CHAPTER 4

TEST PREPARATION

4. TEST PREPARATION

4.1 TEST COAL SELECTION

4.1.1 Combustion variables:

The initial step in the preparation of these tests was the calculation of the coal qualities. It was found (Storm[2]) that with variations in coal quality, an unambiguous steam flow - air flow relationship could not be determined, at least not for Lethabo. The governing coal quality parameter in the above argument being the volatile content of the specific coal. It thus appears that different coal qualities could produce different air flow optima at different machine loads with thermal efficiency as criterion.

The ideal would have been to test as many varying coal qualities as possible, but the permutations thereof with representative loads and air flows would be too numerous. After thorough consideration it was decided to test three batches of coal. The Lethabo coal occurs in three seams as mentioned in Chapter 3.8. The top seam contains low volatile coal, but with a CV and inherent moisture more favourable than the middle seam, which contains coal with higher volatile matter. The bottom seam contains the highest grade coal concerning CV and volatiles. These coals will be referred to as low, spec. and high grade coal respectively. The anticipation was to test coals with as low, as close to specification and as high as possible qualities as far as safety and operational parameters would allow.

The second most important aspect to consider was the combustion variables as defined from a macroscopic plant performance approach. These parameters, as detailed below, contribute to retarded ignition, extended combustion time and a longer flame if their magnitude is unfavourable. This in turn causes the "heat release barrier" to rise. (The heat release barrier can be defined as the geometric centre of thermal gravity which indicates how high up in the furnace combustion is completed.) This results in metal temperature excursions of the platen and super heater tubes, and can also cause a high dry flue gas loss. At their extremes, unfavourable values of these parameters can lead to loss of ignition, or if they are too good, burner damage can occur due to too short a flame, with incorrect heat distribution for evaporation vs. super heating in both cases. These parameters are:

Unit loading:

This dominates most of the other parameters below as it is the most independent variable. Metal temperature excursions are more prone to happen at lower loads where there is the highest ratio of air flow to steam flow.

Total air flow quantity or percentage excess air:

More mass flow of combustion air tends to produce lower unburnt carbon in bottom ash and dust figures, although a higher dry flue gas loss is the inevitable consequence.

Air velocities (resulting from the air mass flow above):

Higher air velocities raise the heat release barrier.

Coal quality (especially volatile matter):

Lower volatile matter delays ignition and lengthens combustion time.

Moisture content of coal:

Higher moisture delays ignition and negatively influences combustion, resulting in lower flame temperatures due to the latent energy of vaporisation.

Secondary air register swirl setting:

This influences the shape of the recirculating zone and the length of the flame.

Secondary air temperature:

Higher air temperatures improve ignition and combustion.

Mill classifier vane setting:

This can reduce the pf fineness up to the limiting point, beyond which the mill throughput is jeopardised due to an excessive recirculating load.

Primary air temperature:

A higher temperature will improve grindability due to the increased drying power, but increases the risk of a mill fire or a pf explosion.

Primary air mass flow:

The higher the mill load, the coarser the pf fineness.

Pf fineness:

Coarser pf fineness causes increased burn out time and promotes less complete burn out (higher unburnt carbon in dust/ash figures).

Mill configuration and loading (PA flow):

Top mills in service cause a raised heat release barrier, while bottom mills contribute more to evaporation and the maintaining of drum pressure.

The state of affairs is thus as follows:

The total combustion air flow (or percentage excess air) was to be altered for each load selected, but this scenario was to be repeated for the different coal qualities. This effectively fixed or established each of the first five parameters listed above, since they were the variables to be tested. To ensure unambiguous results, it could not be allowed that the remaining parameters varied to an unacceptable degree. For this reason these variables were either set or kept constant (eg. air registers, classifier vanes etc.) or the natural reaction of the process allowed to establish a value of the specific parameter that would not upset this purpose (eg. air temperatures resulting from air heater performance).

A problem however was anticipated with pf fineness and the mill configuration and loading. If the pf fineness range and distribution vary greatly, the optimum air flow at each load for a specific coal quality could not be determined unambiguously. Since the one parameter (mill PA flow) determines the other (pf fineness), the method discussed below was adopted to obtain a mill combination and loading that ensured as constant as possible pf fineness, regardless the load and coal quality while catering for the other limitations mentioned as well.

