filters, Pumps and Oil Preheater

These equipments were ordered at week 6 and deliveries were as follows:

The duplex filters and pumps were promised by week 25, but two postponements changed the final delivery to week 38.

In the case of the oil preheater, the original promised delivery was kept and the equipment delivered in week 27.

The erection of these equipments started on arrival and was completed without any particular problem a week later, after delivery.

Modification During Commissioning

In the first oil firing commissioning carried out by the contractor, oil sprayed onto the furnace back wall.

The burner manufacturer was called and indicated that the installation was correct but the atomising jet was obstructed. Subsequently, the contractor proceeded to install filters into the oil and atomising pipe line adjacent to the burner, and ordered a less coarse mesh to be installed in the duplex filters (< 200 micron).

3.8.1.2.2 Flow Meter and Viscometer

Flow Meter. At week 25, the client proposed to supply the flowmeter. This was accepted by the contractor and an agreed amount was deducted from the contract. Later in week 35, it was discovered that the oil flow flowmeter was fitted with female screw connections. These were modified into flanges to BP standard and handed over to the contractor at week 40.

This transaction was not notified to the instrument sub-contractor therefore an orifice plate was devised as a measuring element for the oil flowrate and its complementary instruments, which included a square root extractor and a chart. Later at week 56, during the inspection of the instrument panel, the problem encountered was that the linear signal of the flowmeter was wired to non-linear instrument in the panel. The client decided to bypass the square root extractor and kept it as a spare while the chart was changed.

Viscometer. In the retender the contractor recommended to change the feed forward, ---Firm P--- E.V.T. viscometer by a feedback contraves viscometer on the basis that the latter was cheaper, smaller and less likely to require service by the operating and maintenance personnel.

Despite the above reasons, the client preferred the E.V.T. viscometer which is a cascade loop controller type. This improves the control and also reduces fluctuations.

Before installation, two problems were encountered; firstly the controller in the control room was a standard two term type and not a remote set point control, and secondly, the plinth available was smaller than required.

The viscometer was installed a week after the delivery at week 67.

After the installation, it was discovered that the temperature ranges in the controller of the control room and viscometer were different, 0-200°C and 5-150°C, respectively. The former was corrected by inserting an electric resistance.

Finally, the calibration of the viscometer was not possible due to the absence of calibration charts.

3.9 Atomising Steam

3.9.1 Project Engineering

The atomising steam system (Table 3.9.1) formed by the softener and boiler unit were ordered in two separate packages, where the first contained resin cylinders, regenerating salt drums, and a dosing salt drum; the second package consisted of feed water tanks, dosing and reciprocating pumps; a boiler and a superheater.

The orders for the softener and boiler packages were placed in the 6th and 20th weeks, respectively. Because the boiler required to agree the final price, it was ordered 14 weeks later than the softener. The deliveries were as promised, and in the case of the softener, it could have been delivered earlier, since the unit was available by the 18th week. The boiler unit and softener were received in weeks 39 and 36 respectively.

The erection was carried out as the equipment arrived on site and completed in the 43rd week. This was followed by the piping in the boiler house and the pipe connection from the boiler house to the furnace.

The progress of the pipework in the boiler house was slow until the 49th week when only 10% completion was achieved; but this pipework noticeably improved after week 49, when in only two weeks, the completion reached 80%. This included the connection of the return surplus superheated steam from the boiler house into the main site steam.

All the equipment of the boiler house was precommisioned with a provisional supply of gas in the 59th week; but there was some outstanding pipeworks (3.9.1.1) at the time. On the 66th week, a normal supply of natural gas was connected to the boiler house and 4-19 barg superheated steam was obtained.

Table 3.9.1 Atomising Steam System
Actual Project Engineering Schedule

	BOILER PACKAGE	SOFTENER PACKAGE	ATOM.STEAM PIPE
PLACE ORDER	20th	6th	-
DELIVERY	39th	36th	-
ERECTION	41st	35th	
PIPING & INSTRUMENTATION		41st	49th
80%			51st

Notes: Steam is returned to the site by a second connection

Non Return and isolating valve between boiler and superheater. Rectify pipe

Flue vent not up to standard

Cracked cylinder.

Weak drum support.

3.9.1.1 Modifications in the Boiler House

At the time of the first precommissioning, a series of criticisms of the boiler unit and softener was made.

i) The first observation was that the pipework between and in the units was not neat. This was reported to the contractor who was also dissatisfied and contacted the manufacturer to rectify the pipework.

ii) Similarly, a replacement was required of the pop riveted boiler flue which was not gas tight, by a seamless steel tube. The manufacturer agreed to change the lower part of the tube.

iii) Another inquiry from the client was the installation of isolation and non-return valves between boiler and superheater. The manufacturer agreed to fit them but because these valves were not specified the incurred cost was to be paid by the client.

iv) Modifications related to the softener included; change of the drum hard board support for a more robust one; reliable hoses; and a new resin cylinder to replace the one on site which was cracked.

After the commissioning, it was discovered that wet steam was at the burner. This problem was solved by improving the lagging and installing steam traps. The above measures increased the superheated steam temperature from 1°C to 40°C.

3.10 Instrumentation

The original layout of this chapter (thesis) considered to dedicate only a section to the instrumentation project engineering and modifications but for the following two reasons a complete chapter was done instead.

Firstly, during the project it was realised that it is normal practice in the construction of process plant (including BTR) to consider the instrumentation as a sort of service system (standard equipment) despite that the instrumentation equipment is not more standard than any other major equipment discussed during the tendering period.

Secondly, the operation of major equipment (systems) mostly depends upon the type of instrument installed (including safety systems, interlocks).

The instrumentation chapter considered seven sections from which the Project Engineering (4.4) and Final Works (4.6) are the most relevant sections for this chapter.

3.11 Contractor Planning Documents

In the original tender and later during the beginning and the end of the erection, the contractor issued the following planning documents which are described in this section:

i) Activity Bar Graph
ii) Payment Event Schedule
iii) Manpower Chart
iv) First Network Diagram
v) Second Network Diagram

Also, a real cost "S curve" was added, its construction and description is explained in 3.11.2.

Additionally, this section shows the comparison and deviation of those planning documents (Bar graph, First Network Diagram and Second Network Diagram) which were to indicate the progress of the works.

3.11.1 Activity Bar Graph

The project Activities Bar Graph, Figure 3.11.1 shows the main activities required in the B.T.R. project, as well as their starting and completion times.

These activities are Site Set-Up; Site Clearance and Drainage; Foundations; Lay-by and Ducting; Boiler and Compressor House; Plant Delivery; Instrument Deliveries; Pipework Delivery; Electric Delivery; Plant Erection; Pipeworks Erection; Electric and instrument Installation; Commissioning; and Paths, Fine Grading, Making Good, and Dismantling Temporary Plant. These activities can be regrouped as shown below, with the starting and completion dates.

i) Civil Works were to start at Week 2 and finish at Week 14.

ii) General Deliveries were to arrive from the 17th week up to the 34th week.

iii) Plant Erection was to be achieved between the 19th and 36th week, inclusively. The above deliveries and erection works excluded the furnace which was to be on site by the 42nd week and installed between the 44th and 47th week, inclusively.

iv) The Pipeworks Erection, Instrument and Electric Installation were to be carried out between the 21st and 47th week, inclusively.

v) The precommissioning was to start by the 48th week, with the intention of the B.T.R. being fully operational in the 52nd week. This considered four weeks precommissioning and one week commissioning.

vi) Finally, making good, paths, final grading and dismantling temporary plant was to be completed during the last two weeks before the hand over.

3.11.2 Real Cost "S Curve"

The combination of the activities bar chart and (2.5.2.1) the percentage of the real cost of each activity results in an S-shaped curve. The real costs are obtained from the cost analysis of the Tender. This curve, shown as Figure 3.11.2 has time as abscissa, while the ordinate can be either percentage of project completion or percentage of the real cost incurred during the plant erection.

The "S Curve" (Figure 3.11.2) shows that the beginning and the end of the project the percentage rate of the project completion is lower than at the middle of the curve. Also, the curve shows that between the 14th and 42nd week, which is 49% of total completion time, 83% of the work was to be completed. By contrast, in the rest of the available time 51%, only 17% of the work was to be completed.

Table (3.11.2.A) and (3.11.2.B) shows that the schedule work rate output in the middle of the project, was to be four and ten times bigger than at the beginning, and the end of the project, respectively.

Also, the "S Curve" suggests that the bulk of the incurred cost was during the delivery and erection phases, leaving only 3% for the last 6 weeks of the scheduled project phase.

3.11.3 Payment Event Schedule

This links the different payments with the completion of certain jobs. These jobs are more specific than the activities mentioned above and have more definitive completion dates. Also, most of these jobs are related to major equipments like the furnace which was scheduled to be the last fabricated, delivered and erected; the events which mark the time of payment are as follows:

- i) Plant layout and foundation to be completed by the 4th week.
- ii) Drawing of the furnace to be completed in the 10th week.
- iii) Major material to be received in shop by the 18th week.
- iv) Tank and Vessels to arrive in the 24th week.

v) Shop completion of furnace by the 32nd week.

vi) Delivery of the furnace in the 41st week.

vii) B.T.R. completion including commissioning was due in the 52nd week.

The above planned events correspond with the following percentage of the total contract price 5, 10, 10, 15, 25, 25 and 10, respectively, (2.5.2.2).

Plotting of the percentages of the total contract price against time show an "S Shape Curve", similar to the real cost curve. However, there is a difference in the % of payment and cost along the project which can be summarised as the contractor having a positive cash flow (max. 5%) during the first half of the project and turning negative (max. 5%) in the second half.

3.11.4 Manpower Chart

A third bar chart is a qualitative and quantitative description of the manpower necessary in the project. Figure 3.10.4 shows four irregular blocks, demonstrating the fluctuating manpower required on site during the civil works, first deliveries, construction works and commissioning. These activities were to be done during periods of 12; 6; 26 and 5 weeks, respectively; the manhour required was to be 7500; 1000; 1600; and 1500 so the total manhours was to be 26,000 and the average number of men per week was to be 16; 5; 15; and 8, respectively. The manpower was to be available as follows:

In the first fourteen weeks of the project, when civil works were to be carried out, the Site Engineer was helping a group formed at the most active time by a Civil Engineer, 18 Civil Operatives and a Storeman.

At the completion of the Civil work supposedly to be in the 14th week only the Site Engineer and the Storeman were to remain on site, this personnel was increased by two fitters two weeks later.

This personnel was to be unchanged until the 20th week when a Mechanical Engineer, three Pipe Fitters, five Electricians and another two Fitters were to be added in order to carry out the erection works.

The fitters were to be retired when the plant major equipments were installed. But reinforcement of six Furnace Fitters were to be brought up by the 44th week to help in the furnace erection.

In the 47th week the B.T.R. erection people were to leave site and the Commissioning Engineer was to arrive on site.

3.11.5 First Network Diagram

The network representation issued by the contractor in the 34th week Figure 3.11.5 shows a new erection plan which had to be adjusted due to the manufacturer's late deliveries. This network has the principal function of highlighting the critical path or the priority activities during the B.T.R. construction.

3.11.5.1 Comparison of First Network Diagram and the Activity Bar Graph

The network diagram starts from the 29th week, when civil works were still being done, but they were not considered. Apart from the civil works, the network diagram covered the rest of the activities involved in the B.T.R. project.

The first activity considered in the network diagram was the equipment delivery which were to arrive between the 30th and the 48th week. Figure 3.11.5.1 shows 6 weeks delay in the schedule delivery completion, in relation to Activities Bar Graph.

The erection of the B.T.R. equipment, with the exception of the furnace, was originally estimated to be during weeks 18 and 36 and then the furnace erection between the 44th and 47th weeks. But in the network diagram the B.T.R. erection including the furnace is continuous between the 31st and 54th weeks. So at this stage of progress, the delay is similar to the one of the completion of the deliveries.

The installation of the pipeworks, instruments and electricals were originally estimated to be completed between the 20th and 47th weeks while in the latest plan these activities were to be between the 37th and 55th weeks.

At the completion of the B.T.R. installation, the network diagram shows an eight weeks delay in relation to the activity bar graph.

Finally, the original plan considered a commissioning period between the 48th and 52nd week, while in the network diagram, only precommissioning of the equipment and one week of the furnace operation was considered. The mentioned precommissioning was to start in the 53rd week and for the time of its completion in the 56th week the B.T.R. was to be ready to dry out the furnace refractories. This was to occur by the 57th week and marks the completion of the project by the contractor.

Finally, the overall plan shown in the network diagram has five weeks delay in comparison to the Activity Bar Graph. This is despite the one week commissioning instead of the five considered in the original bar graph.

The above discrepancies are summarised in Figure 3.11.5.1 by comparison of the original Activity Bar Graph and a Bar Graph constructed from the network diagram.

3.11.5.2 First Network Diagram - Critical Path

As it can be seen from the first network diagram, Figure 3.10.5 the reversed order of completion of the different sections in the B.T.R. are as follows:

Furnace System, Wiring of Electrical and Instrumentation, Ductworks Erection and Piping of the Cooling Water, Natural Gas, L.P.G., Oil and Atomising Steam Systems. The slack time between the completion of the furnace system and the above activities (Instrumentation, Ductworks and Pipeworks) are 4, 5, and 9 weeks respectively.

The furnace latest completion results in a B.T.R. critical path comprised by those activities required to erect and installthe furnace. The furnace installation works although it is not shown explicitally in the network diagram can be considered as those required outside the box furnace like walkways, stairs, ancillaries, piping, etc., and those required inside the box furnace like wall lining, tube coil, installation floor lining and burner installation. The network diagram shows that the required jobs to be done inside the furnace box are on the critical path. Before the installation works, the network diagram shows the furnace erection, delivery and shop fabrication which were also to be part of the critical path and subsequently the activities such as furnace drawings approval and detail engineering design.

3.11.6 Second Network Diagram - Comparison with the First Network Diagram

3.11.6.1 System to be Commissioned

In the 54th week the contractor issued a Second Network Diagram S.N.D., Figure 3.10.6 which covered the activities leading to the Dry Out Operation in the 57th week.

Although this dry out operation was planned to be in the same week as scheduled in the First Network Diagram F.N.D., in the latter all the fuels were to be available while in the S.N.D. only natural gas was to be burnt. The exclusion of the L.P.G. and Oil (Atomising Steam) was mainly due to unavailability of these fuels; but also the incompleteness of their systems would not have made possible to fire them in the B.T.R., either. According to the F.N.D., the equipment erection and pipework of the L.P.G., Oil and Atomising Steam System were scheduled to be completed around nine weeks before dry out operation.

3.11.6.2 Outstanding Jobs

The Second Network Diagram included five main jobs which can be described as completion of the Flue Gas and Combustion Air Ductworks as well as installation and connection of the Control Panel, Burner and Pressure

Reducer. By contrast the First Network Diagram only included the Burner connections during the same period.

The extra jobs included in the S.N.D. in comparison to the F.N.D. was caused by:

i) Completion delays of the Flue Gas and Combustion Air Ductworks, which according to the F.N.D. amount to 7 and 11 weeks respectively.

ii) Delivery Delays of the Pressure Reducer Station, Control Panel and Burner whose promised deliveries were changed from the 35th, 46th and 4 th, respectively, to the 55th week.

3.11.6.3 Precommissioning Activites

Finally, in the F.N.D. there was only a reference to precommissioning while in the S.N.D. some precommissioning activities for the Furnace, Combustion Air, Cooling Water and Natural Gas Systems were mentioned. These are described in 5.1.3.2.

Table 3.11.2.A Distribution of Scheduled Work Rate.
Fig. 3.11.1

Position of "S" curve	Time Passed %	Total Time Span %	Total Work Completion %	Work Rate Output %
Front	32	32	14	0.4
Middle	81	49	83	1.6
End	100	19	3	0.16

Table 3.11.2.B Cumulative Schedule Work.
Fig. 3.11.1

Positions of the "S" curve	Total Time Span %	Total Work Completion %	Work Rate Output %
At the beginning and the end of the project	51	17	0.3
At the middle of the project	49	83	1.6

Table 3.11.2.A Distribution of Scheduled Work Rate
Fig. 3.11.1

Position of "S" Curve	Time Passed %	Total Time Span %	Total Work Completion %	Work Rate Output %
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Table 3.11.2.B Cumulative Schedule Work

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Positions of the "S Curve	Total Time Span %	Total Work Completion %	Work Rate Output %
At the beginning and the end of the project	51	17	0.3
At the middle of the project	49	83	1.6

3.12 Actual Site Activities

3.12.1 Actual Network Diagram

The Actual Network Diagram is shown in the Fig. 3.12.1, A, B and C. This figure shows the actual time when the major BTR equipment were delivered, erected and installed. The period of time covered is between the 38th and 67th weeks, exclusively, which correspond to the furnace delivery and the issue of the mechanical acceptance certificate, respectively.

The Actual Network Diagram is similar to the First Network Diagram in relation to equipment grouping in the different systems but differs in the location of the system in relation to each other. Complementary figures are

Civil Work Progress Fig. 3.1.4.1 and
Promise and Actual Delivery Fig. 3.2.1

3.12.2 Actual and Planned Activities Bar Graph

This Bar Graph, (Figure 3.12.2) is a bar representation of the Actual and First Network Diagram of the delivery, erection and piping of most of the BTR major equipment. With the exception of the latest delivered equipment which are: The Air Preheater, Burner, Chimney, Pressure Reducer Station Electrical and Instrument Panel.

The latter equipment's delivery, erection and connection are also represented in the diagram but by asterisks. Also, the time planned and required for the Instrument and Electrical Mounting and connections are bar represented.

Finally, the LPG pipework completion was excluded from the corresponding bar representation, and instead is represented by asterisks.

3.13 Findings about the BTR Project Engineering

1. The first network diagram was issued in order to reschedule the project work activities which were disrupted by delivery delays. For week 52, the reschedule was also affected by delivery delays, therefore a second network diagram was issued which, as its predecessor, was also affected by late deliveries.

The delays were according to the equipment delivered, some were appreciably later than the original promised delivery, while others arrived with the bulk of the equipment. In summary, the bulk of the major equipment arrived between the 37th and 41st week but with the exceptions of the Stack, Air Preheater, Electrical and Instrument Panel, Burner, Pressure Reducer Station and Viscometer which arrived between the 47th and 63rd week.

2. The actual delivery period was two weeks out of phase in comparison to the original network diagram for the same bulk of equipment (Fig. 3.12.2).

3. The actual erection and pipework of the bulk of equipment as well as the electrical equipment and instrument mounting and installation show in the Figure 3.12.2 delays of 2, 7 and 16 weeks, respectively in relation to the planned activites.

4. The erection of the equipment was carried out as they arrived on site; therefore the erection is out of phase by the length of the delivery delay.

5. The pipework started two weeks later than planned and 20% completion was achieved in the first five weeks, representing slow pipework progress. The 20% completion consisted of 10% erection of the boiler pipework, erection of some pipe support racks and prefabrication of some pipeworks for the Oil, Natural Gas and Water Cooling System.

6. The ductworks and LPG pipeworks were completed nine weeks after the rest of the BTR pipework.

7. The electrical equipment and instrument installation started five weeks after schedule; in the first six weeks of this activity, the mounting of instruments achieved one fifth completion instead of the two thirds planned for the equivalent period.

8. The instrument panel arrived at the time the burner was installed; therefore the installation and connection of the control panel was considered part of the critical activities in addition to the burner connection and other jobs described in the Second Network Diagram (3.12.6).

9. Although the Dry Out was postponed indefinitely, the essential instruments required for this operation were ready in the 60th week. These included the three emergency quick shut down valves, Pressure trip system, Rotational fan indicator, Air preheater flame failure, and Manual switches of the Heat Off and Emergency Shut Down.

10. Although the general instrument installation was well in progress at the 63rd week, the client undertook the job of checking the pneumatically operated instruments, while the subcontractor completed the rest of the instrument installation.

11. The mechanical Hand-Over of the rig by the 67th week followed an acceptable completion in the BTR equipment installation. Therefore this date is assumed as the completion of the instrumentation which took twice as long as was foreseen, in week 34.

12. The planned (2nd/3rd promised delivery) and actual deliveries of the airpreheater (3.5.1.2.1), burner (3.3.1.3)

and instrument panel (4.4.3.2.2.1), shown in figure 3.12.2, had a delay of 7, 8 and 10 weeks, respectively.

Also, the pressure reducer (3.6.1.3) and viscometer (3.8.1.2.2) presented a delay which is not shown in figure 3.12.2 because their last promised delivery was before week 34 which is not covered in the mentioned figure.

13. However, of the above delays, only the late arrival of the instrument panel and the pressure reducer station (client responsibility) caused disruption to the pre-commissioning(Dry Out 5.2.3.2.2). The contractor attempted to by-pass or reduce the delay in the Dry Out, by putting more effort in precommissioning essential instruments, (Safety Systems, Furnace temperature indicators), and precommissioning running equipment with temporary low pressure gas and air.

14. Although the stack arrived in time to allow their erection before the scheduled Dry Out operation, misalignment (3.3.3.2) of the stack disrupted the full installation of the furnace system, which was finally completed in the 61st week.

15. As the stack, the LPG equipment system full installation was disrupted by a modification, which in this case was not a repair but an addition to the LPG System, (Drench System, 3.7.1.1), in order to make the system safer.

16. Also seen in Fig. 3.12.2 is that the Oil and LPG systems clearance was required from the Customs and Excise before any of the system could be filled with fuel (Oil/LPG) and their commissioning could be undertaken. The approval of the Oil System and later the LPG System were in the 62nd and 65th weeks, respectively. Then the firing commissioning of these systems started soon after the Oil and LPG arrival in the 65th and 71st weeks, respectively.

CHAPTER FOUR

INSTRUMENTATION & CONTROL

AND

SAFETY CIRCUITS

4.1 Introduction

This chapter has five sections after this Introduction, which are almost strictly ordered as the events happened in time.

This includes the Process Development, which considers the Instrumentation and Control (I & C) as well as the Safety Circuits (SC) of the Original Proposal, the Client Specification and finally As Installed. This allows to establish the main changes of the I & C and SC during the project.

Then, the contractor instrument specification is described in a summarised version so that it shows the most relevant requirement of a typical instrument specification.

The next section (4.4) describes the project engineering, which covers the awarding of the instrument subcontract, delivery and installation of the site instrument, and, fabrication and delivery of the electrical and control panel.

In section 4.5 two tables describe all the "BTR Instrument as Installed".

The "Final Work" section (4.6) carries on the project engineering started in 4.4, by describing the connection of the "Field Instrument" to the control panel and the modification works involved during the BTR precommissioning and commissioning.

The last section (4.7) considers only the findings which are related to the recommendation (4.7.5) given by the author in order to have an improved alternative of the Instrument Specification and a general strategy to deal with instrument activities based on the instrument specification defined.

4.2 Process Development

The objective of this section is to examine the specification changes occurring during the project to the Instrument and Safety system; therefore, it is compared with the Instrumentation and Control and Safety Circuits specified by the client for the "Original Proposal" (2.3.1.5 & 6) and the "Final Client Specification" (2.3.2.3.7 & 8), as well as the latter with the "Instrument as Installed." (4.6).

The detailed comparison (Modification to the original proposal, 4.2.1.1) of the Instrumentation and Control of the Final Client Specification and the Original Proposal also aimed at describing the former.

The above comparisons are summarised in four tables which, by the use of arithmetic symbols, clearly indicate the specification changes during the preparation of the final specification (Table 4.2.1.3A & B) and during the BTR project engineering (Table 4.2.2.1A & B).

4.2.1 Modifications to the Original Proposal - Final Specification

The final specification was issued to make possible the tendering on a lump sum basis therefore this specification was more comprehensive than the original proposal.

The Final Client Specification added more instruments than those deleted from the original proposal and also included certain changes.

The modifications introduced by the Final Client Specification to the Instrumentation and Control and the Safety Circuits are described in 4.2.1.1 and 4.2.1.2, respectively and summarized in 4.2.1.3 and tables 4.2.1.3 A&B.

4.2.1.1 Instrumentation and Control

Furnace System

i) Thermocouple at the furnace case was to be added.

ii) Pressure indicators across the damper were to be deleted.

iii) The flue damper was to be operated manually instead of motorised.

Cooling Water System

i) Flow indicators at each of the furnace inlet coil.

ii) Thermocouples at each of the furnace inlet coil.

iii) Thermocouple at pressurised heat exchanger outlet.

iv) Pressure indicator at the Expansion Drum Vessel instead of being at the furnace inlet and outlet.

v) To control temperature at the pressurised heat exchanger outlet instead of being at the furnace inlet. This required to be rectified because the circulating pumps where relocated between furnace and cooler heat exchanger outlet rather than inlet.

vi) To control temperature at the make up water tank by a thermostat.

vii) To control the level of water between high and low level marks, in the expansion drum vessel.

Combustion Air System

i) Thermocouple at the air preheater outlet instead of at the inlet.

ii) Pressure indicators were to be added at the air preheater outlet.

iii) To control the flow rate at the fan outlet by louvres.

iv) To control the temperature of the process fluid at the air preheater outlet (master controller) by adjusting the set control pressure in the main natural gas supply (slave controller).

Natural Gas System

i) Flow indicator in the gas pilot line to the furnace was to be added.

ii) Temperature indicator at the compressor outlet was to be added.

iii) Pressure indicator at the mixing drum.

iv) Pressure indicators at the control valves upstream in the main and pilot gas lines to the furnace.

v) Pressure indicators at the burner inlet in the main and pilot gas lines to the furnace.

vi) Pressure indicators at the control valves downstream in the main and pilot gas lines to the air preheater.

Pressure Control

vii) Pressure controllers in the main natural gas to the furnace and the air preheater.

viii) Pressure regulator in the pilot natural gas to the furnace and the air preheater.

Fuel Oil System

i) Level indicator at the fuel oil tanks.

ii) Temperature indicator at the fuel oil tanks.

iii) Thermocouples at the oil preheater inlet and outlet.

iv) Pressure indicators at each pump outlet.

v) Pressure indicators at the oil preheater inlet and outlet.

vi) Pressure indicator in the oil preheater shell, (steam).

vii) Pressure indicator at the burner inlet. To control tank temperature by manipulating the steam flow rate into the tank coil heater.

viii) To control fuel oil viscosity and temperature at the oil preheater inlet and outlet, respectively by manipulating the oil preheater steam by a cascade loop controller.

ix) Pressure controller at the oil preheater outlet.

Atomising Steam System

i) Temperature indicators at steam generator outlet and burner inlet.

ii) Pressure indicators at steam generator outlet and burner inlet.

iii) Differential pressure controller to manipulate the atomising steam pressure, by reference to the fuel oil pressure and a set pressure difference, between the fuel oil and atomising steam pressure.

4.2.1.2 Safety Circuits

The original proposal considered six safety circuits (2.3.2.6) which were as follows:-

i) Heat Off.

ii) Emergency Shut-Down.

iii) Air preheater heat off.

iv) Fuel Oil Shut-Down.

v) Oil tank steam heating off.

vi) Alarm Circuit.

The above six systems show different modes or levels of safety which can be classified as:

a) Manual and Automatic 'Shut Down' of the plant and warning by an alarm.

b) Manual and Automatic 'Heat Off' of the plant and warning by an alarm.

c) Automatic partial heat off of the plant which is activated by certain indicators and warning by an alarm.

These levels of safety were modified in the final specification (2.3.3.8) and a fourth was added.

d) Visual and audible indication of an abnormal condition. (2.3.3.8.4).

The difference between the final specification and the original proposal in relation to the safety system is described below by comparing the respective: Emergency Shut-Down; Heat Off; Additional Interlocks; and Alarms and Annunciators.

4.2.1.2.1 Emergency Shut-Down

In the final specification was included a cooling temperature control valve which was to bypass water around the cooling water heat exchanger. This valve was to fail safe during Emergency Shut Down by circulating all the water through the heat exchanger, consequently the water temperature in the loop was to drop and made the system safer.

4.2.1.2.2 Heat Off

The original proposal considered of the furnace, cooling water, combustion air, natural gas, and fuel oil systems were two, three, two, two and two initiators, respectively. While the final specification only considered one initiator per each of the system. This reduction in initiators or abnormal condition detectors would have resulted in a less safe BTR but this was compensated for by the addition of the "pilot heat off" interlock and an extra circuit of Alarms and Annunciator which is described in 2.3.3.8. and fully covered the remaining "heat off" initiators from the original proposal which were not considered in the "Heat Off" of the final BP Specification.

4.2.1.2.3 "Additional Interlocks"

The "pilot heat off" interlock was considered in the original proposal as part of the "Heat Off" system. The advantage of the "pilot heat off" being a separate interlock is that, the actions initiated by low pressure in the pilot gas is more specific and logical, i.e. it limits to heat off the fuel supply to the furnace, including pilot. While the "Heat Off" also unnecessarily (if low pilot gas pressure) will shut down the main gas of the air preheater but not the pilot gas supply to the furnace.

The "Oil tank steam heating off" interlock was not included in the final specification. This seems a contradiction because the BTR specification was in general safer than the original proposal due to the numerous additions and modifications to the original proposal. The missing of this interlock set the checking of the correct tank oil level solely on the operator, therefore firing oil involved the avoidable risk of overheating the oil in the tank.

4.2.1.2.4 Alarms and Annunciators.

As mentioned, this fourth level of safety covered the abnormal conditions considered in the original proposal "Heat Off" and additionally included the following:

i) Smoke detection in the furnace system

ii) Less low pressure in the main and pilot gas lines to the air preheater.

iii) Low Pressure in the atomising steam.

4.2.1.3 Instrument Modification to the Original Proposal.

The above differences between the original proposal and the final specification were due more to better definition and completeness rather than actual modifications and only the following differences are considered as modifications:

Measurement Instrument.

i) Some pressure, temperature and flow rate indicators were added or deleted. (Table 4.2.1.3.A)

Control Instrument

ii) The temperature controller of the cooling water loop was relocated and the damper was to be manually operated instead of a motorised operation.

iii) For the operating conditions control in the cooling water system was added a temperature control to the water make up tank and a pressure regulator to the pressure expansion drum.

iv) The temperature control of the fuel oil and combustion air was to be by a cascade control loop type instead of a single control loop.

Safety Circuits.

v) The initiators in the "Heat off" of the original proposal was divided by the final specification in "Heat Off" and "Alarms an Annunciators".

vi) The latter had some additional initiators.

vii) An interlock related to the tank oil level included in the original proposal was deleted from the final specification but, on the other hand, an interlock classified as "pilot furnace heat off" was added.

Table 4.2.2.1A Modifications to the Final Client Specification. As Installed.

VARIABLE	COOLING SYSTEM	COMBUSTION AIR SYS. AND FURNACE SYSTEM	NATURAL GAS SYSTEM	LIQUID PETROLEUM GAS SYSTEM *	FUEL OIL SYSTEM	ATOMISING STEAM SYSTEM
Pressure	Pump Outlet (+P)	Air Preheater Outlet (+P)	Upstream main gas controller (+P) Upstream air pre-heater gas pilot controller (+P) Compr.Inlet & Outlet (+P) Pressure Vessel Receiver (+P)	7(P)	Preheater Inlet (-P) In preheater steam inlet instead of in preheater Pumps outlet (-P)	
Temperature	Cooling Tower Outlet (-T) Furnace Inlet (+T)	Air Preheater Outlet (+T)	Compressor Inlet & Outlet (+T)			
Other		Analyser: Single X dual (O_2 X CO_2 & O_2)		Level: 2(L)		

Addition (+); Deletion (-); Change (X); Expected equipment/arrangement ( )

* All the LPG Instrumentation

Table 4.2.1.3B Modifications to the Client Original Proposal. Final Client Specification

VARIABLE	FURNACE SYSTEM	COOLING SYSTEM	COMB. AIR SYSTEM	NATURAL GAS SYSTEM	FUEL OIL SYSTEM	ATOMISING STEAM SYS.
CONTROL:	Furnace Damper: Manual (X)Motorised	Loop Temp.Control: H.E.Outlet X Furnace Inlet Make up Water Tank (+TC) Expansion Drum Vessel (+PC)	Fan outlet (FC) Air preheater: Cascade loop (+); Master. Combustion air temperature. Slave. Natural Gas Pressure.	Air preheater: Main gas line (PC) Pilot gas line (PC)	Tank (Local TC) Oil preheater: Cascade loop (+); Master. Fuel oil viscosity at oil preheater inlet. Slave. Fuel oil temperature at oil preheater outlet.	
SAFETY CIRCUIT:	Main Flame Failure (+XBSW)		Power Supply Failure (+ XUSW)		Low level tank (-LLSW)	Low pressure (LPSW)
ALARM & ANNUNCIATOR	Smoke Detection (+A)	Loop (+LFA) Furnace Outlet (+HTA) Pump Outlet (+LPA)		Low Pressure in pilot gas line. (LPA) Air preheater: Main gas line (PA) Pilot gas line (PA)	Low Pressure at Oil preheater outlet (+ LPA)	

Addition (+); Deletion (-); Change (X); New arrangement/equip.( )

viii) The additional independent circuit of "Alarms and Annunciators" included in the BP Specification, resulted in two types of alarm: a klaxon alarm for Heat Off, Emergency Shutdown and Additional Interlocks circuits; and a bell alarm for Alarm and Annunciator circuit.

The above alarms were classified as urgent and emergency alarm, respectively.

4.2.2 Modification to the Client Specification - Instrument as Installed.

Because the client specification did not define either in enough detail or at all, some major equipment or system, the integrated instruments to these equipments were additions to the instrument defined in the client specification. Some of these instruments were totally (L.P.G.System) or partially (Air preheater and Compressor) installed by the contractor while others (Pressure Reducer, Softener, Boiler and Super-heater) were supplied and installed with the equipment. Only the former will be considered as modifications and they are shown in Table 4.2.2.1 A & B accordingly, i.e. Addition (+), Deletion (-), Change (Substitute by: X) and an expected modification ( ).

Additionally, the Tables 4.2.2.1 A & B also consider modifications to the Client Specification in relation to those instruments which are not an integrated part of the equipments.

4.2.2.1 Instrument Modification to Final Specification Instrumentation and Control.

The modifications to the instrumentation and control described in the final specification can be summarised as follows:

The measurement instrument added finally increased the number of these items to four pressure gauges, and two thermocouples (Table 4.2.2.1A).

Also, there were some additional controllers (three flow controllers) apart from the following two changes in the controllers. (Table 4.2.2.1B) A proportional controller type instead of a PID type. (Air Cooler Heat Exchanger). A local control unit (Automatic ignition and shutdown) instead of a cascade loop controller (Air preheater).

Safety System

The changes to the safety system during the BTR installation (Table 4.2.2.1B) were limited to the addition of three switches (High Pressure and Temperature and Low Level) and a safety action (Open Fan Damper)

Table 4.2.1.3A Modifications to the client original proposal. Final Client Specification.

Variable Indication

VARIABLE	FURNACE SYSTEM	COOLING SYSTEM	COMBUSTION AIR SYS.	NATURAL GAS SYSTEM	FUEL OIL SYSTEM	ATOMISING STEAM
PRESSURE P	Across Damper (-P)	At Pressure Drum(X) Loop	Air preheater Outlet (+P)	At the compressor outlet and burner inlet. Main Gas 2(+P) Mixing Drum (+P) Upstream Control Valve & Burner inlet Pilot Gas 2(+P) Air preheater Main & pilot gas 2(+P)		Steam Generator outlet. (+P) Burner Inlet (+P)
TEMPERATURE	Furnace Case (+T)	At each coil outlet 2(+T)	At fan outlet(X) inlet	Compressor outlet (+T)	Tanks 2(+T) Oil preheater inlet and outlet. 2(+T)	
FLOW: F		At each coil(X)loop (+F)		Pilot Gas (+F)		
LEVEL: L					TANK (+L)	

Addition (+); Deletion (-); Change (X); New arrangement/equip.().

Table 4.2.2.1B Modification to the Final Client Specification. As Installed

VARIABLE	COOLING SYSTEM	COMBUSTION AIR SYS. AND FURNACE SYSTEM	NATURAL GAS SYSTEM	LIQUID PETROLEUM GAS SYSTEM	FUEL OIL SYSTEM	ATOMISING STEAM SYSTEM
CONTROL:	Loop Temp.Control: Proportional control (X)PID control	Air preheater: local control unit(X) Cascade Loop TC Furnace Damper: Motorised X Manual	Air preheater: Main gas line (PC) Furnace: Main gas line (+FC)	Vaporisers: Level control 2(LC) Temperature control (2TC)	Fuel Oil line (+FC) Branch feed back controller (PC)	Steam Line (+ FC) Steam Line (+PC)
SAFETY CIRCUIT H : High HH: Very high L: Low LL: Very low	Make up water tank (+LLSW)	Heat Off: Open Louvre (+)	Compressor Outlet (+ HTSW) Air preheater Main (+HPSW)	Drench is initiated: 2(HHPSW); 2(HSW) & 2(LFSW).		Heat Off: Shut Down Boiler (+)
ALARM & ANNUNCIATOR			Air Preheater Pilot (-LPA)	2(LPA) & 2(HPA)		

Addition (+); Deletion (-); Change (X); Expected equipment/arrangement ( ).

4.2.3 Review of the Instrument Process Development

i) The monitoring instrument added (Twenty-One) to the original proposal was as a result of better definition of the BTR so that extra instruments were strategically located to facilitate the plant operation. Later, during detailed design and erection, although not as many instruments were added (six), most of the added instruments were located according to their physical location rather than operational function (the previous twenty-one items). The judgement to physically locate the instruments were: distance between them (pipe line), visibility, control room or site, etc.

ii) The controllers added to the Original Proposal were related to the oil and air preheater (cascade loops), expansion drum and make up water tank and damper. Later, extra controllers (flow) were added to the process fluid lines and two changes caused by the following of common practice, i.e. local control unit and step control for the air preheater and the air cooler heat exchanger, respectively.

iii) The original proposal had the typical safety system which consisted of a Heat Off (mainly Automatic Operated) and Emergency Shut Down (mainly hand operated). This proposed safety system was widened in the Client Specification by the inclusion of Alarm and Annunciator, and Additional Interlocks (Partial/Reduced Heat Off).

Also, two types of alarms were included in the Client Specification, klaxon and bell alarm.

4.3. Instrument Specification

The contractor did not have the resources to install the instrumentation therefore an "Instrument Specification" was issued in order to tender the instrument installation.

This specification was based on the Contractor P&I diagram (Appendix 8) and the Client Specification which presented an instrument subsection in the Sectional Engineering Specification. This was adapted to the BTR required Instrumentation from the BP Engineering Practices and Standards as well as other Institution Standards.

4.3.1 Short Version of the Instrument Specification

The Instrument Specification has been summarized and only the following sections are described. The complete content list of the "Contractor Instrument Specification" is shown in Appendix 2.

GENERAL

4.3.1.1	General
4.3.1.1.1	Scope
4.3.1.1.2	General Description
4.3.1.1.3	Regulation

TECHNICAL SPECIFICATION

4.3.1.2	Instrument and Description
4.3.1.2.1	Recommended Manufacturers
4.3.1.2.2	Standard Requirements
4.3.1.2.3	Instrument Required

DETAILED ENGINEERING

4.3.1.3	Detailed Engineering
4.3.1.3.1	Control Panel Unit
4.3.1.3.2	Measurement Instrument
4.3.1.3.3	Control
4.3.1.3.4	Heat Tracing and Winterisation

FURNACE SYSTEM INSTRUMENT

4.3.1.4	Burner Instrumentation and Safety System.

4.3.1.1 General

This section as such does not exist in the Instrument Specification (Appendix 2). However it is a suitable heading for the following subsections of the Instrument Specification:

i) Scope
ii) General Description
iii) Regulations

4.3.1.1.1 Scope

The instrument subcontractor was to be responsible for the design, supply and installation of all the instrumentation and control equipment except where such equipment is clearly specified as being designed or supplied or installed by others.

Also, the instrument subcontractor was to be responsible (Appendix 2, Miscellaneous Provisions (22)) to provide the following:

i) Flexible tubing to connect burner and fuel supply lines
ii) Cooling water supply and return systems to each furnace sampling port level.
iii) 110V ac 50Hz 20A power socket at each sampling point
iv) A mobile burner transporter and lifter.
v) Site compressed air at each platform for portable experimental instrument usage.
vi) Spare parts to cover normal operation duties for two years.

4.3.1.1.1.1 The design was to be based on Firm C's instrument specification, flow diagram and BP Engineering Practice and was to require the issue of:

i) Schedule of Equipment
ii) Loop Schematic Diagrams and Hook up Drawings
iii) Drawings showing the location of all Equipment
iv) Cable and Piping Routine and Installation Drawings
v) Panel Wiring and Piping Drawings

4.3.1.1.1.2 The supply was to be carried out under the following conditions:

i) Procurement. Three copies of all suborders
ii) Expediting. In conjunction with --Firm C--- expeditors.
iii) Testing. In conjunction with ---Firm C --- and BP representatives.
iv) Delivery. Include, delivery, off-loading, handling into storage or final location.

4.3.1.1.1.3 The installation of the instrumentation and safety system involved.

i) Field Instrument Installation. The position, mounting, and bolting down of all control panels, control devices, transmitters and indicators throughout the plant. This includes the provision of all necessary holding down bolts, brackets, clamps, stanchions, and any welding services required.
ii) Control Panel Design and Assembly described in 4.3.1.3.1.
iii) Installation. The cabling and piping of all site instrument and control equipment including all necessary galvanised tray, conduit, cleats and clamps gland and ferrules.

iv) Commissioning. The site calibration, setting to work and commissioning of all instrument and control equipment. Blank preinstallation sheets and loop check sheets will be provided by GKN Birwelco.

4.3.1.1.2 General Description.

This section describes some general requirements which are as follows:

i) An instruments and control panel is to be provided under this contract and located in a combined control and switch room located in a non-hazardous area
ii) The instrumentation and control is to be based on electronic equipment having a signal level of 4-20 m A or where necessary, pneumatic equipment having a signal level of 3-15 psi.
iii) The extent of supply was to be limited to all the instrumentation and control equipment shown in the FirmCflow diagram, except for the package enclosed in green which were supplied by others. However, the instrument subcontractor was to be responsible for providing and installing all the necessary cable and pneumatic piping to integrate such packages.
iv) The air supplied to pneumatic instrument provided by BP was to use an air filter and a pressure regulator.
v) Instruments in general supplied with package were to conform with:
    a) This specification
    b) Appropriate section in BP Engineering Practice.
vi) Metric Units according to S.I.
vii) All instrument to be marked for identity and labelled at all functions on terminal.
viii) Manuals and labelling in English.

ix) Electric and pneumatic equipment were to be in accordance with BP Engineering Practice.

x) Main cable and run according to BP Engineering Practice.

xi) Segregation of Circuits

a) Thermocouples

b) Transmitter and controller output circuits.

c) Safety Circuits

d) Command Circuits (e.g. pump start/stop)

xii) Wire characteristics

a) Wire above/under ground

b) Crosses to be perpendicular

c) Cable layout to be submitted to Firm C.

d) Overhead wire was to avoid dangerous area such as heater, hot pump, etc.

e) Non isolating material which can be discomposed and produce chloric, fluoric or cyanogenic gases under the influence of heat.

4.3.1.1.3 Regulations

i) In the absence of more rigorous requirement which may be specified by the local or national authorities, instruments were to be installed in accordance to the Institute of Petroleum Model Code of Safe Practice, Part I, Electrical, 1965, and Supplement dealing with lighter than air gases.

ii) The instrument subcontractor was to observe regulations and standards according to the following priorities.

1) Requirement and regulation specified by national and local authorities.

2) This requisition

3) BP Engineering Standards and Practices

4.3.1.2 Type of Instrument Required and Description.

This heading corresponds to the subsection in the Instrument Specification of "Standard Requirements", which was rearranged as follows:

i) Recommended Manufacturers
ii) Standard Requirement
iii) Instrument Required

4.3.1.2.1 Recommended Manufacturers

i) The client had a strong preference for maximum standardization, both vendor and type, with his existing equipment. However, for reasons of economy and to ensure competitive bids, this did not exclude other manufacturers.

ii) Any manufacturer different to those recommended by the client in table 4.3.1.2.1 was to be approved by Firm C.

iii) A list of the vendors or/and manufacturers of the supplied equipment was to be included in the subcontractor proposal.

Table 4.3.1.2.1 Preferred Manufacturer

Equipment	Manufacturer
Control Panels	Imhof
Control Racks	Imhof (7 feet x 22 1/8inches rack)
Panel Mounted Controllers, Recorder and Indicator.	Foxboro
Panel Mounted Multipoint Temperature Recorder	Honeywell Brown, Model 15
Alarm/Shutdown System	Highland Electronic
Analytical Instrument	Taylor/Servomex
Local Pneumatic Controllers	Foxboro
Pneumatic Transmitters	Foxboro
Electronic Transmitters	KD6
Thermocouple	Universal Thermosensors
Pressure Gauge	Dreser/Budenberg
Control Valves	Masoneilan, preferably
Refer to clause 4.3.1.3.3.2 for restriction to camflex valves	"Camflex" and "Micropak"

4.3.1.2.2 Standard requirements

i) Field Mounted Instruments

When a blind transmitter is used in a control loop, the local indication can take the form of:

a) A process pressure gauge on pressure control loops.
b) A pneumatic receiver gauge on level and flow control loops.
c) No provision was made on thermocouples or resistance bulbs.

ii) Instrument Scales

a) Flow, 0-10 square root with scale factor
b) Level, 0-100 linear
c) Pressure, actual scale in process units
d) Temperature, actual scale in process units.

iii) Instrument Charts

a) 0-10; square root
b) 0-100; Linear combined with appropriate scale factor

4.3.1.2.3 Instrument Required

The description of the instrument required was by a seven pages table similar to the table 4.5.1.A, but without the field or control panel instrument code number (e.g. PSW43A/B). It instead explains the function of the instrument and provides the scale range and accuracy.

Extract of such table is shown in Table 4.3.1.2.3.

Table 4.3.1.2.3 Extract from the Instrument Description Table in the Instrument Specification.

Purpose		Tag No.	Range	Minimum Accuracy
Steam	Temperature Local Control	TC10	0-10 Barg	± 1% FSD
Butane Supply	Pressure Local Ind.	PI 1	0-3 Barg	± 1% FSD
Water (Sprinkle)	Pressure Switch	PS12-1/2	0-7 Barg	± 1%
Storage Tanks (HFO)	Level local Indicator	LI-14	0-FULL	± 2% FSD
HFO	Press Local Indicator	PI15-1/2	0-16 Barg	± 2% FSD
Preheater (HFO)	Press Local Indicator	PI 16	0-16 Barg	± 1% FSD
	Temperature Rem. Ind.	TR16-1	0-200°C	± 1% FSD
	Temperature Rem. Recorder	TR16-2	0-200°C	± 1% FSD
	Temperature Rem. Ind & Control	TIC-16	0-200°C	± 1% FSD

4.3.1.3 Detailed Engineering

The next four subsections described below are a rearranged version of the detailed engineering of the BTR instruments which was described in the subsections 7 to 17 (Appendix 2) of the Instrument Specification.

4.3.1.3.1 Control Panel

4.3.1.3.1.1 General

i) Modular Type and Lockable rear access.
ii) Visible Alarm under all conditions
iii) The process instrument panel and associated equipment to be designed to achieve maximum simplicity for fault finding and maintenance.
iv) Pneumatic connection within the instrument control rack in nylon tubing.
v) Instrument label at the front and rear to be permanently affixed and according to the client specification.