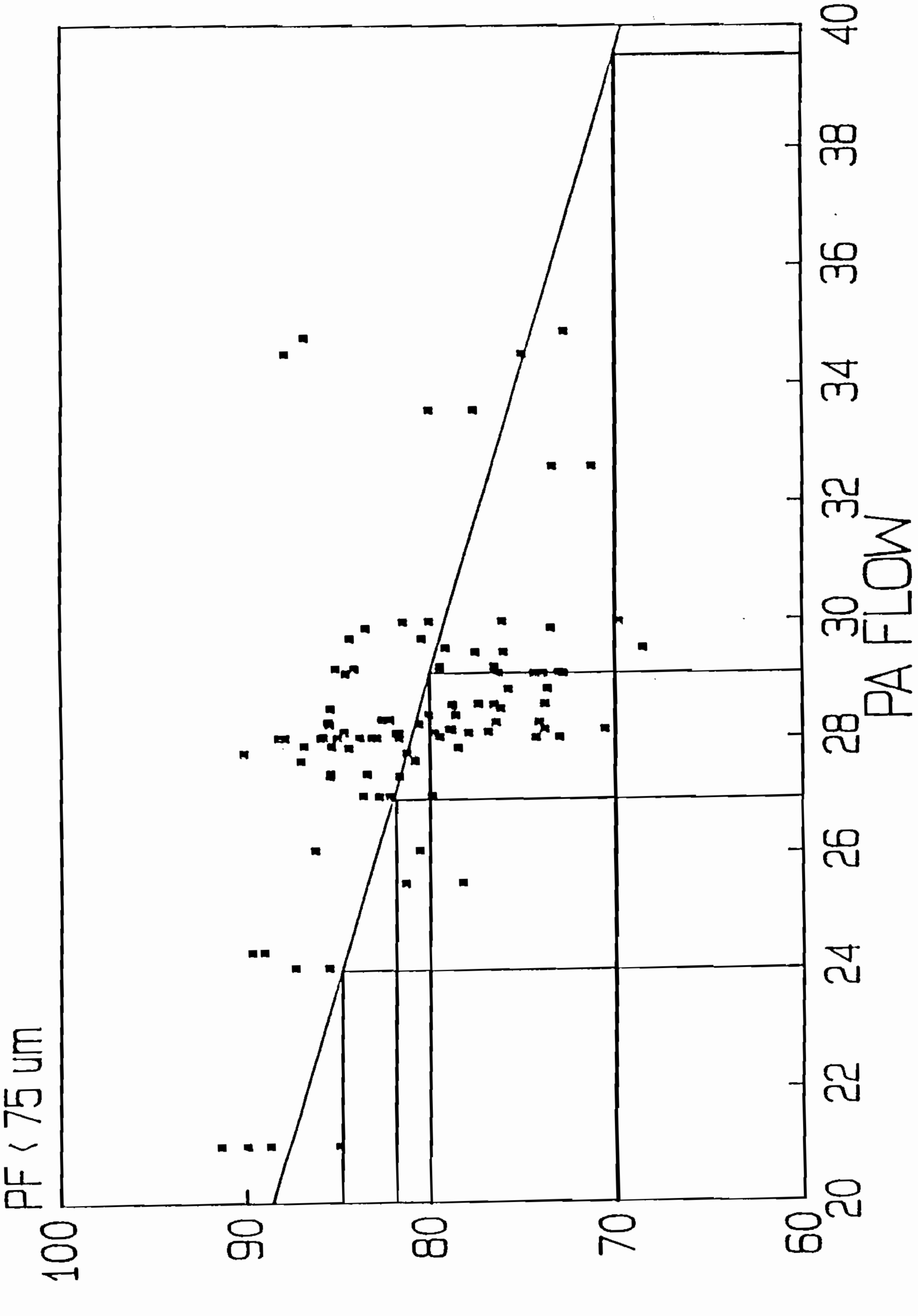
4.1.2 General Mechanism of Coal Quality Calculation:

Due to the number of possible combinations and the resulting repeated calculations, it was found best to utilise the services of a computer spreadsheet package to verify all the conditions and to calculate the coal qualities. A detailed explanation of the formulae and macros used in all the respective columns of these spreadsheets can be found in Appendices C, D and E, which cover the Low, High and Spec. (intermediate) grade coal qualities respectively. A more general explanation is given here to illustrate the philosophies used and goals achieved.

From an array of load percentages and equivalent final electrical energy output, boiler and accompanying mill loads (MW) were calculated backwards via estimations of overall unit efficiencies. The five load percentages covered the range of anticipated testing. All the combinations of the required amount of mills in service were catered for at each load. In order to arrive at the actual percentage burner thermal load (MW), based on the nominal single burner load of 56 MW for Lethabo, the average load per mill or the average load per burner were not simply used. Details of possible extremes of mill biasing and burner maldistribution were incorporated both ways to calculate minimum and maximum burner loads that could occur in all the cases. (The data for this was based on separate tests(12) as explained in Appendices C, D and E.) The reason for this detail was to prevent achieving a satisfactory energy balance for average conditions whilst one single burner with a lean maldistribution on a down biased mill threatened to lose ignition and produce a large amount of CO. Conversely, the energy per burner on average might have proved satisfactory, whilst a single burner with a rich maldistribution of an up biased mill might have been overfiring or suffering damage.

The next step was to calculate the required mill PA flow (load) and resulting pf fineness, which was the main object of the exercise. All the mill data of the pf fineness distribution tests on unit 1, considered reliable since the mills had stable seasoned ball charges, were plotted as a scatter graph of Pf fineness % passing through the 75µm sieve vs PA flow (Figure 4.1). A linear regression approximation of the trend for all these points was calculated to serve as the average indication of the expected Pf fineness % passing through the 75µm sieve for all the unit 1 mills.