4.3.1.3.1.2 Panel Layout

i) Standard module 131mm wide by 222mm high
ii) Logical grouping according to duty, e.g. Pressure indicators; or/and as a second alternative logical grouping according to function, e.g. Cascade loop Instruments.
iii) A 24h digital clock to be included.

4.3.1.3.1.3 Recorders

4 x Chanels Recorder for Flow
4 x Chanels Recorder for Pressure
24 x Chanels Recorder for Temperature 0-300°C
24 x Chanels Recorder for Temperature 0-1200°C

4.3.1.3.1.4 Alarm and Annunciator at the Control Panel.

i) Control panel to be provided with alarm test and accept buttons.

ii) Alarm system to be energised from 24V a.c. power supply.

iii) Alarm light to be in logical groups.

iv) Sequence of the Alarm System.
Condition Normal - No light, no audible alarm.
Condition Abnormal - Flashing red light and klaxon.
Press Accept - Steady red light, silent klaxon
Condition return
to Normal - No light, no audible alarm.

v) All alarm contact to be closed in normal operating condition.

vi) To provide a switch that shut off the power supply to the alarms.

vii) Shut down system for critical duties to be of fail safe type.

viii) Indicating light and audible alarm for:
- Automatic shut down on machinery and equipment
- Alarm prior to heat off.
- As dictated by plant design.

ix) Unless otherwise specified, alarm signals may be derived from the signal of process instrument.

4.3.1.3.1.5 Heat Off and Emergency Shutdown Switches at the Control Panel

These switches were:

i) Coloured yellow and red, respectively.

ii) Two position rotary type that retain the selected position.

iii) Provided with a means to indicate they have been operated (Red linked covers).

iv) Labelled HEAT OFF and EMERGENCY SHUTDOWN. These labels were to be red with white engraved printings.

v) The operation of these switches were not to affect pressure control or distribution of site steam services, or interrupt purge air, breathing air to transmitters or other essential air supplies.

4.3.1.3.1.6 Automatic Shutdown System

4.3.1.3.1.6.1 General

i) All the shutdown circuits were to be designed to operate from a 24V d.c. supply only.

ii) Shutdown circuits were to be kept physically separate from alarm circuits to prevent accidental shutdowns during maintenance on the alarm system.

iii) All equipment associated with shutdown circuits were to be marked with red labels and white engraved printing.

4.3.1.3.1.6.2 Equipment

The shutting off of heat by interrupting the fuel supplies was to be achieved by means of a quick acting tight shut off equipment.

i) Quick acting tight shut off equipments. This is comprised by a pneumatic quick-acting tight shut-off valve, quick-acting vent valves directly mounted on the diaphragm of the shut-off valves and a three-way solenoid valve.

ii) The fuel control valves were to be of a single metal seat, tight shut off and provided with three-way solenoid valve and a pneumatic quick-acting tight shut off valve. The control valve were to close or open according to requirement.

iii) Solenoid valves were only to be installed in air supply lines. They were to be of manual reset type and energised during normal operation conditions.
Also the solenoid values were to meet the following requirements:
   a) Material in inner parts: 316SS; non-ferrous metal was permitted.
   b) Supply voltage: 24 V d.c.
   c) Solenoid coils were to be suppressed with diodes.
   d) Solenoids were to be individual, two poles fused and switched.

iv) Shutdown circuits were to be normally energised and have close contacts.

4.3.1.3.2 Measurement Instrument

4.3.1.3.2.1 Temperature Measurement.

i) The ranges were to be to the manufacturer's nearest standard range suitable for:
   a) The range of plant operating temperature
   b) The range of proportional band settings available as standard.

ii) Thermocouple assemblies were to be designed so that positive contact is insured between the thermocouple hot junction and the wall of the thermowell.

iii) High temperature alarms operated by "filled thermal systems" were to be of the indicating type to check the integrity of the system

iv) Thermocouples were to be of the Chrome/Alumel type. The appropriate compensating cables were to be used for extension lines.

v) Thermowell were to be to BP Standards and positioned in accordance with drawings.

vi) High temperature alarms operated by thermocouples or resistance bulbs were to have upscale burnout.

vii) All temperature controllers were to be provided with a duplex thermocouple. The second thermocouple was to be linked to a recorder.

viii) The furnace was to be provided with thermocouples for measurement of temperature at the following positions:

  i) Flue gas immediately upstream of the damper.

  ii) Inner refractory lining at the furnace arch.

4.3.1.3.2.2 Pressure Measurement

1. Pressure elements in switches, transmitters, local controllers and similar equipment which contain process material were to be suitable to withstand the process material.

2. Physical locations of the pressure gauges and switches, shown in the flow diagram, were to be discussed.
   Pressure gauges were to be 160mm diameter.

4.3.1.3.2.3 Flow Measurement

4.3.1.3.2.3.1 Flow measurement instruments were not to contain mercury and were to feature adjustable damping where necessary, as determined by process conditions or installation. Generally, the following were to be provided:

i) Integral 5-way block manifolds that include two drain valves.

ii) Weather proof instrument housing were to be provided.

iii) Drain-lines were to be run together and end at least 0.5m above ground level.

4.3.1.3.2.3.2 Orifice

i) Calculations were to be in accordance with the latest issue of BS1042 and BP Engineering
ii) Manufacture were to be to BP Engineering Practice and to be discussed before commencing.
iii) Minimum lengths of straight pipeline upstream of orifice plates were to be to BP Engineering Practice.

4.3.1.3.3 Control

4.3.1.3.3.1 Control Valves and Actuators

i) Control valve with double active cylinders were not to be used in heater firing control systems.
ii) Cast iron valves were not to be used.
iii) Control valve trim material were to be 316 or higher quality stainless steel.
iv) As far as possible, control valves were to be supplied with standard spring ranges (3 to 15psi).
v) The use of three way valves were to be avoided wherever possible.
vi) When sizing actuators, particularly piston types, due allowance was to be made for pressure drop in instrument air supply lines.
vii) The minimum flange rating of control valves were to be painted only at manufacturer's works and not by the contractor.
x) The use of butterfly valves were to be submitted to the client for approval.
xi) Double seat valves were not be used on tight shut-off duties.
xii) Composite valve plugs of the double seat, independently adjustable type were not to be used.

xiii) For valves fitted with a side mounted handwheel, the handwheel was to be of a design to prevent use of a wheel spanner.

xiv) All control valve bonnets were to be suitably drilled and tapped to accept a lubricator whether initially specified or not.

xv) Where lubricators are not required the holes were to be fitted with a screwed plug.

xvi) Each control valve was to be hydrostatically pressure tested in its completely assembled state (including final packing) at the manufacturer's works.

xvii) Functional testing of the valve was to follow the hydrostatic test.

xviii) Where possible, control valve parts were to be standardised to minimise spare holdings.

4.3.1.3.3.2 Camflex and conventional control valves. The following conditions were to be imposed on the use of Camflex valves or conventional valves:

i) The manufacturers were to confirm the suitability of each valve for the specified service conditions.

ii) Where Camflex valves were installed between bends, allowance was to be made in the pipework for possible future installation of conventional control valves. This was to include placing the control valve bypass somewhat higher than is necessary for the Camflex valves.

iii) Camflex valves were not to be used where the operating temperature is higher than the auto-ignition temperature of the product.

iv) Where service conditions approach valve design limitations of Camflex valves, conventional control valves were to be used.

v) Short radius bends were not to be used at inlets and outlets of control valves.

vi) Bypasses at control valves were to be in accordance to BP Engineering Practice, furthermore:

a) Bypass valves were to be globe valves wherever possible.

b) Block valves were to be gate valves.

c) Pressure drop across bypass valves was to be the same as that of the control valve.

vii) Noise levels were not to exceed local authority requirements.

4.3.1.3.4. Heat Tracing and Winterisation

i) Heat Tracing was designed to maintain the product in its correct process state for temperature and phase.

ii) Instrument housings and impulse lines were to be steam-traced. Only in those cases where control temperature was required, electrical heat tracing with temperature controller was to be used.

iii) The winterisation of instruments was to be in general accord with BP Engineering Practice. Details of heat tracing were to be obtained from Firm C before installation commenced.

iv) For all instruments installed on the plant (including utilities and offsites) generally weatherproof housings were to be provided.

4.3.1.4 Burner Instrumentation and Safety System

4.3.1.4.1 Burner Instrumentation

i) Instrumentation and control systems were to be as shown in the Firm C Flow Diagram.

ii) Physical location of the sensing points were to be agreed.

iii) The sensing points of temperature and pressure in steam and fuel supplies to the test burner were to be at the burner end of the fixed pipe to the burner.

iv) Flame monitoring were provided by closed circuit television. Two black and white TV cameras were to be located at the furnace roof and first access level, respectively, and a VDU is located in the control room with a switch to select the desired camera. The whole system was to be demonstrably suitable for flame monitoring in an industrial environment.

v) Detail specification of the control and safety systems and instrumentation is described in 4.3.1.3.

4.3.1.4.2 Burner Safety System

The safety system were as defined in the Client Specification (2.3.3.8) but with the following addition.

i) The 'Heat Off' also was to fully open the inlet air louvre to the combustion air.

ii) The 'Emergency Shut Down' also was to shut down the boiler and leave on the air cooler fans.

4.3.2 Client-Contractor Agreed Modifications

Two weeks after the Instrument Specification was issued, a meeting between the contractor and client was held in order to agree the final modifications. The agreed modifications were as follows:

i) the contractor agreed to provide all the signals required for the installation of 'Data Logger' proposed by the client without charging an extra cost.

ii) Additionally to the pressure control in the gas and oil line a flow control was to be incorporated.

iii) An electrical power consumption meter was to be installed on the main control and distribution board.

iv) In order to check the temperature of the gas from the compressor a local temperature indicator was to be placed at its outlet.

v) The original analyser proposed to determine the percentage of oxygen in the flue gases was to be substituted by a dual analyser which could additionally evaluate the percentage of carbon dioxide.

In addition to the above in the contractor-client meeting, the former confirmed to the client their intention of installing the fuel isolating and purge valves at furnace first floor level and explained the operation of the air preheater.

4.4 Project Engineering

This section covers the instrument project engineering from the award of the instrument subcontract until the control panel delivery.

The section is divided into three parts describing:

1. The conditions under which the instrument subcontract was awarded.

2. The final specification agreed between the client-contractor and subcontractor, and the detailed engineering information issued by the subcontractor.

3. The delivery and installation of field instrument as well as the electrical panel contracting and installation, and the fabrication and delivery of the control panel.

4.4.1 Awarding the Instrument Subcontract.

The Firm C proposal of an instrument subcontractor (Firm Q) was conditional on the client approval. This had as a consequence, that BP was to visit Firm Q's premises in order to inspect their facilities, view an installation sample and ensure that they were fully aware of BP's requirements. BP's inspector visited Firm Q's premises and reported that the facilities and workmanship standard of Firm Q were acceptable. Also, he found that Firm C had supervised this subcontractor before. Therefore, the BP's inspector recommended Firm Q to carry out the instrument and electrical works.

Subsequently, in the 31st week Firm Q were awarded the instrument subcontract.

4.4.2 Final Specification and Detailed Engineering.

After the instrument contract was awarded the other modifications described below were added by the subcontractor to the Firm C instrument specification:

i) Flow control to be added to the atomising steam line.

ii) A panel layout Fig. 4.4.2.1 was presented and the following recorders featured were agreed:

One pressure recorder of 4 channels.
One flow recorder of 4 channels.
One temperature recorder of 4 channels; -10 - 50°C.
One temperature recorder of 12 channels; 0 - 300°C .
One temperature recorder of 4 channels; 0 - 1200°C.

The above modifications and those agreed between BP and GKN were considered by the subcontractor in the issue of the instrument schedule and loop schematic diagrams as well as the control panel layout at week 34.

4.4.2.1 Instrument Schedule

The instrument schedule represented in four A1 sheets, had four main columns of which the first three described below were concerned with mechanical equipment and procurement data; and a fourth column showed the number of the instrument control loop drawing and special remarks about the equipment.

The mechanical data included:

i) System or process where the instrument was located.

ii) Function of the instrument.

iii) Maximum operating conditions.

The equipment data included:

i) Equipment description

ii) Equipment manufacturer

iii) Model number

iv) Range scale

v) Scale factor

vi) Signal or power required

The procurement data only had one columns which was:

i) Purchaser order number

The above schedule of instrument included 237 instruments (3rd and 4th column of table 4.5.1.A) which were pressure, temperature, flow and level transmitters, switches, local and remote indicators, recorders, controllers, and control valves.

Additional to the above instruments directly related to pressure, temperature, flow and level measurement, others were included. These were:

Viscometer, oxygen and carbon dioxide analyser, solenoid valve, trip amplifier, electric-pneumatic converter, hand switches, square root extractor and annunciator window panel.

4.4.2.2 Loop Schematic Diagrams.

The loop schematic diagrams were 26 sheets and covered the major BTR instrument loops, and are denoted by an asterix in the table 4.5.1.A.

The safety systems were not represented in loop diagrams although they were an important part of the BTR instrumentation subcontract.

Other missing loop diagrams were those related to the package equipment, such as the Boiler House and Air Preheater and Compressor. The instrument loops of some of this equipment were represented in the flow diagram, but a few details were not shown. Also the manufacturers supplied drawings, but they did not consider the assembly with the rest of the plant and a few details were also missing or redundant.

4.4.2.3 Control Panel Layout

The Fig. 4.4.2.3 shows the suggested and approved panel layout.

Comment: The PIC23 and FIC8 Controller was asked by the operator to be interchanged in order to facilitate operation.

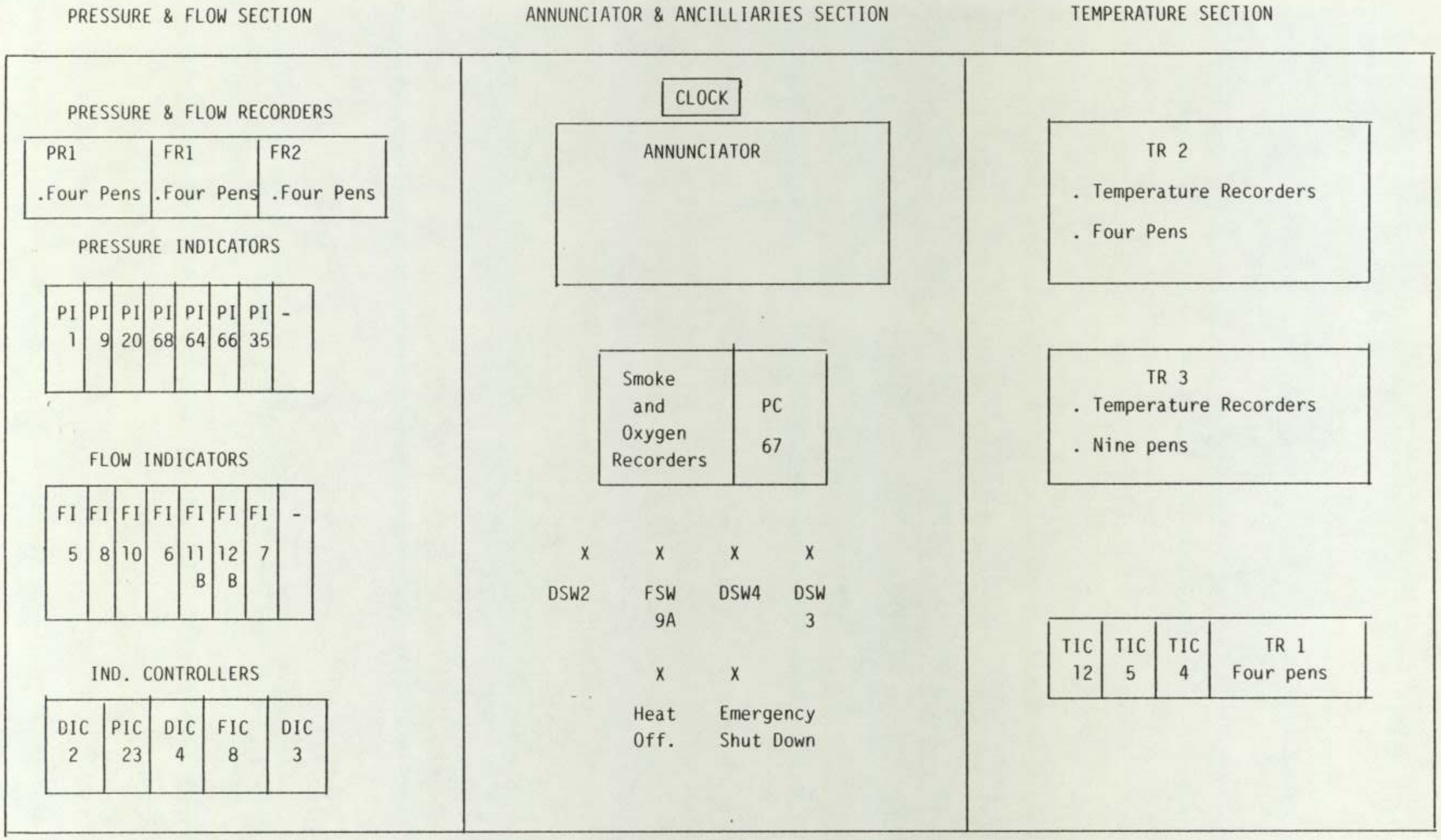

FIG. 4.4.2.3. CONTROL PANEL LAYOUT

4.4.3 Instrument Delivery and Works

4.4.3.1 Field Instruments

4.4.3.1.1 Engineering Details Prior to Installation

Prior to the field instrument installation, the following engineering details were discussed and agreed by the involved parties:

i) Because of lack of space the control valves at the furnace area were to have horizontal spindles.

ii) The cable runs were to be by high level racks rather than by ground ducts.

iii) Earthing rods to be of copper and connected to aluminium strip.

iv) Four rods were to be used in order to obtain the desired resistance in the electrical earthing system (excluding the intrinsically safe instrumentation loops) of 4 ohm.

v) The total free air requirement, including contingency allowance for the rig was to be 35 scfm. This was to cover the following system:

Gas Instrumentation
Natural Gas Compressor - unloading/loading
Burner pilot
Bottom T.V.camera
Flue damper operating mechanism.

4.4.3.1.2 Delivery and Installation

The instrument delivery was dispersed and delayed, although for week 43 enough field instrument equipment arrived to enable the subcontractor to start the following works:

i) The erection and/or installation of the field instrument equipment.

ii) Preparation for their connections to the control room.

Among the field instrument remaining undelivered, at week 43, were the viscometer and oxygen analyser (CO & O_2 modification was reversed). These equipments were still undelivered at week 50 and their promised delivery was shifted to week 57, when all the field instrument equipment was installed (80%).
It was foreseen that only --Firm C's-- commissioning staff would be on site when the above items were scheduled for delivery. Therefore it was agreed that installation piping and wiring drawings were to be obtained and if it was absolutely necessary, BP were to install the above items.

4.4.3.2 Electrical and Control Panel

Contrary to the installation of the field instrument, the electrical and control panel were constructed and assembled offsite. The contracting and work progress for the electrical panel is described below as well as the construction and installation of the control panel.

4.4.3.2.1 Electrical Panel. Contracting - Installation

The design and installation of the electrical panel was subcontracted to ---Firm R ---- who in the 35th week confirmed the electrical panel delivery for the 49th week. Because the electrical panel was required to connect the power supply to the BTR, which at the time was needed for welding, among other functions, the above promised delivery was not fully acceptable. Therefore, BP agreed that Firm C should find a subcontractor who could deliver sooner.

Siemens were contacted; they offered to deliver the panel two weeks earlier than ---Firm R ----. This was preferred by BP and Firm C therefore Firm S were awarded the sub-contract to supply the Electrical Panel.

The panel layout drawings were issued on the 37th week and the delivery was fulfilled as promised. That is, the Electrical panel was delivered on the 47th week and the Electrical Board connected the power supply in the 50th week.

4.4.3.2.2 Control Panel. Shop Construction - First Inspection.

4.4.3.2.2.1 Shop Construction - First Inspection

The original promised delivery of the panel at week 32 was for week 47. But, at week 40 the subcontractor reported a delay in the panel fabrication. This was caused by the late delivery of Imhof rack whose depth was wrongly supplied to the manufacturer by the subcontractor.

The control panel delivery was promised for two months later than originally proposed, but by contractual agreement

BP was to inspect the control panel before delivery. Then the client inspector cancelled such delivery.

This was due mainly to the incomplete state of the panel of which only one loop was tested, PI1.

Also it was reported that the rack was unpainted and the modular control rack system requirement of the client specification was not complied with, although the design was based on a modular principle.

4.4.3.2.2.2 Final Inspections and Completeness at Delivery.

Other inspecting visits were organised by the following week and it was found that:

i) The panel was painted

ii) The following recorders were not delivered:

Temperature recorders TR1 & 2
Pressure recorders PR1
Flow recorders FR1 & 2.

The availability of the recorders was checked, but the manufacturer was not prepared to commit themselves to a delivery date. Input signals were simulated and a voltmeter used to measure the incoming signals. This test checked the wiring installed in the recorder loops.

iii) Temperature indicator controllers were checked satisfactorily apart from the TIC12 which had a conventional two-term controller instead of a remote set point controller.

iv) The pressure indicators passed the inspection satisfactorily, apart from PI30 and PI68 which indicated in an erratic fashion because of a faulty edgewise connector, and PI35 which had a broken front glass.

v) Flow indicators were supplied with square root indicating scales which were wrongly specified in the Firm C specification. Despite this problem, their signals were satisfactorily checked. Additionally, the F10 loop was fitted with a square root extractor instead of a linear 4-20 mA output signal.

The square root extractor was satisfactorily bypassed and kept as a spare.

vi) Pressure and/or flow indicator controllers showed an erratic signal during checking. This was caused by the fitting of incorrect safety barriers and their substitution was required.

Once the incorrect barriers were removed the indicator controllers were checked out again and found to be working properly.

The damper controller which controls the pressure in the furnace was found to be wired satisfactorily.

vii) Other instruments, such as the smoke density unit could not be checked out because the unit had to be energised by the light source and transmitter, which were mounted on the plant.

viii) The heat off and shut down system as well as the alarm panel were checked out. The pilot heat off and fuel oil shutdown were not mentioned.

Despite a few panel equipments being still outstanding (20%) the client's inspector authorised the panel delivery, which took place by week 57. The outstanding jobs were mostly dependent on the delivery of the following equipment:

i) Recorders, TR1 & 2, PR1 and FR1 & 2.

ii) Conversion kit to convert TIC.12 to a remote set point controller.

iii) Pressure indicator (PI.30 & 68).

iv) Glass for pressure indicator (PI.35)

v) Correct safety barriers for DIC.2, 3& 4, DIC.23; and FIC.8.

vi) Linear scales for flow indicators.

4.5 Instrument as Installed.

During the expediting of the instrument installation a list of all the instrument loops of the BTR was issued. This list was revised and complemented and it is shown as the table 4.5.1.A, which contains all the instrument loops installed in the BTR and the corresponding field and control panel instruments as well as the description of the field instrument location.

In this subsection also it is included a second table 4.5.1.B which describes the BTR safety circuits finally installed. This is achieved by listing the initiators and the subsequent action.

4.5.1 Control and Instrumentation

The table 4.5.1. is a schedule of all the instrument installed in the BTR. This schedule is divided into six main parts which are described as:

i) Pressure Measurement
ii) Temperature Measurement
iii) Flow Measurement
iv) Control
v) Level
vi) Miscellaneous Indicator
vii) Shut Down Valve

Some of these parts are subdivided and for Pressure Flow Measurement the subdivisions correspond to the BTR systems in the following order:

Gaseous Fuel System
Atomising Steam System
Combustion Air System
LPG System
Fuel Oil System
Cooling Water System
Furnace System

In the case of the Temperature Measurement the subdivisions are as follows:

Gaseous Fuel System
Combustion Air System
Atomising Steam System
Cooling Water System(close loop)
Air Preheater
Vaporiser
Fuel Oil System
Cooling Water System
Electric Trace Heating

For the level Measurement the subdivisions are:

LPG Storage Tank
Oil Storage Tank
Cooling Water System

The remaining parts contain a small number of items therefore they were not subdivided.

4.5.2 Safety Systems

The table 4.5.2 shows the main safety systems of the BTR

1) Heat Off (HO)
8) Emergency Shut Down (ESD)

and also all the interlocks which order by size are as follows:

2) Pilot Heat Off Circuit (IL1)
3) Fuel Oil Shut Down (IL2)
4) Air Preheater Heat Off (IL3)
5) Compressor (IL4 & IL4A)
6) Boiler (IL5, IL6 & IL7)
7) Drench System (IL8)

Table 4.5.1. INSTRUMENT LOOP FINALLY INSTALLED

Item No.	Loop No.	INSTRUMENTATION Field	Panel	Location
		PRESSURE MEASUREMENT		
GASEOUS FUELS				
Dosing Gases				
1	P1	PT1	PI1	Mixing Drum
2	P2	PI2		
Compressor House				
3	P3	PI3		Pressure Vessel Receiver
4	P4	PSW4;PA4;JV101		Pressure Vessel Receiver
5	P5	PI5		High Press.Vessel Damper
6	P6	PI6		Low Press.Vessel Damper
7	P7	PSW7(L)	PA7	Low Press.VesselDamper
Natural Gas Line 1003				
8	P8	PI8		
9	P9	PT9	PI9	
Furnace gaseous, main line, NG1004				
10	P10	PT10	PR1-1	Control valve upstream
11	P11	PSW11	PA11	Control valve downstream
12	P12	PT12	PR1-2	Control valve downstream
	*		DSW2;DIC2;(DI/P2)(DCV2)	
		DCV2;DSV2	DEAC(HO)	
13	P13	PI13		
14	P14	PSW14(L)	DEAC(HO)	Control valve downstream
15	P15	PI15		

Item No.	Loop No.	INSTRUMENTATION Field	Panel	Location
Furnace pilot line				
16	P16	PCV16		
17	P17	PSW17(L)	PA17	Self control valve downstream
18	P18	PI18		Self control valve downstream
19	P19	PSW19	DEAC (IL1)	Self control valve downstream
20	P20	PI20		
Air Preheater pilot line				
21	P21	PCV21		
22	P22	PI22		
Air Preheater main line				
23	P23*	PT23	PIC23; (DI/P23) (PCV 23)	Control valve downstream
		PCV23; DSV23	DEAC(HO)	
24	P24	PSW24(L)	PA24	Control valve downstream
			DEAC(IL3)	
25	P25	PSW25(H)	DEAC(IL3)	
<u>STEAM</u>				
Pump steam line from superheater to site steam				
26	P26	PI26		Angle valve downstream
27	P27	PC27; PCV27		
28	P28	PI28		
Atomising Steam to furnace				
29	P29	PI29		Superheater Outlet
30	P30	PT30	PI30	Control valve upstream
31	P31	PT31	PA31(L)	Control valve downstream
			PR1-3	
		DSW3;DIC3; (DI/P3)(DCV3)		
32	P32	PSW32	DEAC(IL2)	Control valve downstream
33	P33	PI33		Burner Inlet

COMBUSTION AIR

Combustion air to furnace

	P34	PI34		Air preheater downstream
	P35	PT35	PI35	Air preheater downstream

air to furnace

	P36	PI36		

L.P.G.: (BUTANE) SYSTEM

L.P.G. Line; PG1008

37	P37	PI37		Duplex self control valve downstream

L.P.G. Tanks; B102

40	P40	PI40		Tank "A"
41	P41	PSW41	PA41(L)	Tank "A"
42	P42	PSW42	PA42(H)	Tank "A"
43	P43	PSW43A (HH)	DEAC IL8	Tank "A"
		PSW43B (HH)		Tank "B"
44	P44	PI44		Tank "B"
45	P45	PSW45(L)	PA45	Tank "B"
46	P46	PSW46(H)	PA46	Tank "B"

Pumps J107A & B

47	P47	PI47		At pumps outlet

Vaporisers; H103

48	P48	PI48		Vaporiser "A"
49	P49	PI49		Vaporiser "B"

Return lines to tanks; PG1004 & 1005

50	P50	PCV50		Liquid return line, P1004
51	P51	PCV51		Vapour return line, P1005
52	P52	PI52		Self control valve PCV51 downstream

FUEL OIL SYSTEM

53	P53	PI53		At bypass outlet of Pump "A"
54	P54	PI54		At bypass outlet of Pump "B"
55	P55	PI55		At steam oil preheater line inlet
56	P56	PI56		Oil preheater loop outlet
57	P57	PI57		Control valve upstream in the fuel oil return line
58	P58	PSW58(L)	PA58	Upstream of the fuel oil line return
59	P59	PSW59(LL)	DEAC(HO)	Upstream of the fuel oil line return.
60	P60	PT60	PR1-4	Upstream of the fuel oil line return.
		*	PdT;DSW3,DIC3,(DI/P3)(DCV3)	
		*	DSW4;DIC4;(DI/P4);(DCV4)	
		DCV4; DSV4	DEAC(HO,IL1,IL3)	
61	P61	PI61		Furnace inlet

COOLING WATER SYSTEM

Close loop

62	P62	PI62		Downstream of the make up water pump connection to the close loop.
63	P63	PI63		Circulating water pumps outlet.
64	P64	PSW64(L)	PA64	Furnace cooling water inlet.

Pressurising System

68	P68	PT68	PI68	At Expansion Drum Vessel
69	P69	PI69		At Expansion Drum Vessel
70	P70	PCV70		In the connection nitrogen line to the expansion drum vessel

FURNACE

65	P65	PT65	PI65	Furnace hearth
66	P66	PT66	PI66	Furnace arch
67	P67	PT67 (Aperture)*	PIC67; (PI/P67) (PCD67)	Damper at the flue gases

Others

Pilot gas to air preheater

71	P71	PCV71		Downstream of the supply connection
72	P72	PI72		Upstream the self control valve PCV21 or Downstream self control valve PCV71, supplying valves and filter.

Pilot air to the air preheater

73	P73	PCV73		In air preheater air pilot
74	P74	PCV74		In air preheater air pilot
75	P75	PCV75		In air preheater air pilot
76	P76	PI76		In air preheater air pilot

TEMPERATURE MEASUREMENT

GASEOUS FUELS				
75	T1-2	TE1-1	TR1-1	Furnace gaseous main line NG1004, at control valve upstream (LPG boiling temp. 50°C)
COMBUSTION AIR				
76	T1-2	TE1-2	TR1-2	Blower outlet (Amb.Temp.)
77	T2-1	TE2-1	TR2-1	Air preheater outlet (0-400°C)
FURNACE				
78	T2-2	TE2-2	TR2-2	Arch (1100°C)
79	T2-3	TE2-3	TR2-3	Metal wall (65°C)
80	T2-4	TE2-4	TR2-4	Flue gases (800°C)
ATOMISING STEAM				
81	T3-1	TE3-1	TR3-1	Superheater outlet
82	T3-2	TE3-2	TR3-2	Burner inlet
FUEL OIL				
84	T3-3	TE3-3	TR3-3	Oil preheater inlet
85	T3-4	TE3-4	TR3-4	Oil preheater outlet
COOLING WATER SYSTEM -CLOSE LOOP				
86	T3-6	TE3-6	TR3-6	Furnace inlet
87	T3-7	TE3-7	TR3-7	Furnace coil'A' outlet
88	T3-8	TE3-8	TR3-8	Furnace coil 'B' outlet
89	T3-9	TE3-9	TR3-9	Air cooled heat exchanger outlet
			ta3-9, TA3-9	
AIR PREHEATER				
91	T4	TE4*	TIC4,TRR4; (LOCAL CONTROL PANEL)	Air preheater flue gases
		TCD9	LOCAL CONTROL PANEL	Damper at air preheater fan.

92	T5	TE5*	TIC5,TRR5, (LOCAL CONTROL PANEL	Air preheater outlet
		TCVMI	LOCAL CONTROL PANEL	In the gas supply lines to the burners, (air preheaters)

L.P.G. VAPORISERS H103

93	T6	TC6		Vaporiser "A"
		TCV6		Steam inlet to Vap.A
94	T7	TC7		Vaporiser "B"
		TCV7		Steam inlet to Vap."B"

FUEL OIL SYSTEM

Tanks B102

95	T8	TI8		Tank "A"
96	T9	TT9		Oil in tank "A"
		TC9;TCV9		Steam inlet to tank "A"
97	T10	TI10		Tank "B"
98	T11	TT11		Oil in tank "A"
		TC11;TCV11		Steam inlet to tank "B"
99	T12	TE12	TIC12;(TIC12); (TCV12)	Oil preheater outlet (manual)
		TE12*	TIC12;(TIC12); (TCV12)	Oil preheater outlet and inlet. (Automatic)

COOLING WATER SYSTEM

100	T13	TT13; TC13		Make up tank
101	T14	TSW14(H)	TA14	Furnace outlet
102	T15	TSW15(HH)	TA15	Furnace outlet
103	T16	TT16, TC16		Air cooled heat exchanges outlet

L.P.G. ELECTRIC TRACE HEATING

104	T17	TSW17(L)	TA17	Butane supply line, PG1008
104	T18	TT18; TC18		Butane supply line, PG1008
105	T19	TSW19(L)	TA19	Furnace gaseous main line, NG1004, at burner inlet.
106	T20	TT20; TC20		Furnace gaseous mainline, NG1004, at burner inlet.

FLOW MEASUREMENT

GASEOUS FUELS

Dosing gases

110	F1 to 4	FI1 to4		Between cylinder and mixing drum

Furnace Main Gaseous Line

111	F5	FT5; FT5B	FR1-1	Upstream control valve
			FI5	
		*	FRE;DSW2;DIC2; (DI/P2);(DCV2)	
		DCV2, DSV 2	DEAC(HO,IL1)	

Furnace Pilot line

112	F6	FT6A; FT6B	FI6 FR1-2	Upstream of self control valve
		FT6A1		Connection line between furnace main and pilot.

ATOMISING STEAM

113	F7	FT7A; FT7B	FI7	Upstream of control valve
			FR2-1	
		*	FRE6;DSW3;DIC3 (DI/P3)(DCV3)	

COMBUSTION AIR

114	F8	FT8A FSW8 FI8	FR1-3	Blower J102; outlet
		FT8B *	FIC8;(FI/P) (DCV8)	

DRENCH SYSTEM

115	F9	FSW9D(L)	FA9	
			DEAC(IL11)	
		FCV9	DEAC(IL11)	

FUEL OIL

116	F10	FT10A; FT10B	FI10	Burner inlet
			FR1-4	
		*	DSW4;DIC4; (DI/P4)(DCV4)	
		DCV4; DSV4	DEAC(HO & IL2)	

FURNACE COOLING WATER LOOP

117	F11	FT11A; FT11B;	FI11B	Furnace coil "A" inlet
		FI11A		
			FR2-2	
			ta 11(L); FA13	
118	F12	FT12A; FT12B; FI12A	FI12B	Furnace coil "B" inlet
			FR2-3	
			ta 12(L); FA13	

TV CAMERA COOLING WATER

119	F14	FSW14(NO)	FA14	

CONTROL VARIABLE SELECTOR SWITCHES

123	D2	DCV2; DI/P2	DSW2	Gaseous line, Pressure or Flow
124	D3	DCV3; DI/P3	DSW3	Atomising steam; Pressure or Flow or Differential pressure
125	D4	DCV4; DI/P3	DSW	Fuel Oil; Pressure or Flow

LEVEL MEASUREMENT

L.P.G.STORAGE SYSTEM

128	L2	LI2		LPG tank "A"
129	L3	LI3		LPG tank "B"
130	L4	LC4; LCV4		LPG vaporiser "B" LPG supply line to vap."B"
131	L5	LC5		LPG vaporiser "A"
		LCV5		LPG supply line to vap."A"

FUEL OIL STORAGE TANK

132	L6	LI5		Fuel oil tank "A"
133	L7	LI7		Fuel oil tank "B"
134	L8	L18		Light fuel oil tank

COOLING WATER SYSTEM

136	L10	LC10(H)	LA10A	Expansion Drum vessel
		(L)	LA10B	
137	L11	LSW11(L); TC13		Make up water tank.

MISCELLANEOUS INDICATORS

140	X1	XT1	DEAC(HO)	Blower J102; No rotation
141	X2	XT2	DEAC(IL3)	Air preheater, Flame Failure
142	X3	XT3	TIC12; (TI/P12)(TCV12)	Oil preheater upstream; Viscometer
143	X4	XT4	XA4	Burner pilot flame
144	X5	XT5	XA5(H) DR1-2	Smoke density in the flue gases
	X6	XT6	DEAC(HO)	Furnace main flame.
145	Q1	QT1	DR1-1	Oxygen concentration in the flue gases.

SHUT DOWN VALVES (ESD shut down all the valves below)

146	DEA1	DEACV1	DEAC(HO,IL1)	Furnace gaseous main line
	2	DEACV2		
	3	DEACV3		
147	4	DEAC4	DEAC(IL1)	Furnace pilot line
148	5	DEACV5	DEAC (HO,IL1,IL2)	Furnace fuel oil supply line
149	6	DEACV6	MISSING	Air preheater pilot line.
150		DEACVM1	DEAC(IL3)	Air preheater main line
		2		
		3		
151		DEACVM4	DEAC(IL3)	Air preheater pilot line
		5		

Table 4.5.2 Safety Systems

1) Heat Off Circuit DEAC(HO)

Initiators

Hand switches at control room and furnace

XT6	Flame Failure (Main Flame)
TSW15	Extra high temp. (cooling water loop)
XT1	No rotation (Blower)
PSW14	Extra low press.(Furnace main gaseous line)
PSW59	Extra low press. (Oil supply line)

Shut Down Valves

DEACV1,2,3	Furnace main gaseous line
DEACV 5	Air preheater Main

Other Actions: Open fully the F.D. fan damper.

2) Pilot Heat Off Circuit, (IL1)

Initiator

PSW19 Extra low press. (Furnace pilot)

Shut down valves

DEAC 1,2,3	Furnace main line
DEAC 5	Main oil line
DEAC 6	Furnace pilot line

3) Fuel Oil Shut Down (IL2)

Initiator

PSW32 Atomising Steam

Shut down valve

DEAC 5 Main oil line

4) Air preheater heat off (IL3)

Initiators

PSW24	Extra low press.
PSW24	Extra high press.
XT2	Flame failure
(XT1)	No Rotation of Blower (J102)

Shut down valves

DEACVM 1,2,3	Air preheater main
DEACVM 4,5	Air preheater pilot

5) Compressor (IL4) Unloading and loading

Initiator

PSW4	Range of Pressure

Shut down valves

PSV1; JV101

Compressor (IL4A) Shutdown

Initiators

PSW100	Lubricant Oil Press.
TSW2	Comp. Outlet temp.
PSW7	Comp. Inlet Press.
ESD	Emergency Shut Down

6) Boiler (IL5) Low Firing

Initiators

TSW209	High Steam Temp.
Start Up.	

(Shutdown) valve

OB34 & 35	Hydraulic oil valve
DEACV201	Gas supply valve

Boiler (IL6) Shut Down

Initiators

TSW209A	Extra high steam temp.
TSW210	Extra high flue temp.
BX211	Flame failure

Shut down valve

DEACV200,201,202

Boiler (Blow down) IL7

Initiator

PSW208	Steam high press.
Manually by WB33.	

Shut down valve

OB34	Hydraulic oil valve

7) Drench System (IL8)

Initiators

PSW43A Extra high pressure in tank A

PSW43B Extra high pressure in tank B

Manual switches at control room and furnace

Shutdown valve

FCV9 Drench valve at water supply

8) Emergency shut down (ESD)

Initiators

Hand switches at control room and furnace

Action

Initiate the "Heat Off" circuit

Shut down valve

DEAC 4,5

DSV 2,4

Switch off all motors with the exception of

J103 A&B/J105

4.6 Final Works

This section is the continuation of the Project Engineering section (4.4) and describes the installation progress of the field instruments and control panel as well as the connection between them.

Also described is the instrument precommissioning (pre-firing commissioning) and commissioning (firing commissioning) modifications which were an important cause of delay in the handing over of the plant.

4.6.1 Instrument Works During Week 57-67

The control panel arrived on site at week 57, three weeks after the contractor had been aiming to complete all the work required for the furnace dry out operation.

The contractor defined a set of essential instruments for the dry out. These instruments were: Furnace temperature indicators; Part of the heat off and emergency shutdown system, respectively; and Pilot heat off.

These essential instruments required the completion of the following loop (Table 4.5.1.A):

T2-2	Furnace arch temperature
T2-4	Furnace flue duct temperature
P14	Extra low pressure in furnace main gas line
P59	Extra low pressure in furnace fuel oil line
X1	No rotation in the combustion air blower
P19	Extra low pressure in furnace pilot

All heat off and emergency shut down switches.

These loops were completed by week 60, as well as the installation of the T.V. cameras and the following indicator controllers which were checked by BP's personnel:

DIC2, 3 and 4; PIC23; and FIC8.

A second list of desirable instruments for dry out was prepared by the contractor. These instruments were required for the full precommission of the Furnace, Cooling Water and Natural Gas System. The loop involved (Table 4.5.1.A) was as follows:

Furnace System

P65	Hearth Pressure
P66	Arch Pressure
P67	Damper Control

Cooling System

F11	Coil "A" inlet flow rate
F12	Coil "B" inlet flow rate
T3-7	Coil "A" outlet flow rate
T3-8	Coil "B" outlet flow rate
T3-9	Air cooled H.E. outlet
T16	Air cooled H.E. outlet; Controller

Natural Gas System

P9	Compressor outlet
P10	Control valve upstream
P12	Control valve downstream; Pressure recorder
F5	Control valve upstream; Flow recorder and indicator
T1-1	Control valve upstream

Alarms and annunciators

X4	Pilot flame failure
T14	Low temperature in cooling water loop
P64	Low pressure in cooling water loop
P11	Low pressure in furnace main gas line

Although there was not a final date for the completion of the above loop, they were connected by week 67 as most of the instrumentation of the BTR (90%).

Despite the progress of the instrument works during the weeks 60-67 the client was not satisfied. Therefore it was agreed that the client could carry out the checking of the connected instrumentation.

In order to facilitate the checking activities, the client asked for the wiring drawings of the installations but only inadequate drawings (drafts), which were used by the subcontractor, existed. Despite the client repeatedly asking for a set of wiring drawings they were not supplied.

Another request by the client at week 63 was for the covering of the wire ducts as soon as possible, which were considered a constructional hazard.

Table 4.6.1 Actual Schedule of the BTR Instrument Design and Installation.

	Year	Week	Month	
	1978		. 4	BP Specification
			. 8	Firm C Final Tender
	1979	20th		Firm C Instrument Specification
		22nd	. 1	Modification to the Instrument Specification
PROCESS DESIGN				
			. 2	
		24th		Inst. Subcontractor Proposed by the Contractor
			. 3	(Client visit to Firm C Workshop
		31st		(Instrument Subcontract Awarded
PROJECT ENGINEERING				
		34th	. 4	Approval of Control Panel Layout
Detailed Eng.Design		36th		New Electrical Panel Subcontractor
				(Instrument Schedule List
		38th	. 5	(Loop Schematic Diagram
Manufacturer's Delivery				(Hook-Up Drawings
Inst. Panel Shop Fab.				
			. 6	
		45th		Site Instrument Installation start.
		47th	. 7	[Electrical Panel Delivery]
		50th		[Electrical Power Connected]
			. 8	
Site Installation 20% Completion		54th		1st Panel Promised Delivery
			. 9	
		57th		Instrumentation Panel Delivery
		59th		All instrum. loop were checked
Checking Instrumentation.		60th	. 10	Dry Out Essential Instrument Installed
			. 11	

4.6.2 Instrument Works Dur[illegible]ng

After the mechanical hand [illegible]k 67, it was planned to commissi[illegible]s, but this was not possible becau[illegible]ences which included faulty instru[illegible] the instruments to be completed [illegible] as follows:

1. Furnace System
   i) The oxygen ana[illegible]ncorrectly as there [illegible]ch were horizontal and [illegible]10 slope.

   ii) The whole smoke [illegible]ansmitter receiver and i[illegible].

2. Cooling Water System
   i) The pressure r[illegible] the pressure expansion drum [illegible]o 6 barg.

   ii) The temperature [illegible]ir cooled H.E. outlet a[illegible] by the contractor. T[illegible]d to remind the contractor [illegible]r was in the specification [illegible]n was required as a protection [illegible]rature corrosion of t[illegible]eat exchanger tubes and to a[illegible]rely on manual control.

   iii) Because of fluc[illegible]er flow rate at the furnace [illegible]1 and F12 were to be ch[illegible]he orifice plates FT11A [illegible]

iv) The level switch LSW11, in the make up water tank needed the earth contact to be rectified.

v) The local control unit TC13 in the make up water tank was to be replaced due to damage caused by ineffective weatherproofing.

3. Combustion Air System [3.5.1.2.2.(ii)]

i) The high pressure interlock which was locking out the air preheater before the completion of the ignition sequence programme. This programme is controlled by a Cam Timer in the local control panel and its operation is described in (5.2.3.3.2.3).

ii) The control motor positioner which was opening/closing the air blower (at the air preheater) and control valves in an erratic fashion.

iii) The governor diaphragm in the gas supply line which was perforated.

4. Natural Gas System

i) The mounting of the orifice plates F5 and F6 were to checked for correct insertion as the identification symbols were not consistent with the flow pattern, i.e. identification was to be on the upstream side of the plate.

ii) The recorded flow rate of the furnace pilot FR1-2 (F6) was out of scale, because it was wrongly specified by the client. However, the flow indicator FI6 of the loop was in order so that a second orifice plate FT6A1 in the LPG furnace pilot supply line was to be connected by the client later during plant operation.

5. LPG System

i) The pressure regulator PCV50, in the return liquid line to the tank was to be replaced by a relief valve.

ii) The pressure regulator PCV51, in the return vapour line to the tanks needed resetting at 3 barg.

6. Fuel Oil System

i) The viscometer installation was to be completed and in addition the corresponding controller at the control room still required to be converted into a remote set point controller. The latter was originally reported in week 57.

7. Atomising Steam System

i) Because of erratic readings of the flow rate in the atomising steam line, the loop F7 was to be checked and specially its orifice plate

ii) The control valve PCV70 installed in the steam excess line from the boiler to the steam site line was also suspected as a cause of instability in the steam. A close inspection revealed a faulty part which was to be replaced.

8. Control Panel

i) The broken glass of the combustion air flow rate indicator F18, reported in week 56, still required to be changed.

ii) Panel labels needed to be corrected.

iii) The back panel needed to be tied up as well as the field-panel thermocouple connections.

iv) The emergency shut-down, heat off, additional interlocks, alarm and annunciator were not yet demonstrated to the Client's Safety Officer.

4.6.3 Instrument Works During Commissioning

At week 76 the client approved that the plant was operational, and in the following week embarked on the commissioning of the plant. At the end of such commissioning the client reported the following instruments which either were faulty/repaired or required attention further by the contractor.

1. Furnace System

   i) The smoke density meter and alarm loop was to be provided with a blue filter in order to reduce the effect of the white refractory lining on the sensor. Also an amplifier was to be installed.

   ii) The reinstallation of the bottom camera after being away for repair, was to be checked by the vendor because of air leaks on the back of the flange and at the front window into the furnace.
   Also some adjustable mounting plates were to be installed by the vendor.

   iii) The loop of the low flow alarm F14, for the water cooling system of the T.V.camera was to be repaired by the instrument subcontractor.

   iv) The flame failure detector needed to be orientated.

   v) The oxygen analyser needed to be internally calibrated.

vi) The temperature at the furnace arch was lower than expected; therefore the client suspected that the corresponding thermocouple TE2-2, either required replacing or lengthening of the sensor.

2. Cooling Water System

i) The high temperature switch TSW15 (T15) needed to be reset.

ii) The flow rate loops F11 and F12 at the furnace coils inlet were designed for a maximum of 130 tonne/h, which is the combined flow through two coils. The flow rate through the coils was unbalanced and showed some fluctuation.

3. Combustion Air System

i) A meeting between the contractor, the client and the supplier established that the non-commissioning of the air preheater (3.5.1.2.2) was caused by the incompatibility of the control room controllers TIC4 and TIC5, and the local control unit. It was decided that the supplier was to provide a modification to the local control unit circuitry.

ii) The flow indicator controller at the combustion air system was controlling the air flow by opening/closing the inlet air blower damper. In order to improve the air flow rate turndown, the flow control damper was replaced by vanes. [3.5.1.1.2 (iii)].

4. Natural Gas System

i) The loading and unloading mechanism of the compressor was activated by the pressure vessel receiver. The pressure range of the pressure switch was reduced from (4.8-4.0) barg to (4.25-3.9) in order to solve an undesirable pressure fluctuation at the compressor outlet when operating a low demand. This did not eliminate the fluctuation therefore its correction was agreed to be solved by the contractor after the final take over. [3.6.1.2.2 (iib)]

ii) The pressure recorder PR1-1 upstream of the control valve had a scale range of 0-3 barg similar to the control valve downstream, instead of the required operating range of 0-4 barg.

5. L.P.G. System

i) The alarm which indicates a low deluge water flow in the drenching system had a faulty transmitter and it was to be repaired by the instrument subcontractor.

ii) The thermostatic valve TC6 which controls the vaporiser temperature by manipulating the quantity of steam into the vaporiser was sticking open. A representative of the valve manufacturer was to attend the site to strip the valve for examination and rectification.

iii) The pressure regulator PRV1 in the supply steam line of the vaporiser H103A was leaking and required to be checked.

iv) The electrical trace heating alarm, TA18 (T18) was to be checked by the contractor because it was not working.

6. Fuel Oil System

i) The viscometer was to be calibrated by the client.

ii) The output from the viscometer (5°C to 150°C) was not compatible with controller TIC12 (0°C to 200°C). The subcontractor was to fit a resistor to overcome the problem.

iii) The corresponding thermocouple to TR3-4 (T3-4) mounted in a dead leg, was required to be repositioned. This could not be in the original position because of lack of space.

7. Atomising Steam System

i) The control of the pressure in the atomising steam line by the differential pressure controller PdT31, was very unstable despite that the oil pressure loop (P60) and atomising steam loop (P31) were working correctly. Therefore, the instrument subcontractor was to check the PdT31.

ii) The pressure indicator, PI30, was operating in an erratic fashion which was to be corrected by the subcontractor.

iii) The circuitry of the atomising steam low pressure (P32) which shut down the fuel oil was to be rectified because this interlock undesirably also shut down natural gas supplies.

iv) The steam pressure recorder PR3.1 located downstream of the control valve had a range as it was upstream 0-20 barg instead of 0-15 barg. The instrument subcontractor was to change the scale range.

8. Control Panel

i) The label in the panel control required the following changes: Interchange label FI10 and FI6; correct the alarm window label which said "purging steam" instead of "atomising steam"; and "Large Print" labels were required for the Heat Off and Emergency Shut Down switches.

ii) The glasses of the pressure indicator control PIC23 and DIC3 were broken and required replacement.

iii) It was required to replace the override switch from the back to the front of the panel in order to improve its accessibility.

iv) The four positioned override switch was required to select the firing mode and lock out the unnecessary equipment.
The latter proposal was a consequence of certain items of plant which were not required for particular test operations and were to be operating in order that the Heat Off could function.

v) The overridden circuit was to be checked by the instrument subcontractor, because during Heat Off override only, the automatic mode of the control switches were operating, instead of the manual mode.

4.6.4 Review of the Instrument Project Engineering

i) The instrument subcontractor was awarded the contract on the basis of its good workmanship standard and previous work relations with the contractor (4.4.1).

ii) The "Instrument Specification" was modified before and after the awarding of the instrument sub-contractor.

These modifications and the Instrument Specification, (Final Instrument Specification were the basis of the "Instrument Detailed Engineering") which is described by

Instrument Schedule	4.4.2.1
Loop Schematic Diagram	4.4.2.2

iii) Prior to the field instrument installation some erection engineering details (4.4.3.1.1) were considered. Installation started in week 43 and reached 80% in week 57.

iv) In view of the importance of the electrical panel for the normal progress of the erection activities, the original subcontractor for the electrical panel was substituted by another subçontractor which make possible the connection of the power supply in the 50th week (4.4.3.2.1).

v) The first control panel delivery was cancelled by the client because of incompleteness. Then, although the installation panels and control instruments were outstanding because of late delivery. The control panel was delivered a week later (4.4.3.2.2).

vi) A list of essential and later desirable instruments for the dry out operation (firing precommissioning) was issued so that for week 67 they were connected as most of the BTR instruments (90% completion). As soon as the pneumatic instrument were installed and connected the client tested them.

vii) During the firing precommissioning (weeks 67-73) a first list of faulty missing uncalibrated instrument appeared. This was a main factor to stop the precommissioning of the following major equipment system.

Expansion Drum	[4.6.2.2(i)]
Air Preheater	[4.6.2.3(i,ii & iii]
LPG System	[4.6.2.5(i & ii)]
Atomising Steam Line	[4.6.2.7(i & ii)]

viii) During the firing commissioning between the Operational Hand Over (week 76) and the Final Hand Over (week 80) the following major equipment/ system were uncommissioned due to instrumentation problems.

Air Preheater	[4.6.3.3(i & ii)]
LPG System	[4.6.3.5(ii & iii)]
Atomising Steam System	[4.6.3.7(i)]

ix) Additionally to the major equipment/system which could not be precommissioned/commissioned, the faulty/missing/uncalibrated instruments shown in 4.6.2 & 3 also caused a great disruption and uncertainty in the rest of the BTR system precommissioning and commissioning.

4.7 Finding About the Instrumentation and Control an Safety Systems in the BTR Project

1. The LPG System and Air Preheater were out of order during and after the commissioning period due to faulty instruments. [4.6.1.(viii)].

2. The Atomising Steam System could not be commissioned because of faulty instrumentation. Also, most of the BTR systems had a degree of uncertainty in their commissioning due to faulty/missing/uncalibrated instruments [4.6.1(viii & ix)].

3. Table 4.2.2.1 A & B shows the additions, deletions and changes of the client specification instrument loops during the BTR tendering and project engineering period. These were a small proportion in comparison to the total number of instrument loops finally installed (Table 4.5.1.A); i.e. during the tendering period most of the installed BTR instruments were as planned (expected).

4. The "Instrument Specification" was issued at week 20. It was five and nine months later than the client specification and the Final Tender, respectively (Fig.4.6.1).

5. The "Instrument Specification" was based on the Contractor's P & I Diagram and the Client Final Specification (Instruments BP Engineering Practice).

6. The "Instrument Required" section 4.3.1.2.3 of the "Instrument Specification" was based on the Contractor's P & I Diagram while the rest of "Instrument Specification" sections were based on the Instrument BP Engineering Practice. Therefore, the main contribution of the "Instrument Specification" was the compilation of the BTR Instrumentation & Control and Safety System by an extension of the Table 4.3.1.2.3.

7. Considering the previous paragraphs of this section, this chapter recommends that for a similar project:

i) The Instrumentation and Control and Safety Circuits should be considered as an additional plant system which would be discussed and described during the Process Development Stage.

ii) The section of "Client Final Specification" related to the Instruments and Control and Safety System should include a table of the type (table 4.3.1.2.3) shown in the "Instrument Specification'.

iii) The type of the table mentioned above can follow the format of the table (4.5.1A & B) designed by the author for the BTR project. This table would be valuable to the participants in following the progress of the work and start up during the project engineering stage and commissioning period, respectively.

CHAPTER FIVE

OPERATION

5.1 Commissioning

In this section is described the BTR project between the 54th week (start of the contractor's revised commissioning programme) and the 77th BTR client commissioning. Contrary to the project engineering and instrumentation chapters which described the events during this period as erection activities, this section used a commissioning approach. Therefore, this period of time is divided in this section as Commissioning Preparation and Activities. Also, this section includes at the beginning of the section the description of those commissioning programmes presented by the client and contractor.

Finally, "Finding about the BTR Commissioning" subsection is added so that the most relevant events in the BTR commissioning are pointed out. These findings are referring to the content of this section as well as to the content of the two previous chapters to which commissioning is directly related.

Later, the mentioned findings are to be generalised and transformed into recommendations to follow during the commissioning of a similar project or as part of an improved client specification.

5.1.1 Scope

Plant commissioning aims to bring the performance of a plant to a set of operating condtions which have been defined previously in the design phase. In the case of the BTR, most of the operatng conditions to be checked during commissioning were defined in the BP Specification and complemented by others defined in the Firm C tender.

A summary of these variables is described by the contractor in the General Information Section of the Operating Instructions Manual (5.2.3.1.1).

5.1.2 Commissioning Programmes

5.1.2.1 Client

The programme proposed by the client was in three parts which are described below:

i) Pressure Testing

In this part the following systems were to be pressure tested: Furnace, Cooling Water, Fuel Gas, Fuel Oil and Atomising Steam System. Also, it was included in the pilot gas line.

ii) Prefiring Commissioning

This was scheduled to test and verify the instrumentation and control system followed by: Hydraulic performance of the Combustion Air and the Fuel Oil Systems. General Performance Tests applied to the Cooling Water System and the package units. The latter are Air Preheater and Steam Generator.

Noise levels for individual equipment.

iii) Burner Firing Commissioning

This program was to test the rig using a 6446 Kw burner, which was to be supplied by the contractor. The burner type and manufacturer was to be discussed and agreed by the BP project engineer.

The commissioning firing test included:

i) Verification of the thermal performance of the cooling water system.

ii) The fuel systems hydraulic performance during the firing.

iii) The pilot gas system performance.

iv) The furnace hydraulic and thermal performance test.

5.1.2.2 Contractor Commissioning Programmes

5.1.2.2.1 Tender Commissioning Programme

In the GKN retender was proposed a five week BTR pre-commissioning followed by five days of continuous burner firing commissioning during which the plant was to be put on stream.

The five days of continuous firing was to be carried under the following conditions:

i) A commissioning engineer was to supervise and direct the client operating staff and that of vendors.

ii) Utilities, services and consumables required for commissioning were excluded but were assumed to be ready and available prior to commissioning.

iii) It was excluded the training of client operators. Later in the final tender a five weeks commissioning was estimated. This was confirmed by the First Network Diagram which shows four weeks of pre-commissioning and one week of Dry Out (Continuous Firing Commissioning).

5.1.2.2.2 Contractor Revised Commissioning Programme.

In the 54th week, the site manager proposed a revised commissioning programme, which is reviewed in 3.12.6 in relation to pending constructional work.

The programme was scheduled to cover a three weeks period which included two weeks of precommissioning and one week of continuous firing commissioning for the Furnace, Combustion Air, Cooling Water and Natural Gas System. The activities planned during the two weeks precommissioning are described below.

i) Furnace System. Commissioning of the mechanical damper and furnace temperature indicator after their respective installation. Also, during this time the stack realignment and connection Stack-Furnace was to take place.

ii) Combustion Air System. This involved the precommissioning of the combustion air blower after the duct connection blower-air preheater-furnace was accomplished.

iii) Cooling Water System. This system was to be filled with town water in order to carry out the hydrostatic pressure test and later to flush the complete system. Then, the system was to be refilled with town water in order to precommission the pumps and the fans. The system was to be flushed again and finally refilled with softened water.

iv) Natural Gas System. It was planned that the compressor would be precommissioning after connecting the system to the gas supply (Pressure Reducer Station) and testing the pipework.

5.1.2.3 Commissioning Programmes Review

i) The client commissioning programme excluded:

- The test and verification of the Furnace, Natural Gas, LPG and Atomising Steam system during the prefiring commissioning.

- Precommissioning Firing (Dry Out)

ii) On the other hand the contractor commissioning programme only established the conditions in which (5.1.2.2.1) the commissioning was to be carried out. This assumed four weeks for the prefiring commissioning and a week for the Dry Out (Natural Gas) Operation.

iii) A revised contractor commissioning programme (5.1.2.2.2) reduced to half the time assigned to the prefiring commissioning and referred only to those systems which are required to accomplish the Dry Out Operation.

5.1.3 Preparation for Commissioning (Pre-firing Commissioning)

5.1.3.1 Equipment Required by the Contractor for the Dry Out Operation

The equipment precommissioning was planned by the network programme issued by the contractor in the 54th week.

At this time, the dry out of the refractories was the first priority so the equipment planned to be precommissioned were as follows:

Furnace

Damper and temperature indicators at the furnace arch and flue ducts.

Cooling System

Circulating water pump, pressurising pump, air cooled heat exchanger, pressurising expansion drum and make up water tank.

Combustion Air System

Blower and ducts

Natural Gas System

Pressure reducer, compressor and pressure vessels.

Instrumentation

Additionally to the furnace temperature indicators, part of the heat off and emergency shutdown system and the pilot heat off, were required for the Dry Out operation.

5.1.3.2 Activities Between Weeks 54 and 57

The scheduled equipment to be precommissioned during weeks 54 and 57 could not be carried out mainly due to the degree of incompletness in the equipment erection and the unavailability of natural gas.

However, during this period erection works related to the dry out operation such as the air cooled heat exchanger modifications, burner connections, damper, air preheater flue ducts and chimney were completed before week 57. Also, the natural gas compressor, blower and air cooled heat exchanger were precommissioned but, only the compressor, which was precommissioned with air, did not require further mechanical adjustment.

5.1.3.3 Activities Before Mechanical Hand Over

Despite all the outstanding erection works at week 57, the contractor and client continued to expedite those works related to the firing commissioning, until week 65. Then the contractor and client agreed to complete all the small pending jobs before week 67, in order that the contractor could mechanically hand over the plant.

5.1.3.3.1 Activities Related to Natural Gas Dry Out Operation

At week 57, there were the following outstanding jobs for the Natural Gas Dry Out operation and their completion were as indicated.

1) Duct connection between the chimney and furnace by week 61.

2) Delivery and mounting of control panel before week 58, permitted the connection of the essential instruments for dry out by week 60.

3) The following jobs were required in the cooling water system equipment and completed as indicated.

   i) Some final connections of the pressure expansion drum and make up water tank at week 61.

   ii) Modification of the air chamber and adjustment of the fan blades in the precommissioned air cooled heat exchanger at week 50.

   Because the cooling system is filled with treated water, the water softener also was included for the precommissioning of this system.

4) The softener already commissioned by week 56 had the following outstanding jobs at week 57 and were completed as indicated.

   i) Change of a cracked resin cylinder at week 59.

   ii) Pipework rectification in the boiler house at week 61.

   iii) Change of the original hose by a high pressure type at week 65.

5) Repair of the precommissioned combustion air blower by week 58.

6) The following activities were required in the Natural Gas System and completed as indicated.

   i) Delivery and installation of the pressure reducer station at week 65.

   ii) Modification of non return valve at week 65.

5.1.3.3.2 Activities Related to Fuel Oil Dry Out Operation

The main impediments for carrying out the Dry Out with fuel oil at week 57 were a clearance certificate of the system by C & E and the oil delivery, whose order was held by the former. These activities were cleared up at weeks 61 and 65 respectively.

The fuel oil firing is carried out with atomising steam, therefore this system was to be commissioned before any Fuel Oil Firing Commission could be carried out.

The atomising steam commissioning required the precommissioning of the softener and boiler. The former is explained in 5.1.3.3.1 with the Natural Gas Dry Out and the latter was as follows:

> The first boiler commissioning at week 58 was preceded by a temporary gas connection from the site at week 56. This was due to the unavailability of a normal supply of natural gas. At this time, the boiler performance could not be

fully tested because an intermittent gas supply caused by a non-return valve at the pressure reducer station outlet.

A proposal at week 60 for a possible fuel oil dry out operation mentioned that in addition to the C & E certificate and tank filling, the following jobs related to the boiler were required:

i) The reconnection of the temporary gas line, which was cut as soon as the boiler was partially precommissioned.

ii) Modification of the non-return valve.

iii) Rectification of the boiler house pipework, which was confirmed by the subcontractor as an outstanding job at week 58.

After the completion of the latter two jobs at week 65 and 61 respectively, the boiler was commissioned and generating steam to the manufacturer's specifications at week 65.

5.1.3.3.3 Activities Related to Non-Dry Out Equipment

Additionally, to the erection and precommissioning activities related to dry out equipment, other similar activities related to the Non-Dry Out Equipment, such as Air Preheater, LPG-related equipment and Instrumentation were carried out and they were as follows:

1) The air preheater at week 57 only had two outstanding jobs which were completed as indicated.

   i) Connection of the common air preheater-furnace flue duct to the chimney at week 60.

ii) Completion of pipeworks and other connections at week 65.

Following the final connection at week 65, an attempt to precommission the air preheater at week 66 did not succeed. This is explained in 3.5.1.2.2.

2) At week 57, the LPG system had the following outstanding jobs which were completed as indicated.

   i) Modification of the drench system at week 64.

   ii) Completion of pipework and final connections at week 65.

   iii) Fireproofing of the bottom of the tanks at week 67.

3) Due to the variety and the number of small jobs involved in the instrumentation work, it is a major task to evaluate its state of progress; but in this particular case, according to the instrument works described in chapter four the installation of the field instruments (4.4.3.1.2) and the control panel (4.4.3.2.2.2) achieved a completion of 80% while the completion for the control panel field instruments connection was nil in week 57; the latter activity (4.6.1) achieved a completion of 90% at week 67.

   Therefore, during week 57-67 the following works were carried out:

i) Connection of control panel-field instrument for the whole BTR instrumentation.

ii) Completion of the installation of a few control panel and field instruments, i.e. Temperature recorders, viscometer, oxygen analyser, etc.

iii) Control panel wiring of safety circuits, i.e. pilot heat off, fuel oil shutdown, etc.

5.1.3.4 Mechanical Hand Over

At week 67 there was no major outstanding erection or installation works therefore the client agreed to mechanically take over the plant.

A certificate of acceptance was signed by both parties at week 67. This certified that the client discharged the duties described in their tender for the design, supply and installation of the following items on the Burner Test Rig.

Items;

Furnace

Furnace Water Cooling System

Combustion Air Fan

Combustion Air Preheater

Natural Gas Compressor

Oil and LPG storage and supply facilities.

Water Treatment Plant

Steam Generator and Superheater

All buildings, pipework and services

Controls and Instrumentation.

Also the certificate included the following comments and exceptions.

The certificate was issued with respect to mechanical acceptance of the plant only; Performance acceptance was to be subjected to a separate certificate.

Acceptance of the above items of plant was conditional on the satisfactory completion of all items of work listed and issued to the contractor by the client.

The issue of the mechanical acceptance made the site technically under the control of the client. Consequently, the guarantee period of 24 months started running from week 67. This involved the client insuring the site and contents against damage caused by component or structural failure arising from their neglect.

Also, from week 67 the client could operate the plant under the supervision of the contractor's personnel.

5.1.4 Commissioning Activities

5.1.4.1 Contractor Precommissioning Activities

After the rig was mechanically handed over, the contractor proposed to complete the commissioning of the rig and to train the client operators in two weeks.

This was accepted by client, but the contractor only could precommission the system of the BTR which involved firing with:

Natural Gas

Heavy Fuel Oil

The main factors for the contractor being not able to commission the rig were due to the blockage of the jet atomiser (3.8.1.2.1) and general faulty instrumentation (4.6.2).

Also during this period the following activities were carried out.

i) The problems encountered in the first air preheater precommissioning attempt were evaluated and despite that some measures were taken in this respect (3.5.1.2.2), the air preheater precommissioning still was outstanding.

ii) Short runs of LPG firing were carried out and some modifications related to the control valves in the return LPG liquid and vapour lines to the tanks were recommended. [4.6.2.(5)].

iii) The client operators who were on the site during the precommissioning were instructed in the operation of the plant.

iv) The rig was subjected to dry out operation for four days with natural gas.

5.1.4.1.1 Operational Acceptance Certificate

At week 76, the client and contractor agreed to sign the Take-Over Certificate, which stated that:

i) The plant was operational with the only exception of the air preheater.

ii) A final aceptance certificate subject to comment and exception was to be provided as soon as the client had undertaken the necessary tests to ensure compliance with the plant specification.

iii) The contractor had instructed the client personnel in the safe operation of the plant.

iv) The operating instructions issued by the contractor were not entirely approved by the client.

The signing of the operational certificate authorised the client operators to operate the plant without the contractor's supervision, therefore the contractor's commissioning team completed its duty and a post-commissioning team remained on site in order to solve outstanding jobs.

5.1.4.2 Client Commissioning Activities

Following the issue of the operational acceptance certificate the client started operation of the plant at Week 77. During this week, the client carried out the BTR commissioning which involved the Natural Gas, LPG and Fuel Oil firing. This involved the checking of the COMMISSIONING VARIABLES (Key process conditions of the BTR, 5.2.3.1.1) by comparing their specified value during the tendering period (Client and Contractor Commissioning) with the recorded value during commissioning.

The table 5.1.4.2 shows the most relevant of such commissioning variables checked by the client so that their specified and recorded value comparison was used as major criteria to partially/fully accept the BTR system (major equipment).

Below is described the process of the partial/full acceptance of the BTR systems by client using the above criteria. This excluded the instrumentation and safety systems whose acceptance was based on a more qualitative criteria rather than quantitative (as above).

Furnace System

The deviation between the specified and recorded value of the furnace case temperature was expected by the client who agreed with the contractor that the possible benefits of bringing the temperature down to the specified value would not compensate the extra cost involved. Also, the deviation of the recorded flue gas temperature from the value specified was agreed between the contractor-client (800± 100°C instead of 760°C), however that as a consequence the specified furnace size as well as the maximum heat removal capacity (4400 Kw, 75% Thermal Efficiency), were to be affected as a minimum requirement.

Cooling Water System

The recorded commissioning process conditions of this system show that the maximum heat removal capacity of 50.5% (2960 Kw) instead of 75% (4400 Kw); however, as explained above, this was accepted by the client who originally agreed to increase the flue gas temperature with the subsequent reduction of the maximum heat removal capacity.

Combustion Air System

The air flow rate capacity finally obtained (25-250 scmm instead of 20-200 scmm) was accepted by the client who previously agreed with the contractor's modification of the blower so that a fluctuation turndown 10:1 can be obtained. The deviation of the air preheater process conditions did not allow the client to accept this equipment.

Natural Gas System

The fluctuation of the natural gas pressure when low fire was not accepted by the client.

L.P.G. System (11 MBTU/h)

The L.P.G. flow rate fluctuation and insufficiency of heat release caused a client's conditional acceptance of the system.

Fuel Oil System (20 MBTU/h)

This system operation tested according to specification so it was accepted by the client.

Atomising Steam System. (Boiler)

The boiler operation shows that was working as specified (21 barg, 40°C of superheat) therefore it was accepted.

The Systems/Major Equipment which were not accepted, such as the Natural Gas [3.6.1.2.2(ii)],Air Preheater [3.5.1.2.2(ii)] and LPG [3.7.13] were repaired and accepted by the client;on the other hand, the atomising steam system which was accepted only on the basis of the good working order of the boiler, later was found that the overall system was not operating as specified so it was repaired by the client [3.9.1.1].

Table 5.1.4.2 Tabulation of the values specified for BTR system key process conditions (Commissioning Variable) and their recorded value during commissioning

COMMISSIONING VARIABLE	CONDITIONS	SPECIFIED VALUE	RECORDED VALUE
Furnace System. (20 MBTU/h; 10% Xs Air and 75% Thermal Eff.)			
Forced Draught of Furnace Arch. (m barg)	Max. Fan Output	> 0.25	1.22
Flue Gas Temperature(°C)	As Furnace System	760	820
Furnace Case Temperature(°C)	As Furnace System	t < 65	t > 76 t < 96
Leak Test (0.5m barg)	Smoke bomb test.	Leak in TV camera	
Noise Test(dB)	During the Night	< 43	40
Cooling Water System			
Minimum Loop Temperature(°C)	Nitrogen Pressurised (19.9 barg)	> 149	161
Water Flow Rate (Ton/h)	Nitrogen Pressurised (19.9 barg)	130	137
Max.Heat Removal Capacity(MBTU/h) or	As Furnace System	15	10.1
Thermal Efficiency %	As Furnace System	75	50.5
Combustion Air System			
Air Flow Rate (scmm)	Pressure at burner 35iwg	200	250
AirFlow Rate Turndown(scmm)	Without Fluctuation	(20-200)	(25-250)
Preheated Comb. Air Temp.(°C)	Ambient Temp. 15°C	(100-400)	(108-200)

Natural Gas System (To release 5-20 MBTU/h)

	Low Firing	2	2 ± 10%
Natural Gas Pressure (barg)	High Firing	2	2·

LPG System (To release 5-20 MBTU/h

LPG Flow Rate (scmh)	High Firing	179	97.1 ± 10%

Fuel Oil System

Oil Flow Rate Kg/h	20 MBTU/H Burner Cond.	492	539
	10 Barg 130°C		8.8 Barg 135[C

Atomising Steam System (Boiler)

Operating Pressure (Barg)	40°C of Superheat	21	21

5.1.5 Findings about the Commissioning.

1. The commissioning programmes presented by the client and contractor were complementary of each other (5.1.2.3)

2. The conditions (5.1.2.2.1) in which the commissioning is carried out should have been clearly defined in a schedule where additional to the Dry Out commissioning programme (5.1.2.2.2) the Natural Gas, LPG and Fuel Oil Firing Commissioning (Sub)/Programmes were included.

3. The assigned time to carry out the BTR Dry Out (one week) did not allow any extra time for possible contingency. Neither, the assigned precommissioning (prefiring commissioning) time, of the revised commissioning programme (SND), allowed enough time, 5.1.3.2, to complete the precommissioning. Although the prefiring commissioning time assigned (reduced by two weeks, half 5.1.2.3) may have been justifiable considering that only about half of the BTR systems (Dry Out Systems) were to be precommissioned.

The actual prefiring commissioning (5.1.3.2 & 3) took (Start Precommissioning, 54th - Mechanical Hand Over, 67) 14 weeks and the contractor firing commissioning (5.1.4.1) (Mechanical Hand Over, 67 - Operational Hand Over, 76) another ten weeks.

4. Any delay in equipment delivery directly affects the erection works (3.13.12) as a whole but only certain equipment delivery delay (control panel, 4.4.3.2.2.1; pressure reducer, 3.6.1.3) could also disrupt the commissioning (Dry Out). Therefore, expediting the delivery of the equipment mentioned (5.1.3.3.1.2 & 6) had priority but the disruption of the commissioning by late deliveries could not be avoided.

5. Also, additionally to the installation of the above equipment, a full installation of other Dry Out essential equipment (3.13.14) was expedited (5.1.3.3.1).

6. On the other hand, the completion (Drench System) of the LPG System (3.13.15) was a prioritory activity in the LPG firing precommissioning as, in the latter stage, was LPG installation approval by the appropriate authorities.

7. As the LPG, the oil system installation approval and oil delivery (3.13.16) were critical activities in the oil firing precommissioning.

8. Checking the commissioning variables of the BTR systems (5.1.4.3) was the main client's criteria to fully or partially accept any major equipment or system during commissioning.

9. Because, "During the early stages of commissioning, a complex plant may be expected to have a high failure rate" (61), the safety circuits (3.13.9) are required to be in good working order from the beginning of the commissioning.

10. Although the completeness of the instrument installation (3.13.9) is only a good index to accept or not a major equipment/system mechanical hand over, the same instrumentation is vital to undoubtedly accept such major equipment/ system [4.6.4.(ix)].

11. The full acceptance of the BTR System was constrained because of the unreliability of the instrumentation calibration

5.2 Operating Instructions

In this section is examined the preliminary and revised operating instructions manual as well as the most relevant manufacturing operating instructions so that within the space available the "BTR Operating Instructions Manual" is described and examined. On this examination the author based the "Operating Instruction Findings" which are used later to back the author's recommendations (some to be included in the "Client Specification"), so to produce an improved version of the operating instruction manual.

Also this section contributes in the overall description of the BTR case study and to the applciation of CAFOS to the BTR.

5.2.1 Preliminary Operating Instruction Manual

The preliminary operating instruction manual was issued at week 55 and divided into the following five parts:

i) General Information of the plant.
This part describes the main mechanical and operational features of the BTR. Also, it provides the operating values of relevant conditions for the designed operation of the BTR.

ii) Instructions for the Safety Operation of the plant.
This part recommends the measures required before the plant is initially started up as well as the sequence to operate the plant. This included, the initial start up, the dry out or normal operation.

iii) Manufacturer Instructions.
This section has a list of the equipment information supplied by manufacturers and vendors. This information is compiled in three books and consisted of manual instructions and inspection reports.

The compressor and air preheater manual instructions supplied by the manufacturers complement the contractor operating instructions.

iv) Instrumentation and Control Equipment.
This section describes the logic in the operation of the main control instrument installed in the BTR.

v) Miscellaneous Information.
This last section contains information about: Maintenance routine - for certain equipment supplied by the contractors; List of the major equipment; and schedule of the contractor engineering drawings.

5.2.1.1 Comments and Criticisms.

In the second section of the 'Preliminary Operating Instructions' was described the main activities to operate the basic systems such as Furnace, Cooling Water, Combustion Air and Pressurised Gas Supplied (Furnace Pilot) Systems as well as the fuel systems which included the Natural Gas, LPG, Light Fuel Oil and Heavy Fuel Oil - Atomising steam systems.

In the latter fuel systems, operating instructions for the storage and handling of the LPG and fuel oil as well as the generation of vapourised LPG were missing. Also, in this section the following set of operating instructions were mentioned but not included:-

Shut Down Procedures.
Change over from one fuel to another and
LPG Safety Precautions.

Apart of the missing set of instructions described above, another important criticism to the preliminary operating instructions included the fact that the operating instructions provided were not completely satisfactory. This mainly was due to:

i) Incompleteness in the description of the operating instructions and specially for those concerned with cooling water, fuel oil and atomising steam systems.

ii) Small details like the incorrect numbering and wording of certain instructions.

iii) Contradictory instructions like:
Different recommended pressures in the burner windbox when firing the same fuel.

Different recommended air blower damper aperture (Minimum flow - low fire) for similar firing conditions.

5.2.2 Revised Operating Instruction Manual

The revised manual of the operating instructions has the same sections than the first issue but with the difference that the second section of this manual which corresponds to the operating instructions was enlarged as well as the section corresponding to Miscellaneous Information.

The information added to the operating instructions section to produce the revised version complemented the preliminary operating instruction so that the operation of the whole BTR was described.

The extra information included two other separate subsections for the oil and LPG which considered these fuel storage and handling, detail firing sequence operation and in the case of the LPG safety precautions.

Also, it was added the following subsections.

i) Shut Down Procedure

ii) Emergency Shut Down

iii) Check list for Safe Plant Operation

The latter of these subsections was subdivided as follows:-

i) Starting Auxiliaries and Services

ii) Pilot Ignition

iii) Starting up of cooling system

iv) Ignition of Main Fuel Gas

v) Furnace warm up

vi) Operating Conditions when Continuous Running

vii) Changing from Fuel Oil to Gas or LPG

viii) Changing from Gas or LPG to Fuel Oil

ix) Changing from Gas to LPG

x) Changing from LPG to Gas

The miscellaneous section of the revised operating instructions in comparison to the preliminary operating instructions additionally described the maintenance of the compressor and air preheater as well as the "Valves Status List" which considered the aperture of the valves, (close/open) for the whole rig when it is firing either Natural Gas or LPG or Fuel Oil or it is not operating. Also, in the revised version of the manual operating instructions, the contractor additionally of annexing the preceeding described information to the preliminary operating instructions also modified some of its instructions. These instructions, described as unsatisfactory in 5.2.1, included incorrect numbering and wording; and the elimination of redundant operating conditions.

5.2.3 Summarized Operating Instruction Manual

The operating manual instructions as described in section (5.2.1) consisted of five sections of which a short version of the first two sections are described below.

The first section concerned with general description of the plant specified the required variables for commissioning and the second section described the main instructions to operate the plant.

Additionally, it is added the manufacturer's instructions for the compressor and air preheater which complements the operating instructions provided by the contractor.

5.2.3.1 General Information of the Plant

This section describes the main mechanical and operative features of the Furnace, Cooling Water, Combustion Air, Natural Gas, Oil and Atomising Steam Systems. The LPG system was excluded. Also, general guidelines related to the layout of the plant and instrumentation were described.

In the description of the systems comprising the plant some relevant design conditions in the operation of the plant were included. These variables were to be achieved during the commissioning.

5.2.3.1.1 Commissioning Variables

1) Furnace System

Combustion Design Conditions

Flue Gas Temperature (FGT)	760°C
Heat release	20MBTU/h
Force Draught	
At the hearth	0.5 inwg
At the arch	0.1 inwg
Pressure at the windbox with 10% excess air	6.4 inwg

Mechanical Design Conditions

External Surface Temperature

Wall at FGT of 850°C:	< 85°C
Floor at FGT of 850°C:	< 96°C
Floor at FGT of 1100°C:	< 120°C

2) Cooling Water System

Flow rate (125,000kg/h) 456gpm

Pressure at the loop:

At Furnace Outlet	16 barg
At Pump Outlet	21 barg

Temperature at the loop:

At the Furnace Outlet	195°C
Air Cooler Outlet	160°C

3) Combustion Air System

Air Blower Operating Conditions

Flow Rate of Combustion Air	$200 sm^3/min$
Flow Rate Turn Down	10:1
Pressure Output	(21 inwg) 52m barg

Air Preheater Operating Conditions

Process Fluid Operating Conditions:

Flow rate required to burn any of the client specified fuel at 10%	
Excess Air and Release Heat, of	20 MBTU/h
Preheated temperature of the process fluid:	100-400°C
Preheated Temperature Turn Down	4:1

4) Natural Gas System

Main Natural Gas Supply

Pressure Reducer Outlet	(6-10 inwg) 15.25 m barg
Compressor Outlet	(51 psig) 3.5 barg
Flow rate (max)	(760 sm^3/h) 1260 lb/h
Filter mesh size	2 micron

Pilot Furnace Supply

Natural Gas Pressure	(5 psig) 0.34 barg
Air Pressure	(8 psig) 0.55 barg

5) Oil System

Heavy Fuel Oil

Flow rate	(522 kg/h) 1150 lb/h
Pressure at the burner	(185 psig) 12.7 barg
Temperature at the burner	170°C

Running Time with the storage fuel (Two 6000 gallon tanks)	55h

Oil Preheater:

Process Fluid Operating Conditions:

Flow rate	(540 kg/h) 120 gph
Preheated temperature of the process fluid	
Oil Preheater Inlet	(82°C) 180°F
Oil Preheater Outlet	(132°C) 270°F

6) Atomising Steam System

Softener

Flow rate	12 gpm (3240 kg/h)
Total Dissolved Solids	300 ppm
Chemical consumption with a charge (10 hours running at the above flow rate)	31.7 kg salt
Running time with the storage brine (8 recharges)	80 h

Steam Generator

Flow rate of saturated steam at 21 barg	1000 lb/h

Superheater

Flow rate of steam which is superheated 50°C at 21 barg	800 lb/h
Turn down of the steam generator and superheater	4:1

5.2.3.2 Instructions for the Safe Operation of the Plant

5.2.3.2.1 Preparation for Initial Start up

Before it was attempted to light the BTR certain precautionary measures are to be taken so that, an adequate state of the plant and all items necessary for the control of the burner flame is ensured. The precautionary measures are as follows:-

5.2.3.2.1.1 General

i) It is recommended to institute a start up permit issued by the Safety Division or Department.

This permit is to be signed, by a safety department representative only when the operation of the plant is free of dangerous or unsafe situation.

ii) Manufacturer Operating Instructions
The individual operating instructions are to be read before any initial start up is carried out.

iii) Clear Operation Area
The operative area is to be free from debris.

iv) Protective Guards
The protective guards for exposed rotating parts and hot surfaces are to be checked that they were positioned correctly.

v) Valve Status List

The contractor supplied a "VALVE STATUS LIST" which contains in tabular form instructions on which valves should be open or closed when the plant is burning Natural Gas, LPG and Fuel Oil as well as when the furnace is not operating.

Before using the plant, the correct position and status of the valves are to be checked against the flow diagram and the above list, respectively.

vi) During light up it is inevitable that the "heat-off" valves are shut and need to be opened manually. Only those valves required for the operation in turn are to be opened, if lighting on gas only, the pilot gas valve and the main gas valve are to be opened.

5.2.3.2.1.2 Basic Operational System

The firing in the rig with any of the fuels requires that the furnace, cooling water and combustion air systems are operational. Thus, the following 'Preliminary Checks' are referred to the equipment and parts that comprise the above basic operational systems and will require the electrical power supply on as well as the pneumatic system pressurised.

i) The motors and fans are to be running in the right direction.

ii) Ensure by direct observation that the dampers are operated by hand and their actuators.

iii) Burner Connections.
The fuels shut down valves operated from the furnace landing are checked if they were closed and a downstream inspection is needed to confirm that the fuel lines burner connection are tight.

If any of these fuel lines are disconnected the spectacle plates are to be turned to the closed position.

iv) Refractories.
Before any normal operation was attempted, the furnace, stack and burner refractories were to be dehydrated, i.e. "Dry Out" furnace operation.

v) Furnace Apertures.
The furnace apertures such as access, observation and sample doors were to be tightly shut off. If any of these doors were to be opened during operation, a negative pressure in the furnace box was to be ensured.

vi) Cooling Water to Furnace Accessories.
Flowing of cooling water to the TV cameras and sample probes were to be confirmed.

5.2.3.2.2 Dry Out Operation

The dry out operation was based on the gradual elimination of the water which is chemically bounded to the refractories therefore the dry out procedure was a considerably slower rate temperature increase than the normal firing procedures.

The rate of temperature increase for the dry out recommended by the stack manufacturer and also applicable to the furnace refractories is shown in table 5.2.3.2.2 This table shows that the firing was to be kept for six hours at each of the specified temperatures which was to be reached by temperature rise not bigger than 25 °C/h therefore the necessary time to obtain the desired temperature at each period will be at least another six hours in addition to the six hours of the dry out firing in each period. Thus the total duration of dry out operation was at least 72.

During dry out the operation of the air preheater was excluded and the draught in the furnace box was to be between the limit values of 0.05 and 0.5 inwg.

5.2.3.2.3 Firing Sequence Operation

5.2.3.2.3.1 Natural Gas Firing Sequence Operation

After the preliminary procedures described in 5.2.2.1 are carried out. The operation sequence to the fire natural gas either in dry out or normal operation is as follows:-

Combustion Air System

i) Start the FD fan, and run the FD fan to fully purge the furnace, that is for at least long enough for three complete air changes to have been effected in the furnace.

Table 5.2.3.2.2 Rate Temperature Increase to dry out the furnace ducts and burner refractories.

Period	Operating Temperature °C (°F)	Duration (hour)
1	150 (302)	6
2	300 (572)	6
3	450 (842)	6
4	600 (1112)	6
5	750 (1382)	6
6	900 (1652)	6

* The increase of temperature shall not exceed 25°C/h. At least 6 hours are required to reach the higher temperature of the following period.

If burner does not light at a first attempt repeat this procedure before proceeding.

ii) Adjust the air flow by means of the damper on the fan, to its minimum flow. The hand operated damper of the burner should be maintained opened at this stage; but during operation, it can be used to control the pressure at the burner wind box.

Natural Gas System

Pressurised Natural Gas

iii) Open the isolating valves NG1, NG3, NG4 and NG7.

iv) Prove gas supply is available to compressor by opening sample tap NG46.

v) Before the compressor initial start up the pressure vessel receiver is to be drained in case any liquid had built up in there.

vi) Undertake the initial start up procedure for IR gas compressor as given in the IR handbook. This is described in section 5.2.3.3.1.

vii) Check that the pressure in the receiver is the correct. If it is not, shut down and adjust the pressure switch controlling the unloader valves.

Pilot Gas Ignition and Operation

i) Open NG11, NG48 and NG27.

Ensure DEACV4 (pilot gas "heat off" valve) is open.

Open NG29 and NG31

Open NG33 (spectacle plate) if necessary.

ii) Set pressure shown on PI18 using PCV16. Ensure pressure shown on PI20 is correct (0.2 barg) for the installed burner.

iii) Open NG49 and set pressure of pilot air on PI36 to correct figure (0.6 barg) on installed burner.

iv) Open NG32 and light the pilot flame with the Dr. Bell ignition.

v) Vary the air blower flow rate from maximum to minimum to ensure pilot flame stability.

Set the recommended wind box pressure by the burner manufacturer which varies according to the fuel.

vi) During dry out run the pilot flame alone for 2-3 hours to commence drying out procedure.

Cooling Water System

Filling the Cooling Water Loop.

i) Close all drain valves on the cooling water system.

ii) Ensure that the manual vent valve on the cooling coil at the top of the furnace is open.

iii) Ensure that the isolating valves at the base of the expansion drum is open.

iv) Check that the water tank feeding the make up pump is full.

v) Operate the make up pump to fill the cooling water system. Carefully monitor the level in the make up tank. Either operate the pump intermittently or throttle the outlet from the pump to maintain a constant level in the tank.

vi) When the water in the expansion tank has reached a suitable level, close the valve at the base of the expansion tank to divert the water into the rest of the cooling water circuit.

vii) When water issues from the manual vent valve at the top of the furnace, switch off the make up pump.

viii) Close the manual vent valve at the top of the furnace and open the valve at the base of the expansion tank.

ix) Pressurise the cooling water circuit using nitrogen to its normal working pressure (16 barg).

Start Up Circulating Pump

i) Check the oil level in the pumps and top up if necessary.

ii) Ensure that, on the pump to be operated the suction isolating valve is open and the discharge valve is closed.

iii) Switch on the appropriate pump and open the discharge isolating valve. Check that the pump is producing the anticipated head of approximately 4 barg.

iv) After the pump has been running for a few minutes, open the vent valve at the top of the furnace for a few seconds to 'bleed' any air in the system.

v) Check that the water flow is correct and is balanced between the two coils.

Air Cooled Heat Exchanger

i) Initially the air cooler fans will not be required as natural draught cooling through the air cooler will be adequate. As the water temperature rises the air cooler fans should be successfully started to maintain a water temperature of below 195°C (383°F).

During initial start up it may be necessary to over cool the water to help keep down the furnace temperature rise.

Gaseous Fuel at the Burner, Ignition and Operation.

i) Open NG13 and NG19

Open "heat off" valves DEACV1 and DEACV2 and ensure that DEACV3 is closed.

ii) Check pressure on PI15. If correct first open spectacle NG22 if closed, close NG19 and open NG20.

iii) Open NG19 to allow gaseous fuel to burner and light immediately.

iv) Adjust NG19 to the lowest stable flame, setting excess air at about 200-300 percent.

v) According to choice either NG19 or DCV2 can control the flame. Open NG14 and NG19 if DCV2 is selected. In any case direct manual control should be maintained.

vi) Check for hot spots on the furnace and duct wall. The cold face temperature is to be under 85°C at 15°C still air.

vii) Thoroughly check the furnace structure for any sign of distress and for any point of tramp air ingress. Check that the hot flue duct is allowed to expand by the compensator fitted between the furnace and the stack.

viii) If the fuel gaseous firing operation is 'Dry Out' or Normal the maximum temperature increase rates allowed are 25°C/h and 200°C/h, respectively.

5.2.3.2.3.2 L.P.G. (Butane) Firing Sequence Operation

Before attempting to use the L.P.G. system thoroughly study the documents published by the HMSO on the safe use of L.P.G.

The L.P.G. is a dangerous substance when used incorrectly. An example of the many ways that L.P.G. can form an explosive mixture is by its accumulation in instrument ducts as a result of its high density (heavier than air).

The Liquified Petroleum Gas sequence operation is as described for the Natural Gas Firing Operation but with the addition of "LPG Vapour Supply"; and in the "Gaseous Fuel at the Burner, Ignition and Operation" the first instruction is substituted by two others which instruct on how to purge and fill with LPG the common gaseous fuel line (NG1004).

LPG Vapour Supply.

i) Open outlet valve at the bottom of LPG tank.

ii) Open isolating valves between tank and pump. Also, the isolating valve at the discharge pump side.

iii) Start the LPG pump

iv) Ensure that discharge pump pressure is about 6.5 barg. If necessary adjust by opening bypass valve to pressure control valve.

v) Open isolating valves on either side of level switches and associated solenoid valves.

vi) Discharge pressure from pump will fall as LPG vaporisers fill.
Check level if necessary using sample points on side of vaporisers.
When pump discharge pressure returns to within 0.5 barg of value before opening isolating valves, switch on steam to vaporisers and ensure that the condensate drain valves are open.

vii) Monitor pressure in vaporiser which should be in the range 4 to 7 barg and check the condensate system.

viii) Ensure that the electric tracing of the butane line is switched on. The tracing extends right to the burner along the line shared with natural gas. Ensure that the temperature control of the tracing is operational and correctly set.

ix) Open the isolating valves on either side of the LPG Governors and check the pressure.

Gaseous Fuel at the Burner, Ignition and Operation

i) Purge the gas line downstream LP55 with nitrogen until all air has been driven out of the line. The purge point provided is through the valve NG43.
Open the valve NG19 and ensure that NG13 SG16 and LP55 are shut.
Open "heat off" valve DEACV1 and DEACV2 and ensure that DEACV3 is closed.

ii) Open the valve LP55

The remaining instructions are as described in the Natural Gas Firing Sequence Operation.

5.2.3.2.3.3 Fuel Oil

Before any attempt to fire fuel oil it is required that the following preliminary checks are carried out.

i) Level in the tank to be above that of the temperature sensors which otherwise would not be capable of monitoring the oil tank temperature and consequently the control of the oil temperature in the tank will be lost.

ii) If using special fuels ensure that connections to the tanker are securely made.

iii) Check that the oil temperature in the tank is 50°C in case of heavy fuel oil, or another temperature required to bring the viscosity of the oil into the required range.

iv) Ensure that the twin bowl strainer is in good condition and correctly set up.

v) Ensure steam tracing along oil lines is working if heavy fuel oil is to be used.

Following the above checking the fuel oil firing sequence operation is as described in the "Natural Gas Firing Sequence" with the exception that the set of instructions headed "Gaseous fuel at the burner, ignition and operation" is substituted by the following set of instructions.

Check Oil Pumps and Relief Valves

i) Open FT7 and either F12 or F13 depending on which pump is selected.

ii) Start pump and check pressure with PI53 or PI54. The pressure should not exceed 185 psig. If it does it indicates that the relief valve of the pump is not operational. Check and correct before proceeding.

iii) If the pressure does not build up within a few seconds shut the pump down immediately. Damage will be done to the pump if it is run dry. Check for any obstruction at the suction side and restart.

iv) Shut down the duty pump and check stand pump is also operational .

v) Shut down both pumps.