Figure 4.1: MILL PERFORMANCE: PF FINENESS vs PA FLOW



Thereafter, the previously established graphs for Mill PA flow vs. Coal Feeder output (Figure 4.2) and Feeder volumetric/gravimetric relationship (Figure 4.3) were used in conjunction with the constructed Figure 4.1 to calculate pf fineness from a defined machine load and mill combination for a specific coal CV, as explained in more detail in Appendices C, D and E.

The remainder of the columns in the spreadsheets are the resultant coal qualities which were calculated as explained in the above mentioned appendices, only to serve as an indication for coal ordering. A point that should be highlighted here is that the coal qualities in these latter columns of the spreadsheets (for the lowest and highest possible CV, as well as the coal orders) were calculated according to trend history of Lethabo coal statistics. These include properties like total and inherent moisture, volatile content, etc. They were all forecast as a function of CV, but excluding heat in volatiles. This were forecast as a function of percentage volatiles. As will be seen later, that where the actual test coals received were checked using the criteria built into the spreadsheets discussed above, the actual properties such as moistures etc. were used. This was because only then were these coal properties known. The inaccuracy was due to the coal statistics being based on blends of coal from the three seams and also since Lethabo does not appear to have a constant relationship of ash to CV, CV to volatile matter, etc.

Figure 4.2: MILL PA FLOW vs COAL FEEDER OUTPUT

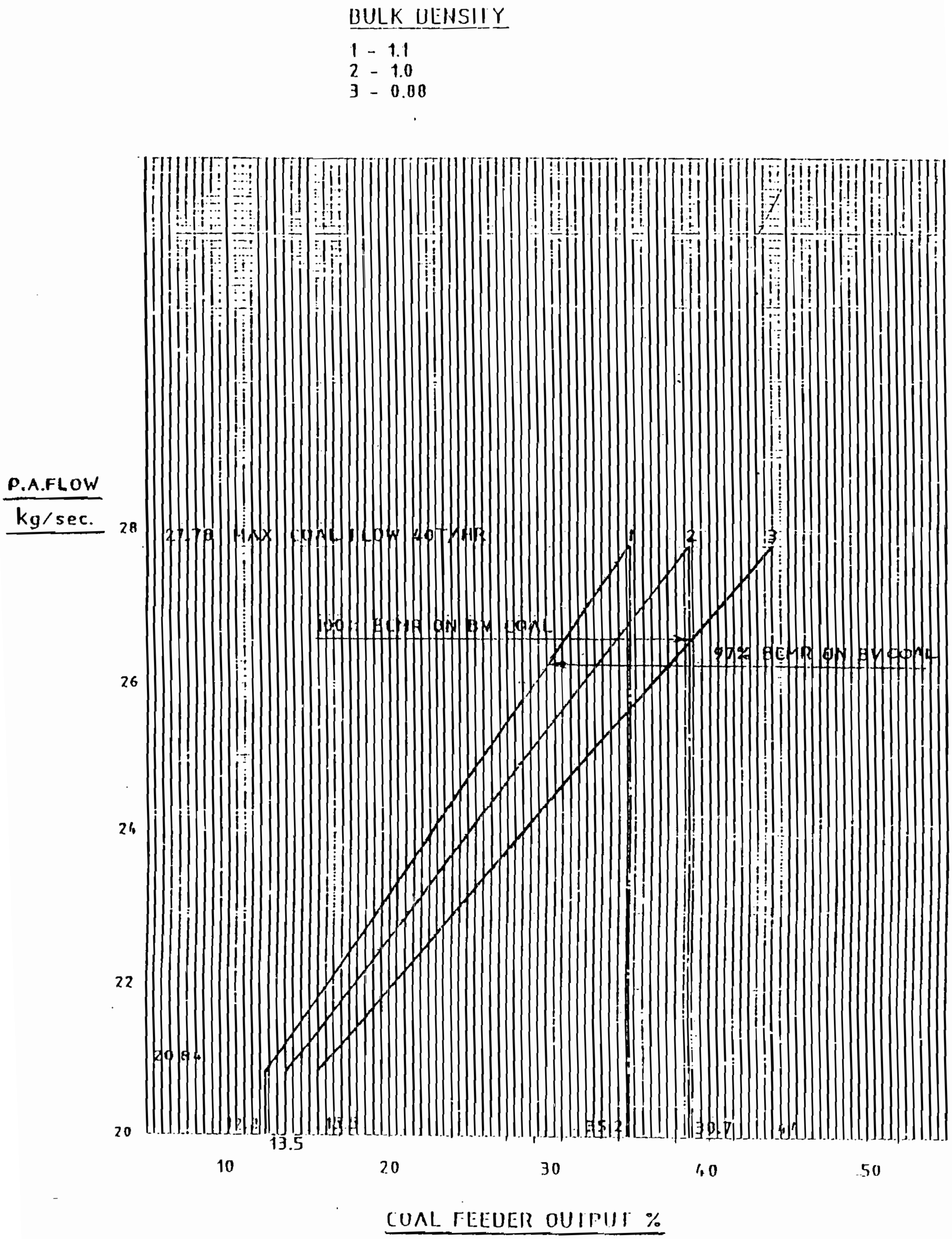
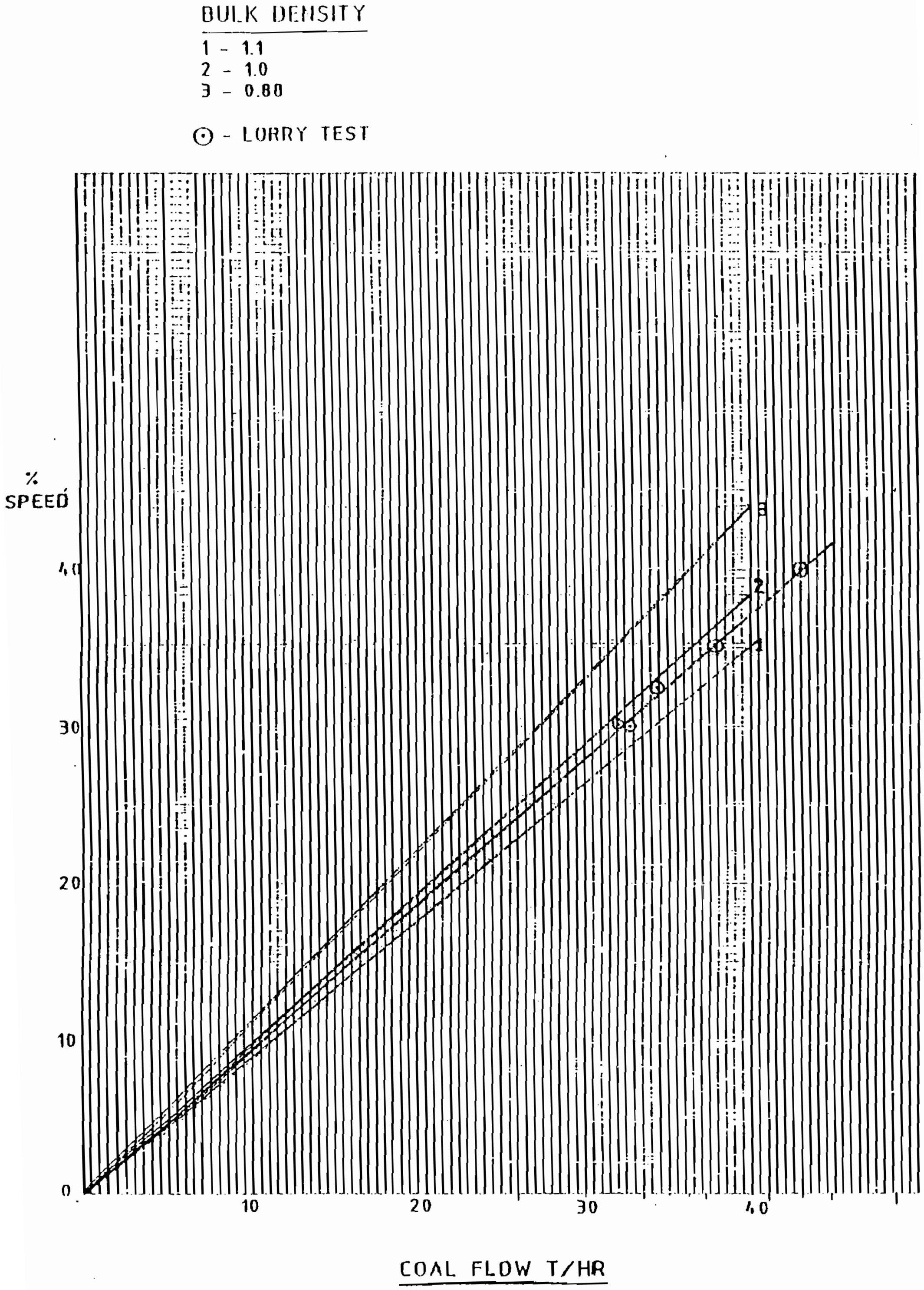