Atomising Steam

Steam Generator - Boiler

i) Ensure gas supply is available to the boiler.

ii) Ensure water treatment equipment is switched on and treated water is available to boiler.

iii) Switch on power to boiler at main panel.

iv) Start up boiler, check that ignition light comes on and ensure that the steam pressure climbs to the normal working pressure (20 barg).

Superheater

i) Ensure the gas supply is available

ii) Ensure that temperature switch (blue) is set to the required temperature (265°C) and pressure switch (red) is set above zero (7 barg) but below normal operating pressure.

iii) Ensure Boiler is operating

iv) Switch on the superheater in the local control panel. Orange light will come on. Purging sequence will operate automatically. After a few minutes a green light will come on indicating ignition. If red light (lock out) comes on, press button to reset and try again.

v) Temperature will slowly rise to the selected temperature.

Atomising steam line

i) Open HS1, HS7 and HS9 (spectacle) if closed open the valve HS1 slowly

ii) Check and set correct pressure of atomising steam. DCV3 can be employed as an alternative to HS6 by opening HS4 and HS5. In normal running DCV3 will normally be employed.

Oil Preheater and its relief valve.

i) Check three way lockable valve FT9 is correctly set to spill back oil to the duty tank.

ii) Open valve FT18 at oil preheater inlet.

iii) Start duty pump and ensure oil flows into preheater.

iv) Check oil preheater relief valve FT32 is correctly set and is operational.

v) Open the steam control valve to the oil preheater. Set the required oil temperature on the appropriate controller.

Preparation Before Firing Oil

i) Open FT19, DEACV5 and FT30 and recirculate oil through the preheater until temperature recorder TR3-5 shows the oil at the correct temperature for the burner.

ii) Open LS22 and purge burner for a few minutes to ensure that atomiser is clear.

Oil Ignition and Operation

i) Open FT23 and light off on oil. If the main flame does not light immediately shut FT23, open LS22 to repurge, check pressures and temperatures of oil and atomising steam are correct and that pilot is alight. Then try to relight on oil.

Switch off the oil pump if the shut down is for several minutes, also shutting the steam to the oil preheater at the same time. Ensure that the steam tracing is kept on.

ii) When alight adjust the steam, the air and fuel oil to give the required flame.

iii) Try to limit the temperature rise to below 200°C per hour. Adjust the oil flow by means of FT18.

Normal Start Up on Light Fuel Oils

Generally follow the instructions above, ignoring the instructions on the oil preheater and ensure that the steam tracing is switched off.

5.2.3.3 Manufacturers Instructions

This section of the instruction manual only has a list of contents of the information provided by the manufacturers and vendors about the supplied BTR equipment. This information is in three filing books and consists of instruction manuals for equipment such as Boiler, Compressor and Air Preheater among other minor equipment.

As mentioned, certain equipment manufacturers' operating instructions complemented the contractor operating instructions and this is particularly so for the compressor and air preheater whose operating instructions are described below.

5.2.3.3.1 Compressor Operation

5.2.3.3.1.1 Preparation for Initial Start Up.

Before starting up the compressor it is required that the following checking activities are carried out:

i) Ensure that the cylinder inlet valves are forcibly held open by the connection of the compressed air to the tapped hole in the piston housing cover. This will not allow that pressure build up in the cylinder.

ii) Satisfactory operation of the relief valves at the compressor discharge is to be checked.

iii) Ensure adequate level of oil in the frame up sump and lubricator reservoir. The former has a gauge glass which facilitates the level monitoring and also it is advisable to check during operation.

iv) The cooling water must be clean filtered and softened to prevent corrosion or plugging of the water passage in the packing cups.

v) Ensure the flowing of cooling water and that the water entering the cylinder is at least 5.6°C (10°F) above the suction temperature. If the water inlet temperature is above the cylinder gas inlet temperature condensation will not form on the cylinder walls in most cases.

vi) Ensure that if the compressor was to be shut down for longer than 10 minutes the cooling water must be shut down as well otherwise it can cause condensation on compressor walls.

vii) The compressor is to be turned manually through several revolutions in the direction shown by the arrow located above the frame oil pump to make certain that moving parts are clear and move freely without binding.

viii) Exposed rotary parts are to be covered adequately by protective guards.

5.2.3.3.1.2 Initial Start Up
- Operation Sequence to Start the Compressor.

Some modification to the start up procedure may be required, however, a standard starting sequence is desirable to be followed consistently by the operators. The following operating sequence is proposed by the manufacturer.

i) If the compressor has been shut down for several days, it may be necessary to prime the oil pump.

ii) Turn on a full supply of cooling water through the compressor cylinder jacket cooler.

iii) Prepare the driver for start up according to the manufacturer's instructions; check the direction of the motor rotation.

iv) Start the driver and run the compressor for a few minutes to warm up the unit. Listen for any unusual noise during the warm up period.

v) Check the oil pressure in the frame lubrication system; the normal operating pressure should be 15 to 40 psig.

vi) The flow rate of cooling water must be adjusted at a value where the temperature rise across the cylinder is in a range between 5.6 and 11.2°C. The minimum flow rate is 7.6 l/min at 25psig. If the flow rate is too low, the possibility of building up deposits to the point of cutting all flow exists.

vii) The compressor is to be loaded when the unit has warmed up and shown that it runs satisfactorily.

viii) The pressure in the cylinder is to build up gradually noting the gas temperature as abnormal temperatures are often the first indication of trouble.

ix) Adjust the cooling water flow and temperature as described in (vi).

x) When pressure and temperature in the process fluid are stabilized, record them for future reference as operation and maintenance guidelines.

5.2.3.3.1.3 Stopping Routine

i) Unload the unit

ii) Stop the driver according to the manufacturer's instructions.

iii) Shut off the cooling water on applicable units.

iv) Prepare the unit so that it can be started in short notice.

5.2.3.3.2 Air Preheater Operation

5.2.3.3.2.1 Preparation for Initial Start Up

Before attempting the initial start up of the air preheater, the following points are to be checked:

i) The heater chamber is free from any tools, equipment, surplus material or debris.

ii) All the doors, sight tubes, inspection parts etc., are correctly fitted and sealed off.

iii) The pipe lines and burner tips are free from loose scale, rust, dust and rubbish.

iv) All control instrumentation as well as safety system function correctly. Additionally to the permanent installed instrument equipment, some temporary one may be required during the commissioning period. These are to monitor:

- Draft at stack and burner levels
- Fuel flow to the burner
- Air/fuel ratio; orsat or other analysing equipment will be required for setting up this ratio.
- Fuel pressure at the burner.

v) The air fan rotate in the right direction.

vi) An adequate cooling medium is flowing through the process coil. At least 30% of the design flow.

5.2.3.3.2.2 Manual Start Up

i) Check availability of fuel in pilot and main gas supply. Set required pressure in the main.

ii) Purge the firing chamber with three volumes of air and set the fan damper to a low fire position (15% to 20% open).

iii) Ignite the pilot and check its stability by openning the fan fully. If positive, return the fan damper to low firing position.

iv) Open the main fuel valve gradually until low flame is established.

v) Keep the low fire condition for 10 minutes to ensure that the burner refractory quarl is sufficiently warmed up before increasing the flame condition.

vi) Check the flame failure circuit.

vii) Ensure that the installed instrumentation is working properly.

viii) Check that the process fluid complies with the specification.

5.2.3.3.2.3 Automatic Start Up

When the air preheater is provided with a local control unit the following safety interlocks are included in addition to a cam timer motor that allow an automatic air preheater start up.

- Flame failure
- No flow of process fluid (No rotation in air blower)
- Low and high gas pressure

Control Panel Start up Sequence

i) Check that low fire potentiometers are set to low fire.

ii) Close main insulator. Power lamp will light.

iii) Adjust air and gas pressure if incorrect.

iv) Set the ON-OFF switch to ON.

Sequence of the control panel programme.

a) Purger timer PT and damper is open to high fire.

b) Energising relay IL set the aperture of the following valves and damper.

The three quick shut down valves are set closed.

Gas control valves and damper are set to low fire.

Cam timer sequence

c) Pilot valve 1 & 2 are open and the ignition transformer is energised

d) De-energise the ignition transformer to prove pilot is lit.

e) If the above is not proved the start up sequence will be lock out in 47 seconds.

f) If pilot ignition is lit the main gas valves are opened.

h) The damper and gas control valves are released from "Low Fire Set Position".

i) The cam timer motor stops.

5.2.4 Findings about the BTR Operating Instructions

1. The "Operating Instruction Manual" was meant to contain all the information necessary for the plant operation (5.2.1).

i) General Information of the Plant.

ii) Instruction for the Safety Operation of the Plant.

iii) Manufacturer's Instructions.

iv) Instrumentation and Control Equipment.

v) Miscellaneous Information.

2. The Precautionary Measures and Start-Up Preparation can be defined in relation to the BTR

General Operation (5.2.3.2.1.1)
Basic Operational System (5.2.3.2.1.2)
Particular System Sequence Operation.

The latter is implicitly included in the Firing Sequence Operation (5.2.3.2.3) and specifically described in the Safety Checking List (Excluded from this thesis for space reasons) .

3. The "Instructions for the Safe Operation" of the BTR are generally structured as follows:

Precautionary Measures (General and Particular).
Start-Up Preparation (Safety Checking List).
Operation Sequence.

4. The "Preliminary Operating Instruction Manual" although not fully satisfactory for reasons described below, was available before the commissioning stage started.

i) Missing of instructions which included: Precautionary Measures (LPG Sytem); Sequence Operation Modules (LPG and Fuel Oil storage tanks filling, LPG vaporisation and Fuel changes during the firing); Shut Down Procedure, and Check List for Safe Plant Operation.

ii) Incorrect instructions caused by incompleteness, miswording and wrong value of some operating conditions.

5. The operation of the BTR can be classified according to the following firing modes:

Dry Out Precommissioning (5.2.3.2.2)
firing with any fuel although natural gas is preferred.

Natural Gas Firing (5.2.3.2.3.1)

Fuel Oil Firing (5.2.3.2.3.3)

The operation sequence of these firing modes can be divided into operation modules (system/major equipment) of which the following are common for all the firing modes (5.2.3.2.3.1).

Combustion Air System.
Pressurised Natural Gas.
Pilot Gas Ignition and Operation.
Cooling Water System.

6. As a common practice, the "Instructions for a Safe Operation" are normally explained (including this thesis) by defining operation modules and firing modes so that the latter can be described by grouping the required modules. This way of description, although efficient, can be confusing (especially when the required modules are cross-referenced) even to the operators who know the sequence operation by the everyday experience of carrying it out.

7. Also, a comon practice is to accept and use the major equipment operating instructions as a module but this caused the following problems during the BTR project.

i) Despite the late supply of the LPG system instructions, they did not sufficiently explain the LPG operating instructions, so that its operability study could not have been carried out with the information supplied.

ii) As the LPG System, also the boiler house (softener, boiler, superheater), compressor and air preheater, did not have clear operating instructions of the systems where they were installed; therefore their available operating instructions were insufficient, especially so for carrying out their operability study.

CHAPTER SIX

OPERABILITY STUDY

6.1 Introduction

The main purpose in applying CAFOS to the BTR is to examine in detail its operation and identify the causes of potential operating problems and unsafe situations.

Such examination allows the author to produce recommendations which aim to improve the operability, reliability and safety of the BTR.

In addition to this introduction this chapter contains five sections:

Section 6.2 describes in general terms the application of the CAFOS technique to the BTR.

Section 6.3 gives the definitions required for such application.

Section 6.4 describes the actual BTR OPERABILITY STUDY and the section is subdivided into the different BTR systems mentioned in 1.3. The only exception is the Instrumentation and Control System which is already considered in the operability study of the other systems.

6.2 CAFOS Application to the BTR

CAFOS involves the use of cause and symptom equations which are based on three subsets of words of which the first two are known in the literature (55) as the subset key words:

i) 'Property words' which focus attention on possible deviation.

ii) 'Guide words', which focus attention on possible deviation.

iii) 'Components' which describes the substance involved.

The subset words required for the application of CAFOS to the BTR are described in table 6.3.2.A in which the Meaning of Index Numbers used in the cause/symptom equations are identified.

Also, the Index Number required to describe the failure mode (deviation) of the different equipment is tabulated and shown in table 6.3.2.B.

Finally, the situation in which the index numbers are applied in the cause/symptom equations are defined in the section 6.3.1 which is referred to as "Rules for Cause Equation" while the index numbers used in the symptom equations are used according to the rules set for the heat exchange (H104), evaporator (H103) and boiler (Q103).

The end of the chapter has a set of findings which are set out as recommendations (Action Required by the Operability Study) to improve the operability, reliability and safety of the BTR.

6.3 Definitions for the BTR Operability Study

6.3.1 Meaning of Index Numbers

The index numbers used in the cause and symptoms equations of the BTR operability study are defined by the tables 6.3.1 A & B.

The first table, 6.3.1.A, shows the meaning of the index numbers as proposed by The Chemical Industry Association (55) but with the required alterations for the BTR.

The second table, 6.3.1.B, shows the index numbers [1,0,-1] which indicate failure modes of the basic BTR equipment.

Table 6.3.1A Meaning of Index Number

Indicate Deviation From Normal Conditions

INDEX NUMBER	Property Word (1st Number)	Guide Word (2nd Number)	Component (3rd Number)
1	Flow	No	Oxygen
2	Temperature	Less	Hydrocarbon Liquid
3	Pressure	More	Hydrocarbon gas
4	Level	As well as	Natural gas
5	Concentration	Part of/ Fluctuation	Steam/ Vapour
6	Purge	Reverse	Water (liquid)
7	Heat transfer	Other than	Emissions
8	React (Burn)	-	Hydrogen
9	Calorific Value	-	Nitrogen
10	PH	-	Water hardness

Table 6.3.1B Meaning of Index Numbers Indicate Failure Mode

Equipment	Index Number *		
	0	-1	1
Compressor	Stopped or Unloaded	Valves bypassing	-
Controller	No signal	Set low	Set high
Filter	Fully blocked	Partly blocked	-
Flowlinear converter	No signal	Sending a low signal	Sending a high signal
Heat exchanger	Tubes fully blocked	Tubes partly blocked	-
Indicator	No signal	Indicating low	Indicating high
Level switch	-	Stuck low/ Set high	Stuck high/ Set low
Line	Fully blocked	Partly blocked	-
Orifice plate	Blocked	Orifice too large/ Density low	Orifice too small/ Density high
Pneumatic trip valve (Three-way)	Vent isolated	Leaking to vent	Open to vent
Pump	Stopped	Cavitating	Running
Safety interlocks	Fails to operate	-	Operates
Transmitter/ Transducer	No signal	Indicating too low	Indicating too high
Valve	Closed/ Blocked	Insufficiently open/ Leaking	Abnormally Open/open too much

* Hand Switch Control Mode

(P) = Pressure

(PD) = Pressure differential

(F) = Flow

* Miscellaneous Equip.Mode

(L) = Leaking

6.3.2 RULES FOR CAUSE EQUATION

6.3.2.1 Pipelines - Flow

Index 1

No flow may be caused by any of the following:

No flow in the line(s) immediately upstream
A valve shut in the line
A filter fully blocked in the line
A pump in the line stopped
No flow at the node where the line leaves an equipment
The supply tank empty

Index 2

Less flow may be caused by any of the following:

Less flow in the supply line(s) immediately upstream
More flow in a branch line (judged by the relative magnitudes of the normal flows)
A valve insufficiently open downstream of a pressure control
A pressure or flow controller set too low
A pressure or flow transmitter indicating too high
A pneumatic trip valve leaking to vent
The flow control valve fully open AND valve in the line insufficiently open or other blockage

Index 3

More flow may be caused by any of the following:

More flow in the line(s) downstream
Leaks in the line(s) downstream without flow control
Leaks upstream of flow controllers in downstream line(s)
Pressure or flow controller set too high
Pressure or flow transmitter indicating too low
Control valve stuck open
By-pass flow around a pump too low
More flow at the nodes where the line leaves or enters an equipment
(Leaks from a line are equated to drain or bleed valves open or leaking, filters leaking, etc.)
By-pass around a control valve fully open.

Index 4

Flow, as well as may be caused by any of the following:

Contamination in inlet lines
Contamination in storage tanks
Tubes leaking in exchanges
Steam or nitrogen purge valves leaking
Supply tank level low and air enters the discharge pipe
Steam trap leaking or its by-pass valve leaking

Index 5

Fluctuating flow may be caused by an on/off controller or an unstable control loop

Index 6

Reverse flow may be caused by differential pressures, unequal levels AND no non-return valves fitted or non-return valve leaking

Index 7

Flow, other than may be caused by gas or vapour entering the discharge pipe from an empty supply tank.

6.3.2.2 Pipelines - Temperature

Index 2

Less temperature may be caused by any of the following:

Low temperature at the node where the line leaves an equipment
Trace heating not on or failed
Temperature indicator indicating too high
Temperature controller set too low

Index 3

More temperature may be caused by:

High temperature at the node where the line leaves an equipment
Trace heating on when it should be off
Temperature indicator indicating too low
Temperature controller set too high

6.3.2.3 Pipelines - Pressure

Index 2

Less pressure may be caused by any of the following:

Less pressure in the supply line
A valve insufficiently open downstream of a pressure controller
Pressure or flow controller set too low
Pressure or flow transmitter indicating too high
Pneumatic trip valve leaking to vent
Control valve fully open AND a valve in the line insufficiently open or other blockage
Less pressure at the node where the line leaves an equipment

Index 3

More pressure may be caused by any of the following:

High pressure at the beginning of the line and no pressure or flow control

High pressure at the end of the line and flow is controlled

Flow or pressure controller set too high

Control valve stuck open

By pass valve around a control valve is fully open

Flow control AND flow transmitter indicating too low

Pressure control and pressure transmitter indicating too low

Pressure regulator set high or its valve stuck open (Downstream P.C.V. only, if two present)

6.3.2.3.1 Pressure Gradient in a Closed Circuit

Pressure falls linearly, with distance from the pump delivery to the pump suction:

A partly opened valve or other sudden pressure drop reduces the flowrate so the pressure gradients are less (see Figure 1)
A leak produces a reduced flow downstream or thus a reduced pressure gradient downstream. (See Figure 2)

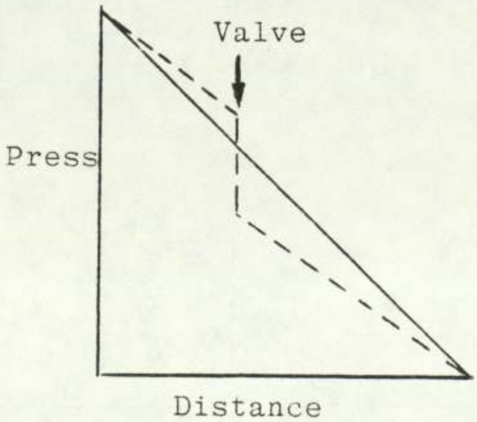

Figure 1

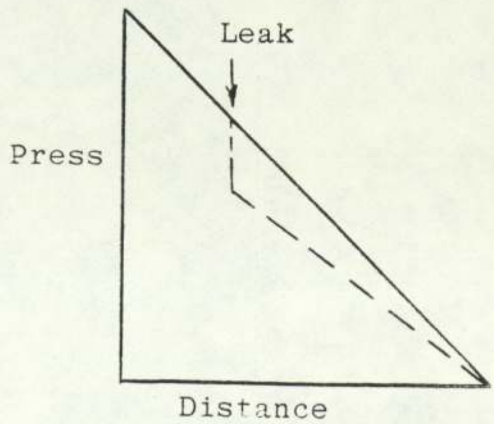

Figure 2

6.3.2.4 Pipeline Junctions

Where line L3 is supplied by line L1 and/or line L2 the following rules are used to construct cause equations for line L3:

No flow is caused by no flow in L1 AND no flow in L2
Less flow is caused by less flow in L1 OR less flow in L2

Less temperature is caused by less temperature in L1 OR less temperature in L2

More temperature is caused by more temperature in L1 OR more temperature in L2

Less pressure is caused by less pressure in L1 OR Less pressure in L2

6.3.2.5 Vessels - Level

Index 1

No level, means the vessel is empty

Index 2

Low level may be caused by any of the following:

Level transmitter indicating too high
Level controller set low
Lower isolating valve on level indicator/
transmitter is closed
No flow into vessel
Low flow into vessel

Index 3

High level may be caused by any of the following:

Level transmitter indicating too low
Level controller set high
Upper isolating valve on the level indicator/
transmitter is closed
Level control valve stuck open
By-pass open around the level control valve
Kick-back liquid flow going to a non-supply
storage tank

6.3.3 RULES FOR EQUIPMENT PERFORMANCE

6.3.3.1 Steam - heated Exchanger H104

Flow rate of steam is equal to the Condensation rate
Condensation rate = Heat transfer rate divided by the latent heat of steam
Heat transfer rate is equal to Heat transfer coefficient multiplied by Heat transfer area multiplied by (steam temperature - Sink temperature)
Steam temperature is raised by the steam condensation pressure

6.3.3.2 Steam - heated Evaporator H103

Sink temperature is raised if the evaporator pressure rises
Evaporation rate is equal to Heat transfer rate divided by the latent heat if evaporation

6.3.3.3 Steam Boiler Q102

Steam pressure rises if the Evaporation rate exceeds the Demand rate
Evaporation rate is directly related to combustion rate
Evaporation rate equals Demand rate at a steady Boiler pressure
Evaporation rate is equal to Heat transfer rate divided by the latent heat of steam
Heat transfer rate is equal to Heat transfer coefficient multiplied by Heat transfer area multiplied by (combustion temperature - steam temperature)

6.4 BTR OPERABILITY STUDY

Description of the BTR Systems for the Operatability Study

The required description of the BTR Systems for the operability study is in function of the inlets and outlets of the main equipments, so that it is possible to interrelate them by the symptom equations. The mentioned inlets and outlets usually correspond to the pipes which come from or go to another equipment.

Also, the relevant controllers are described as well as the controlled and manipulated variables when it was considered necessary.

Finally, in this description is included the operating conditions supplied by the manufacturers.

General Description of the BTR Operability Study

The operability study usually started from the most upstream pipe/s so that it begins at/from the boundaries of the plant or the services, respectively. The operability study is followed down to the furnace or the respective equipment/s. This with the exception of the cooling water system which is a loop. The BTR operability study usually starts with the cause equation of the most upstream pipe of the system and it is followed by other cause equations until it reaches an equipment where symptoms equations are applied. By the nodes of the symptom equations the equipment in question is analysed and also allow to relate the pipes at down and upstream of the equipment. The equipment with symptom equations are the Furnace, Air Cooled Heat Exchanger, Air Preheater, Compressor, Vapourisers, Oil preheater, Boiler and Superheater.

6.4.1 FURNACE SYSTEM

This consists of the test burner H102 and the water-cooled furnace H101. Combustion air for H102 is supplied, with the appropriate preheat, by line CA1004. There is a damper CAV1 at the air inlet to allow the draught to be adjusted in H101. This damper is set manually.

The principal control of furnace draught is by the damper PCV67 in the flue gas discharge to stack. This damper is remotely controlled from the control room and provides open-loop control of either the arch draught or the hearth draught in H101.

Cooling water from line CW1005 splits into separately metered lines CW1005 A/B to enter the coils HE101 A/B. On leaving the top of H101, the water flows combine into line CW1000.

The pilot burner HPB102 in H102 is supplied by compressed natural gas or vaporised LPG via line NG1007. Air for the pilot burner is taken from the compressed air service line via line CA1005 which has an isolating valve NG49.

The test burner H102 can be fired by various fuels as described below.

i) Compressed natural gas or vaporised LPG via line NG1004, entering H102 via four tubes.
ii) Fuel oils via line FT1006 which enter H102 via a central pipe. With heavy fuel oils and special fuels, atomising steam at 21 bar guage is supplied via line HS1001. The steam and liquid fuel are mixed external to H102 and can be shut off separately by valves HS51 and FT46, located at the mixer.

The furnace arch contains an oxygen indicator recorder QIR1-1 and an emissions transmitter, alarm recorder ST5, SA5, SR1-2.

Pilot Burner HPB102. Cause equation

HPB102(81) = NG1007(11) + NG1007(12) + CA1005(11) +
CA1005(13)

Line CA1005. This delivers combustion air from a compressed air service, designated TP506, to the pilot burner HPB102.

CA1005(11) = NG49(0) + TP506(11)

CA1005(13) = NG49(1) + TP506(33)

Test Burner H102 and Furnace H101 Symptom Equations. Nodes are numbered as follows:

N8 main combustion air inlet from line CA1004
N9 pilot gas or LPG inlet from line NG1007
N10 pilot air inlet from line CA1005
N11 main gas or vaporised LPG inlet from line NG1004
N12 atomising steam inlet from line HS1001
N13 liquid fuels inlet from line FT1006
N14 arch location in H101
N15 combustion space in H101
N20 cooling water inlet from line CW1005A to coil HE101A
N21 cooling water inlet from line CW1005B to coil HE101B
N22 outlet from coil HE101A into line CW1000
N23 outlet from coil HE101B into line CW1000

The symptom equations listed below, have been grouped according to the separate systems which serve H101 and H102.

Symptoms caused by Cooling Water System

CW1005A(11) - N14(23) * N15(16) * N20(11) * N22(11) * N22(23)

CW1005B(11) - N14(23) * N15(16) * N21(11) * N23(11) * N23(23)

CW1005A(12) - N14(23) * N20(12) * N22(12) * N22(23)

CW1005B(12) - N14(23) * N21(12) * N23(12) * N23(23)

CW1005A(13) - N14(22) * N20(13) * N22(23) * N22(22)

CW1005B(13) - N14(22) * N21(13) * N23(13) * N23(22)

CW1005A(22) - N14(22) * N20(22) * N22(22)

CW1005B(22) - N14(22) * N20(22) * N22(22)

CW1005A(23) - N14(23) * N20(23) * N22(23)

CW1005B(23) - N14(23) * N21(23) * N23(23)

CW1005A(32) - N14(22) * N22(145)

CW1005B(32) - N14(22) * N23(145)

CW1000(23)- N20(33) * N21(22) * N22(33) * N23(33)

HE101A(72) - N14(23) * N22(22)

HE101B(72) - N14(23) * N23(22)

Symptoms caused by Combustion Air System

CA1004(11) → N8(11) * N14(22) * N14(173) * N15(22) *
N22(22) * N23(22)

CA1004(12) → N8(12) * N14(521) * N15(23)

CA1004(13) → N8(13) * N14(22) * N14(531) * N15(22) *
N22(22) * N23(22)

CA1004(22) → N8(22) * N15(22) * N22(22) * N23(22)

CA1004(23) → N8(23) * N15(23) * N22(23) * N23(23)

CAV1(-1) → N8(32) * N15(32)

QT1(1) → N14(147) * N14(521)

QT1(-1) → N14(531)

Symptoms caused by Gaseous fuels Systems

NG1004(11) → N11(11) * N14(22) * N14(531) * N15(22) *
N22(22) * N23(22)

NG1004(12) → N11(12) * N14(22) * N14(531) * N15(22) *
N22(22) * N23(22)

NG1004(13) → N11(13) * N14(23) * N14(521) * N15(23) *
N22(23) * N23(23)

NG1004(14) → N14(147)

NG1004(142) →N11(142) * N14(147)

NG1004(145) - N11(13) * N14(13) * N14(22) * N14(535) *
N15(22) * N22(22) * N23(22)

NG1004(22) - N11(13) * N14(13) * N14(23)
N14(521) * N15(23) * N22(22) * N23(23)

NG1004(23) - N11(12) * N14(12) * N14(22) * N14(531) *
N15(22) * N22(22) * N23(22)

NG1004(32) - N11(12) * N11(32) * N14(12) * N14(22) *
N14(531) * N15(22) * N22(22) * N23(22)

NG1004(33) - N11(13) * N11(33) * N14(13) * N14(23) *
N14(521) * N15(23) * N22(23) * N23(23)

NG1004(92) - N14(22) * N14(531) * N15(22) * N22(22) * N23(22)

<u>Symptoms caused by Liquid Fuels Systems</u>

FT1006(11) - N13(11) * N14(22) * N14(531) * N15(22) * N22(22) *
N23(22)

FT1006(12) - N13(12) * N14(22) * N14(531) * N15(22) * N22(22) *
N23(22)

FT1006(13) - N13(13) * N14(23) * N14(521) * N15(23) * N22(23) *
N23(23)

FT1006(22) - N13(22) * N14(147) * N14(531) * N15(142) * N15(85)

FT1006(32) - N13(32) * N14(147) * N14(531) * N15(142) * N15(85)

Symptoms caused by Atomising Steam System

HS1001(11) - N12(11) * N14(147) * N14(22) * N14(531) * N15(142)
N15(85) * N22(22) * N23(22)

HS1001(12) - N12(12) * N14(147) * N14(531) * N15(142) * N15(85)

HS1001(13) - N12(13) * N14(13) * N14(22) * N14(535) * N22(22) *
N23(22)

HS1001(146) - N12(146) * N14(22) * N14(535) * N15(22) *
N22(22) * N23(22)

HS1001(32) - N12(32) * N14(147) * N14(531) * N15(142) *
N15(85)

6.4.2 WATER COOLING SYSTEM

The heat released in the test furnace H101 is transferred to cooling coils HE101 through which pressurised water is circulated.

The water is cooled in an air-cooled heat exchanger H108 with three fans HJ108A/B/C. At least two of these fans are switched off automatically if the water temperature is too low. The temperature of water leaving the coils HE108 is monitored, but not controlled. The water circulating pumps J103 A or B are water-cooled.

The system pressure is controlled by nitrogen supply to a pressurising expansion drum B106 which is rated at 21 bar gauge. If the level in B106 is too low, make up water from tank B105 is supplied by pump J105. Tank B105 is fitted with a heater to protect against frost. This ensures a minimum temperature of 5^0C.

Line CW1000. To transfer water at 120,000kg/h from node N22 and N23 at the exits from coil HE101, at a temperature to 195^0C, corresponding to a saturation pressure of 200 psia. Line CW1000 ends at node N24, where it enters the coil HE108 of the air cooled exchanges. Pressure at N24 is quoted as $19kg/cm^2$ (18.62 bar or 270 psi). This pressure corresponds to a saturation temperature of 209^0C.

CW1000(11) = N22(11) * N23(11) + HE108(0)

CW1000(12) = N22(12) + N23(12) + HE108(-1) + CW1000(145)

CW1000(145) = CW1000(23) + CW1000(32)

CW1000(L) = CW17(-1) + CW24(-1) + CW40(-1) + CW41(-1)

CW1000(22) = N22(22) * N23(22)

CW1000(23) = N22(23) + N23(23)

CW1000(32) = N22(32) + N23(32)

CW1000(33) = N24(33)

Line CW1001 To take cooled water from HE108 to the suction of either pump J103 A or B. There is a line filter CWZ15. The following cause equations are for J103 A in service.

CW1001(11) = N25(11) + CWZ15(0) + CW1(0)

CW1001(12) = N25(12) + CWZ15(-1) + CW1(-1)

CW1001(L) = CW25(-1)

CW1001(22) = N25(22) + TC16(-1) + CW1007(22)

CW1001(23) = N25(23) + TC16(1) + HJ108A(-1) +
HJ108B(-1) + HJ108C(-1)

CW1001(32) = N25(32) + CW1007(32)

CW1001(33) = CW1007(33)

When pump J103B is in service the following exchanges are needed:

CW2 for CW1
CW26 for CW25

Cooler H108. To cool water at 120,000kg/h from 195^{0}C using three fans. The water makes two passes through the tubes HE108. The fans HJ108 A/B/C each have manual and automatic control. On the manual setting the fans run continuously; on automatic setting a fan is switched on and off by TC16 in the water outlet line CW1001.

Cause equation

H108(72) = HJ108A(0) + HJ108B(0) + HJ108C(0) +
HE108(72)

Symptom equations

CW1000(11) - N24(11) * N25(11) * N25(22)

CW1000(12) - N24(12) * N25(12) * N25(22)

CW1000(L) - N24(12) * N24(32) * N25(12) * N25(22) *
N25(32)

CW1000(22) - N24(22) * N25(22)

CW1001(33) - N24(33) * N25(33)

H108(72) - N25(23)

HE108(-1) - N24(12) * N24(33) * N25(12) * N25(22)

HW108(L) - N25(12) * N25(22) * N25(32)

Line CW1005. To circulated cooling water back to the coils HE101 in the test furnace. The line splits into CW1005A/B before entering the coils at nodes N20 and N21, respectively. There are two pumps J103A/B; the following cause equations are for J103 A in service.

CW1005(11) = CW1001(11) + J103A(0) + CW3(0)

CW1005(12) = CW1001(12) + J103A(-1) + CW3(-1)

CW1005(L) = J103A(L) + CW43(-1) + CW11(-1)
+ CW44(-1) + CW46(-1)

CW1005(22) = CW1001(22) + J103A(73)

CW1005(23) = CW1001(23) + J103A(72)

CW1005(32) = J103A(-1) + CW3(-1) + CW1005(L) +
CW1007(32)

When pump J103B is in service the following exchanges are required

J103B for J103A
CW4 " CW3
CW42 " CW43
CW23 " CW22
CW21 " CW20

Line CW1005A. To feed coil HE101A at node N20, with cooling water at 60 000 kg/h and 165^{0}C from line CW1005. This line has a flow indicator recorder 11, with a common alarm FA13 which is shared with line CW1005B. The flow transmitter FT11A feed FI11A, FI11A, FI11B and FR2-2

CW1005A(11) = CW1005(11) + CW8(0) + FT11A(0)

CW1005A(12) = CW1005(12) + FT11A(1) + FT11B(1) +
FI11A(1) * FI11B(1) * FR2-2(1) + CW8(-1) +
CW1005(L) + CW1005B(13)

CW1005A(13) = FT11A(-1) + FT11B(-1) + FI11A(-1) *
FI11B(1) * FR2-2(-1)

CW1005A(22) = CW1005(22)

CW1005A(23) = CW1005(23)

CW1005A(32) = CW1005(32) + CW8(-1)

Line CW1005B. To feed cooling water to coil HE101B at node N21 from line CW1005. This is an identical line to CW1005A and the cause equations are formed by the following exchanges.

CW1005	for	CW1005A
CW7	"	CW8
FI12A	"	FI11A
FI12B	"	FI11B
FR2-3	"	FR2-2
FT12A	"	FT11A
FT12B	"	FT11B

Line CW1007. To transfer make-up cooling water to replenish leaks in the closed-circuit which cools H101. The supply comes normally from B106; but when the level in B106 is low and pump J105 is working, the supply will be from an B105 via line CW999.

CW1007(11) = [B106(41) + CW37(O)] * [CW999(11) +
LTL10(O)]

CW1007(12) = CW37(-1) * [CW999(11) + CW999(12)]

CW1007(13) = CW1000(L) + CW1001(L) + HE108(L) +
CW1005(L) + HE101A(L) + HE101B(L)

CW1007(141) = CW999(141)

CW1007(149) = CW1007(13) * B106(41) * CW999(11)

CW1007(171) = CW999(171)

CW1007(22) = B106(22) + CW999(22)

CW1007(32) = B106(32) + CW1007(11) + CW1007(12)

CW1007(33) = B106(33)

CW1007(L) = CW95(-1)

Tank B106. To maintain pressure on the closed cooling water circuit to H101 at 21 bar gauge maximum. Also to allow for expansion of water and supply make-up water to replenish leaks. Tank B106 is pressurised from N_2 cylinders via line CW1008. When the level in B106 is rising, N_2 is dicharged via the pressure relief valve CW18. The level maintained between $\frac{1}{4}$ and $\frac{1}{3}$ by the control system LC10 which switches on and off the motor for pump J105 in line CW999. The level control system has 4 level detecting probes of differing lengths: The longest will trigger the low level alarm LA10B while the shortest triggers LA10A to signal high level. The other two probes, designated LTL10 and LTH10 act through LC10 to switch J105 on and off, respectively.

In the following cause equations leaks of nitrogen from above the water level are distinguished from water leaks, by (L9) and (L6) respectively.

B106(22) = B106(73)

B106(32) = PC70(-1) + PI69(1) * [PI68(1) + PT68(1)] +
CW1008(11) + CW1008(12)

B106(33) = PV70(1) + PCV70(1) + CW18(0) * J105(1) +
PI69(-1) * [PI68(-1) + PT68(-1)]

B106(L6) = CW48(1) * CW49(-1) + CW45(-1) + B106S(L6)

B106(LO) = CW18(-1) + CW12(-1) + CW53(-1) + B106S(L9)

B106(42) = LC10(-1) + LTL10(1) + CW999(16) + B106(L6) +
[CW1007(13) + CW1007(L)] * CW999(12)

B106(43) = LC10(1) + LTH10(-1)

Line CW999. To supply make-up water from tank B105 to the pressurised tank B106 using pump J105. This line contains a NR valve CW31.

CW999(11) = CW24(0) + J105(0) + CW30(0) + CWZ33(0)

CW999(12) = CW24(-1) + CWZ33(-1) + J105(-1) + CW30(-1)

CW999(13) = CW1007(13) + CW1007(L)

CW999(141) = B105(41) * [CW998(12) + CW19(1)]

CW999(16) = CW31(-1) * [J105(0) + LTL10(0)]

CW999(171) = B105(41) * CW998(11)

CW999(22) = B105(22)

CW999(53/10) = CW998(53/10)

<u>Tank B105</u>. This is an atmospheric pressure tank containing treated boiler water as make-up water for the pressurised tank B106, which is supplied via line CW999. There is an immersion heater controlled by TC13 to maintain B105 at 60^0C; this has a low level cut out switch LSW11.

B105(22) = BH105(0) + TC13(-1) + LSW11(-1)

B105(23) = TC13(1) + LSW11(1)

B105(42) = CW999(13) + CW19(1) + CW998(12)

B105(43) = LCV11(1) + CW999(16)

<u>Line CW998</u>. To supply treated water from line WB1001 to tank B105.

CW998(11) = LCV11(0) + CW14(0)

CW998(12) = LCV11(-1) + CW14(-1)

CW998(13) = CW999(13) + CW19(1)

CW998(53/10) = WB1001(53/10)

<u>Line CW1008</u>. To maintain a pressure of 21 bar gauge in tank B106 by supplying N_2 from cylinders when the level in B106 is falling.

CW1008(11) = PCV70(0) + CW50(0) * CW51(0) * CW52(0)

CW1008(12) = PCV70(-1) + CW50(-1) + CW51(-1) + CW52(-1)

CW1008(13) = CW13(-1) + B106(L9) + B106(L6) +
CW1007(13) + CW1007(L)

Note that water in B106 is not replenished from B105 until the level has fallen enough for LTL10 to start pump J105. Thus leakage of water from the system will cause a continual demand for nitrogen.

6.4.3 COMBUSTION AIR SYSTEM

(Drawing No D2)

The air for the test burner can be preheated in an indirectly heated, fired preheater H105. This has been designed to heat 5887Nm^3/h of air from -10 ^{0}C to 400^{0}C by heat exchange with combustion products from a separate combustor, fired by natural gas at 2m bar gauge.

The burners should be supplied with 10% excess air; but there is also a considerable amount of dilution air added to reduce the temperature of the combustion products and increase their mass flow. Thus TIC4, at node N3, controls the combustion product temperature, before the exchanger HE105 at 950^{0}C, by adjusting the amount of dilution air by means of the damper FCV9 in the suction of blower J109.

The temperature of the combustion air to the test burner, which leaves via line CA1004, is controlled by TIC, in the range 100/400^{0}C, by means of adjusting the fuel supply to the burners in H105.

Two burners are supplied from line NG1011 via NG1011A and NG1011B. On low firing, line NG1011B is closed. Two pilot burners are supplied from line NG1009 via lines NG1009A/B, respectively.

Combustion air is supplied by a fan J102 via line CA1001. The flow is measured by either of two transmitters FT8A or FT8B and controlled automatically by adjusting lowers in the suction of J102. The air makes two tube-side passes in HW105 with 130mm water gauge pressure drop.

Line CA1001. To deliver 1200 m^3/h of air with a turndown ratio of 10:1 to the heat exchanger HE105, where it enters at node N5. Delivery pressure from the fan J102 is 35 inches w.g. and the pressure at the main burner is required at 24 inches w.g. The pressure drop of 5 inches w.g. across HE105 leaves 6 inches water gauge for flow control and line pressure drop. Flow control is by lowers FCV8 in the suction of fan J102.

CA1001(11) = FCV8(0) + J102(0) + HE105(0)

CA1001(12) = FCV8(-1) + J102(-1) + HE105(-1) + FI/P8(-1) + FIC8(-1) + FSW8(A) * FT8A(1) + FSW8(B) * FT8B(1)

CA1001(13) = FCV8(1) + FI/P8(1) + FIC8(1) + FSW8(A) * FT8A(-1) + FSW8(B) * FT8B(-1)

CA1001(33) = N4(33) + HE105(-1)

Line CA1002. To supply combustion air, from fan J109, to the burners in H105 to produce combustion products at 950^{0}C at node N3.

CA1002(11) = FCV9(0) + J109(0)

CA1002(12) = FCV9(-1) + J109(-1) + TI4(-1) + TC4(1)

CA1002(13) = FCV9(1) + TI4(1) + TC4(-1)

CA1002(32) = FCV9(-1) + J109(-1)

<u>Line CA1004</u>. To transfer preheated air in the range 100/400^{0}C from node N4 in the exchanger HE105 to the test burner H102. There is a damper CAV1 just before H102.

CA1004(11) = N4(11) + CAV1(0)

CA1004(12) = N4(12) + CAV1(-1)

CA1004(13) = N4(13)

CA1004(22) = N4(22)

CA1004(23) = N4(23)

CA1004(33) = CAV1(-1)

<u>Line NG1011</u>. To supply natural gas at a maximum rate of 187 Nm^{3}/h and 2 bar gauge to the main burners in the indirectly fired air preheater H105. This line is a branch from line NG1003 from the compressor J101 which delivers at 4 bar gauge.

NG1011(11) = NG1003(11) + NG37(0) + NG39(0) +
PCV23(0) + NG40(0) + NGM5(0) +
DEACM1(0) + DEACM(0)

NG1011(12) = NG1003(12) + PT23(1) + PIC23(-1) +
DI/P23(-1) + DSV23(-1) + PCV23(-1) +
PCV23(1) * [NG37(-1) + NG39(-1) + NG40(-1)]
+ NGM5(-1) + DEACM1(-1) + DEACM2(-1)

NG1011(13) = NG1011A(13) + NG1011B(13)

NG1011(L) = NG38(-1) + NG42(-1) + DEACM3(-1)

NG1011(23) = NG1003(23)

```
NG1011(32) = NG1003(32) + PT23(1) + PIC23(-1) +
             DI/P23(-1) + DSV23(-1) + PCV23(-1) +
             PCV23(1) * [NG37(-1) + NG39(-1) + NG40(-1)]
             + NGM5(-1) + DEACM1(-1) + DEACM2(-1)

NG1011(33) = PT23(-1) + PIC23(1) + DI/P23(1) +
             PCV23(1) + NG41(1) * [PC72(1) + PCV72(1)]
```

Line NG1011A. To transfer natural gas from line NG1011 to the bottom burner in H105. This is used as the base-rate burner for low firing. Both burners contribute to increasing firing rate.

```
NG1011A(11) = NG1011(11) + CVM1(0) + NGM1(0)

NG1011A(12) = NG1011(12) + CVM1(-1) + TI5(1) +
              TC5(-1) + TRR5(-1) + CVM1(1) * NGM1(-1)

NG1011A(13) = CVM1(1) + TI5(-1) + TC5(1) + TRR5(1)

NG1011A(32) = NG1011(32) + CVM1(-1) + NGM(-1)

NG1011A(33) = NG1011(33) * CVM1(1)
```

The cause equations for line NG1011B are similar to those for NG1011A, with the following exchanges:

NG1011B for NG1011A

CVM2 " CVM1

NGM2 " NGM1

Line NG1009. To supply natural gas to the pilot burners in H105. The branch lines to the burners are labelled NG1009 A/B. Line NG1009 starts from line NG1003 between B104 and valve NG11.

NG1009(11) = NG1006(11) + NG1002(11) + PCV71(0) +
NG25(0) + Z103(0) + NG34(0) + DEACM6(0)
+ NGM6(0) + PCV21(0) + NGM7(0) +
DEACM4(0) + DEACM5(0)

NG1009(12) = PCV71(-1) + NG25(-1) + Z103(-1) + NG34(-1) +
DEAC6(-1) + NGM6(-1) + PCV21(-1) + NGM7(-1) +
DEACM4(-1) + DEACM5(-1)

NG1009(13) = NG1009A(13) + NG1009B(13)

NG1009(L) = NG26(-1) + Z103(L)

NG1009(23) = B104(23)

NG1009(32) = B104(32) + PC71(-1) + PCV71(-1) + NG25 (-1) +
Z103(-1) + NG34(-1) + DEAC6(-1) + NGM6(-1)
+ PC21(-1) + PCV21(-1) + NGM7(-1) +
DEACM4(-1) + DEACM5(-1)

NG1009(33) = PC21(1) + PCV21(1)

Lines NG1009A/B. To supply premixed natural gas and air to the pilot burners in the air preheater H105. Both burners should be alright during operation of H105. Natural gas comes from line NG1009; air is supplied from the site compressed air supply by line CA1005, which has 3 reducing valves in sevice.

The following equations are for NG1009A which supplies the lower pilot burner in H105.

NG1009A(11) = NG1009(11) + NGM4(0)

NG1009A(12) = NG1009(12) + NGM4(-1)

NG1009A(13) = NG1009(33) * NGM4(1)

NG1009A(531) = NG1009A(12) + NGM9(1) * [CA1005(33) + CA1005(35)]

NG1009A(521) = NG1009A(13) + CA1005(12) + NGM9(-1)

NG1009A(511) = CA1005(11) + NGM9(0)

The cause equations for line NG1009B are formed by the following exchanges:

NG1009B for NG1009A
NGM3 " NGM4
NGM8 " NGM9

Line CA1005. To supply combustion air from the site compressed air supply at terminal point TP1, to the pilot burners in the air preheater H105.

CA1005(11) = TP1(11) + NGM10(0) + NGM11(0) + PCV73(0) + PCV74(0) + PCV75(0)

CA1005(12) = NGM10(-1) + NGM11(-1) + PCV73(-1) + PCV74(-1) + PCV75(-1)

CA1005(15) = CA1005(35)

CA1005(33) = PC75(1) + PCV75(1)

CA1005(35) = PC74(1) + PCV74(1) + PC73(1) + PCV73(1)

Air Preheater H105. Cause equation

H105(81) = NG1009A(11) * NG1009B(11) + CA1005(11) +
NGM8(0) * NGM9(0)

Symptom equations. The nodes on H105 and HE105 are numbered as follows:

N1 where NG1011A enters the lower burner
N2 " NG1011B enters the upper burner
N3 " TIC4 measures the combined combustion products after dilution with excess air.
N4 " CA1004 leaves HE105
N5 " CA 1001 enters HE105
N6 " combustion products enter the flue
(See Drawing No. D2)

CA1001(11) - N4(11) * N5(11) * N6(23)

CA1001(12) - N4(12) * N4(23) * N5(12) * N6(23)

CA1001(13) - N4(13) * N4(22) * N5(13) * N6(22)

CA1002(12) - N3(12) * N3(23) * N4(23) * N6(12)

CA1002(13) - N3(13) * N3(22) * N4(22) * N6(13)

CA1004(11) - N4(11) * N5(11) * N6(23)

CA1004(12) - N4(12) * N4(23) * N5(12) * N6(23)

CA1004(33) - N4(33) * N5(33)

HE105(L) - N4(12) * N6(13) * N6(22)

HE105(-1) - N4(12) * N4(23) * N5(12) * N5(55) * N6(23)

HE105(72) - N4(22) * N6(23)

NG1011A(11) - N1(11) * N3(12) * N4(22) * N6(12) * N6(22)

NG1011A(12) - N1(12) * N3(12) * N4(22) * N6(12) * N6(22)

NG1011A(13) - N1(13) * N3(13) * N4(23) * N6(13) * N6(23)

NG1011B(12) - N2(12) * N3(12) * N4(22) * N6(12)*N6(22)

NG1011B(13) - N2(13) * N3(13) * N4(23) * N6(13) * N6(23)

6.4.4 NATURAL GAS SYSTEM

6.4.4.1 GAS BOARD REDUCER/METER

(Drawing No. D 3A)

This consists of two identical parallel lines NGB 1006 A/B containing reducing valves plus a gas meter with by-pass in NG 1006, to meter the gas used by the boiler, superheater, air preheater and test burner.