Figure 4.3: FEEDER VOLUMETRIC/GRAVIMETRIC RELATIONSHIP



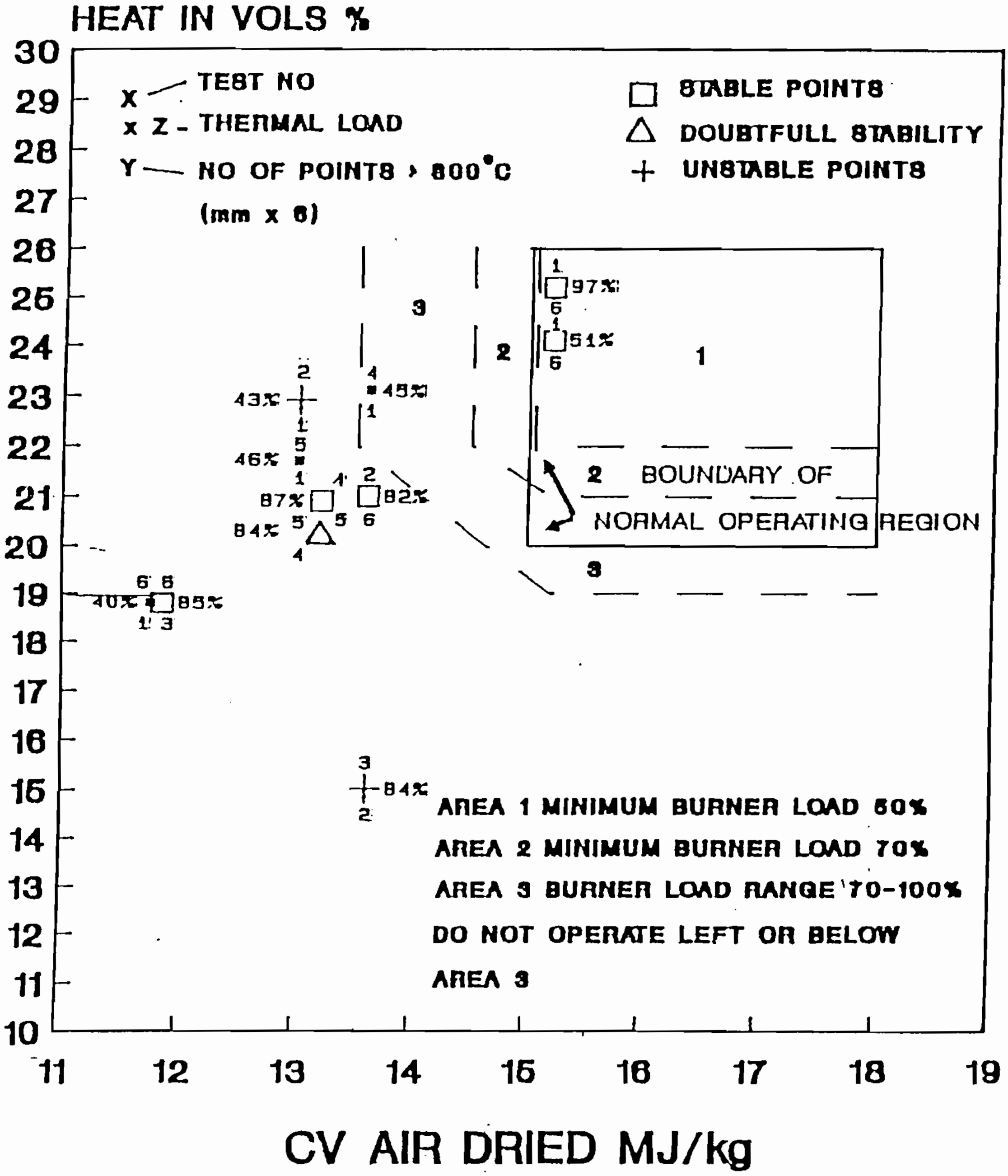
The computer package allowed the construction spreadsheet that would automatically iterate and do the following:

For a specified CV entered in an iteration column (not shown), the PA flow was stepped up in small increments for all the separate combinations of load, mills (including biasing) and burners (including maldistribution) to stop at a PA flow that would satisfy the energy balance for each case, with resulting indications of other coal qualities and pf fineness.

4.1.3 Calculating the Lowest and Highest possible coal qualities:

The limiting criterion for the low grade coal was risk of loss of ignition due to too low a burner load (MW). These limits were obtained from the Burner Stability Diagram (Figure 4.4) which resulted from previous tests performed on Lethabo for this purpose (Palsgraaf(3)). It was found that a minimum burner load has to be maintained for a specific product of CV and heat in volatiles (HIV), to prevent loss of ignition. Since all the volatiles in Lethabo coal are not combustible, as some are inert, it is more accurate to refer to the HIV % than the mass percentage volatiles. These percentage burner load limits are: Lower than 50% burner load is never permitted, regardless of the CV or HIV%. Burner loads between 50 - 70% are only permitted with coal of 15 MJ/kg and/or 22% HIV (minimum). Burner loads between 70 - 100% are to be maintained if the coal is below 14.5 MJ/kg and/or 21 % HIV. Burner loads between 100 -

Figure 4.4: BURNER STABILITY DIAGRAM



125 % are to be maintained with coal below 13.5 MJ/kg and/or 19% HIV. The 125% burner load is the maximum for an individual burner (biasing of mills and maldistribution taken into account) and not the average burner load, as specified by the manufacturer on request for this purpose. (Also see Appendix C.)

A consecutively decreasing CV was entered in the spreadsheet and the iteration performed until the above criteria was just exceeded on the low side to produce a "NO GO" flag in the last column. This was how the lowest possible limit of coal quality was determined. These are the underlined cases in Table C.1 which produced an as fired CV of 13.5 MJ/kg and very similar pf fineness and PA flows for all loads.