Line NGB 1006A. To reduce the pressure of natural gas from 2 bar to 30 m bar in two stages.

NGB1006A (11) = NG 100(0) + PCV 100(0) + PCV 101(0) + NG 102 (0)

NGB 1006A (12) = NG 100(-1) + PCV 100(-1) + PCV 101(-1) + NG 102(-1)

NGB 1006A (13) = NGB 1006 (13)

NGB 1006A (32) = PC 100(-1) + PC 101(-1) + NG 102(-1)

NGB 1006A (33) = PC 101(1) + PCV 101(1)

NGB 1006A (L) = NG 101(-1)

When NGB 1006B is being used to reduce the gas pressure the above cause equations require the following exchanges.

NGB 1006B for	NGB 1006A	PCV 102 for	PCV 100
NG 103	NG 100	PC 102	PC 100
NG 104	NG 101	PCV 103	PCV 101
NG 105	NG 102	PC 103	PC 101

Line NGB 1006. To meter natural gas at 30 m bar into line NG 1006. The gas meter GM 1 is not large enough to cope with the total flow of gas, so the by pass valve NG 108 is open. The following cause equations are for NGB 1006A in service. When NGB 1006B is in service it should replace NGB 1006A in the cause equations.

```
NGB 1006(11) = NGB 1006A(11) + NG 108(0)*[NG106(0) + NG107(0)]

NGB 1006(12) = NGB 1006A(12) + NG 108(-1) + NG 106(-1) +
               GM 1(0) + NG 107(-1)

NGB 1006(13) = NG 1006(13) + NG 1006(L) + NG1001(13) + NG1001(L)

NGB 1006(32) = NGB 1006A(32) + NG 108(-1) + NG 106(-1) +
               GM 1(0) + NG 107(-1)

NGB 1006(33) = NGB 1006A(33)
```

6.4.4.2 COMPRESSOR UNIT

(Drawing No. D 3A)

This consists of a positive displacement compressor J101 which runs continuously. There is a kick-back line NG1015 from the high pressure supply tank B104 to the low pressure suction drum B111. The pressure in B104 controls the kick-back flow in NG1015. Compressed gas is cooled by an air cooler H109 in the line NG1002; in addition, there is a water - cooled jacket JH101 on the compressor J101.

Line NG 1006. To transfer natural gas at 30 m bar (12"wg) from the Gas Corporation's reducing station to the compressor suction from B111, which is designated node N41. The maximum flow rate is specified as 800 sm^3/h at ambient temperature. The off-take line NG1001 to the steam boiler is after valve NG1.

```
NG1006(11) = NGB1006(11) + NG1(0) + NG3(0) + Z104(0) +
             NG4(0) + N41(11) + B111(33)
NG1006(12) = NGB1006(12) + NG1(-1) + NG3(-1) + Z104(-1) +
             NG4(-1) + B111(33)
NG1006(13) = NG1003(13) + NG1003(L) + B111(L) + B112(L) +
             NG1002(L) + H109(L) + B104(L)
NG1006(L) = NG109(1) + Z104(L) + NG5(1) + NG6(1) +
            NG45(1) + NG46(1)
NG1006(141) = [NGB1006(32) + NG1(-1)]* NG1006(L) +
              [NG3(-1) + Z104(-1)]*[NG5(1) + NG6(1) +
              Z104(L) + NG45(1) + NG46(1)] +
              NG4(-1) * [NG45(1) + NG46(1)]
NG1006(32) = NGB1006(32) + NG1(-1) + NG3(-1) + Z104(-1) +
             NG4(-1)
```

NG1006(33) = NGB1006(33) + B111(33)

Line TS 998. To deliver cooling water to the jacket JH101 on the compressor. Cooling water is discharged via line TS1001 which contains only one valve (TS8) which is included in the cause equations for line TS998.

TS998(11) = TS(0) + TS8(0) + TS998(0) + JH101(0)

TS998(12) = TS7(-1) + TS8(-1) + JH101(-1)

Compressor J101. A double acting piston compressor to deliver 800 sm^3|h of natural gas at 4.26 bar (61.8psia) and an adiabatic compression temperature of 400K (260^0F). The inter-stage valve JV101 can be opened by the safety interlock IL4. The electric motor drives the compressor by multiple belts; the drive is designated JD101.

J101(23) = TS998(11) + TS998(12) + JH101(72)
J101(0) - N41(11) * N42(11)
J101(0) = JV101(1) + JD101(0)
J101(1) = JV101(-1) + JD101(-1)

Drum B111. This is the suction drum for the compressor J101. It recieves natural gas at 30 m bar from line NG1006, plus recycle flow from B104 via NG1015. A pressure control valve in NG1015 controls the pressure in B104 by adjusting the kick-back flow rate in NG1015. B111 is fitted with a low pressure switch PSW7 which operates the safety system IL4 if the pressure in B111 is low. These are two pressure relief valves fitted to B111; these are NG110 and NG111. Node N41 is the outlet from B111 to J101.

B111(L) = NG110(-1) + NG111(-1)
B111(32)= NG106(32)

B111(33) = PCV13(1)

B111(23) = NG1015(23)

Drum B112. This is the discharge drum for the compressor J101. It receives natural gas at 4.26 bar and 400K from the compressor J101. Node N42 is the inlet to B112. There is a high temperature switch TSW2 in the discharge line from J101, which actuates the safety system IL4. B112 is fitted with a pressure relief valve NG50.
B112(23) = J101(23) + B111(23)

B112(32) = J101(-1)
B112(33) = NG1002(33)

B112(L) = NG50(-1)

Line NG1002. To transfer natural gas at 800S m^3/h and 4.26 bar to the high pressure supply tank B104. This line contains an air cooled exchanger H109 and a pressure relief valve NG54.
NG1002(11) = J101(-1) + NG7(0) + H109(0)
NG1002(16) = J101(0) + J101(-1)
NG1002(L) = NG8(-1) + NG9(-1) + NG10(-1) + NG54(-1)

NG1002(23) = B112(23) + H109(72)

NG1002(33) = NG7(-1) + H109(-1) + B104(33)

Tank B104. This is the high pressure natural gas supply tank which delivers to line NG1003. The pressure in B104 is controlled by PIC13 which controls the kick-back flow rate in line NG1015, by PCV13. There is a drain containing valves NGD2 and NGD4 in parallel with NGD5; there is a condesate trap NGD3.
B104(L) = NGD5(-1) + NGD3(1)
B104(23) = NG1002(23)

B104(32) = PIC13(-1) + NG1015(13) + NG7(-1) +
H109(-1) + J101(-1)

B104(33) = PIC13(1) + NG1015(11) + NG1015(12)

Line NG1015. This is the kick-back line for the compressor J101, from B104 to B111. It contains the control valve PCV13, a manual valve NG113 and the DEAC10 valve which is closed by the safety system IL4.

NG1015(11) = DEAC10(0) + PCV13(0) + NG113(0)

NG1015(12) = DEAC10(-1) + DSV10(-1) + PCV13(-1) +
NG113(-1)

NG1015(13) = PCV13(1)

NG1015(23) = B104(23)

NG1015(33) = B104(33)

6.4.4.3 PILOT AND MAIN GAS SUPPLY TO THE FURNACE

(Drawing No. D 3B)

The supply of fuel gas to the main (test) burner is via line NG1004 and be pressure or flow rate controlled. Compressed natural gas is supplied from tank B104 to line NG1004 by line NG1003. Vaporised LPG is fed to line NG1004 by line PG1008.

There is provision to admit nitrogen, hydrogen or sour gases to NG1004 via SG1006.

The pilot burner is supplied by line NG1007 which is pressure controlled. When vaporised LPG is used as pilot full, it enters NG1007 via line PG1009 which branches from NG1004.

Line NG1003. To convey natural gas at 4 bar gauge to line NG1004 from the supply tank B104. This line contains filter Z102 and terminates at NG13. This valve allows the air preheater H105 and the pilot burner in the test burner H102 to be supplied with natural gas while the test burner is operating on liquid fuels.

NG1003(11) = NG1006(11) + NG1002(11) + NG11(0) + Z102(0) + NG13(0)

NG1003(12) = NG1006(12) + B104(32)

NG1003(13) = NG1004(13) + DSW2(P) * NG1004(L) + NG1007(13) + NG1007(L) + NG1009(13) + NG1009(L) + NG1011(13) + NG1011(L)

NG1003(L) = Z102(L)

NG1003(23) = B104(23)

NG1003(32) = B104(32) + NG11(-1) + Z102(-1) + NG13(-1)

NG1003(33) = B104(33)

Line NG1004. This line conveys natural gas or vaporised LPG to the main test burner H102. For either fuel, hydrogen, nitrogen or sour contaminants can be added from the mixing drum B101 via line SG1006. The following equations are for natural gas only. The pressure or flow rate of fuel to the burner is controlled by DCV2. Line NG1004 is connected to the burner by a flexible hose NGF1004.

NG1004(11) = NG1003(11) + FT5A(0) + NG14(0) + DCV2(0) + DSV2(1) + DI/P2(0) + DIC2(0) + NG18(0) + DEAC1(0) + DEAC2(0) + NG20(0)

NG1004(12) = NG1003(12) + NG1011(13) + DIC2(-1) + DI/P2(-1) + DSV2(-1) + DCV2(-1) + DCV2(1) *[NG14(-1) + NG18(-1) + DEAC1(-1) + DEAC2(-1) + NG20(-1)] + DSW2(F) *[FTSA(1) + FT5B(1) + FRE5(1) + NG1004(L)] + DSW2(P) * [PT12(1) + DEAC1(-1) + DEAC(-1) + NG20(-1)]

NG1004(13) = DIC2(1) + DI|P2(1) + DCV2(1) + NG19(1) + DSW2(F) *[FT5A(-1) + FT5B(-1) + FRE5(-1)] + DSW2(P) * PT12(-1)

NG1004(14) = NG14(1) * NG16(1) *[SG1(1) * SG18(1) + SG2(1) * SG19(1) + SG3(1) * SG20(1) + SG4(1) * SG21(1) * SG5(1) * SG22(1) + SG6(1) * SG23(1)]

```
NG1004(145) = NG23(-1)

NG1004(91) = SG1006(148) + SG1006(149)

NG1004(L) = NG44(-1) + DEAC3(-1) + NGF1004(L)

NG1004(23) = NG1003(23) + ETH(1)

NG1004(33) = DIC2(1) + DI|P2(1) + DCV2(1) + NG19(1) +
             DSW2(F) *[FT5A(-1) + FT5B(-1) + FRE5(-1)] +
             DSW2(P) * PT12(-1)

NG1004(32) = NG1003(32) + DIC2(-1) + DI/P2(-1) +
             DSV2(-1) + DCV2(-1) + DCV2(1) *[NG14(-1) +
             NG18(-1) + DEAC1(-1) + DEAC2(-1) +
             NG20(-1)] +
             DSW2(F) *[FT5A(1) + FT5B(1) FRE5(1)] +
             DSW2(P) *[PT12(1) + DEAC1(-1) + DEAC2(-1) +
                  NG20(-1)]
```

When line NG1004 is transferring vaporised LPG for line PG 1008 to the burner, the following exchanges are required in the above cause equations:

```
PG1008 replaces NG1008
NG1004(23) = PG1008(23) + TC20(1) + TT20(-1)
NG1004(92) = NG1004(144) + SG1006(148) + SG1006(149)
NG1004(13) = DIC2(1) + DI/P2(1) + DCV2(1) + NG19(1) +
             DSW2(F) *[FT5A(-1) + FT5B(-1) + FRE5(-1) +
                  NG1004(144)] + DSW2(P) * PT12(-1)
```

The following cause equations are additional for LPG fuel:

```
NG1004(142) = PG1008(142) + NG1004(22)

NG1004(144) = NG13(-1)

NG1004(22) = PG1008(22) + TC20(-1) + TT20(1) +
             ETH(0)
```

Line NG 1007. To supply natural gas at 375 m bar gauge to the pilot burner in H102. Natural gas comes from the compressor via NG1003 and branches from line NG1011 before valve NG13. Alternatively, vaporised LPG (with or without contaminants from SG1006) can be supplied from the beginning of line NG1004 via line PG1009.

The following cause equations are for natural gas supply:

NG1007(11) = NG1006(11) + NG1002(11) + NG11(0) + Z102(0) +
NG48(0) + NG57(0) + NG27(0) + NG29(0) +
PCV16(0) + NG31(0) + NG32(0) + DEAC4(0)

NG1007(12) = NG48(-1) + NG57(-1) + NG27(-1) + DEAC4(-1) +
NG29(-1) + PCV16(-1) + PC16(-1) + NG31(-1) +
NG32(-1) + FT6A(1) + FT6(1)

NG1007(13) = PC16(1) + PCV16(1) + NG30(1) + NGF1007(1) +
FT6A(-1) + FT6(-1)

NG1007(143) = N55(-1)

NG1007(23) = NG1003(23)
NG1007(32) = [NG48(-1) + NG57(-1) + NG27(-1) + NG29(-1)] +
PCV16(1) + PCV16(-1) + PC16(-1) + NG31(-1) +
NG32(-1)

NG1007(33) = PC16(1) + PCV16(1) + NG30(1)

When LPG is the fuel to the pilot burner the following changes are required to the above cause equations:

NG1007(11) = PG1008(11) + NG55(0) + NG27(0) + NG29(0) +
PCV16(0) + NG31(0) + NG32(0) + DEAC4(0)

Delete NG48 and BG1007(143)
Replace NG57 with NG55
Replace FT6A with FT6B
Replace NG1003 with PG1008

Add the following cause equations:
NG1007(142) = PG1008(142) + NG1007(22)
NG1007(22) = PG1008(22) + ETH(0)
NG1007(144) = NG48(1) * NG57(1)

6.4.5. LPG FUEL SYSTEM

(Drawings No. D 4A and 4B)

This consists of duplicate, pressurised storage tanks B107 A/B of 5 tonnes capacity, two steam - evaporators which produce LPG vapour at 4 bar gauge (50^0C), which are fed by duplicate pumps J106 A/B. Excess LPG is returned to the supplying tank by the liquid kick-back line PG1004. The pressure in the storage tanks is the saturated vapour pressure of commercial butane at ambient temperature; typically 2.7 barg at 15^0C. Pressure in the tanks can be caused by back pressure from the vaporisers via line PG1005. The storage facility has a water drench system which is controlled by the safety interlock IL8.

Line PG1000. To transfer LPG at ambient temperature and 2 bar gauge to storage tanks B107 A/B. Cause equations for filling B107A are listed below for PG1000, PG1002 and tank B107A. The exchanges required for filling B107B are stated after these 3 sets of cause equations.

PG1000(11) = LP1(-1) + LP2(-1) + LP5(-1) + PG1002(11) + PG1002(12)

PG1000(L) = PG61(-1)

Line PG1002. This is a balance line from B107 A/B back to the road tanker, which ensures equal pressure in the tank being filled and in the tanker.

PG1002(11) = LP9(0) + LP10(0) + LP11(0) + LP60(0)

PG1002(12) = LP9(-1) + LP10(-1) + LP11(-1) + LP60(-1)

Tank B107A. This is a vertical cylindrical vessel, with dished ends, capable of storing 5 tonnes of LPG at ambient conditions. The maximum working pressure is specified as 70 psig (4.75 bar g). All top and bottom connections have internal check valves as well as external valves. There is an internal vertical standpipe, fitted with a 1.4 mm diameter orifice, the top of which is at the 97% capacity level. During filling the external valve LP62 on this stand pipe should be open. In addition there is a sight glass LI2 to indicate the liquid level of LPG; this has top and bottom isolating valves LPIV7 and LPIV8, respectively.

Purging air. Before B107A is put into service the concentration of oxygen must be reduced to less than 9% v/v. This can be achieved by steady purging through LP58 and LP59, or by filling the tank 4 or 5 times to a pressure of 1 bar gauge, with nitrogen.

In listing the causes of leaks from B107A, the shell B107A as well as valves are considered as sources leaks.

B107A(L) = LP18(1) * LP19(1) * [LP20(-1) + LP21(-1)] +
LP62(-1) + LP13A(-1) + LP13B(-1) + LP65(-1) +
LP58(-1) * LP59(1) + B107As(L)

B107A(22) = B107A(32) * PG1000(13)

B107A(23) = PG1004(23)

B107A(32) = B107A(22) * PG1005(32)

B107A(33) = B107A(23) + PG1005(33)

B107A(41) = LPIV8(0)

B107A(43) = LP62(0) + LPIV7(0) + LPIV8(0) +
LP43(1) * LP25(0)

B107A(531) = B107A(65) + B107A(32) * LP62(-1)

The cause equations for filling, or delivering from, B107B are formulated from the above equations for PG1000, PG1002 and B107A by the following exchanges:

B107B	for	B107A	LP23	for	LP25
LP3	"	LP5	LP56	"	LP59
LP7	"	LP9	LP57	"	LP58
LP8	"	LP10	LP63	"	LP62
LP12A	"	LP13A	LP64	"	LP65
LP12B	"	LP13B	LPIV9	"	LPIV7
LP14	"	LP18	LPIV10	"	LPIV8
LP15	"	LP19	B107Bs	"	B107As
LP16	"	LP20	LP41	"	LP43
LP17	"	LP21			

Line PG1001. To transfer liquid LPG from either B107A or B107B to the evaporators H103A and/or H103B, using either pump J106A or pump J106B.

LPG flow in excess of the evaporation rate is returned to the supply tank via line PG1004. The pressure controller PCV50 in PG1004 sets the pressure at the end of line PG1001. The line PG1001 branches into lines PG1003A/B which supply LPG at an appropriate rate to maintain the liquid levels in the evaporators.

The following cause equations are for J106A supplying LPG from B107A.

PG1001(11) = B107A(41) + LP24(0) + LP25(0) + LP27(0) +
LP28(0) + J106A(0) + LP32(0)

PG1001(12) = LP24(-1) + LP25(-1) + LP27(-1) + LP28(-1) +
J106A(-1) + LP32(-1)

PG1001(13) = PG1004(13) + PG1003A(13) + PG1003B(13) +
PG1004(L)

PG1001(143) = [LP24(-1) + LP25(-1) LP27(-1) + LP28(-1)]*
[B107A(32) + B107A(23)]

J106A(-1) = PG1001(143)

J106A(23) = PG1004(11) * PG1003A(11) * PG1003B(11)

PG1001(33) = PG1004(33)

PG1001(L) = LP26(-1) + LP52(-1) + J106A(L) + LP35(-1) +
LP66(-1) + J106B(L) * [LP29(-1) + LP34(-1)]

When J106B is pumping LPG in place of J106A the following exchanges are to be made in the cause equations:

J106B for J106A
LP29 " LP27
LP30 " LP28

LP34 for LP32
LP53 " LP52

When B107B is the supply tank the exchanges are:
B107B for B107A
LP22 " LP24
LP23 " LP25

<u>Line PG1004.</u> To return excess LPG to the storage tank from which the feed pump J106A or J106B takes suction. PC50 controls the pressure up stream of PCV50 at 4 bar gauge. The pressure in the storage tank is the vapour pressure of Commercial butane at the ambient temperature. But if this is low, the pressure should be maintained by PCV51 in the vapour balance line PG1005 from the evaporators. The following cause equations are for B107A as the supply tank.

PG1004(11) = LP36(0) + PCV50(0) + LP37(0) + LP43(0) +
PG1001(11)

PG1004(13) = LP38(1) + PCV50(1) + PC50(-1) + PG1003A(16) +
PG1003B(16)

PG1004(L) = LP39(-1) + LP40(-1)

PG1004(23) = PG1003A(16) + PG1003B(16)

PG1004(32) = PC50(-1) + LP38(1) + PCV50(1)

PG1004(33) = PC50(1) + PCV50(-1) + PCV50(1) + [LP36(-1) +
LP37(-1) + B107A(33) + LP43(-1)]

When B107B is the supply tank the following exchanges are required to the above cause equations:
B107B for B107A
LP41 for LP43

Evaporator H103A. To produce commercial butane gas from LPG at a saturation temperature of 50^0C at 4 bar gauge. Liquid feed rate via PG1003A is controlled by level controller LTC5. Vaporised LPG leaves via PG1008A.

Steam condenses in the tubes HE103A at 7 bar gauge corresponding to 165^0C. Condensate in drained from the steam header into a vent chamber B108 via line LS1005, from which it removed by a steam eductor J108. Steam is supplied from a medium pressure main LS999 via line LS1000.

The nodes on H103A are numbered as follows:
N47 where PG1003A enters H103A
N48 " PG1008A leaves H103A
N49 " LS1001 enters HE103A
N50 " LS1005 leaves HE103A
(See Drawing No. D 4B)

(Drawing No. D 4B)

Line PG1003A. To supply LPG to H103A at the rate required to maintain a fixed level in the shell.

PG1003A(11) = PG1001(11) + LT5(1) + LC5(-1) + LV3(0) +
LCV5(0) + LV4(0) + LVZ32(0)

PG1003A(12) = PG1001(12) + PG1004(13) + LCV5(-1) +
LCV5(1) * [LV3(-1) + LV4(-1) + LVZ32(-1)]

PG1003A(13) = LV31(-1) + LV33(-1) + N47(13)

PG1003A(16) = PG1004(32) * N48(33)

Evaporator H103A Cause Equations

H103A(L) = LV25(-1) + LV29A/D(-1) + H103AS(L) +
LV47(1) * [LV50(-1) + LV49(-1)] + LV27(-1)

H103A(42) = PG1003A(11) + PG1003A(12) + LV2(0) +
PG1003A(16)

H103A(43) = LV9(1) + LCV5(1) + LT5(-1) + LC5(1) +
LV1(0)

H103A(436) = HE103A(L)

Line LS999. To supply medium pressure site steam from the terminal point TP100 to the LPG evaporators, the tank heaters in the heavy fuel oil tanks and to purge the test burner.

LS999(11) = TP100(11) + LS2(0) + LS3(0)

LS999(12) = LS3(-1)

LS999(13) = LS1000(13) + LS1007(13) + LS1008(13)

Line LS1000. To supply site steam from line LS999 to the LPG evaporators.

LS1000(11) = LS999(11) + LS24(0)

LS1000(12) = LS999(12) + LS24(-1)

LS1000(13) = LS1001(13) + LS1002(13) + LS1003(13) +
LV39(1) * [LV7(1) + LV17(1)]

Line LS1001. To supply steam to the tubes of HE103A at a pressure required to maintain the temperature in the shell of H103A at 50^{0}C at an LPG evaporation rate equal to the demand rate.

LS1001(11) = LS1000(11) + LV5(0) + LVZ37(0) + PRV2(0) +
TCV7(0) + LV6(0) + HE103A(0)

LS1001(12) = LS1000(12) + TCV7(-1) + TCV7(1) *
[LV5(-1) + LVZ37(-1) + PRV2(-1) + LV6(-1)]

LS1001(13) = N49(13) + LV46(1)

LS1001(32) = TC7(-1) + PRV2(-1)

LS1001(33) = TC7(1) + TCV7(1) + LV39(1) * LV8(1)

Line LS1005. To transfer steam condensate from node N50 on the header of HE103A to the vent chamber B108.

LS1005(11) = N50(11) + LV7(0) + LV40(0) + LVZ41(0) + LVT42(0)

LS1005(12) = N50(12) + LV7(-1) + LV40(-1) + LVZ41(-1)

LS1005(13) = N50(13)

LS1005(145) = LVT42(1)

LS1005(143) = HE103A(L) * N49(32)

LS1005(22) = N50(22)

LS1005(23) = N50(23)

Line LS1003. To supply medium pressure steam from line LS1000 to the condensate eductor pump J108. Condensate from the line is discharged to B108 via the steam trap LVT45.

LS1003(11) = LS1000(11) + LV43(0) + LVZ44(0) + J108(0)

LS1003(12) = LS1000(12) + LV43(-1) + LVZ44(-1)

LS1003(13) = LVT45(1)

J108(-1) = LS1003(12)

Line LS1004. To empty the condensate collector B108 to drain. This line contains the eductor J108.

LS1004(12) = J108(-1)

Tank B108. To collect steam condensate from the evaporator coils HE103 A/B and from line LS1003.

B108(143) = LS1005(143)

B108(145) = LVT42(1) + LVT45(1)

B108(43) = LS1008(13) + LS1004(12)

Evaporator H103A. Symptom Equations

LS1001(11) - N49(11) * N50(11) * N48(11)

LS1001(12) - N49(12) * N49(32) * N50(12) * N50(22) * N48(12)

LS1001(32) - N49(32) * N50(22) * N48(22) * N48(32)

LS1001(33) - N49(33) * N50(23) * N48(23) + N48(33)

LS1005(11) - N49(11) * N50(11) * N48(11)

LS1005(143) - N47(13) * N49(32) * N50(22)

LS1005(145) - N50(13) * N49(13)

PG1005(13) - N48(13) * N47(13) * N49(13) * N49(33) *
N50(13) * N50(23)

PG1008A(13) - N48(13) * N47(13) * N49(13) * N49(33) *
N50(13) * N50(23)

PG1008A(142) - N47(13)

H103A(L) - N47(13) * N49(13) * N50(13)

H103A(42) - N48(12) * N47(12) * N49(12) * N50(12)

H103A(436) - N47(12) * N48(12) * N49(33) * N50(23)

HE103A(72) - N49(33) * N50(23)

HE103A(L) - N49(33) * N50(23)

B108(43) - N50(15) * N50(25) * N49(35) * N48(25) *
N48(35)

Line PG1008A. To transfer commercial butane from the vapour separator in H103A to line PG1008 and PG1005.

PG1008A(11) = N48(11) + LV19(0) + H103A(41) + H103A(476)
PG1008A(12) = N48(12) + LV19(-1)

PG1008A(13) = PG1008(13) + PG1008(L)

PG1008A(142) = H103A(43)

PG1008A(22) = N48(22)

PG1008A(23) = N48(23)

PG1008A(32) = N48(32) + LV19(-1)

PG1008A(33) = N48(33)

PG1008A(35) = N48(35)

Evaporator H103B. This is identical to H103A. The following exchanges in the cause and sympton equations are required when H103B is operating in place of H103A.

H103B	for	H103A	LV18	for	LV9
HE103B	"	HE103B	LV20	"	LV19
PG1003B	"	PG1003A	LV26	"	LV25
PG1008B	"	PG1008A	LV28	"	LV27
LS1002	"	LS1001	LV34	"	LV31
N51	"	N47	LV36	"	LV33
N52	"	N48	LV30A/D	"	LV29A/D
N53	"	N49	LV48	"	LV47
N54	"	N50	LCV4	"	LCV5
LV10	"	LV1	LVZ35	"	LVZ32
LV11	"	LV2	LVZ38	"	LVZ37
LV12	"	LV3	LT4	"	LT5
LV13	"	LV4	LTC4	"	LTC5
LV14	"	LV5	TC6	"	TC7
LV15	"	LV9	TCV6	"	TCV7
LV16	"	LV7	PRV1	"	PRV2
LV17	"	LV8			

Line PG1005. To supply commercial butane to the LPG supply tank, to replace the volume of liquid evaporated, if the vapour pressure at ambient temperature is less than 2 bar gauge. The pressure is regulated by PC51 which sets the pressure downstream of PCV51.

The following cause equations are for B107A as the supply tank.

PG1005(11) = PG1008A(11) * PG1008B(11) + LP45(0) +
PCV51(0) + LP46(0) + PG1005(0) +
LP49(0) + LP51(0)

PG1005(12) = PCV51(-1) + PC51(-1) + PG1005(-1) +
PCV51(1) * LP45(-1) + LP46(-1) + LP49(-1) +
LP51(-1)

PG1005(13) = PG1001(13) + PG1004(12) + B107A(L)

PG1005(142) = PG1008A(142) + PG1008B(142)

PG1005(21) = PG1005(142)

PG1005(22) = PG1008A(22) + PG1008B(22)

PG1005(23) = PG1008A(23) + PG1008B(23)

PG1005(32) = PG1008A(32) * PG1008B(32) + PC51(-1) +
PCV51(-1) + LP46(-1) + PCV51(1) * LP45(-1)

PG1005(33) = LP47(-1) + PC51(1) + PCV51(1)

When B107B is the supply tank the following exchanges are required to the above cause equations:

LP48 for LP49

LP50 for LP51

Line PG1008. To supply commercial butane at 3 bar gauge to line NG1004 which supplies the main burner and/or to line NG1007 which supplies the pilot burner. Line PG1008 has two pressure regulators in parallel PCV38 and PCV39. It is electrically traced (ETH) with controller TC18 downstream of the pressure regulators. The following equations are for one or both of the evaporators H103A/B working and PCV38 controlling.

```
PG1008(11) = PG1008A(11) * PG1008B(11) + LP55(0) +
             LV21(0) + LV22(0) + PCV38(0)

PG1008(12) = PG1008(12) + PG1008B(12) + LP55(-1) +
             LV22(-1) + PCV38(-1) + PC38(-1) +
             PCV38(1) * LV21(-1)

PG1008(13) = NG1004(13) + NG1004(L) * DSW2(P) +
             NG1007(13) + NG1007(L)

PG1008(142) = PG1008A(142) + PG1008B(142) +
              PG1008(22)

PG1008(22) = PG1008A(22) + PG1008B(22) + TC18(-1) +
             ETH(0)

PG1008(23) = PG1008A(23) + PG1008B(23) + TC18(1)

PG1008(32) = PG1008A(32) + PG1008B(32) + LP55(-1) +
             LV22(-1) + PC38(-1) + PCV38(-1) +
             PCV38(1) * LV21(-1)

PG1008(33) = PC38(1) + PCV38(1)

PG1008(35) = PG1008A(35) + PG1008B(35)
```

When PCV39 is controlling pressure the following exchange are required in the above cause equations.

LV23 for LV21   PC39 for PC38

LV24 for LV22   PCV39 for PCV38

Cause Equations for both Evaporators H103A/B operating simultaneously

The cause equations for H103A and H103B are to be used together with the following replacements.

```
PG1003A(12) = PG1001(12) + PG1004(13) + LCV5(-1) +
              LCV5(1) * [LV12(-1) + LV13(-1) + LVZ35(-1)] +
              PG1003A(13)

PG1003A(16) = N48(33) * [PG1004(32) + N52(32) * LV19(-1)]

PG1003(16) = N52(33) * [PG1004(32) + N48(32) * LV20(-1)]

H103A(32) = N48(32) * N52(32)

H103B(32) = N48(32) * N52(32)

H103A(33) = N48(33) + N52(33)

H103B(33) = N48(33) + N52(33)
```

6.4.6 FUEL OIL SYSTEM

(Drawings No. D 5A and 5B)

This consists of two steam-heated tanks B102A/B capable of storing 6000 gallons of heavy fuel oil and one 3000 gallons tank B103 for gas oil. In addition special liquid fuels can be delivered directly from a road tanker. There is a ring main with duplicate rotary, positive displacement pumps and a steam heated preheater for heavy fuel oil. Supply of fuel oil to the test burner H102 in the furnace H101 is controlled by adjusting the by-pass flow in the ring main. Additionally, the fuel supply is metered by a turbine meter.

Line FT1000. This is an 80 mm diameter, steam traced, line from road tankers to the upper side of the heavy fuel oil storaged tank B102A which is splash filled. The steam tracing is designated STFT1000 which is supplied by site steam.

FT1000(11) = FT2(0) + FT1000(0)

FT1000(12) = FT2(-1) + FT1000(22) + FT35(-1)

FT1000(22) = STFT1000(0)

Line FT1001. This is the filling line for the heavy fuel storage tank B102B.

FT1001(11) = FT3(0) + FT1001(0)

FT1001(12) = FT3(-1) + FT1001(22) + FT36(-1)

FT1001(22) = STFT1001(0)

<u>Line LS1007</u>. This is a site steam line from LS999 to the heating coil HE112A in the heavy fuel oil tank B102A.

LS1007(11) = LS999(11) + LS25(0) + LS4(0) + LSZ5(0) + TCV9(0) + LS7(0)

LS1007(12) = LS999(12) + LS25(-1) + TCV9(1) * [LS4(-1) + LSZ5(-1) + LS7(-1)] + TCV9(-1)

LS1007(13) = B102A(22) + HE112A(L) + LS1009(145)

LS1007(32) = TC9(-1) + TT9(1)

LS1007(33) = TC9(1) + TT9(-1) + B102A(42) + TCV9(1) + LS12(1)

<u>Line LS1008</u>. This conveys site steam to the heating coil HE112B in tank B102B. It is similar to line LS1007 with similar cause equations formed by the following exchanges:

LS1008	for	LS1007	B102B	"	B102A
LS8	"	LS4	HE112B	"	B112A
LSZ9	"	LSZ5	LS1010	"	LS1009
LS11	"	LS7			
LS13	"	LS12			
TCV11	"	TCV9			
TC11	"	TC9			
TT11	"	TT9			

<u>Line LS1009</u>. To discharge steam condensate, from tank B102A heater, to drain. This line joins LS1010 before going to drain.

LS1009(11) = LS1007(11) + LS14(0) + LST15(0)+LS16(0)

LS1009(12) = LS14(-1) + LST15(-1) + LS16(-1)

LS1009(13) = B102A(22)

LS1009(145) = LST15(1) + LS17(-1)

LS1009(22) = LS1007(32)

LS1009(23) = LS1007(33)

Line LS1010. This line discharges steam condensate, from tank B102B heater, to drain. The cause equations are similar to line LS1009 with the following exchanged:

LS1010	for	LS1009	LST19	for	LST15
LS1008	"	LS1007	LS21	"	LS17
LS18	"	LS14	B102B	"	B102A
LS20	"	LS16			

Tank B102A. This is a vertical cylindrical storage tank with flat bottom and domed fixed roof, fitted with a vent and cap(FT35). The tank is lagged and heated by internal finned coils HE112A. There are two temperature indicators T18 the top and T19 about $\frac{1}{3}$ up, which is used for temperature Control. The tank has a drain valve FT33. Level indicator L16 is connected to the bottom of B102A only. The high pressure relief line FT1016 from FT1012 returns to whichever tank is supplying heavy fuel oil via a lockable 3-way valve FT9.

B102A(22) = LS1007(11) + LS1007(12) + LS1007(32) +
HE112A(72) + LS1009(11) + LS1009(12)

B102A(23) = LS1007(33) + FT32(1) * FT9(A)

B102A(32) = FT35(-1) * FT1002(13)

B102A(33) = FT35(-1) * FT1000(13) + B102A(436) * B102A(23)

B102A(L) = FT33(-1) + B102AS(L)

B102A(42) = L16(1) + B102A(L)

B102A(43) = LI6(-1) + FT32(1) * FT9(A) * FT5(0)

B102A(436) = FT33(0) + HE112A(L)

Tank B102B. This is the duplicate storage tank similar to B102A. The cause equations are similar with the following exchanges:

B102B	for	B102A	L17	for	L16
B102BS	"	B102AS	FT7	"	FT5
HE112B	"	HE112A	FT9(B)	"	FT9(A)
FT1001	"	FT1000	FT34	"	FT33
LS1008	"	LS1007	FT36	"	FT35
LS1010	"	LS1009	T110	"	T18
			TI11	"	T19

Line F1001. This is an 80 mm diameter line which transfers gas oil from road tankers to tank B103. This line is not steam traced.

F1001(11) = F2(0) + F1001(0)

F1001(12) = F2(-1) + F1001(-1) + F6(-1)

F1001(0) = F1001(17)

Tank B103. This is an unheated vertical cylindrical storage tank for gas oil. It has a flat bottom with drain valve F5 and a level gauge LT8 connected near the bottom.

B103(L) = F5(-1) + B103S(L)

B103(32) = F6(-1) * F1002(13)

B103(33) = F6(-1) * F1001(13)

B103(41) = LI8(1)

B103(42) = LI8(1) + B103(L)

B103(43) = LI8(-1)

Line SF1000. This is an 80 mm diameter, steam traced, line for transferring special fuels from road tankers (SFT) to the liquid fuels supply line FT1002 which it enters just up stream of the twin bowl oil filter Z101.

SF1000(11) = SF2(0) + SF3(0) + SFT(41) + SF1000(0)

SF1000(12) = SF2(-1) + SF3(-1) + SF1000(22)

SF1000(22) = STSF1000(0)

SF1000(23) = SFT(23)

Line F1002. This unheated line transfers gas oil from tank B103 to the filter Z101. It joins line FT1002 just after the non-return valve FT6.

F1002(11) = B103(41) + F3(0)

F1002(12) = F3(-1)

F1002(13) = FT1006(13) + FT1006(L) + FT1005(L) +
Z101(L) + FT1012(L)

<u>Line FT1002.</u> This unheated line conveys heavy fuel oil from B102A to the twin bowl filters Z101.

FT1002(11) = B102A(41) + FT5(0) + FT1002(0)

FT1002(12) = FT5(-1) + FT1002(22)

FT1002(13) = FT1006(13) + FT1006(L) + FT1005(L) +
Z101(L) + FT1012(L) + H104(L)

FT1002(146) = B102A(436)

FT1002(22) = B102A(22)

FT1002(23) = B102A(23)

<u>Line FT1003</u>. To convey heavy fuel oil from tank B102B to the twin bowl filters Z101.

FT1003(11) = B102B(41) + FT7(0) + FT1003(0)

FT1003(12) = FT7(-1) + FT1003(22)

FT1003(13) = FT1006(13) + FT1006(L) + FT1005(L) +
Z101(L) + FT1012(L) + H104(L)

FT1003(146) = B102B(436)

FT1003(12) = B102B(22)

FT1003(23) = B102B(23)

Line FT1005. This is a 50 mm diameter, steam-heated line which transfers liquid fuels from the bowl filters Z101 to the oil preheater H104. When gas oil is being burnt H104 is isolated by closing valves FT18 and FT19: then FT1005 delivers directly to line FT1012 by opening valve FT20. Line FT1005 contains duplicate positive displacement pumps J107A/B. The following cause equations are for heavy fuel oil being supplied from tank B102A via line FT1002 and for J107A pumping.

FT1005(11) = FT1002(11) + FT12(0) + J107A(0) + FT15(0) +
FT18(0) + Z101(0)

FT1005(12) = FT1002(12) + Z101(-1) + FT12(-1) + J107A(-1) +
FT46(-1) + FT15(-1) + FT18(-1)

FT1005(146) = FT1002(146)

FT1005(L) = J10LA(L)

FT1005(22) = FT1002(22) + FT1014(22) + STFT1005(0)

FT1005(32) = FT46(-1) + FT15(-1) + FT18(-1) + H104(-1)

FT1005(33) = FT1012(33) + FT31(0)

When B102B is supplying heavy fuel oil exchange FT1003 for FT1002. For special fuels exchange SF1000 for FT1002. The cause equations for J107B pumping are as above with the following exchanges:

J107B for J107A

FT13 " FT12

FT17 " FT15

FT47 " FT46

PI54 " PI53

When FT1005 is being supplied with gas oil from tank B103 the above cause equations are modified to allow for the preheater H104 being isolated and valve FT20 being open.

FT1005(11) = FT1001(11) + FT12(0) + J107A(0) + FT20(0) + Z101(0)

FT1005(12) = F1001(12) + Z101(-1) + FT12(-1) + J107A(-1) + FT46(-1) + FT20(-1) + FT1005(-1)

FT1005(L) = J107A(L)

FT1005(-1) = F1005(14)

FT1005(23) = STFT1005(1) + STFT1014(1) + H104(73)

FT1005(32) = FT46(-1) + FT15(-1) + FT20(-1)

FT1005(33) = FT1012(33) + FT31(0)

Line HS1007. To supply saturated steam at 21 bar gauge, from the packaged boiler H109, to the tubes HE104 in the oil preheater. The steam pressure is controlled by the outlet temperature of heavy fuel oil or special fuels in line FT1012 through TRC12. The hand switch PSW12 allows the viscosity controller XC3 in line FT1005 to reset the set point of TRC12 automatically. Line HS1007 starts from node NGO at the outlet of the steam separator HS109.

HS1007(11) = N60(11) + HS25(0) + HS11(0) + TCV12(0) + HS12(0)

HS1007(12) = N60(12)

HS1007(13) = FT1005(13) + FT1005(12)

HS1007(146) = N60(146)

HS1007(L) = HS40(-1)

HS1007(32) = N60(32) + HS25(-1) + HS11(-1) + TCV12(-1) +
HS12(-1) + PSW12(T) * TIC12(-1) +
TI/P12(-1) + TT12(1) + PSW12(X) * XC3(1)

HS1007(33) = TCV12(1) + HS13(1) + PSW12(T) * TIC12(1) +
TI/P12(1) + TT12(-1) + PSW12(X) * XC3(-1)

Line HS1008. To transfer steam condensate from the tubes of the oil preheater H104 to the drain.

HS1008(11) = HS14(0) + HST17(0) + HS15(0)

HS1008(12) = HS14(-1) + HST17(-1) + HS15(-1)

HS1008(145) = HST17(1) + HS16(1)

HS1008(13) = N70(13)

Oil preheater H104. This is a coil in shell exchanger designed to preheat 3500 lb/h of fuel from 117^0C to 150^0C at 13 bar gauge, using steam condensing at 15 bar gauge and 198^0C. The oil passes through the shell, entering at N67 and leaving at N68. The steam condenses in the tubes HE104, entering at N69 and leaving at N70.

FT1005(11) - N67(11) * N68(11) * N70(11) * N69(11)

FT1005(12) - N67(12) * N68(12) * N69(12) * N70(12)

FT1005(146) - N68(146)

FT1005(22) - N67(22) * N69(13) * N70(13)

FT1005(23) - N67(23) * N69(12) * N70(12)

FT1005(32) - N67(32) * N68(32)

HS1007(11) - N68(22) * N69(11) * N70(11)

HS1007(12) - N68(22) * N69(12) * N70(12)

HS1007(146) - N68(22) * N69(33) * N70(13) * N70(23)

HS1007(32) - N68(22) * N69(12) * N69(32) * N70(12) * N70(22)

HS1007(33) - N68(23) * N69(13) * N69(33) * N70(13) * N70(23)

HS1008(11) - N68(22) * N69(33) * N69(11) * N70(11)

HS1008(12) - N68(22) * N69(12) * N69(33) * N70(12)*N70(23)

HS1008(145) - N69(13)

HE104(L) - N68(146)

HE104(72) - N69(33) * N70(23)

HE104(0) - N68(22) * N69(11) * N69(33) * N70(11)

H104(436) - N68(146) * N69(33) * N70(23)

H104(436) = FT1005(146) + HE104(L)

Line FT1012. To transfer fuel oils to line FT1006. When heavy fuel oil is being burnt the oil preheater H104 is used and there is a pressure relief valve FT32 to protect the shell. This valve is in line FT1016 which is connected to whichever storage tank B102A/B is supplying fuel. The switching is arranged by the lockable 3-way valve FT9. There is a by-pass flow via line FT1015 which is adjusted by valve FT31; this ensures that the pump J107A/B does not pump against a closed valve if the flow control value DCV4 in line FT1014 closes.

The following cause equations are for heavy fuel oil or special fuels being burnt. Under their circumstances FT1012 starts at node N68 on the oil preheater.

FT1012(11) = N68(11) + FT19(0) + DEAC5(0)

FT1012(12) = N68(12) + FT32(-1) + FT19(-1) + FT31(1) + DEAC5(-1)

FT1012(L) = FT22(-1)

FT1012(145) = N68(146) * [FT1012(32) + FT1012(23)] +
H104(436) * N70(23)

FT1012(22) = N68(22) + FT20(1) + STFT1012(0)

FT1012(23) = N68(23)

FT1012(32) = FT1005(32) + FT31(1) + FT19(-1) + DEAC5(-1)

FT1012(33) = FT1014(33)

FT32(1) = FT1012(33) + FT19(-1) DEAC5(0) * FT31(-1)

When gas oil is being burnt the following equations are applicable;

FT102(11) = FT1005(11) + DEAC5(0)

FT1012(12) = FT1005(12) + DEAC5(-1)

FT1012(L) = FT22(-1)

FT1012(23) = FT1005(23) + STFT1012(1)

FT1012(22) = FT1005(22)

FT1012(32) = FT1005(32) + FT31(1) + DEAC5(-1)

FT1012(33) = FT1014(33)

Line FT1014. This is the fuel oil return line which contains the control valve DCV5 which fixes the pressure or flow in the fuel oil line FT1006 to the burner.

FT1014(11) = FT1012(11) + FT28(0) + DCV4(0) + FT29(0)

FT1014(12) = FT1012(12) + DIC4(1) + DI/P(1) + DCV4(-1) +
DCV4(1) * [FT28(-1) + FT29(-1)] + DSW4(P)* PT60(-1) +
DSW4(F) * [FT10A(-1) + FT10B(-1)]

FT1014(13) = DIC4(-1) + DI/P(-1) + DSV4(-1) + DCV4(1) +
FT30(1) + DSW4(P) * PT60(1) +
DSW4(F) * [FT10A(1) + FT10B(1)]

FT1014(22) = FT1012(22) + STFT1014(0)

FT1014(23) = FT1012(23)

FT1014(32) = FT1012(32) + DIC4(-1) + DI/P4(-1) + DSV4(-1) +
DCV4(1) + FT30(1) + DSW4(P) * PT60(1) +
DSW4(F) * [FT10A(1) + FT10B(1)]

FT1014(33) = DIC4(1) + DI/P4(1) + DCV4(-1) +
DCV4(1) * [FT28(-1) + FT29(-1)] + DSW4(P) * PT60(-1) +
DSW4(F) * [FT10A(-1) + FT10B(-1)]

Line FT1006. To transfer fuel oils to the test burner H102. The flow or pressure in this line is adjusted by a control valve DCV4 in line FT1014 which recycles from line FT1012 back to line FT1005. The following cause equations for flow deviations are common to all fuels:

FT1006(11) = FT1012(11) + FT10A(0) + FT23(0) + FT35(0) +
FTZ40(0) + FT41(0) + FT42(0)

```
FT1006(12) = FT1012(12) + FT1014(13) + [DCV4(0) + DSW4(P)] *
             [FT23(-1) + FTZ40(-1) + FT41(-1) + FM40(0) +
             FT42(-1) + DSW4(F) * FT44(1) * FT45(1) +
             FT1006(145)

FT1006(13) = DIC4(1) + DI/P4(1) + DCV4(-1) + DCV4(1) *
             [FT28(-1) + FT29(-1)] + DSW4(P) * PT60(-1) +
             DSW4(F) * [FT10A(-1) + FT10B8-1)]

FT1006(145) = FT1012(145) + LS22(-1)
```

When heavy fuel oils or special fuels are being burnt the following cause equations for temperature apply:

```
FT1006(22) = FT1012(22) + STFT1006(0)

FT1006(23) = FT1012(23)
```

When gas oil is being burnt delete FT1006(22) and substitute
FT1006(23) = FT1012(23) + STFT1006(1)

The following cause equations for pressure are common to all fuels:

```
FT1006(32) = FT1014(32) + DSW4(P) * [FT23(-1) + FTZ40(-1) +
             FT41(-1) + FM400(0) + FT42(-1)]

FT1006(33) = FT1014(33)
```

6.4.7 ATOMISING STEAM

(Drawings Nos. D 6A and 6B)

This system produces saturated steam at 21 bar gauge and superheated steam at 265°C and 21 bar gauge. It contains duplicate resin-type water softeners B201A/B, dosing tank B202 and boiler feedwater tanks B203 and B204. The boiler H109 contains no steam drum; but an excess flow-rate of boiler feedwater of about 200lb/h is continuously separated in HS109 and returned to the tank B204. The supply rate of natural gas fuel to H109 is directly related to the water feedrate, which is controlled by the steam pressure in the separator HS109.

The superheater H110 is fed by natural gas also. It contains one burner only, which is turned down to 10% when the steam superheat temperature is attained. Surplus superheated steam is admitted to the site steam main. The boiler and superheater are used only when burning heavy fuel oil or special fuels.

Line WB1000. To supply boiler feed water at a maximum rate of 12 Imperial gallons per minute to the separate lines WB1000A/B which feed the water softener resin cylinders B201A/B. The specification for the raw water is 300 ppm total carbonates plus 420 ppm total dissolved solids at a pH of 7.8. The terminal point of supply is numbered TP200,

WB1000(11) = TP200(11) + WB1(0)

WB1000(12) = TP200(12) + WB(-1)

WB1000(13) = WB1000A(13) + B201A(L) + WB1000B(13) + B201B(L)

<u>Line WB1000A/B</u>. To supply water to the resin cylinders B201A/B. These are regenerated every 12 hours. The following cause equations are for B201A in service and B201B being regenerated.

WB1000A(11)= WB1000(11) + WB3(0) + WB4(0) + B201A(0)

WB1000A(12) = WB1000(12) + WB3(-1) + WB4(-1) + B201A(-1)

WB1000A(13) = WB1001A(13)

If cylinder B201B is in service, the following exchanges are required in the above cause equations:

WB1000B	for	WB1000A	WB3 is to be deleted
WB8	"	WB4	
B201B	"	B201A	

<u>Line WB1001A/B</u>. To convey softened water to the common line WB1001 which supplies tank B203. The total hardness of the water is to be less than 5ppm. The following cause equations are for cylinder B201A in service.

WB1001A(11) = WB1000A(11) + WB5(0) + WB6(0) + WB7(0)

WB1001A(12) = WB1000A(12) + WB5(-1) + WB6(-1) + WB7(-1)

WB1001A(13) = WB1001(13) + WB1001(L)

WB1001A(530) = B201A(85)

The cause equations when B201B is in service are formulated by the following exchanges:

WB1001B	for	WB1001A	WB7 is to be excluded
WB9	"	WB5	
WB10	"	WB6	

Cylinders B201A/B. These contain resin-type water softeners. The resins will require regeneration every 12 hours at the specified maximum flowrate of 12 Imp. gallons per minute and raw water hardness. Each regeneration will consume 31.kg of salt from B200A or B200B, respectively. These tanks contain enough salt for 8 regenerations.

B201A(85) = B200A(41) + WB5(1) + FM200(-1) + FSW200(1)

B201B(85) = B200B(41) + WB9(1) +FM200(-1) + FSW200(1)

Line WB1001. To convey softened boiler feed water at a rate required to maintain the level in tank B203. This line is supplied by lines WB1001A/B or line WB1000 via valve WB13. It supplies the cooling water to H101.

WB1001(11) = WB1001A(11) * WB1001B(11) * WB13(0) +
LCV201A(0) + WBZ11(0)

WB1001(12) = WB1001A(12) + WB1001B(12) + LCV201A(-1) +
WBZ11(-1) + FM200(0)

WB1001(13) = CW998(13) + B203(L) + B203(43) + B204(L) +
B204(43) + SB1007A + WB1002(L) + WB1005(L)

WB1001(53/10) = WB1001A(530) + WB1001B(530) + WB13(-1)

Tank B203. To store softened water for the header tank B204, the level of which is maintained by a ball float valve LCV207. Dosing chemicals consisting of sodium hydroxide and sodium bisulphite are added from tank B202, directly into tank B204, by pump J109. This addition is actuated by the level switch in B203, which opens LCV201A and starts J109 simultaneously.

B203(41) = WB1001(11) + LSW201(1)

B203(42) = WB1001(12) + LC201(-1) + WB1002(13) *
[B204(L) + B204(43) + WB1005(L)]

B203(43) = LC201(1) + LSW201(-1) + LCV201A(1)

B203(53/10) = WB1001(53/10)

Tank B204. This is the boiler feed water header tank containing softened and treated water. B204 is heated by direct injection of steam from the high pressure separator HS109. Boiler feedwater is taken via line WB1002 at a rate varying from 450lb/h to 1340lb/h. The non-evaporated water is returned via line WB1005 at about 200lb/h. This stream is used to preheat feed water in H111.

B204(19/2) = J109(0) + J109(-1) + B202(41)

B204(10/3) = WB1001(11) + WB1001(12) + J109(1)

B204(22) = WB1006(12) + SB1006(11) + SB1006(146) +
TC202(-1) + TCV202(-1)

B204(23) = TC202(1) + WB1005(23) + TCV202(1)

B204(33) = TCV202(1) * [PCV213(1) + PC213(1)] +
WBT34(1)

B204(42) = LCV207(-1) + B203(41) + WB1002(13) *
[WB1005(12) + WB1005(L) + B204(L)]

B204(43) = LCV207(1)

B204(53/10) = B203(53/10)

B204(L) = WB27(-1)

Line WB1005. To return excess boiler feed water to the header tank B204 at rates varying from 190lb/h to 240lb/h. This line contains a bucket-type steam trap WBT34 to drop the water pressure from 21 bar gauge to atmospheric pressure. Following this, there is a small coiled heat exchanger H111 to preheat the boiler feed water in line WB1002; the return water flows through the coil of H111.

The only flow rate measurement available for the excess boiler feed water is the rate of emptying of the bucket in WBT34. This should discharge 12 times per minute.

Owing to the large pressure difference between lines WB1002 and WB1005, any leak in HE111 will significantly reduce the rate in WB1003 to the boiler, after it has passed through the flow ratio controller FTrC203. This could cause the boiler tubes to be overheated.

WB1005(11) = HS109(0) + N59(11) + WB28(0) + WBZ29(0) +
WBT34(0) + HE111(0) + WB30(0)

WB1005(12) = HS109(-1) + N59(12) + WB28(-1) + WBZ29(-1) +
WBT34(-1) + HE111(-1) + WB30(-1)

WB1005(13) = N59(13)

WB1005(145) = WBT34(1)

WB1005(L) = WB33(1) + WB34(-1) + WB31(1) * LCV201B(-1) +
WB32(-1)

WB1005(23) = N59(23) + WB1005(145) + HE111(72)

<u>Line SB1006</u>. To heat the header tank B204 by direct injection of steam. The steam pressure is reduced from 21 bar gauge by PCV213.

SB1006(11)=SB22(0) + PCV213(0) + SB25(0) + SBZ26(0) + TCV202(0)

SB1006(12) = [SB22(-1) + PCV213(-1) + SB25(-1) + SBZ26(-1)] * TCV202(1)

SB1006(13) = TC202(1) + TCV202(1) + PCV213(1)

SB1006(146) = HS109(43)

SB1006(L) = WB24(-1)

<u>Line WB1002</u>. To supply boiler feed water from the header tank B204 to the preheater shell H111. This line contains a reciprocating pump J110 whose discharge rate is controlled by a by-pass containing FCV208. This valve is opened if the pressure in the steam separator is too high. The water flow rate between a tapered metering pin and a collar in the centre of a diaphragm, causes FTrC203 to adjust the fuel and air flow rate, by hydraulic oil pressure. The metering pin, designated FT203, is moved hydraulically to accommodate start-up and low-fire situations. The water feed rate ranges from 405lb/h to 1340lb/h at a pressure which is 0.5 to 2 bar more than the steam pressure, respectively.

WB1002(11) = WB13(0) + WBZ14(0) + J110(0)

WB1002(12) = WB13(-1) + WBZ14(-1) + J110(-1) + WB15(1) + FCV208(1) + FC208(-1)

WB1002(13) = SB22(-1) + WB16(-1) + WB16(0) * WB15(-1) +
FCV208(-1) + FC208(1)

WB1002(L) = WB17(-1)

WB1002(22) = B204(22)

WB1002(23) = B204(23)

WB1002(32) = J110(-1)

WB1002(33) = WB1003(33) + H111(-1)

WB1002(53/10) = B204(53/10)

WB1002(10/1) = B204(10/2)

WB1002(10/3) = B204(10/3)

Line WB1003. To convey preheated boiler feed water from H11 to node N55 at the inlet to the boiler coils HE109.

WB1003(11) = WB1002(11) + WB19(0)

WB1003(12) = WB1002(12) + HE111(L) + WB19(-1)

WB1003(13) = WB1002(13)

WB1003(22) = WB1002(22) + HE111(72) + N59(22)

WB1003(23) = WB1002(23) + N59(23) + WB1005(145)

WB1003(32) = WB1002(32)

WB1003(33) = WB19(-1) + N55(33)

WB1003(53/10) = WB1002(53/10)

WB1003(10/2) = WB1002(10/2)

WB1003(10/3) = WB1002(10/3)

Line NG1001. To supply natural gas to the main burner in the boiler H109. This is taken from the line NG1006, just after value NG1, which is at 30m bar gauge. This pressure is reduced to 15m bar gauge by two reducing valves PCV200 and PCV201. Flow is controlled by FC203B, in order to maintain the appropriate ratio to the boiler feedwater rate, which is set by FTrC203. Turndown is effected by the safety system IL5; whereupon FTrC203 falls to the lowest position and DEA201, closes. Gas is supplied to the main burner, during turndown, via the by-pass line containing valve GB202 which is set beforehand to obtain the appropriate low-firing rate. Cause equations for the low-fire situation are listed under H109LF.

NG1001(11) = NGB1006(11) + NG1(0) + GB200(0) +
GB201(0) + PCV200(0) + PCV201(0) + DEAC202(0) +
GB203(0) + [DEAC200(0) + GB202(0)]
[FCV203B(0) + DEAC201(0)]

NG1001(12) = NGB1006(12) + NG1(-1) + NG1006(13) +
GB200(-1) + GB201(-1) + PCV200(-1) +
PCV201(-1) + DEAC202(-1) + GB203(-1) +
FCV203B(-1) + DEAC201(-1) + FTrC203(-1) +
FT203(-1) + FC203B(-1)

NG1001(13) = FTrC203(1) + FT203(1) + FC203B(1) +
FCV203B(1) + SB1007(13) + HE111(L)

NG1001(L) = DEAC203(-1)

NG1001(32) = PC200(-1) + PC200(-1) + PC201(-1) + PCV200(-1) +
PCV201(-1) + NGB1006(32) + GB200(-1) +
GB201(-1) + DEAC201(-1) + DEAC202(-1) +
GB203(-1)

NG1001(33) = PC201(1) + PCV201(1)

The following equations are for H109 on turndown

H109LF(82) = GB200(-1) + GB201(-1) + PCV200(-1) +
PCV201(-1) + PC201(-1) + DEAC200(-1) +
GB202(-1) + DEAC202(-1) P GB203(-1)

H109LF(83) = PC201(1) + PCV201(1) + DEAC201(-1)

H109LF(32) = GB200(-1) + GB201(-1) + NGB1006(32) +
PCV200(-1) + PC200(-1) + PCV201(-1) + PC201(-1) +
DEAC200(-1) + GB202(-1) + DEAC202(-1) +
GB203(-1)

H109LF(33) = PC201(1) + PCV201(1)

Line NG999. To supply natural gas at 10m bar gauge to the pilot burner in the boiler H109. This supply is shut off by DEAC204 about 14 seconds after ignition. The following cause equations are for this ignition period.

NG999(11) = NGB1006(11) + NG1(0) + GB200(0) +
GB201(0) + GB204(0) + PCV202(0) +
DEAC204(0(+ GB206(0)

NG999(12) = NGB1006(12) + NG1006(13) + NG1(-1) +
GB200(-1) + GB201(-1) + GB204(-1) + PCV202(-1) +
GB205(0) + DEAC204(-1) + GB206(-1)

NG999(32) = PC202(-1) + PCV202(-1) + GB204(-1)+
GB205(-1) + DEAC204(-1) + GB206(-1)

NG999(33) = PC202(1) + PCV202(1) + NGB1006(33)

Line CA1006. To supply combustion air for the boiler H109. This is provided by a blower J111 fitted with a suction damper FCV203A which is controlled by the boiler water feed rate. J111 supplies air to the pilot burner also. There is no safety device to detect restricted air flow to the boiler.

CA1006(11) = J111(0) + FCV203A(0)

CA1006(12) = J111(-1) + FCV203A(-1) + FC203A(-1) + FTrC203(-1) + FT203(-1)

CA1006(13) = FCV203A(1) + FC203A(1) + FTrC203(1) + FT203(1) + WB1002(13) + HE111(L)

Boiler H109. This produces dry saturated steam at 21 bar gauge (215^{0}C) at rates ranging from 260lb/h to 1100lb/h. The boiler is top-fired and combustion air enters through and around the flame stabilising cone. The burner is designated HB109.

The coil HE109 is in three parts. The outer coil, consisting of three concentric helical coils, of smaller diameter than the other two parts, from the convection section. Water flows upward through these outer coils, then downward through an intermediate coil which partitions the radiant and convection sections. Water and steam flow up the inner coil which receives direct radiation from the flame. The inner diameter of the burner quarl is 230mm.

HE109(-1) = WB1003(53/10) + SB1004(116)

HE109(L) = WB1003(10/3)

HE109(72) = WB1003(53/10) + WB1003(10/3) + HE109(23)

HB109(521) = FCV203A(-1) + FC203A(-1) + FCV203B(1) +
FC203B(1) + J111(-1) + NG1001(32)

HB109(53) = FCV203A(1) + FC203A(1) + FCV203B(-1) +
FC203B(-1) NG1001(33)

<u>Boiler H109 Sympton Equations</u>. Nodes are numbered as follows:

N55 feed water inlet from line WB1003
N56 outlet from coil HE109 to steam separator HS109
N57 combustion air inlet from line CA1006
N58 natural gas inlet from line NG1001
N59 water outlet from bottom of steam spearator HS109
to line WB1005
N60 steam outlet from separator HS109 to line SB1007
N61 flue gas outlet to the stack

WB1003(11) - N53(11) * N56(11) * N56(23) * N56(32) * N57(12) *
N58(12) * N59(11) * N60(11) * N60(32) * N61(12) *
N61(23)

WB1003(12) - N55(12) * N56(12) * N56(32) * N60(12) * N60(32) *
N57(12) * N58(12) * N61(12)

WB1003(13) - N55(12) * N56(12) * N56(32) * N60(12) * N60(32) *
N58(13) * N59(13) * N59(23) * N59(33) * N60(146) *
N60(33) * N61(23)

WB1003(22) - N55(22) * N61(22)

WB1003(23) - N55(23) * N61(23)

WB1003(32) - N55(32) * N55(22) * N56(32) * N59(22) * N60(32)

HE111(L) - N55(12) * N56(12) * N56(23) * N59(12) * N60(23) *
N61(23)

HE109(L) - N56(12) * N59(12) * N61(13) * N61(22)

HE109(-1) - N55(33)

HE109(72) - N55(13) * N57(13) * N58(13) * N59(13) * N60(146) *
N61(13) * N61(23)

NG1001(11) - N55(13) * N56(22) * N56(32) * N59(13) * N59(22) *
N60(146) * N60(32) * N61(12) * N61(22) * N61(171)

NG1001(12) - N55(13) * N56(536) * N58(12) * N59(13) *
N60(146) * N61(12) * N61(22)

NG1001(13) - N56(526) * N58(13) * N59(12) * N61(13) * N61(23)

HB109(521) - N61(521) * N61(23)

HB109(531) - N61(531) * N61(22)

CA1006(11) - N55(13) * N56(22) * N56(32) * N57(11) *
N59(13) * N59(22) * N60(32) * N61(12) * N61(174)

CA1006(12) - N57(12) * N61(12) * N61(23)

CA1006(13) - N57(13) * N61(13) * N61(22)

HS109(43) - N60(146)

SB1004(116) - N56(23) * N59(11) * N60(23)

The following sympton equations are for the boiler on low fire:

H109LF(82) - N56(536) * N58(12) * N59(13) * N59(22) * N60(12) *
N60(22) * N60(32) * N61(12) * N61(22) * N61(531)

H109LF(83) - N56(526) * N58(13) * N59(12) * N59(23) *
N60(23) * N60(33) * N61(13) * N61(23) * N61(521)

Steam Separator HS109

Steam and excess water are separated in HS109 which is about 4" inner diameter and 3 ft tall. There is no level control nor level indicator on HS109. The separation of water is by centrifugal action. Sediment is blown down from the separator base, by a foot operated value WB33. However, WB33 is kept open hydraulically during start up of the boiler, until the steam pressure attains 10 bar.

HS109(-1) = WB1003(53/10)

HS109(0) = WB33(0)

HS109(32) = N60(32)

HS109(33) = N60(33)

HS109(43) = WB1005(12) + WB1005(11)

Line SB1004. To transfer steam and water from the boiler coil HE109 to the steam separator HS109

SB1004(116) = NG1001(13) + HE111(L)

SB1004(22) = N56(22)

SB1004(23) = N56(23)

<u>Line SB1007</u>. To transfer saturated steam at 21 bar gauge from the separator HS109 to the super heater H110. The flow rate of steam ranges from 260lb/h to 1100lb/h.

SB1007(11) = N60(11)

SB1007(12) = N60(12)

SB1007(13) = HS1007(13) + HS1007(L) + SB1008(13)

SB1007(146) = N60(146)

SB1007(23) = SB1004(116)

SB1007(32) = N60(32)

SB1007(33) = N60(33)

<u>Line SB1008</u>. This is the continuation of line SB1007 after the off-take of saturated steam via HS1007 to the oil preheater H104.

SB1008(11) = SB1007(11) + HS26(0)

SB1008(12) = SB1007(12) + HS26(-1)

SB1008(13) = HS1004(13) + HS1004(L) + HS1001(13) +
HS1001(L) * [DSW3(DP) + DSW3 (P)] + HE110(L) +
HS27(-1) + HS28(-1) + HSIV8(-1)

SB1008(146) = SB1007(146)

SB1008(23) = SB1007(23)

SB1008(32) = SB1007(32) + HS26(-1)

SB1008(33) = SB1007(33)

Steam Superheater H110. To produce steam at 21 bar gauge and 26^{0}C given saturated steam from the boiler H109. The coils HE110 are two concentric coils with steam flowing in parallel. The feed pipe SB1007 and discharge pipe HS1001 are both 1.5 inches diameter (37mm); they are butted together in H110 to produce a steam header from which HE110 is hung. The maximum rated capacity of H110 is 800lb/h steam at 265^{0}C. The superheat temperature is controlled by an on/off temperature switch TSW214. This opens and closes two solenoid valves DEAC205 and DEAC206 in the "main" gas line NG100A. The "pilot" gas supply to the burner, flows through a by-pass NG100B around DEAC205 and DEAC206. This maintains ignition of the burner during turn-down. Both the main gas and the pilot gas supplies have pressure regulators PCV203 and PCV204, respectively.

All three DEAC valves will close if any of the following occur:

- Low combustion air pressure from the fan J113
- Steam pressure less than 7 bar; initiated by PSW213
- Flame failure

Line NG1000. To supply natural gas to the burner HB110 in the steam superheater H110. The governors PCV203 and PCV204 are used to set the flow rates in the "main" line NG1000A and in the "pilot" line NG1000B. The latter flow rate should be 10% of the former. Line NG1000 starts from NG1001 just after block valve GB201.

```
NG1000(11) = NGB1006(11) + NG1(0) + GB200(0) +
             GB201(0) + GS200(0) + NG1000A(11) *
             NG1000B(11)

NG1000A(11) = PCV203(0) + DEAC205(0) + DEAC206(0)
              + GS201(0) + TSW214(-1) + NG1000(11)
```

```
NG1000B(11) = PCV204(0) + DEAC207(0) + GS202(0) +
              NG1000(11)

NG1000(12) = NGB1006(12) + NG1(-1) + NG1006(13) +
             GB200(-1) + GB201(-1) + GS200(-1) +
             NG1000A(12)

NG1000A(12) = PCV203(-1) + DEAC205(-1)
              DEAC206(-1) + GS201(-1) + TSW214(-1) +
              NG1000B(33)

NG1000(13) = SB1008(13) + NG1000A(13)

NG1000A(13) = NG1000A(33) + DEAC205(1) * DEAC206(1) +
              TSW214(1)

NG1000(32) = NGB1006(32) + GB200(-1) + GB201(-1) +
             GS200(-1)

NG1000A(32) = NG1000(32) + PCV203(-1) + PC203(-1)

NG1000B(32) = PCV204(-1) + PC204(-1)

NG1000A(33) = PCV203(1) + PC203(1)

NG1000B(33) = PCV204(1) + PC204(1)
```

The following cause equations are for H110 on turn-down, when fuel gas is supplied via the by-pass line NG1000B only.

```
H110LF(81) = NG1000B(11)

H110LF(83) = NG1000B(33) + DEAC205(-1) * DEAC206(-1)
```

The combustion air fan J113 is fitted with a suction damper FCV215 which is manually adjusted to obtain 9% CO_2 when the main gas is flowing.

J113(11) = J113(0)

J113(12) = J113(-1) + FCV215(-1)

J113(13) = FCV215(1)

Steam Superheater H110 Sympton Equations. Nodes are numbered as follows:

N62 saturated steam inlet from line SB1008
N63 superheated steam outlet to line HS1001
N64 natural gas inlet to HB110 from line NB1000
N65 combustion air inlet from fan J113
N66 flue gas outlet to the stack

NG1000(11) - N63(22) * N64(11) * N66(22) * N66(531)

NG1000(12) - N63(22) * N64(12) * N66(22) * N66(531)

NG1000A(13) - N63(23) * N64(13) * N66(23) * N66(521)

J113(12) - N65(12) * N65(32) * N66(12) * N66(23) *
N66(521)

J113(0) - N63(22) * N65(11) * N65(32) * N66(12) * N66(174) *
N66(22)

FCV215(1) - N65(13) * N66(13) * N66(22) * N66(531)

SB1008(11) - N62(11) * N63(11) * N63(23) * N66(23)

SB1008(12) - N62(12) * N63(12) * N63(25) * N64(15) *
N66(15) * N66(25)

SB1008(13) - N62(13) * N63(22) * N64(13) * N66(23) *
N66(521)

```
SB1008(146) - N26(146) * N63(146) * N63(22) *
              N64(13) * N66(13) * N66(22)

SB1008(23) - N62(23) * N64(12) * N66(22) * N66(531)

SB1008(32) - N62(32) * N63(22) * N63(32) * N64(13) *
             N66(23)

SB1008(33) - N62(23) * N62(33) * N63(33) * N64(12) *
             N66(22)

H110LF(81) - N66(22) * N66(144)

H110LF(83) - N66(23) * N66(521)
```

Line HS1001. To supply atomising steam to the test burner in H101 when fuel oil is being burnt. The steam is to be at 165^{0}C and at a controlled pressure, up to 21 bar gauge. The flow rate of steam to the burner may be boiler H109; the excess is sent to the site steam main via linė HS1004. Line HS1001 starts at node N63 and terminates with a flexible hose connection to the test burner. Steam supply is controlled by flow, or pressure excess above the oil pressure.

```
HS1001(11) = N63(11) + HS1(0) + FT7A(0) + HS4(0) +
             DCV3(0) + HS5(0) + HS7(0) + HS9(0)

HS1001(12) = N63(12) + DCV(-1) + DI/P3(-1) + DIC3(-1) +
             DCV3(1) * [HS1(-1) + HS5(-1) + HS5(-1) + HS7(-1) +
             DSW3(F) * [FT7A(1) + FT7B(1) + HD1001(L)] +
             DSW3(P) * [PT31(1) + HS7(-1)] +
             DSW3(DP) + [PT31(1) + HS7(-1) + PT60(-1) +
             PdT31(-1)]
```

```
HS1001(13) = DCV3(1) + HS6(1) + DI/P3(1) + DIC3(1) +
             DSW3(F) * [FT7A(-1) + FT7B(-1)] + DSW3(P) *
             PT31(-1) + DSW3(DP) * [PT31(-1) + PT60(1) +
             PdT31(1)]

HS1001(146) = N63(146) + HS1001(73)

HS1001(L) = HS3(-1) + HS30(-1) + HSF1001(L)

HS1001(22) = N63(22) + HS1001(73)

HS1001(23) = N63(23)

HS1001(32) = N63(32) DCV3(-1) + DI/ P3(-1) + DIC3(-1) +
             DCV3(1) * [HS1(-1) + HS4(-1) + HS5(-1) + HS7(-1)] +
             DSW3(F) * [FT7A(1) + FT7B(1)] +
             DSW3(P) * [PT31(1) + HS(-1)] +
             DSW3(DP) * [PT31(1) + HS7(-1) + PT60(-1) +
             PdT31(-1)]

HS1001(33) = DCV3(1) + HS6(1) + DI/P3(1) + DIC3(1) +
             DSW3(F) * [FT7A(-1) + FT7B(-1)] +
             DSW3(P) * PT31(-1) + DSW3(DP) *
             DSW3(P) * PT31(-1) + DSW3(DP) *
             [PT31(-1) + PT60(1) + PdT31(1)]
```

<u>Line HS1004</u>. To allow excess steam which is produced in the boiler H109 and superheater H110 to pass into the site steam main.

```
HA1004(11) = N63(11) + HS10(0) + HS23B(0) + PCV27(0) +
             PC27(-1) + HS23A(0) + HS22(0) + HS31(0)

HS1004(12) = HS10(-1) + HS23B(-1) + PCV27(-1) +
             HS23A(-1) + HS31(-1)
```

HS1004(13) = PCV27(1)

HS1004(146) = N63(146) + HS1004(73)

HS1004(L) = HS24(-1)

HS1004(22) = N63(22) + HS1004(73)

HS1004(23) = N63(23)

HS1004(33) = PCV27(1) + PCV27(1) + HSIV9(0)

6.4.8. SAFETY SYSTEM

These comprise 8 interlocks which react to one or more initiators and act on certain isolation/bleed valves. In addition there is the Heat off system, designated HO, which shuts off the main fuel supplies to the test burner. At a more complete level, there is the Emergency shutdown system (ESD) which shuts down and isolates all equipment. The following cause equations include opurious and genuine trip. Also failure of the safety system(4.5.1).

Safety System IL1. This shuts down all fuel supplies to the test burner H102 if the pressure of natural gas to the pilot burner in line NG1007 is extra low.

IL1(1) = NG1007(32) + PSW19(1)

IL1(0) = PSW19(-1) + NG32(-1) + DEAC1(-1) + DEAC2(-1) + DEAC3(0) + DEAC5(-1)

IL1(1) - DEAC1(0) * DEAC2(0) * DEAC3(1) * DEAC5(0) * DEAC6(0)

Safety System IL2. This shuts DEAC5 in line FT1012, which stops liquid fuels being supplied to the burner. IL2 is initiated by a low steam pressure in line HS1001.

IL2(1) = HS1001(32) + PSW32(1)

IL2(1) - DEAC5(0)

IL2(0) = PSW32(-1) + HS7(-1) + DEAC5(-1)

Safety System IL3. This shuts off the main and pilot gas supplies to the air preheater. The initiating causes are:

- Low gas pressure in NG1011, which triggers PSW24
- High gas pressure in the base-load supply line NG1011A
- Flame failure in H105, which is detected by XT2
- Low pressure of combustion air from fan J109 which triggers PSW2
- No rotation of the fan J102 which supplies air through HE105 to the test burner; this is detected by XT1.

The IL3 system is not interlocked with the main emergency shutdown (ESD) system.

```
IL3(1) = NG1011(32) + PSW24(1) + NG1011A(33) +
         PSW25(-1) + H105(81) + XT2(0) + CA1002(32) +
         PSW2(1) + J102(0) + XT1(0)

IL3(1) - DEACM1(0) * DEACM2(0) * DEACM3(1)
         DEACM4(0) * DEACM5(0)

IL3(0) = PSW24(-1) + PSW25( 1) + XT2(1) + PSW2(-1) +
         XT1(1) + DEACM1(-1) + DEACM2(-1) +
         DEACM3(0) + DEACM4(-1) * DEACM5(-1)
```

Safety System IL4. This interlock opens the four interstage valves JV101 (via DSV1 and DSV8) in the natural gas compressor J101 and closes DEAC10 (via DSV10) in the kick-back line NG1015. The causes which initiate IL4 areas follows:

- High pressure in tank B104, which triggers PSW4
- Low pressure in the suction tank B111, which triggers PSW7
- High temperature in the delivery tank B112, which triggers TSW2
- Low pressure in the lubricating oil system for J101, which triggers PSW100

IL4(1) = B104(33) + PSW4(-1) + B111(32) + PSW7(1) + B112(23) + TSW2(-1) + PSW100(1)

JV101(1) = IL4(1) + DSV1(1) + DSV8(1)

DEAV10(0) = Il4(1) + DSV10(1)

IL4(0) = PSW4(1) + PSW7(-1) + TSW2(1) + PSW100(-1) + DSV1(0) + DSV8(0) + JV101(0) + DSV10(0) + DEAC10(1)

Safety System IL5. This causes a reduction in natural gas supply to the boiler H109, by closing DEAC201. Simultaneously, the fuel/water ratio is reset to its lowest value by a hydraulic servo set-down operating on FTrC203; this is effected by venting the hydraulic oil OB35 back to the low pressure tank B205. IL5 is a self-resetting interlock which is initiated by TSW209 in the saturated steam line SB1004 from the boiler to the separator HS109. The temperature switch should be set to operate at a superheat temperature of 20^0C to 34^0C above the saturation temperature of H109. At 21 bar gauge the saturation temperature is 265^0C.

IL5(1) = SB1004(23) + TSW209(-1) + OB35(1)

IL5(1) - FTrC203(-1) * DEAC201(0) * OB35(1)

IL5(0) = TSW209(1) + FTrC203(1) + DEAC201(-1) + OB35(0)

Safety System IL6. This shuts off both gas supplies to the boiler H109. The initiating causes are:

. Steam in line SB1004 is very superheated, triggering TSW209A which is set between 75^0C and 89^0C of superheat
. Flue gas temperature exceeds 480^0C, triggering TSW210
. Failure of main flame, triggering BX211
. Low pressure in fuel supply line, triggering PSW213 which is set at 15 m bar
. High pressure in fuel supply line, triggering PSW212 which is set at 35 m bar

IL6(1) = SB1004(23) + TSW209A(-1) + N61(23) +
TSW210(-1) + NG1001(11) + BX211(0) +
NG1001(32) + PSW213(1) + NG1001(33) +
PSW212(-1)

IL6(1) - DEAC200(0) * DEAC201(0) * DEAC203(1) *
DEAC204(0)

IL6(0) = TSW209(1) + TSW210(1) + PSW213(-1) PSW212(1)
+ [DEAC200(-1) + DEAC201(-1)] * DEAC202(-1) +
DEAC203(0) + DEAC204(-1)

Safety System IL7. This opens the blowdown valve WB33 at the base of the steam separator HS109 when the steam pressure is less than half of the required working pressure. The switch PSW208 opens and closes the solenoid valve OB34 in the hydraulic oil system. There is an isolating valve SB22 between PSW208 and the steam separator HS109.

IL7(1) = N60(32) + PSW208(1) + OB34(0) + SB22(-1)

IL7(1) - WB33(1)

IL7(0) = PSW208(-1) + OB34(1) + WB33(0)

Safety System IL8. This actuates the drench system around the LPG storage tanks B107A/B. It is initiated by high pressure in either tank which triggers PSW43A/B, respectively. IL8 responds also to hand switches FSW9A/B/C in the control room, on the wall of the compressor house and in the LPG area itself. The alarm FA9 should prompt the manual operation of one of these 3 valves.

IL8(1) = B107A(33) + PSW43A(-1) + B107B(33) +
PSW43B8(-1) + FSW9A(1) + FSW9B(1) +
FSW9C81)

IL8(1) - FCV9(1) * FA9(1)

IL8(0) = PSW43A(1) + PSW43B(1) + FSW9A(0) +
FSW9B(0) + FSW9C(0) + FA9(0) * [WD4(0) +
WD3(0) + FCV9(0)]

Heat-off System HO. This shuts off all main fuel supplies to the test burner but leaves the pilot fuel supply on. This is initiated by the following causes:

- High temperature by cooling water leaving the heater H101 via line CW1000, triggering TSW15.
- No rotation of the main air fan J102, which triggers XT1.
- Low pressure of gas or LPG vapour in line NG1004, which triggers PSW14.
- Extra low pressure of the fuel oil supply in line FT1012, triggering PSW59.
- Main flame failure.

HO(1) = CW1000(23) + TSW15(-1) + J102(0) +
XT1(0) + NG1004(32) + PSW14(1) +
FT1012(32) + PSW59(1)

HO(1) - DEAC1(0) * DEAC2(1) * DEAC3(1) * DEAC5(0)

HO(0) = TSW15(1) + XT1(1) + PSW14(-1) + NG20(-1) +
PSW59(-1) + DSW4(P) * [FT23(-1) + FT40(-1) +
FT41(-1) + FT42(-1) + FM400(0)] + DEAC1(-1) +
DEAC2(-1) + DEAC3(0) + DEAC5(-1)

Emergency Shutdown ESD. This is initiated manually. It shuts off both main and pilot fuel supplies to the test burner and to the air preheater. It shuts off the electricity to the motor driving the natural gas compressor J101 and opens the interstage valves JV101. It switches off the main air fan J102. Additionally, ESD open the solenoid valves to trip shut the control valves on all the fuel supplies.

ESD - DEAC1(0) * DEAC2(0) * DEAC3(1) * DEAC4(0) *
DEAC5(0) * DCV2(0) * PCV23(0) * DCV4(1) *
JD101(0) * JV101(1) * J102(0)

ESD(0) = DEAC1(-1) + DEAC2(-1) + DEAC3(0) + DEAC4(-1)
+ DEAC5(-1) + DSV2(0) + DCV2(-1) + DSV23(0) +
PCV23(-1) + DSV4(0) + DCV4(0) + JD101(1) +
DSV1(0) + DSV8(0) + JV101(0) + J102(1)

6.5 ACTION REQUIRED BY THE BTR OPERABILITY STUDY

This section shows below some recommendations for minor alterations and additions to the BTR equipment, in order to improve operability, reliability and safety. When these modifications have been effected, it will be necessary to alter the cause equations to take account of the improvements.

Cooling Water System

There is not frost protection of the pressurised tank B106 while the supply tank B105 is fitted with an immersion heater. There should be a low temperature alarm on B106 and/or it should be lagged.

Natural Gas System

If IL4 operates to open the valves JV101 in the compressor, will there be a reverse flow B112 to B111, causing a high pressure in B111? Should these be a non-return valve in line NG 1002?

The valve DEAC10 in line NG1015 is operated by IL4; it closes in an emergency. If a high pressure in B104 has caused PSW4 to actuate IL4, the cause could be less flow in line NG1015, closing DEAC10 does not help. The non-return valve NG112 in line NG1015 seems redundant.

L.P.G. System

Non-return valves should be placed in lines PG1003A/B to prevent reverse flow or hot LPG from the evaporators back to the storage tanks. High pressure in the liquids return line PG1004 would produce the reverse flow.

If the tubes in the LPG evaporators are found to be leaking by the appearance of water in the shell, the evaporator should be shut down to repair the leak or plug the leaking tubes; because if the steam pressure falls below 4 barg in the exchanger LPG will leak out and butane will emerge from the vent on B108.

Fuel Oil System

If the tubes in the oil preheater H104 leaks water may collect in the shell and/or steam may pass via FT1012 in line FT1006 causing an incorrect oil flowrate. Should there be a drain on the shell of H104?

The safety system IL2 shuts DEAC5 to prevent any liquid fuel being supplied to the burner. IL2 is initiated by low pressure in the atomising steam. But distillate fuels such as gas oil do not require atomising steam; will IL2 be switched off when distillate fuels are being burnt? If it is switched off, can we ensure that IL2 will be rearmed when residual fuels are being burnt?

Boiler Package

The boiler feed water preheater H111 has a 20 barg differential pressure between the water flows any leak will cause a high fuel to water ratio of flows to the boiler. A leak of 200 lb/h would cause the coils in the boiler to run dry. The preheater should be upstream of the flow ratio controller FTrC203. There should be a water flow indicator in the return line WB1005 after H111.

If the pressure reducer PCV213 in the steam line SB1006, which heats the boiler feed water tank B204 fails there will be a sudden flow of steam which could over pressure B204. The vent on this tank would be choked with water. Similarly, if traps WBT34 in line WB1005 sticks open, 21 barg steam will enter B204.

There is a high (35 mbarg) and low (15 mbarg) switch PSW212 in the natural gas line NG1001 to the boiler; however, there are control valves, DEAC valves and manual valves between the position of PSW212 and the burner. Another switch should be at the burner, to initiate a low pressure alarm.

Loss of combustion air to the boiler will eventually cause shut down of the fuel supply because of flame failure. Should there be a most immediate shutdown, e.g. if the air pressure is low.

Either valve GB200 or GB201 in line NG1001 to the boiler should be eliminated. Similarly, valve GB206 in line NG999 to the boiler pilot burner is redundant.

Valve SB22 between the steam separator HS109 and PSW208 should be moved downstream in line SB1006. In its present position if SB22 is incompletely open, the control of feed water rate and of the blowdown will be responding to a lower pressure than the actual pressure in HS109.

There should be an indication of the water level in the steam separator HS109. There may be water entrained with the steam entering the superheater. The cause of this entrainment may have been identified as follows:

More water flow rate in the feedline WB1003

Fouling or scaling of the boiler tubes HE109

Low Fuel flow rate in NG1001

High level in HS109 caused by reduced flow rate in the water return line WB1005

Superheater and Softener Units

The on/off characteristics of TSW214 will cause the superheat temperature of steam leaving H110 to fluctuate. The firing rate falls to 10% when TSW214 closes the two DEAC valves 205 and 206 in the "main" fuel line.

Valve WB3 in the boiler feed water supply line WB1000A resin cylinder B201A is redundant. Similarly, valve WB7 in line WB1001A is redundant.

There should be a direct proportional flowrate between boiler feed water header tank B204 and closing chemical from B202, instead of the softened water tank B204 and dosing pump J109.

The boiler feed water header tank B203 can be over dosed if there is restricted flow of softener water in WB1001. Conversely, underdosing will occur if the dosing pump J109 stops or is cavitating or if B203 is empty.

Safety Circuits

The following low pressure switches have a block valve downstream. If the valve is not completely open, the pressure at the end of the line will be less than the pressure on the switch. Low pressure switches should be at the end of the lines.

PSW14 in NG1004 should activate heat off if the gas pressure to the burner is low. NG20 is downstream.

PSW58 in FT1012 actuates PA58. Similarly, PSW59 in FT1012 actuates heat off if the fuel oil pressure is low. But line FT1006 which connects the ring main to the test burner can be at much lower pressure due to valves FT23, FT41, FT42 being incompletely open. Also filter FT40 may be partly blocked; Flow transmitter FT10A and flow meter FM400 can cause pressure losses also.

PT31 is connected to the low pressure alarm PA31 in the superheat steam main HS1001. But valve HS7 is downstream.

PSW64 actuates a low level alarm PA64 in the cooling water circulating line CW1005. This has valves CW7 and CW8 in the branches CW1005A/B leading to the furnace coils.

The correct operation and sequencing of the automatic double block and bleed DEAC valves on fuel lines NG1001, NG1004 and NG1011 must be checked regularly. If the upstream DEAC valve fails to close or leaks, there will be a gas leak from the bleed valve. Similarly, if the bleed valve fails to reseat, there will be gas leaks on start up.

CHAPTER SEVEN

CONCLUSIONS

CONCLUSIONS

Presented here are the conclusions obtained as a result of the case study on the BP Sunbury Burner Test Rig project and on the application of CAFOS to the BTR.

Therefore this chapter summarises the major conclusions from the "Findings", recorded at the end of the preceding chapters.

Process Development
Project Engineering
Instrumentation & Control and Safety Systems
Operation
Operability Study

In order to be consistent with the aim of this thesis, "The Effect of the Plant Specification on the Design, Installation and Commissioning of Refinery Process Heaters", the conclusions are expressed in the form of recommendations which can be directly added to a Process Heater Specification or applied during the desing, installation and commissioning of a plant.

The preparation of these recommendations was done by considering the BTR which was designed and erected in a very special circumstance, i.e:

For research and development and in a research environment.

However, the BTR can be catalogued as a "Medium Industrial Process Plant" as implied by the overall cost and procedure followed to complete the project.

Therefore, the folowing "Recommendations/Conclusions" are valid for and applicable to a range of process plants related to refineries, covering their Process Development, Project Engineering and Operation.

PROCESS DEVELOPMENT

i) During the feasibility study of an experimental project the objectives and experimental programme are defined but also the technical feasibility should be defined and represented by the Technical Specification of the project.

ii) The selection of a Lump Sum contract to achieve rapid Plant Installation, is very much dependent on the plant circumstances, but once chosen, it should

. Be based on a comprehensive 'Specification'
. Avoid direct or indirect client responsbility for any part of the plant which is covered by the Lump Sum Contract.

iii) The Technical Specification (Hardware Description) can be effectively described using the following format:

. Process Design Specification
. Detailed Process Design
. Detailed Engineering

An example of the above format is shown in (2.4.4.) for the different systems comprising the BTR.

iv) The Final Specification should precisely define the "Process Design Specification" (core of the spiral, explained in vii below) alternatives to major equipment or systems may be allowed.

v) The "Process Design Specification" should consider the design philosophy and at least the minimum requirements of operation.

vi) During the "Tender Modification Period" the final selection of all the major equipment/systems should be fixed.

vii) The development of a Technical Specification can be visualised as a growing spiral formed by the Process Design as the core, and followed by the Detailed Process and Detailed Engineering.

Because the amount of information in the Technical Specification increases at every stage, i.e. Specification Preparation, Tendering, Tender Selected Modification and Project Engineering, the above mentioned spiral will grow from one stage to another; a final limited larger spiral should emerge at the end of each stage.

PROJECT ENGINEERING

i) In view of the disruption caused to the activity schedules by delivery delays (3.13.1) excluding any other contingency, it is recommended as a mandatory regulation to include in the specification at least two complete network diagrams to be issued during the project engineering (3.13.1).

ii) In order to facilitate the visualisation of the work schedule from bar and/or network diagram, it is recommended to use the same time scale (say, 1 week = 10mm) for the schedules issued.

iii) Due to the special design, fabrication and installation requirements of the ducts (3.13.6) they should be treated as a major equipment and not as pipework.

Also the pipeworkof each system with the required instrumentation should be treated as a major equipment and should be represented in either the bar and/or network diagram (Fig. 3.12.1.A, B & C).

iv) The electrical and control panel should be classified as essential major equipment because their delay can critically disrupt the erection (4.4.3.2.1) and pre-commissioning (3.13.9), respectively.

INSTRUMENTATION & CONTROL AND SAFETY SYSTEM

i) The Instrumentation & Control and Safety System should be considered as a "System" (4.4.7.6(i)) of any process plant similar to the one described in this thesis.

ii) Descriptive and comprehensive tables, similar to Tables 4.5.1. A & B of Instrumentation, Control and Safety Circuits should be supplied with the Client's Specification (4.7.6(ii)).

iii) The instrumentation tables described above can be useful during Tendering, Installation and the Commissioning (4.7.6.(iii)).

OPERATION

Commissioning

i) The client specification should include commissioning programme (5.1.2.1 & 3(i)) with open questions to be answered by the contractor about estimated time to carry out the prefiring and firing commissioning as well as the description of the commissioning personnel.

ii) The time assigned to the prefiring commissioning (precommissioning) as well as the firing commissioning (5.1.5.2) should include extra time for possible contingencies.

iii) Expediting the delivery (5.1.5.4) and full installation (5.1.5.5.) of equipment required for pre-commissioning firing (Dry Out) should be a priority.

iv) Safety Authority approval of certain systems installation and fuel deliveries should be considered in any commissioning programme involving fuels such as LPG (5.15.6) and fuel Oil (5.1.5.6.).

v) The Instrument and Control and Safety Systems (5.1.5.8 & 9) are essential to fully carry out commissioning; therefore, it is recommended that COMPLETE installation of these instruments must occur before the prefiring commissioning.

vi) Due to the importance of the Plant Key process conditions (Commissioning Variables), a list as shown in 5.2.3.1. of the most relevant process conditions of the plant should be drawn up to be validated during the firing commissioning.

Operating Instruction Manual

i) The Client Specification should state that the "Operating Instructions Manual" must describe all that is required for the everyday operation of the plant (5.2.4.1).

ii) Also, the Client Specification should advise the contractor that a "Preliminary Operating Instruction Manual" (5.2.4.4.) should be available at the time when the bulk of the project engineering detail is complete and/or all the major equipment has been ordered.

iii) Additionally to the description of the "Instructions for the Safe Operation" by Firing Modes and the Operation Modules (5.2.4.6) the operation sequence of each Firing Mode should be self-contained and have a simple (5.2.4.6) and proven (5.2.4.5 & 7) sequence of operating instructions. It must not need reference to other sources.

iv) In view of the many consecutive instructions which are likely to result from 'Self-contained Operating Instructions', the use of a simple block diagram is recommended to illustrate the detailed self-contained instructions.

OPERABILITY STUDY

i) The objective of examining the BTR by an operability study, in order to detect possible faults, was a success as demonstrated by the list of recommendations shown in 6.5.

ii) The equations derived from the BTR operability study (6.4) can be used with a computer programme to identify the possiblecauses of faulty states.

iii) CAFOS is sufficiently flexible to be applied to any medium size industrial process plant.

Note: The identification of the cause of a faulty state by the operator is done by the display of a "Fault Tree" produced by CAFOS with the aid of a microcomputer.

The BTR OPERABILITY STUDY (6.4) has already been codified into computer language.

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APPENDICES

1. General Contract Conditions (List of Content)

2. Contractor Instrument Specification (List of Content)

3. Client Specification (List of Content)

4. Final Tender (List of Content)

5. Furnace Design Calculations

6. Planning Documents (Diagrams)

7. Actual Work Activities Diagrams-Comparison

8. Actual Flow Diagram (BTR)

APPENDIX 1.

GENERAL CONTRACT CONDITIONS (List of Content)

This appendix shows the recommended clauses issued by the Chemical Engineering Institute (1) in relation to the General Conditions required in a Lump sum

Lump Sum Clauses.