The next step was to calculate the highest possible coal quality that could be tolerated by the burners and furnace walls. The limiting factor here was not to exceed the specified 125% burner load on any one burner and not only the average burner load, (mill biasing and burner maldistribution taken into account). A consecutively increasing CV was entered and the explained iteration performed until the above criteria was just exceeded on the high side to produce a "NO GO" flag in the last column. By this means the highest possible limit of coal quality was determined. These are the underlined cases in Table D.1 which produced an as fired CV of 18.5 MJ/kg and very similar pf fineness and PA flows for all loads, even if compared to the lowest possible limit of coal quality above.

The spreadsheet derived criteria thus provided the basis against which the coal properties matched to ensure that the key parameter variations could be achieved with minimal variation in pf fineness, irrespective of load, for each mill combination. The criteria used for selecting a mill combination at a particular load for a certain coal quality were:

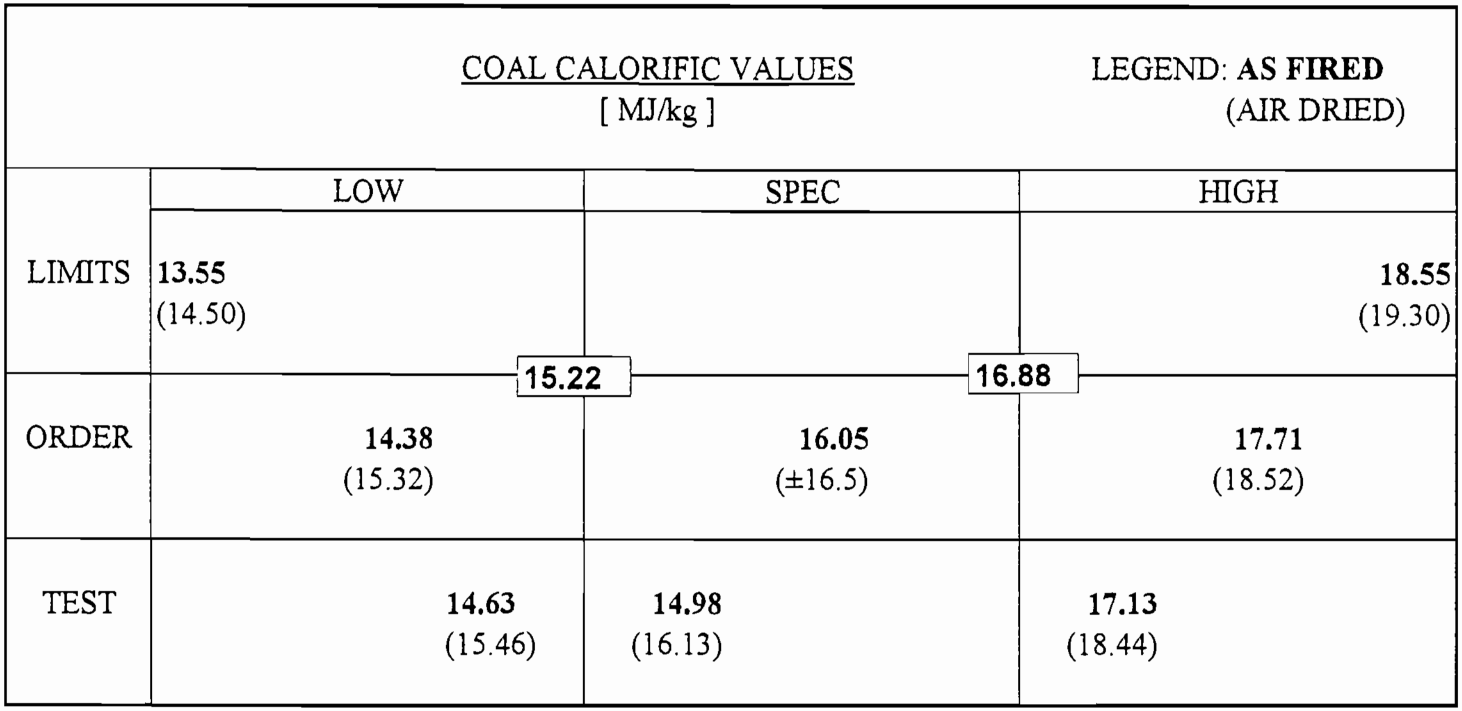
(i) The PA flow had to be within the range of 24.75 - 27.0 kg/s. Although the linear approximation of the pf fineness as shown in Figure 4.1 was used for calculation purposes, in practice the mill has its mid-range there and the pf fineness tends to vary less within that range. It is above 28 - 30 kg/s that the fineness becomes increasingly coarse, since factors other than the ratio of increasing PA flow to increasing fineness bear weight. The classifier for example, which should be seen as a unit with the mill, will become congested at a certain stage of overload from too high PA and pf flow, resulting in a sudden reintrainment of coarser particles. Experience has also shown that mills start to increasingly overgrind below 24 - 25 kg/s. The mill load line minimum limit was also increased from 21 to 24 kg/s, following the Boiler 3 furnace explosion(13). Overgrinding and too low a PA flow was one of the contributory causes determined at the inquiry.