1. Definition of Terms
2. Interpretation
3. Contractor's Responsibilities
4. Provision of Work, Facilities, Services or Information by the Purchaser.
5. Sufficiency of Contract Price and Unforeseen Conditions.
6. Statutory and Other Obligations
7. Patent and Other Protected Rights
8. Assignment and Sub-contracting
9. Nominated Sub-contractors
10. The Engineer
11. Contractor's Project Manager and Staff
12. Programme of Work
13. Progress of the Works and Suspension
14. Delays and Extension of Time
15. Damages for Delay
16. Variations
17. Contractor's Variations
18. Valuation of Variations
19. Secrecy
20. Drawings
21. Mistakes in Drawings
22. Inspection and Off-site Tests
23. The Site
24. Delivery to Site
25. Ownership of Materials

Appendix 1 (continued)

26. Setting Out
27. Site Services
28. Site Working Conditions
29. Site Meetings
30. Site Clearance
31. Care of the Works
32. Insurance
33. Completion
34. Taking-over
35. Performance Tests
36. Liability for Defects
37. Acceptance
38. Final Certificate
39. Payment
40. Provisional and Prime Cost Sums
41. Contractor's Default
42. Termination by the Purchaser
43. Force Majeure
44. Limitation of Contractor's Liability
45. Giving of Notices
46. Reference to an Expert
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APPENDIX 2

CONTRACT INSTRUMENT SPECIFICATION (List of Content)

APPENDIX 3

CLIENT SPECIFICATION (List of Content)

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1.1 Scope of Work
1.2 Design Policy
1.3 Design Practice
1.4 Guarantees
1.5 Alternatives
1.6 Departures from Specification
1.7 Layout
1.8 Commissioning

PART 2 - SITE INFORMATION

2.1 Site Description and Conditions of Contract
2.2 Meteorological Data
2.3 Utilities Date

PART 3 - TECHNICAL SPECIFICATION

3.1 General
3.2 Thermal Design of Furnace
3.3 Mechanical Design of Furnace
3.4 Combustion Air System
3.5 Fuel Supply Systems
3.6 Furnace Cooling
3.7 Steam Supply
3.8 Control and Instrumentation
3.9 Safety Systems
3.10 Miscellaneous Provisions

PART 4 - GENERAL ENGINEERING SPECIFICATIONS

4.1 Standards and Codes
4.2 Language, Nomenclature and Units
4.3 Safety
4.4 Welding

Appendix 3 (continued)

4.5 Spares
4.6 Documents required with Technical Proposal
4.7 Works Inspection Procedures
4.8 Control and Gas Fired Steam Generator Plant Building

PART 5 - SECTIONAL ENGINEERING SPECIFICATIONS

5.1 Utilities
5.2 Noise Control
5.3 Foundations and General Civil Works
5.4 Drainage Systems
5.5 Plant Structures
5.6 Unfired Pressure Vessels
5.7 Heat Exchange Equipment
5.8 Rotating Machinery
5.9 Piping Systems
5.10 Thermal Insulation
5.11 Pressure Relieving Systems
5.12 Fire Protection
5.13 Electrical System and Installation
5.14 Instrumentation
5.15 Tankage
5.16 Painting

APPENDIX 4

FINAL TENDER (List of Content)

Section 1 - GENERAL

1.1 Introduction letter 20.7.78

1.2 Lining Manufacture letter 20.7.78
(Guarantee

1.3 Form of Agreement
(Including some General Conditions)

1.4 Analysis of Tender

1.5 Form of Guarantee

1.6 Civil Eng. Contractor telex 20.7.78
(Revised Quantity)

1.7 Technical comments in answer to point raised in "Meeting held on 6.7.78 and reported on 13.7.78".

1.8 Revised State of Proposal Drawings

Section 2 - CONSTRUCTION

2.1 Daywork Rates

2.2 Equipment for the constuctional works

2.3 Escalation Formula Data and Determinants

Section 3 - CONSTRUCTION PLANNING

3.1 List of proposed subcontractors

3.2 Supervision and Labour force schedule

3.3 Schedule of contractor equipment
Drw. M8E/7116

3.4 Schedule of material procurement
Dr. M8E/7116

Section 4 - TECHNICAL SPECIFICATION

4.1 General Description of Plant

1. Design Philosophy
2. System Flow Sheets
3. Layout
4. Major Equipment

4.2 Description of Furnace Design, Construction and Operation
1. General
2. Thermal Design
3. Mechanical Design
4. Operational Testing
5. Mobile burner transporter and lifter
6. Data Sheet
    1. Process Design Conditions
    2. Combustion Design Conditions
    3. Fuel Characteristics
    4. Mechanical Design Conditions
7. Outline Sketches of Proposed Test Burner.

4.3 Furnace Cooling

1. Winterisation
2. Direct Air Cooling System
3. Comparison of Alternative cooling systems
4. Data Sheet of Air Cooled Heat Exchange

4.4 Combustion Air System

1. Air Blower
2. Flow measurement
3. Air Preheater
4. Ducting
5. Data Sheet
    1. Operating Conditions
    2. Thermal Design Data
    3. Fuel Data
    4. Burner Data
    5. Heating Surface
    6. Structural Data
    7. Recuperator Safeguards and Instrumentation
6. Outline sketch of indirect air pre-heater

4.5 Combustion Atomising Steam Raising Plant

1. Water Softening Plant
2. Steam Boiler Package
3. VAPORAX steam generator
   Wanson Co.Ltd.
    1. Technical Specification
    2. Outline of "Vaporax 400R"

4.6 Fuel Oil Supply System

1. Storage Tanks
2. Oil Pumps
3. Oil Filters
4. Oil Preheater
5. Oil Piping System

4.7 LPG Supply System

1. Storage Tanks
2. Vapourisers
3. LPG Pumps
4. Pipework, Fitting, Values and Supports
5. Electrical
6. Fire Protection
7. LPG Compound

4.8 Gas Supply System

1. Natural Gas
2. Bottle Gas Supply

4.9 Pump Specification

1. LPG pumps
2. Oil pumps
3. Circulating Water pumps
4. Combustion Air fan

4.10 Description of Civil Works

1. Control Building and Compressor House
2. Oil Storage Compound
3. LPG Storage Compound
4. Furnace Base Slab
5. H.E. Fan Bases

4.10 (continued)

6. Tanker lay by
7. Interceptor
8. Drainage
9. Paving
10. Electric Cable Trench Work
11. General Levelling and Grading
12. Making Good

4.11 Description of Electrical Works

1. Scope
2. Applicable Standards and Regulations
3. Temporary Services
4. Main Distribution and Motor Control centre
5. Distribution Cabling, Cable Ducts, Voltage Drops
6. Alarm System
7. Electric Motors
8. Lighting
9. Sockets outlets
10. Earthing and Bonding
11. Supply to Instrumentation
12. Electric Tracing
13. Electrical Installation
14. Documents

4.12 Description of Instrumentation, Control and Alarm System

1. General
2. Control Panel
3. Closed Circuit Television
4. Instrumentation and Control Cabling, Pipes.

4.12 (continued)

5. Installation of Control System and Instrumentation
6. Vendors
7. Spares
8. Documentation

4.13 Erection Schedule

1. Supervision
2. Construction
3. Commissioning
4. Access
5. Welfare
6. Toilet Facilities

4.14 Utilities Summary

1. Normal Operation
    1. Treatment Chemical
    2. Site Steam
    3. Water
    4. Natural Gas
    5. LPG
    6. Electricity
    7. Compressed Instrument Air
2. Temporary Requirement
    1. Water
    2. Electricity

4.15 Spare Parts

1. Test Furnace
2. Combustion Air Preheater
3. Steam Generator
4. Natural Gas Compressor
5. Oil Preheater

4.15 (continued)

6. Air Cooler
7. LPG Vpouriser
8. LPG tracing heating
9. LPG transfer pump
10. Main gas and Pilot filters
11. Oil Filter
12. Oil Pumps
13. Combustion Air Blower
14. Water make up pump
15. Test burner
16. Instrumentation
17. Motor Control Centre

4.16 Measures taken to attain required noise limits

4.17 Measures taken to attain maximum energy conservation

4.18 Measures taken to achieve a minimum 2-year maintenance free operation

4.19 Pipework Specification

APPENDIX 5

FURNACE DESIGN CALCULATIONS

NOMENCLATURE

Symbol	Description	Units
ag	Weighting factor of grey component of gas medium	dimensionless
A	Area	m^2
D	Diameter	m
Fij	View Factor	dimensionless
$(\bar{GS}_1)_r$	Total Exchange area between the gas and surface one zone in presence of refractory	m^2
h	Local Heat Transfer Coefficient	$Kw/m^2\ °K$
k	Thermal Conductivity	Kw/m °K
L	Mean Beam Length of Intervening Gas	m
P	Partial Pressure	atm
R	Area Ratio	dimensionless
S	Pitch	dimensionless
T	Temperature	°C/°K
α	Hottel/Effectiveness Factor	dimensionless
σ	Boltzman Constant	$Kw/m^2\ °K^4$
	Hottel's Factor (Fa)	dimensionless

Subscripts

c	Carbon Dioxide
cp	Cold Plane
e	Area envelope
r	Refractory
S	Surface (Tube)
m	Mean Beam
w	Water
1	Tubes
2&3	Border Tubes
/ /	Equation
( )	Reference

Thermal Efficiency of the BTR

Fig. 5A shows the best fit curve of the early operation of the Burner Test Rig (BTR) when Thermal Efficiency is plotted against Firing Rate. The latter is evaluated by considering the heat release by the mass/volume of the fuel fire and the former is the ratio of the heat release and the heat removed by the process fluid circulating by the coil.

The operating conditions plotted were steady state conditions (one day operation) but the author recognised that instrument error (Early BTR life) and different operators carrying out the running, may affect the reliability of the obtained data. However, the plotting of this curve considers the evaluation of the data collected during the first five operation months of the BTR (40 runs); therefore, it is the author's belief that the data is reliable, despite that non-specific run was done to fully check the furnace operating condition.

The Fig. 5A permits the determination of the characteristic thermal efficiency (52.5%) of the Furnace when firing 20 MBTU/h with 10% excess air and a flue gas temperature of 800 ± 20°C.

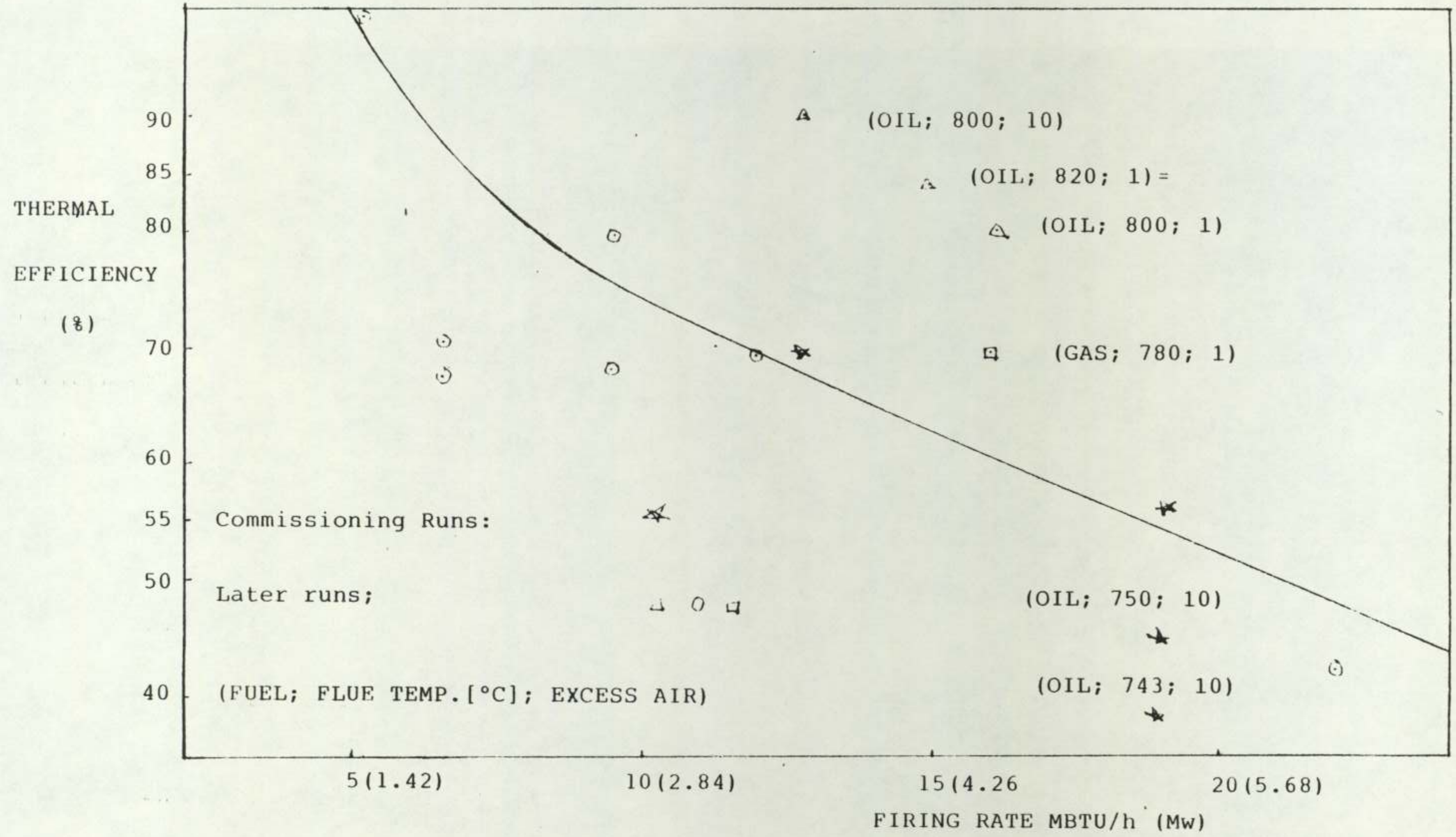


Fig. 5.A Variation of Thermal Efficiency with Firing Rate

FURNACE ACTUAL DATA

Heat Release	20 MBTU/h
Heat Removed	10.5 MBTU/h
Flue Gas Temperature	800 ± 20°C
Excess Air	10%
Natural Gas/Fuel Oil.	
Dimension (mXmXm)	3X3.66X9.6
Tubes Diameter	
Internal	10.16 cm
Outside	11.43 cm

Lobo Method Calculations (17), (22) and (23)

The following calculations are as Lobo (17) but with few modifications introduced by Kern (23). The modifications are indicated.

View Factor

Fig. 19.11 (15) or (23) or

$$S = \frac{\text{Pitch}}{\text{Diameter}} \qquad /1/$$

$$F = 1 + \frac{1}{S} \left| \tan^{-1}(S^2-1) - (S^2-1)^{\frac{1}{2}} \right| \qquad /2/$$

S	1.75	2.00
F	0.73	0.65

Effectiveness Factor As (23) instead of (17)

$$\alpha = F\ (2-F) \qquad /3/$$

α	0.927	0.8775

Area Ratio

$$AT = Ar + \alpha.Acp \qquad /4/$$

$R = \frac{Ar}{\alpha.Acp}$	1.517	1.659	/4a/

Refractory View Factor As (23) instead of (17)

0 <	R	<	0.5	$Frc,1 = 1/R + 1$	/5/
0.5 <	R	<	4	Interpolate	/6/
4 <	R	<	7	$Frc,1 = 1/R$	/7/

Frc,1	0.473	0.408

Beam Length

$$L = \frac{2}{3}\ (\text{VOLUME})^{\frac{1}{3}} = \frac{2}{3}\ (\text{DIMENSIONS})^{\frac{1}{3}} \qquad /8/$$

DIMENSIONS (m x m x m)	3 x 3 x 9	3 x 3.66 x 9.6
L m(ft)	2.88(9.46)	3.14(10.32)

Partial Pressures

The partial pressure was assumed to be similar to the composition of wet waste gas for heavy fuel oil (31)

$H_{20} = 10.2\%$; $CO_2 = 13\%$

$P_w = 10.2$ atm Pc= k3 atm

Pressure -Beam Length Term /9/

PwL (atm ft)	0.96	1.05
PcL (atm ft)	1.23	1.34

Surface and Gases Tempèrature

Duct Temperature °C(°K):Tg	820(1093)	780(1053)
Average Tube Wall Temperature °C(°K):Ts		200(473)

Flue Gas Emissivity As (22) instead of (17) or (23)

(°K) Ts=473;	Tg= 1100	1053
$Ec_{(PcL)}$ 0.14	0.16	0.17
$Ew_{(PwL)}$ 0.30	0.21	0.23

$$Eg = \frac{(Ec + Ew)^{at\ Tg}\ Tg^4 - (Ec + Ew)^{at\ Ts}\ Ts^4}{Tg^4 - Tg^4} \quad /10/$$

Eg	0.338	0.366

Furnace Emissivity

$$Ef = Eg \left| 1 + \left(\frac{Ar}{Acp}\right) \left(\frac{1}{1 + \left(\frac{Eg}{1-Eg}\right)\frac{1}{Frc}}\right) \right| \quad /11/$$

Ef	0.587	0.616

Tube Emissivity E = 0.8

Overall Exchange Factor

$$Feo = \frac{1}{\frac{1}{Eg} + \frac{1}{E} + 1} \qquad /12/$$

Feo	0.512	0.534

Total Heat Absorption Rate (Q = 3080Kw)

$$Q = \gamma .Acp.Feo.\left| 5.67X10^{-11}(Tg^4 - Ts^4) + 0.04(Tg - Ts) \right| \qquad /13/$$

$$Error = \frac{70 - Acp}{70} \times 100 \qquad /13a/$$

	t= 820°C(S=1.75)	t=780°C(S=2)
DIMENSIONS	3 x 3 x 9	3 x 3.66 x 9.6
Acp(m^2)	64(-9%)	74(6%)
Acp at 780°C (S = 2)		$74m^2$ (6%)

Wimpress Method Calculations (20)

Effectiveness Factor Fig.2 (20) or (15)

S	1.75	2.00
F/α	0.73	0.65

Area Ratio

DIMENSIONS (m x m x m)	3 x 3 x 9	3.66 x 3 x 9.6	
Ae (m^2)	126	150	
Acp (m^2)	54	70	
$\frac{\alpha \, Acp}{Ae}$	0.31	0.30	/14/

Beam Length

L = 3.6 V/Ae = 3.6 (DIMENSIONS)/Ae

L(m)	2.31	3.27

Partial Pressures Fig.3 (20)

10% Excess Air

Pc+w = Pw + Pc = 2Pw /15/

	Oil	Gas
Pc + w:	0.28	0.26

Pressure - Beam Length Term

PL =	0.65	0.62

Gas Emissivity Fig. 4 (20) (PL & $\frac{\alpha . Acp}{Ae}$)

$Eg_{(1073°k)}$	0.44	0.46
$Eg_{(973°k)}$	0.46	0.47

<u>Overall Exchange Factor</u> Fig.5 (20)

$Feo_{(1073°k)}$	0.715	0.725
$Feo_{(973°k)}$	0.725	0.735

<u>Total Heat Absorption Rate</u> Fig.6 (20) Ts = 200°C

$\left(\frac{Q}{\alpha . Acp\ Feo} \right)_{1073°k}$	85000
$\left(\frac{Q}{\alpha . Ac\ Feo} \right)_{973°k}$	60000

<u>Cold Plane</u> (Q absorbed = 2.65 MK cal/h)

$\alpha . Feo . Acp_{(1073°k)}$	31.13
$\alpha . Feo . Acp_{(973°k)}$	44.1

For$_1$ Gas/Fuel Oil

$\alpha . Acp_{(1073°k)}$	43.25
$\alpha . Acp_{(973°k)}$	60.5

S	1.75	2
$Acp_{(1073°k)}$	59(-16%)	67(-4%)
$Acp_{(973°k)}$	83 (18%)	93 (33%)

$$\% \text{ Error} = \frac{70 - Acp}{70} \times 100 \qquad /13a/$$

Acp at 800°C (S = 2) = 67 m^2 (-4%)

Note: The figure numbers in this section refer to those in Wimpress' publication.

Hottel Method Calculation (19)

View Factor

$S = 2$

$$F_{11} = \frac{\sin^{-1}(1/S) + (S - 1)^{-\frac{1}{2}} - S}{\pi} \qquad /16/$$

$F_{11} = 0.0184$

$F_{11} + F_{12} + F_{13} = 1 \qquad F_{12} = F_{13} \qquad /17/$

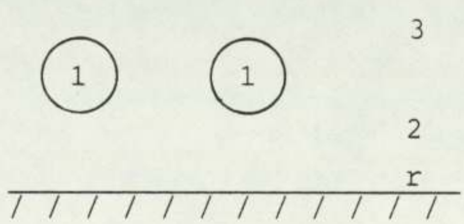
$F_{12} = 0.72$

$F_{12} \cdot A_1 = F_{21} \cdot A_2 \qquad /18/$

$A_1 = D.Lt \qquad A_2 = P.Lt = Ar \qquad /19/$

$F_{21} = 1.13 \qquad F_{21} = F_{r1} \qquad /20/$

$F_{r1} = 1.13 \qquad \frac{Ar}{A_1} = \frac{2}{\pi} = 0.64 \qquad /21/$



1: Tubes

2 & 3: Tube Borders

r: Refractory

Fig. 5B Furnace Partition

Mean Beam Length (See Wimpress' Calculations)

$$Lm = 3.6 \frac{(Volume)}{Ae}$$

DIMENSIONS	3 x 3.66 x 9.6
L(m)	2.37

Partial Pressures 10% Excess Air

	$CH_4 + 2O_2 =$	CO_2 +	$2H_2O$ +	N_2	Total
Final Moles		1	2	7.53	10.53
(10% Excess Air)	0.2	1	2	8.28	11.48
Composition (%)	1.7	8.7	17.4	72.1	

$Pc + Pw = 3Pc = 3(8.7) = 0.261$ atm /22/

Surface and Gases Temperature

Tube Temperature $T_1 = \frac{To^5 - Ti^5}{5(To - Ti)}$ /23/

BP Eng. Practice tsurface = tfluid + 15°C /24/

$T_1 = 456°K$; $Tg = 1073°K$ $Tg_1 = \frac{T1 + Tg}{2}$ /25/

$Tg_1 = 889°K$ $k = \frac{Tg1}{T_1}$ /26/

$k = 1.71$ Temp. Correction: $\frac{1 - k^3}{1 - k^4} = 0.53$ /27/

<u>Gas Emissivity</u> (19) & (29)

$r = Pc + w.L$ /28/

For PcLm 0.206 and 0.412 $\therefore$ r = 0.618 and 1.236

$y = f1\ (r)$ and $z = f2\ (PcL)$ /29/

$Eg = y(z - Tg)/10^5$ /30/

<u>Weighting Factor (Gray Components)</u>

$Eg = a_1 \times [1 - \exp(-k_1 L)]$ /31/

a_1 and k_1 can be found from 2 values of Eg so, let us say L = Lm and L = 2Lm.

$$\text{In}(1 - \frac{Eg}{a_1}) = -K_1 Lm$$

$$\text{In}(1 - \frac{Eg_2}{A_1}) = -2k_1 Lm$$

$$1 - \frac{Eg_2}{a_1} = (1 - \frac{Eg}{a_1})^2$$

$$a_1 = \frac{Eg^2}{2Eg - Eg_2}$$ /32/

For PcLm 0.244 and 0.488 $\therefore$ z = 3000

For r 0.618 and 1.236 $\therefore$ y = 18.3 and 20.70

So Eg = 0.347 and Eg_2 = 0.393

$$a_1 = 0.400$$

Radiactive Properties of Combustion Product (19) and (29)

CH_4 fuel

$z = 2700$ for $PcL < 0.15$

$z = 3000$ for $0.15 < PcL < 0.3$

Oil fuel

$z = 2700$ for $PcL < 0.25$

$z = 3000$ for $0.25 < pcL < 0.5$

Values of y corresponding to z = 3000

	r = 0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.04
For CH_4	y = 12	14.1	15.6	17	18	18.9	19.6	20.2	20.4	20.5
For Oil	y = 11.1	13	14.2	15.4	16.8	17.9	18.7	19.3	19.8	

Values of y corresponding to z = 2700

	r =	0.15	.02	.03	.04	.05	.06	.07	.08	.09
For CH_4	y	5.3	5	6.1	7.1	7.9	8.5	9.1	9.5	10.2
For Oil	y	4.9	4.6	5.7	6.7	7.4	7.9	8.5	9.0	9.6

	r	.1	.15	.2	.3	.4	.5
For CH_4	y	10.8	12.5	14.3	16.8	18.7	20
For Oil	y	9.9	11	12.9	15.5	17.2	18.5

Area Ratio Tube Area to Direct Flux Area

$$\frac{A1}{(\bar{GS}_1)_r} = \frac{1 - E_1}{a_1 E_1} + \frac{1}{Eg\left(1 + \frac{Ar/A1}{1 + Eg/(a_1 - Eg)F_{r1}}\right)} \qquad /33/$$

Area ratio (evaluated as above): 2.99(1/0.335)

Area ratio (evaluated without a_1): 2.22 (1/0.451)

Convection Effect (31) C.G.S. Units

$$h_1 = 0.023 \frac{k}{\bar{W}} \cdot Re^{0.8} \cdot Pr^{0.4} \qquad /34/$$

$k = 1.29\ 10^{-4}$; $W = 14.5$; $Re = 4290$; $Pr = 0.84$

$h_1 = 5.36\ 10^{6}$

$h_1\ (\frac{Kw}{m^{\circ}k})$	0.013	0.017 (17)

Overall Average Radiative Flux to Tubes

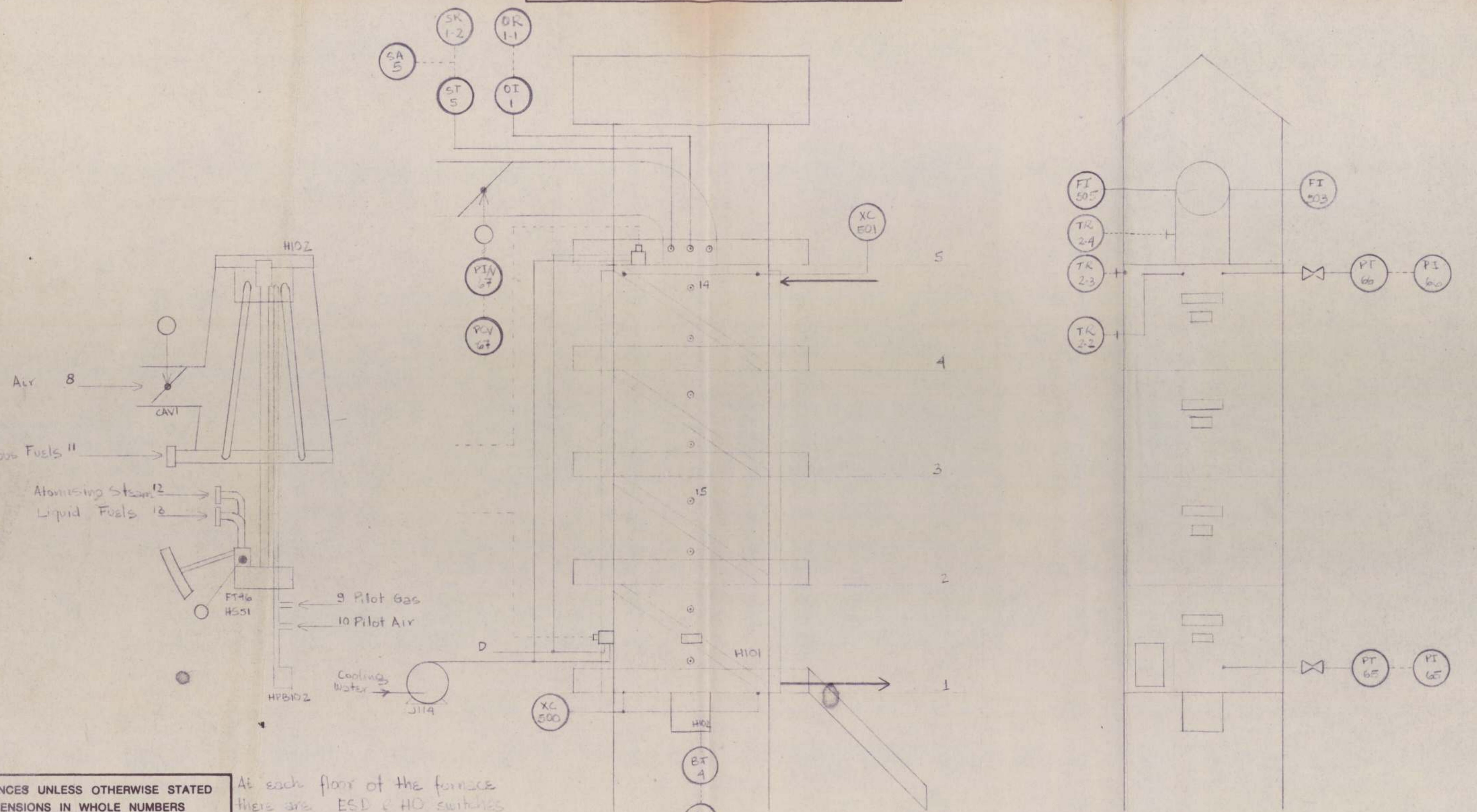
$$\frac{Q_g - L}{A_1} = \left| \frac{(G\bar{S}_1)_r}{A_1} \cdot \frac{1 - k^3}{1 - k^4} + \frac{h_1}{4 . \sigma . T_{g1}^{3}} \right| (T_g^{4} - T_1^{4}) \qquad /35/$$

$$A_1 = 38.21 \div \left| \frac{(G\bar{S}_1)_r}{A_1} \cdot \frac{1 - k^3}{1 - k^4} + \frac{h_1}{0.1068} \right|$$

$$\text{Error} = \frac{110 - A_1}{110} \times 100 \qquad /35a/$$

h	0.013	0.017 (17)
A_1	128 (16%)	114 (4%)
A_1 (without a_1)	103 (-6%)	94 (-16%)
A_{tubes} at 800°C (S = 2) =		112 m^2 (4%)

THIRD ANGLE PROJECTION



TOLERANCES UNLESS OTHERWISE STATED		
DIMENSIONS IN WHOLE NUMBERS		
UP TO	300	± 0,5
300 TO	1000	± 1,0
OVER	1000	± 1,5
DIMENSIONS IN DECIMALS		± 0,15

At each floor of the furnace there are ESD & HO switches in addition to water, steam and electrical (120V & 240V) points.

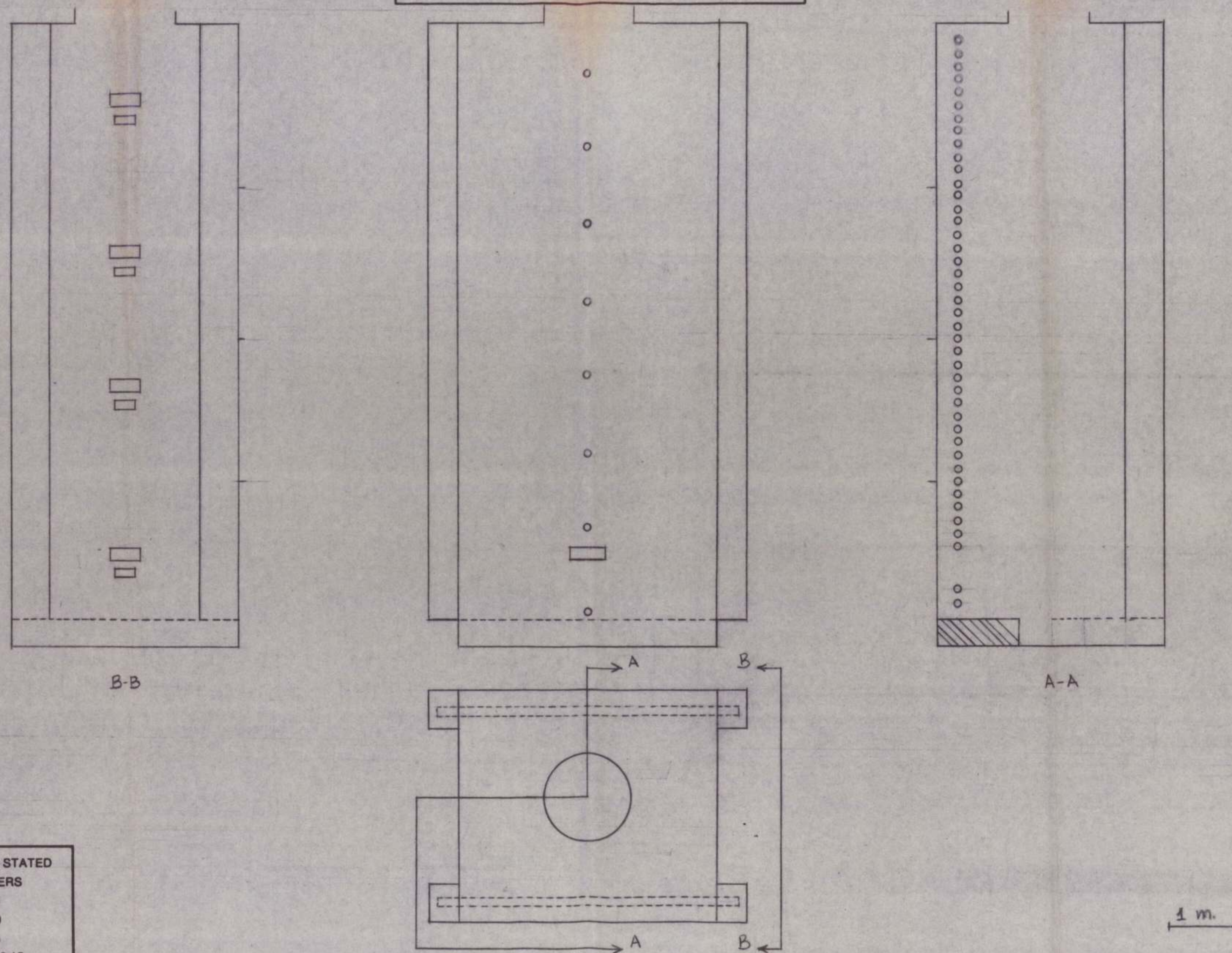
ALL DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE STATED	DRAWN	CHECKED	DES. ENG.	APPROVED	ENG. I/C. D.O.	SCALE	ISSUE	DATE	THE EFFECT OF PLANT SPECIFICATION ON THE DESIGN, INSTALLATION AND COMMISSIONING OF REFINERY PROCESS HEATERS J R BOLIVAR, OCTUBRE 1983 MODIFICATION	DR'N

BP RESEARCH CENTRE
SUNBURY-ON-THAMES

TITLE: FURNACE SYSTEM

APPENDIX 8
DRG. No. D.1A

THIRD ANGLE PROJECTION



TOLERANCES UNLESS OTHERWISE STATED
DIMENSIONS IN WHOLE NUMBERS

UP TO	300	± 0,5
300 TO	1000	± 1,0
OVER	1000	± 1,5

DIMENSIONS IN DECIMALS ± 0,15

ALL DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE STATED

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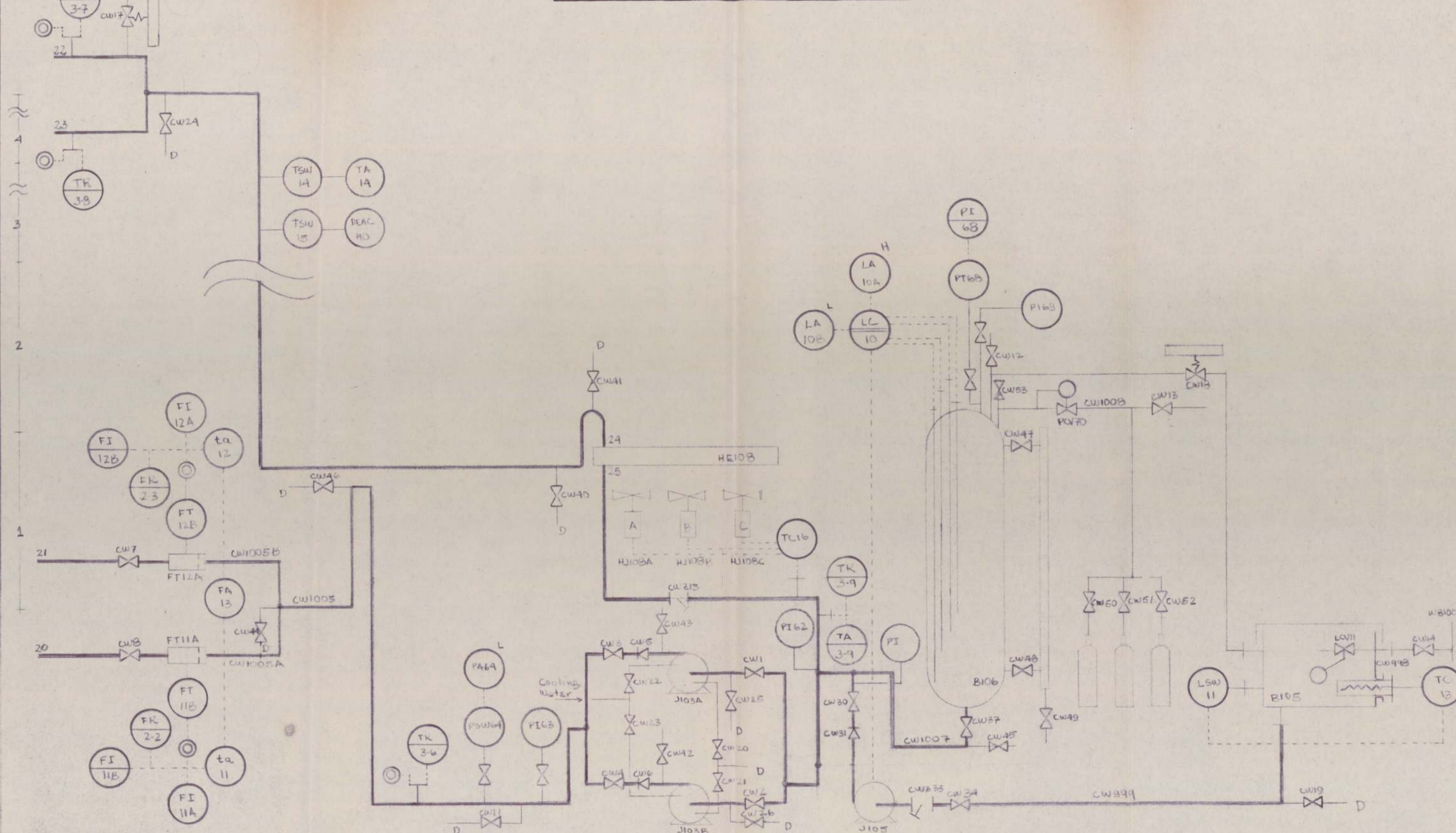
TITLE FURNACE (DETAILED DRAWING)

APPENDIX 8
DRG. No. D-1A'

THIRD ANGLE PROJECTION



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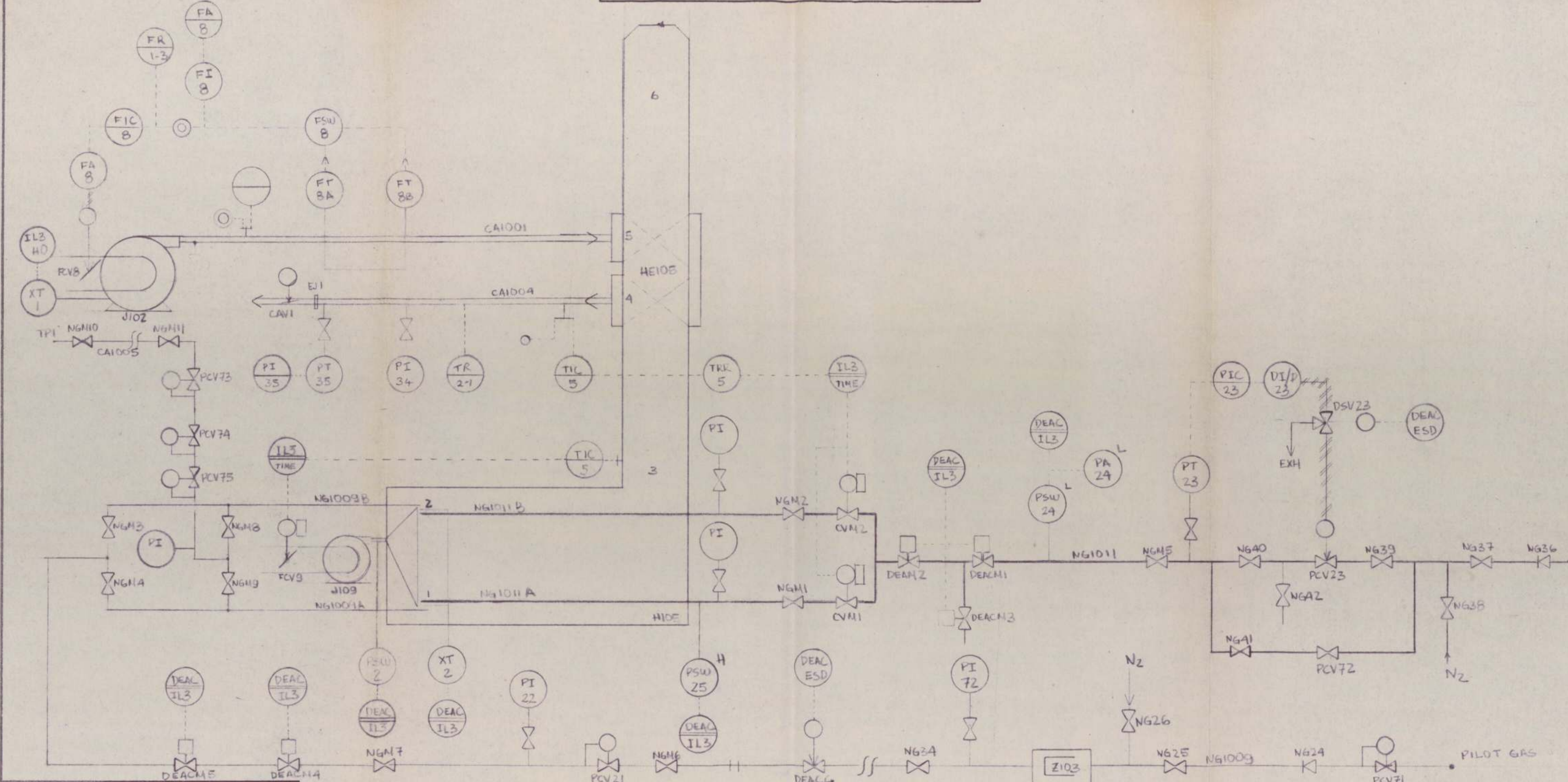
TITLE
COOLING WATER SYSTEM

DRG. No. D1B

THIRD ANGLE PROJECTION



TOLERANCES UNLESS OTHERWISE STATED		
DIMENSIONS IN WHOLE NUMBERS		
UP TO	300	± 0,5
300 TO	1000	± 1,0
OVER	1000	± 1,5
DIMENSIONS IN DECIMALS		± 0,15

ALL DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE STATED	DRAWN	CHECKED	DES. ENG.	APPROVED	ENG. I/C. D.O.	SCALE	ISSUE	DATE	THE EFFECT OF THE PLANT SPECIFICATION ON THE DESIGN, INSTALLATION AND COMMISSIONING OF REFINERY PROCESS HEATERS — JR BOLIVAR, OCTUBER 1983 MODIFICATION	DR'N

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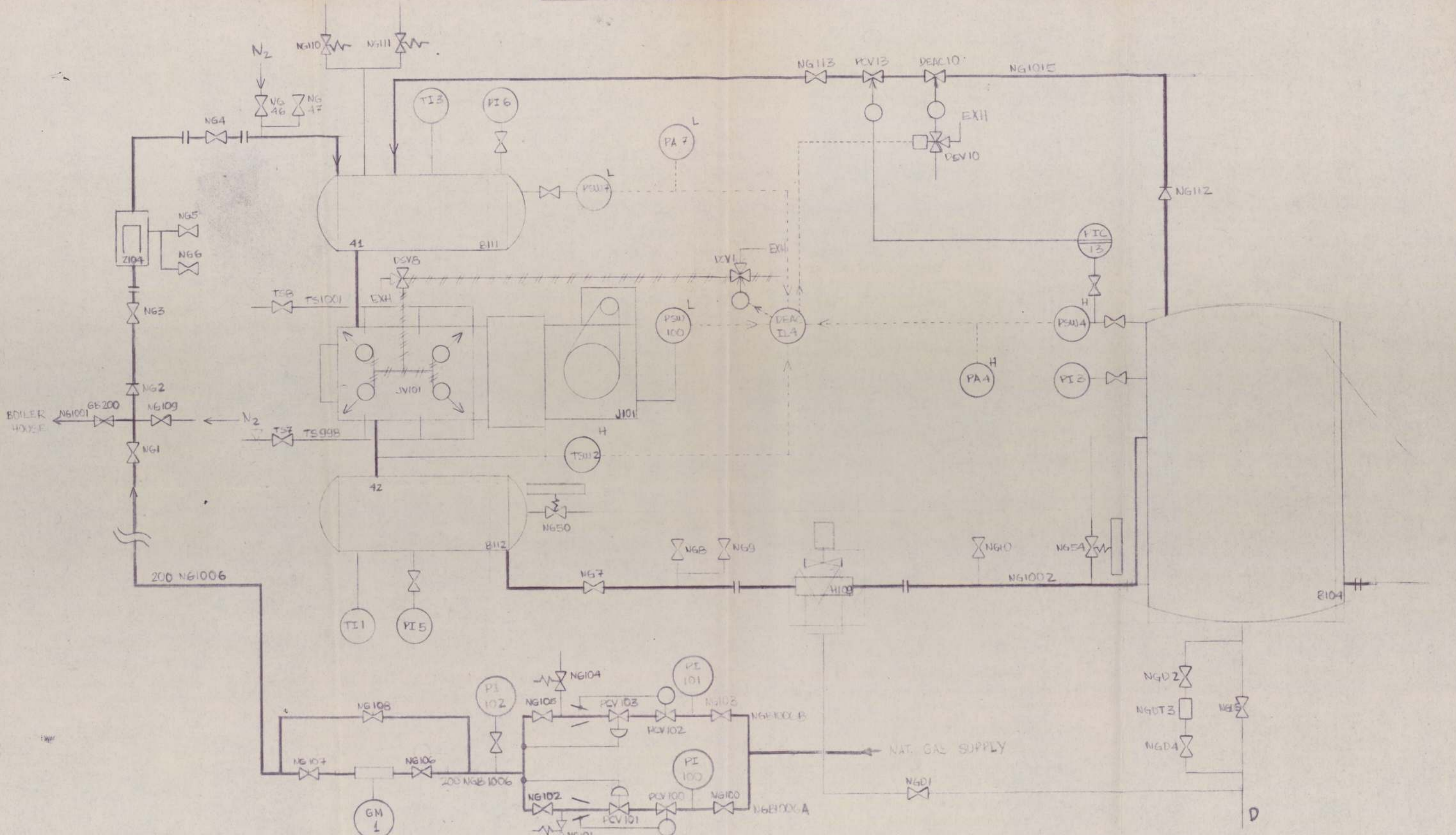
TITLE CONBUSTION AIR

DRG. No. D.2

THIRD ANGLE PROJECTION



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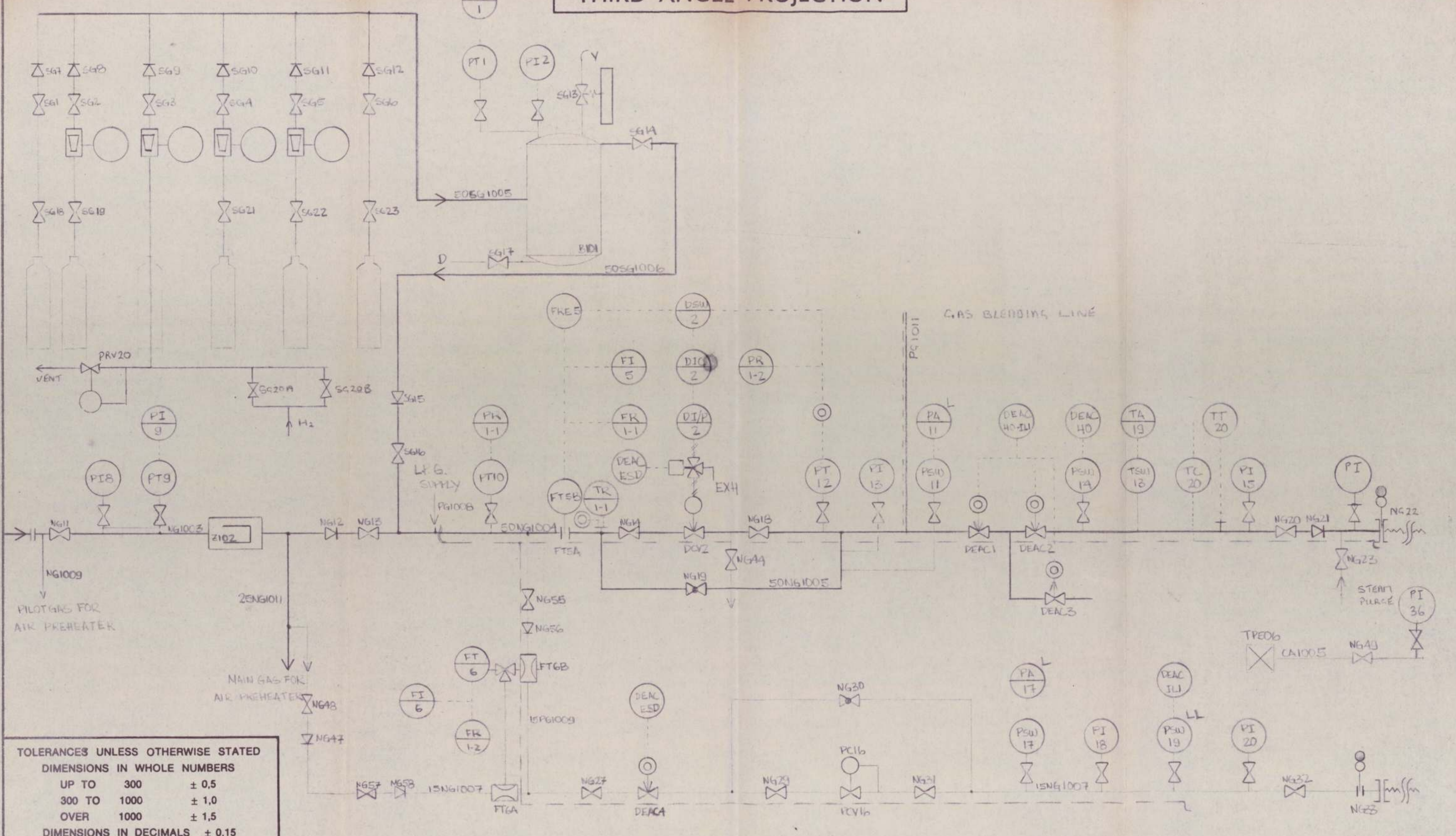
TITLE NATURAL GAS SUPPLY

DRG. No. D.3A

B7.

THIRD ANGLE PROJECTION



TOLERANCES UNLESS OTHERWISE STATED		
DIMENSIONS IN WHOLE NUMBERS		
UP TO	300	± 0,5
300 TO	1000	± 1,0
OVER	1000	± 1,5
DIMENSIONS IN DECIMALS		± 0,15

ALL DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE STATED

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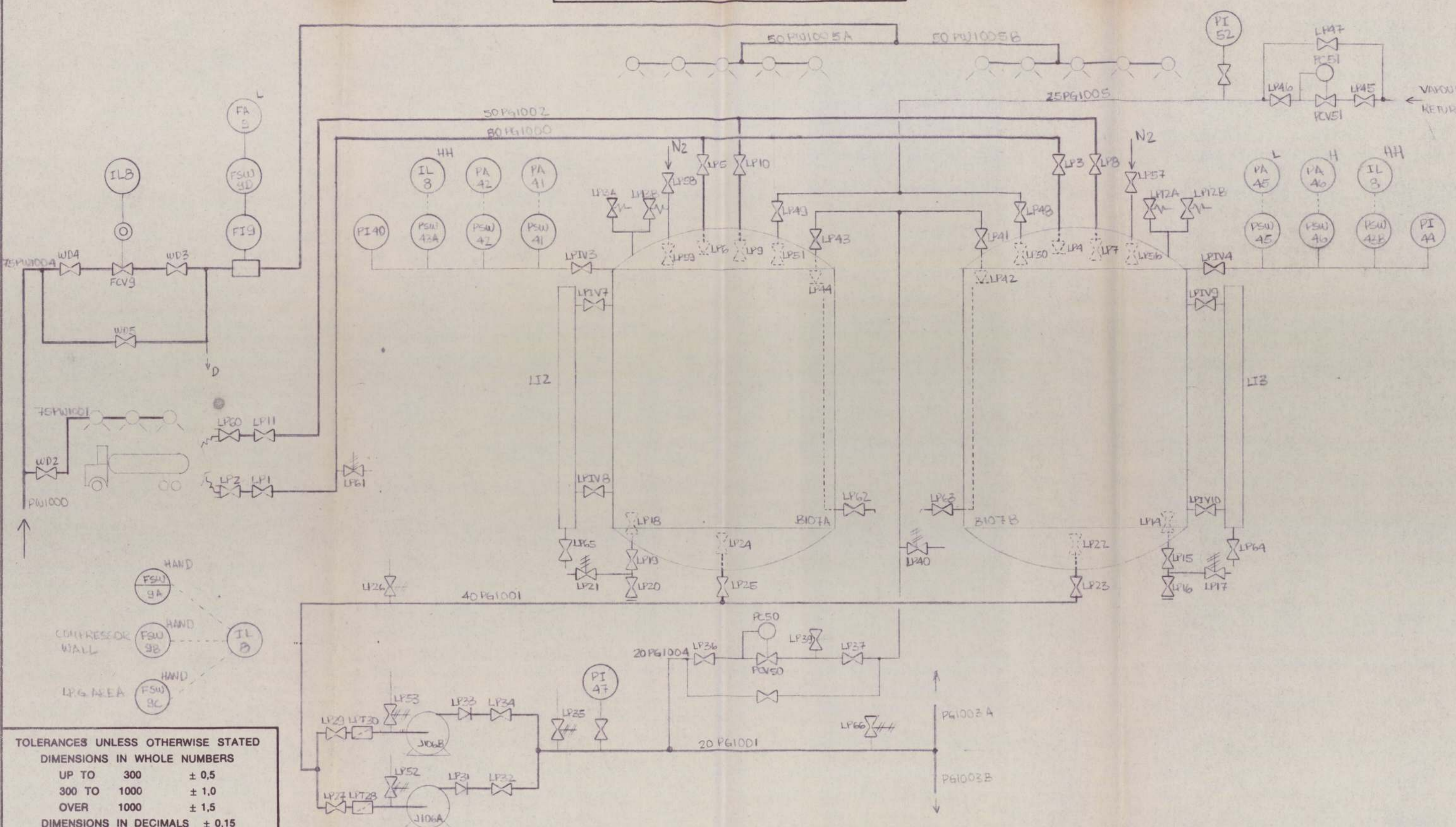
TITLE MAIN AND PILOT GAS LINES TO FURNACE + CONTAMINANT GAS LINES

APPENDIX 8
DRG. No. D3B

3B

THIRD ANGLE PROJECTION



TOLERANCES UNLESS OTHERWISE STATED		
DIMENSIONS IN WHOLE NUMBERS		
UP TO	300	± 0,5
300 TO	1000	± 1,0
OVER	1000	± 1,5
DIMENSIONS IN DECIMALS		± 0,15

ALL DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE STATED

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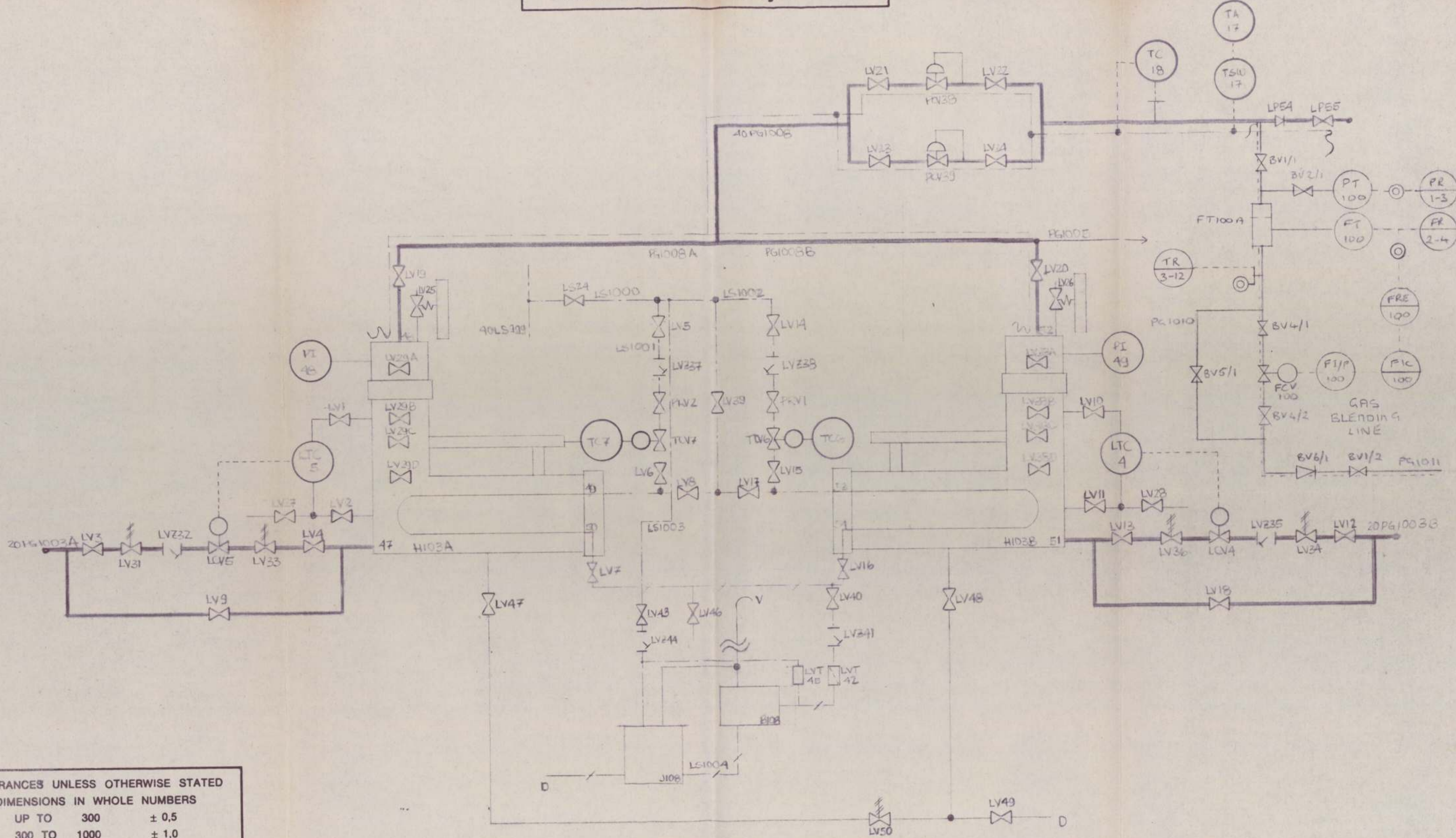
TITLE
LPG. TANKS AND PUMPS

APPENDIX 8
DRG. No. D 4A

THIRD ANGLE PROJECTION



TOLERANCES UNLESS OTHERWISE STATED		
DIMENSIONS IN WHOLE NUMBERS		
UP TO	300	± 0,5
300 TO	1000	± 1,0
OVER	1000	± 1,5
DIMENSIONS IN DECIMALS		± 0,15

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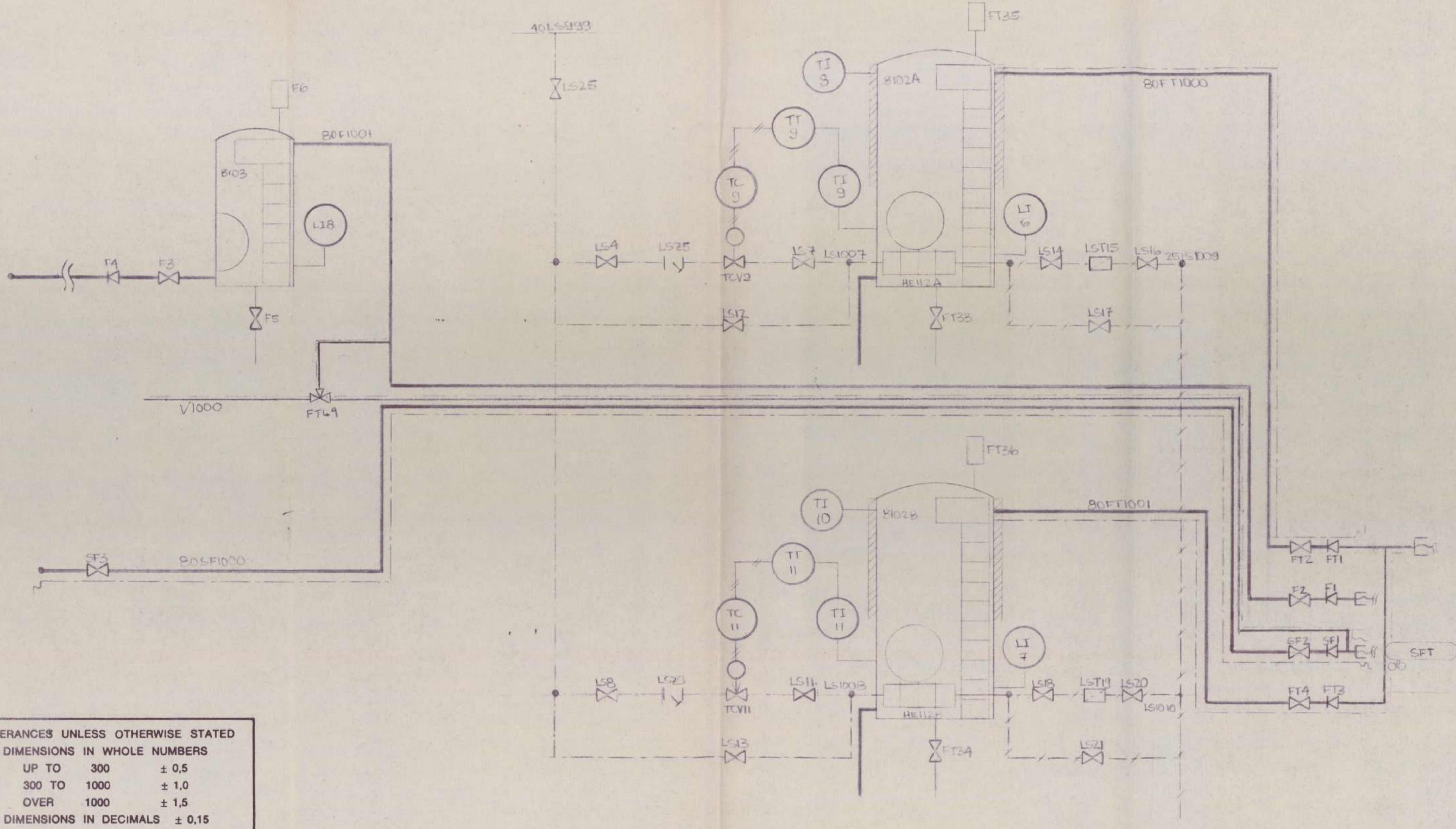
TITLE L. P. G. EVAPORATORS

DRG. No. D4B

10

THIRD ANGLE PROJECTION



TOLERANCES UNLESS OTHERWISE STATED
DIMENSIONS IN WHOLE NUMBERS

UP TO	300	± 0,5
300 TO	1000	± 1,0
OVER	1000	± 1,5

DIMENSIONS IN DECIMALS ± 0,15

ALL DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE STATED

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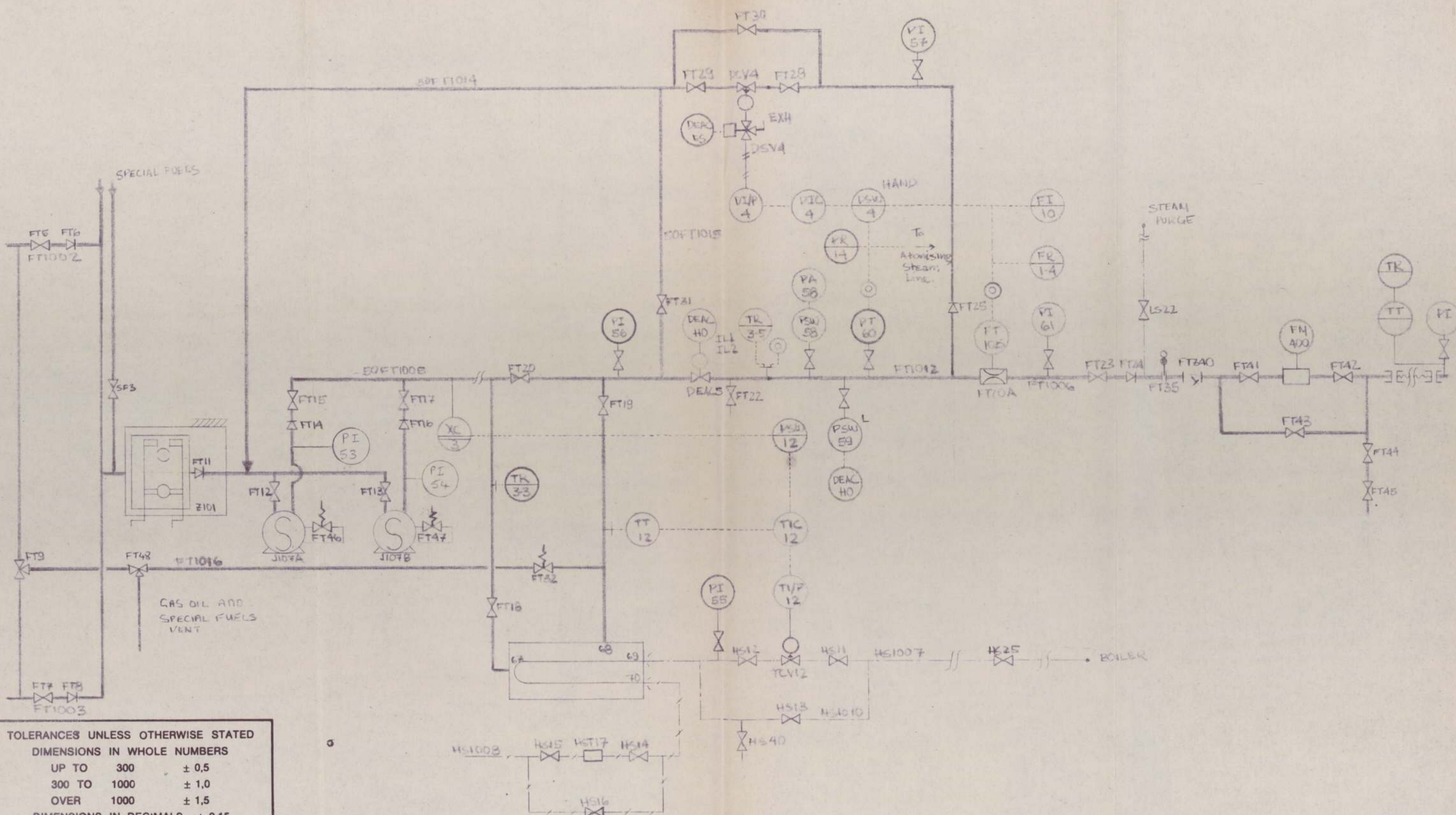
TITLE
DELIVERY LINES AND TANKS OF LIQUID FUELS

APPENDIX 8
DRG. No. D5A

5A

THIRD ANGLE PROJECTION



TOLERANCES UNLESS OTHERWISE STATED	
DIMENSIONS IN WHOLE NUMBERS	
UP TO 300	± 0,5
300 TO 1000	± 1,0
OVER 1000	± 1,5
DIMENSIONS IN DECIMALS	± 0,15

ALL DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE STATED	DRAWN	CHECKED	DES. ENG.	APPROVED	ENG. I/C. D.O.	SCALE	ISSUE	DATE	MODIFICATION	DR'N
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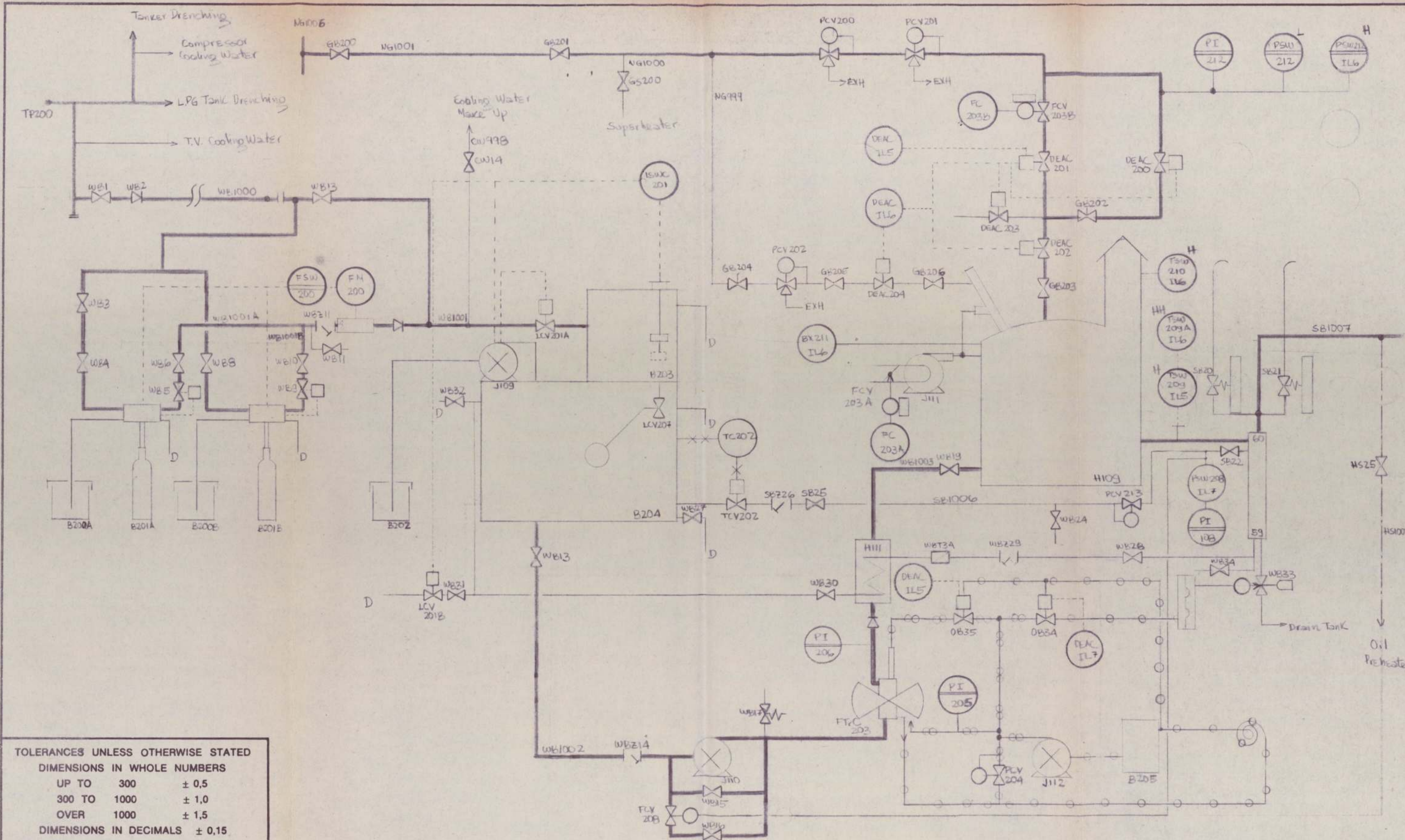
TITLE OIL LINES TO FURNACE

APPENDIX 8
DRG. No. D.5B



TOLERANCES UNLESS OTHERWISE STATED
DIMENSIONS IN WHOLE NUMBERS

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300 TO	1000	± 1,0
OVER	1000	± 1,5
DIMENSIONS IN DECIMALS		± 0,15

ALL DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE STATED

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BP RESEARCH CENTRE
SUNBURY-ON-THAMES

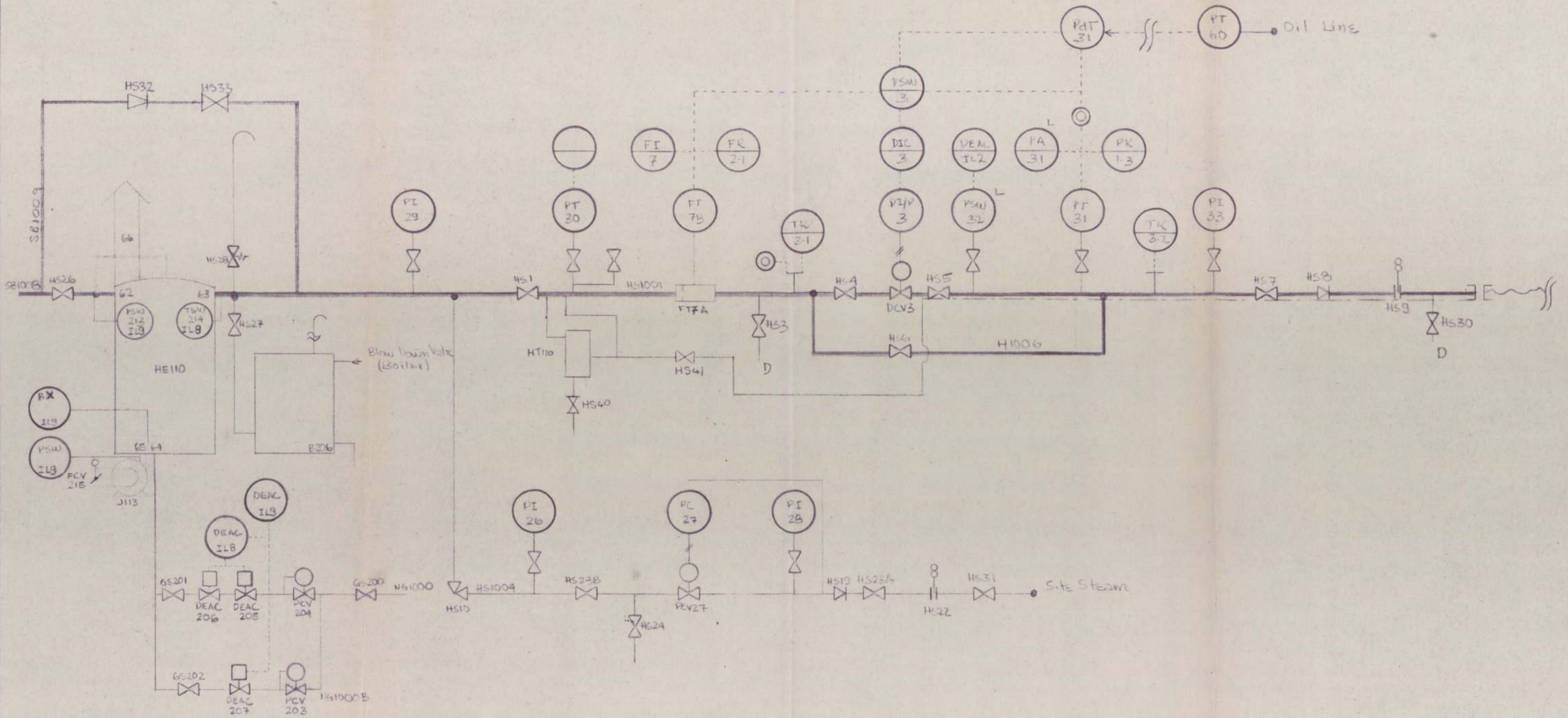
TITLE: STEAM GENERATOR (SOFTENER & BOILER)

APPENDIX 8
DRG. No. D6A

6A

13

THIRD ANGLE PROJECTION



TOLERANCES UNLESS OTHERWISE STATED		
DIMENSIONS IN WHOLE NUMBERS		
UP TO	300	± 0,5
300 TO	1000	± 1,0
OVER	1000	± 1,5
DIMENSIONS IN DECIMALS		± 0,15

ALL DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE STATED

DRAWN	CHECKED	DES. ENG.	APPROVED	ENG. I/C. D.O.	SCALE

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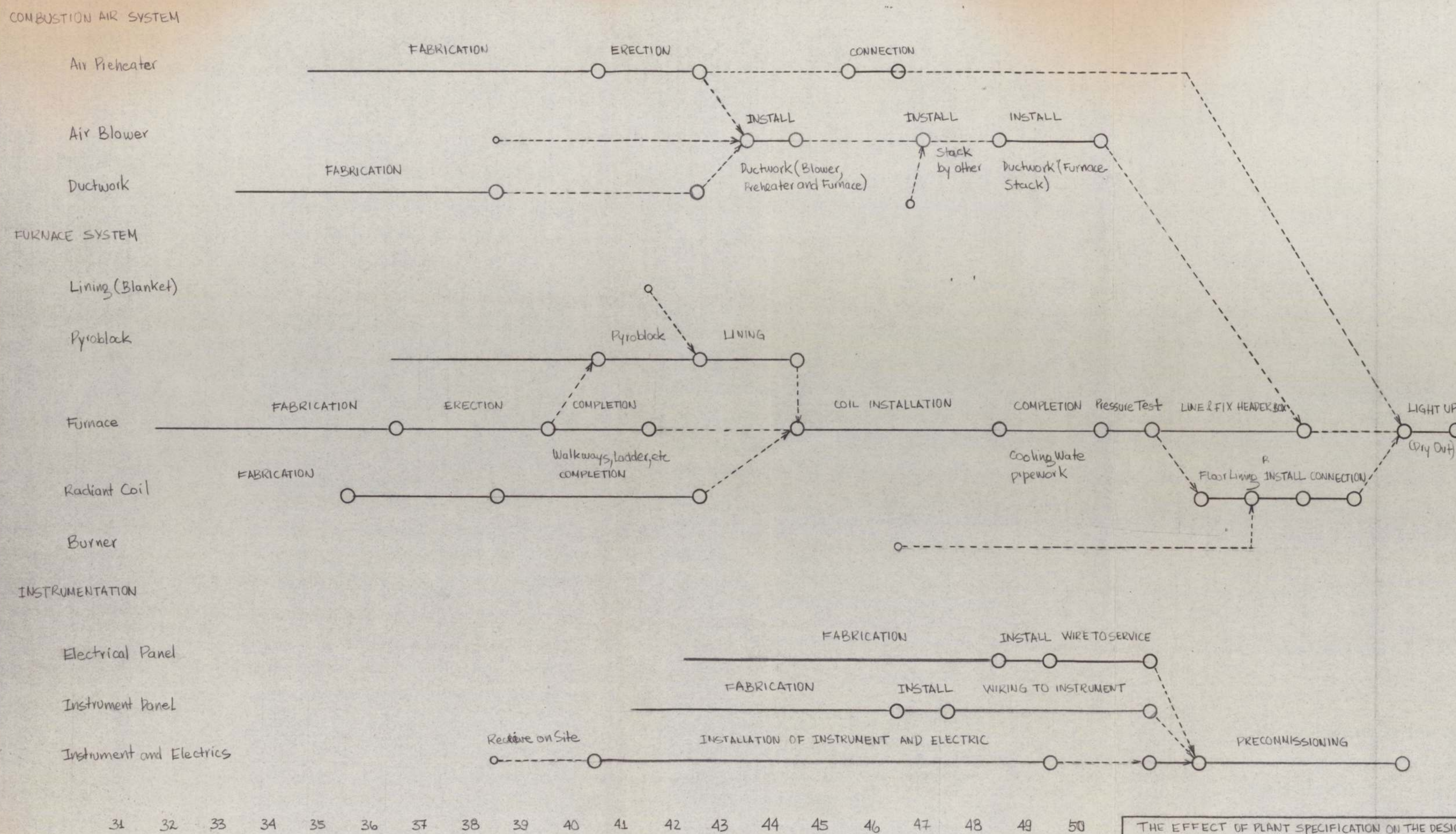
TITLE SUPERHEATED STEAM

APPENDIX 8
DRG. No. D 6B

APPENDIX 6

PLANNING DOCUMENTS (Diagrams)



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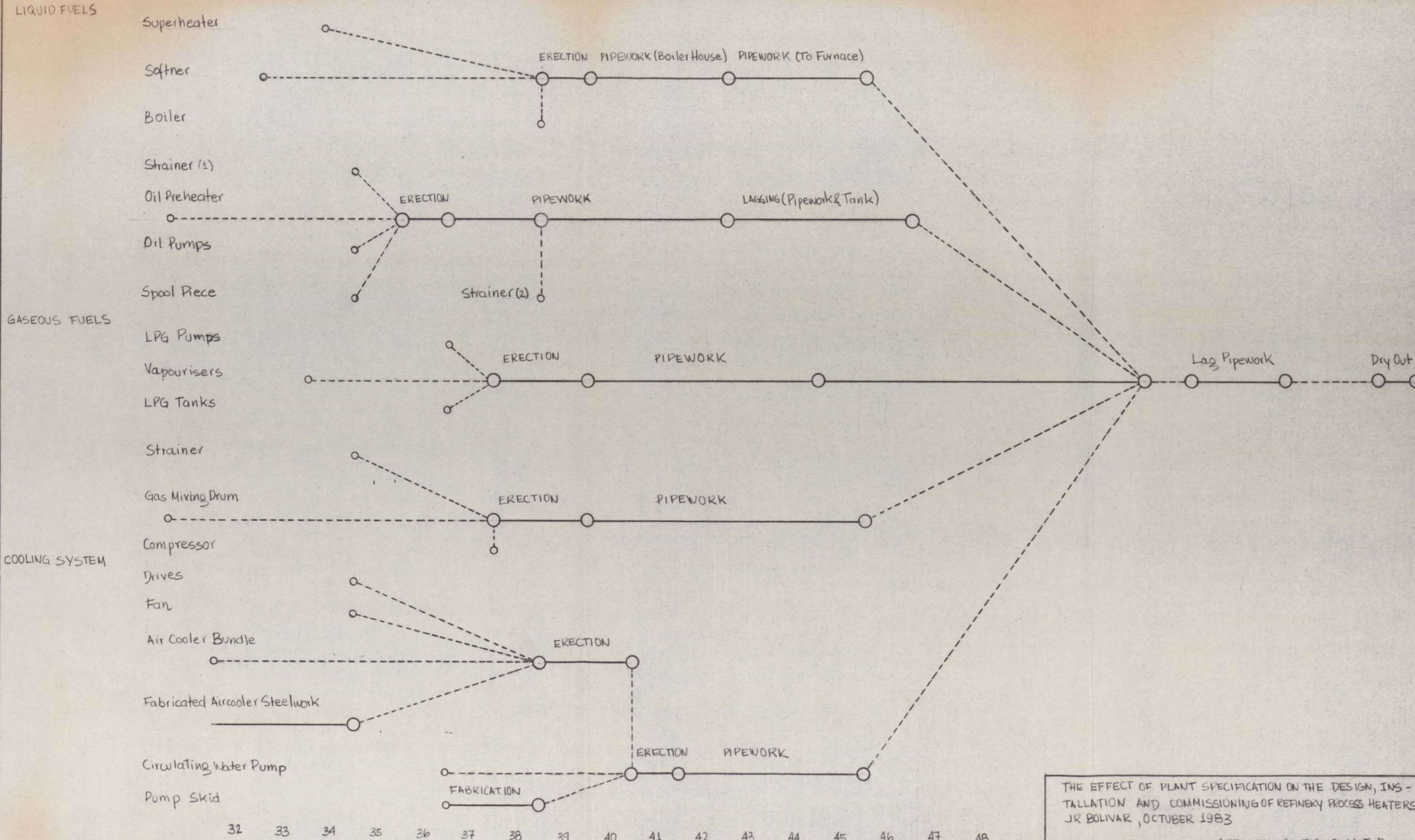
APPENDIX 6 FIGURE 3.11.5A
Furnace and Combustion Air



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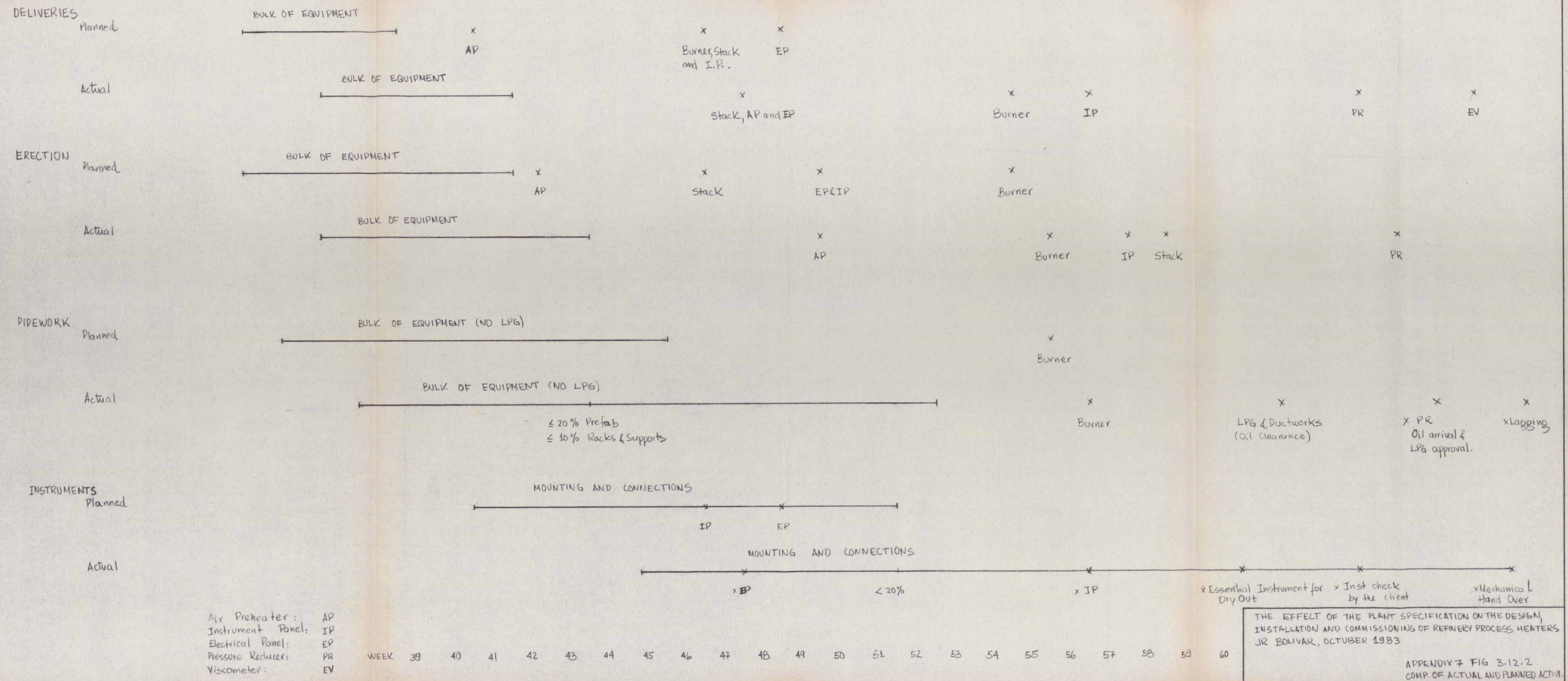
APPENDIX 6 FIG. 3-11.5.B
COOLING SYSTEM AND GASEOUS AND LIQUID FUELS SYSTEM

APPENDIX 7

ACTUAL WORK ACTIVITIES DIAGRAMS - COMPARISON

Fig. 3.1.4.1.A &B	Civil Work Progress.
Fig. 3.1.4.1A	Civil Work Schedule.
Fig. 3.1.4.1B	Actual Civil Work Progress.
Fig. 3.2.1	Promised and Actual Deliveries.
Fig. 3.11.1.A,B & C.	Actual Network Diagram.
Fig. 3.11.1A	Furnace, Cooling Water, and Combustion Air Systems.
Fig. 3.11.1B	Gaseous Fuel Systems.
Fig. 3.11.1.C	Liquid Fuel Systems.
Fig. 3.12.2	Comparison of Actual and Planned Activities.



THE EFFECT OF THE PLANT SPECIFICATION ON THE DESIGN, INSTALLATION AND COMMISSIONING OF REFINERY PROCESS HEATERS
JR BOLIVAR, OCTUBER 1983

APPENDIX 7 FIG 3.12.2
COMP. OF ACTUAL AND PLANNED ACTIVI.

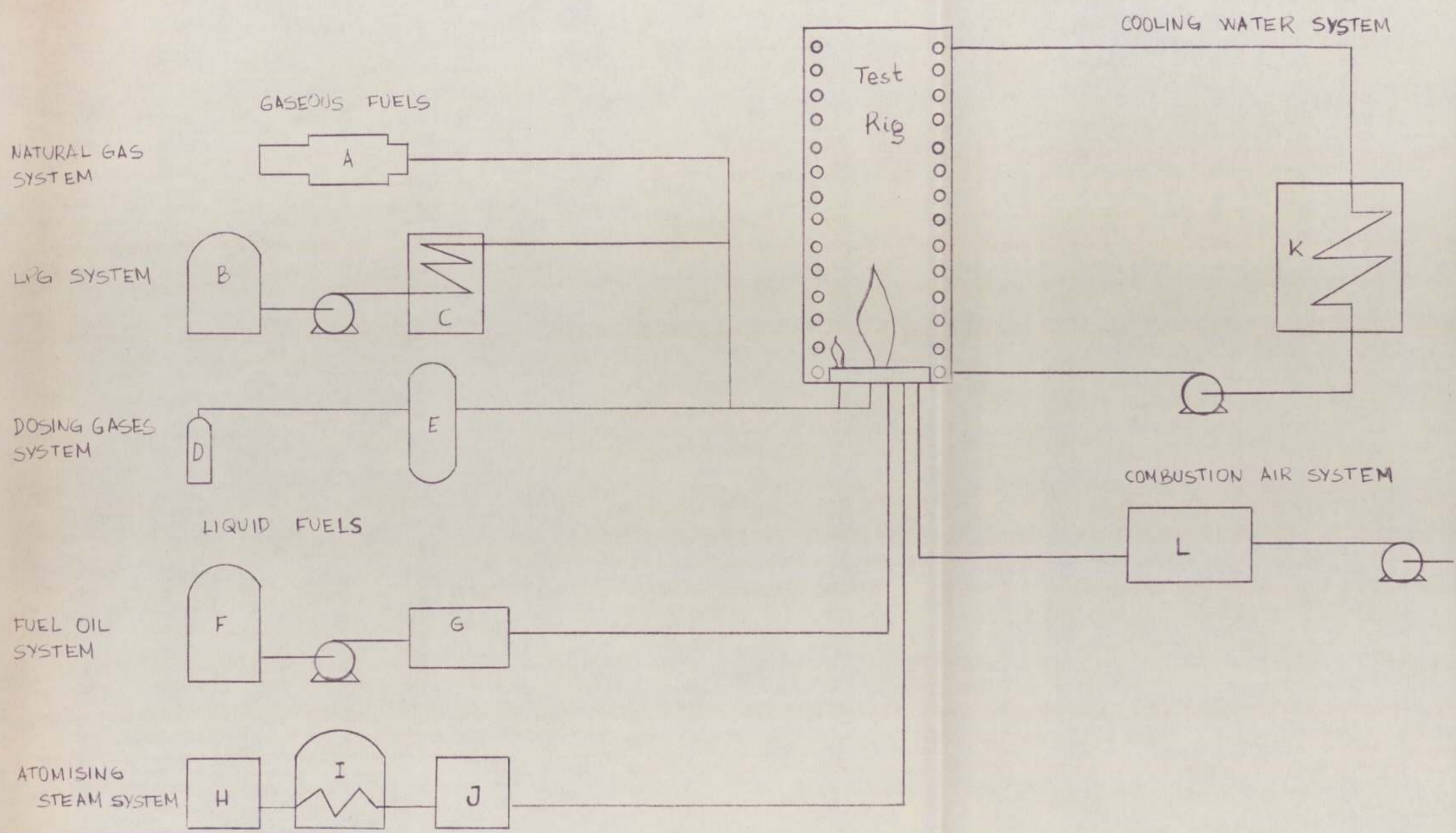
APPENDIX 8

ACTUAL FLOW DIAGRAMS

The modified Flow Diagrams based on the contractor P & I Diagram and with the required numbering for the operability study are presented on this appendix as follows:

D.1	Block Diagram
D.1A	Furnace System.
D.1B	Cooling Water System.
D.2	Combustion Air System.
D.3A & B	Natural Gas System.
D.3A	Natural Gas System - Natural Gas Expansion and Compression.
D.3B	Main and Pilot Natural Gas pipelines to Furnace and Dosing Gases pipelines.
D.4A & B	LPG System.
D.4A	LPG Tanks and Pumps.
D.4B	LPG Evaporators.
D.5A & B	Fuel Oil System.
D.5B	Fuel Oil Pipe Line to Furnace .
D.6A & B	Atomising Steam System.
D.6A	Softener and Boiler Unit.
D.6B	Superheated Steam Generator and Pipeline.

THIRD ANGLE PROJECTION



MAJOR EQUIPMENTS

A NATURAL GAS COMPRESSOR
B BUTANE STORAGE
C BUTANE VAPORISER
D DOSING GAS CYLINDERS
E MIXING DRUM
F FUEL OIL STORAGE
G FUEL OIL PREHEATER
H WATER TREATMENT PLANT
I STEAM RISING BOILER
J SUPERHEATER
K AIR COOLER HEAT EXCHANGER
L AIR PREHEATER

TOLERANCES UNLESS OTHERWISE STATED
DIMENSIONS IN WHOLE NUMBERS

UP TO	300	± 0,5
300 TO	1000	± 1,0
OVER	1000	± 1,5

DIMENSIONS IN DECIMALS ± 0,15

ALL DIMENSIONS IN MILLIMETRES UNLESS OTHERWISE STATED

DRAWN	CHECKED	DES. ENG.	APPROVED	ENG. I/C. D.O.	SCALE

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TITLE BLOCK DIAGRAM

APPENDIX 8
DRG. No. D