(ii) The pf fineness had to be in the region of 82% passing through the 75μm sieve. The Rosin and Rammler standard for pf states that at least 70% should pass through the 75 µm sieve. Gill$^{(14)}$ considers a mill to enter the over grinding range somewhere between 80 - 85% passing through the 75µm sieve. Since the Lethabo coal has considerably less volatiles than a typical European steam coal, it can be afforded to have pf fineness bordering on the fine limit, to compensate during ignition.

4.1.4 Calculating the qualities of the Coal to be Ordered:

In addition to the low and high limits detailed above, (a third prerequisite to the two criteria of PA flow and fineness magnitudes had to be included) the coal order was calculated for low, high and spec. grades. The selected mill combination at defined test load could not have a "NO GO" flagged in the last column. The limits of the set criteria could not be exceeded here. It should be noted that the fineness calculated in the spreadsheets was the average of all the mills. One mill could be grinding slightly finer than another and the PA flows (especially due to biasing) would not be the same for all mills, even at the same instant during a test. It will be seen in sections 4.2 and 4.3 of this chapter that considerable effort went into preparing the unit and mills, during the outage and subsequent optimisation prior to testing, in order to achieve a high degree of homogenising on certain components of plant and process.

The methodology for calculating the coal order can be followed graphically in Figure 4.5. Initially the lowest and highest possible



COAL CALORIFIC VALUES
[MJ/kg]

LEGEND: **AS FIRED**
(AIR DRIED)

	LOW	SPEC	HIGH
LIMITS	**13.55** (14.50)		**18.55** (19.30)
	15.22	**16.88**	
ORDER	**14.38** (15.32)	**16.05** (±16.5)	**17.71** (18.52)
TEST	**14.63** (15.46)	**14.98** (16.13)	**17.13** (18.44)

Figure 4.5: GRAPHIC LAYOUT: COAL LIMITS, ORDERS AND ACTUALS

coal qualities as calculated in Tables C.1 and D.1 were plotted in the top extreme left hand [13.55, (14.50)] and right hand [18.55, (19.30)] of the diagram respectively. The bold stated values are As Fired while the values in brackets are the related (Air dried) values. The energy balances in the spreadsheets had to be based on as fired values but the mine follows standard chemical convention of reporting their figures on an air dried basis. The orders thus had to be placed in compliance of this convention.

The next step was to divide the numeric interval between these two extremes into equal thirds. The resulting Low range proved to be from 13.55 - 15.22 MJ/kg, the Spec. range from 15.22 - 16.88 MJ/kg and the high range from 16.88 - 18.55 MJ/kg. The arithmetic mean of each of these three ranges of CV gave the average value of each of the respective coal orders, namely Low: 14.38 (15.32), High: 17.71 (18.52), Spec.: 16.05 (16.5) MJ/kg as shown in the "ORDER" row. The air dried values were derived from the as fired and the anticipated moistures according to the standard formula. (see Appendix C, D and E.) The low and high values above were tested in Tables C.2 and D.2. in the same appendices. The spec. values lay in between and were hypothetical at that stage. It is interesting to note that the average spec. CV, 16.05 MJ/kg, that calculated out from the limiting criteria on both high and low side, almost equals the original spec. coal contract value of 16.1 MJ/kg. This was reassuring for both the methodology and criteria used.

To move from the theoretically calculated to a more practical scenario, it would have been ridiculous to expect any mine to provide large batches of coal within these precise qualities. The values were rounded off and an effective gap between batches was built in to try and avoid excessive overlap:

Table 4.1: QUALITIES OF COAL TO BE ORDERED

	LOW GRADE	SPEC. GRADE	HIGH GRADE
Lower CV Limit	14.5	16.0	17.5
Average batch CV	15.0	16.5	18.0
Upper CV Limit	15.5	17.0	18.5
Volatiles % Approx.	17.5	19.5	>20.0
Volatiles % upper Limit	18.5	-	-
Volatiles % lower Limit	16.0	-	-
Lower HIV % Limit	19.0	-	-
Quantity (tons)	60000	55000	50000

The stated values are air dried basis. The quantities were calculated such that the unit could operate on the batch of coal for a week (five loads, lasting one day each with various air flows during the day). The change over to another coal grade took place over a weekend when ample purging of all silos and bunkers could be done. Blending for volatiles is not possible at Lethabo when CV is the specified criterion, so when difficulty was experienced the mine had to supply low CV-low volatile, or high CV-high volatile coal.

The following factors contributed to complexity of the arrangements:

- To fit the preparation of the required coal batches into the mining production plan.

- The time phasing of the coal supply with the test schedule regarding the outage of the unit to rectify all non-conformances and deficiencies.

- The coordination of the above with the availability and loading aspects as dictated by ESKOM National Control.

- High grade coal is not very abundant in the pit, compared to the other grades, meaning a large quantity such as that requested was best reclaimed from the Cornelia stockpile. (The Cornelia stockpile was a stockpile located at the old Vaal Power Station, adjacent to Lethabo, which was closed down. Its coal was of similar quality to the high grade coal requested. Since this stockpile had been sold to Sigma mine serving Sasol, extensive negotiations were carried out to obtain the required quantity of this coal timeously.)

- The spec. coal was thought to present the least problems to obtain and was produced as normal ROM (run of mine) with little extra care.

- The low grade was considered the most difficult (and in many aspects the most important) batch to compile. It was suggested that whenever suitable coal for this batch was encountered in the pit during the normal mining process, it would be stockpiled on a seasonal pile until testing.

- An extensive production plan to manipulate and synchronise these large amounts of specific batches, to be fed into one unit only while the rest of the station was receiving normal ROM, was drawn up. This can best be seen in Chapter 5 where the actual execution thereof is explained, together with the other actual operational procedures.

4.1.5 Evaluating the actual Test coal received:

The actual test coal received had the following values and can also be seen in Figure 4.5 in the TEST row.

Table 4.2: QUALITIES OF ACTUAL TEST COAL RECEIVED

	LOW GRADE	SPEC. GRADE	HIGH GRADE
As fired CV MJ/kg	14.6	15.0	17.1
Air dried CV MJ/kg	15.5	16.1	18.4
Total moisture %	8.4	10.7	12.6
Inherent moisture %	3.2	3.9	5.9
Ash %	45.9	40.3	29.6
Volatiles %	14.4	19.0	22.0
HIV %	20.0	26.0	24.7

These actual test coal figures were entered and calculated on the iterative spreadsheets to finally verify that the coal was suitable for testing and to derive mill combinations for the different qualities and loads for as constant as possible pf fineness. The results can be seen in Tables C.3, D.3, E.1 and E.2. (Appendices C, D and E respectively). The ash, volatiles and HIV values stated are air dried. As was previously mentioned no spreadsheet runs had been performed for the spec. coal thus far, since it was hypothetically calculated with values midway in between the low and high grades. The actual test coal had now to be tested according to the criteria mentioned for both the high (burner damage or overfiring) and the low limitations (loss of ignition due to too low burner load). These results are contained in Tables E.1 and E.2 respectively.

An interesting point to note is that the as fired CV's of the low and spec. grade coals did not differ much. This was mainly due to the higher moisture of the spec. coal, but the significant difference in volatiles for a smaller difference in CV promised interesting testing and results. Suitable mill combinations could now be chosen for testing (the underlined rows in all the above mentioned tables) and concerning coal quality, mill combinations at the different loads, pf fineness etc. it was possible to commence testing.

4.2 UNIT 1 PRE-TEST OUTAGE AND REPAIRS

The tests could fortunately be arranged for a date where an outage (21 February 1994 to 21 March 1994) for interim repairs could precede the tests (May 1994). The above mentioned dates included the decommissioning and controlled shut down of the unit, air heater and other pressure tests, as well as the commissioning, run-up, load swings etc. of the unit when brought back into service. Motivations, costing, and return on investment calculations were put forward for justifying certain non-conformances and deficiencies to be attended to that would normally not happen on such an outage, with the tests noted as the priority. The outage entailed the normal array of duties assembled from defects that could only be performed on stationary plant, but also the additional aspects that could affect the priorities of this test. An extraction of the latter follows below:

4.2.1 CONDENSER

Since the unit was to be tested as a whole, some important turbine side components were also given attention. The thermocouples and/or transducers of the following temperatures were recalibrated: CW inlet temperature (T_1) and CW outlet temperature (T_2), hotwell condensate temperature (T_c), the condenser vacuum saturation pressure (P_s) and the "Vacubarometer".

4.2.2 HIGH PRESSURE ORIFICE PLATE (FEED WATER FLOW)

Concerning the steam side (Rankine cycle) the accuracy of the mass flow of the working fluid is very important. Since the STEP calculations are also accordingly sensitive to this feed water flow to the boiler a special laboratory calibrated orifice plate was installed in a Sempell block that is specifically designed to accommodate the plate (Figure 3.32). This operation could not be performed with the unit on load. The accompanying high pressure transducers were also fitted and calibrated.

4.2.3 MILLS

The optimising of the mills is discussed in section 4.3 but the following aspects had to be performed on stationary plant:

- The charge grading was checked visually to verify absence of excessive spoils or breaking up of grinding media. The ball level in the mill was measured (distance below the trunnion) and the tonnage calculated from charge density obtained from power-sonic and stripping peak data. The mass of the ball charge was cross-checked with the empty running power (kW) data obtained during the shut down of the mills just before the unit itself was shut down. The charge was then topped up to the standard of 97 tons on all six mills where necessary.

- The bypass dampers were stroked and the travel measured internally.

- The trunnion division plates were measured (650 mm pf side, 850 mm coal side) and adjusted where necessary and the welding thereof checked.

- All mill control systems were calibrated including the power-sonic system, kW transducers etc.

- The volumetric coal feeders seal air flow was measured and the feeder profile bars were set according to the required measurements and calibrated. A correction factor was determined for the coal mass flow from the belt speed to the feeder integrator (% feeder speed).

- The mill classifier vane settings were checked, set and corrected according to Rosin and Rammler pf sampling results, to achieve even results between drive and non-drive end per mill.

- Classifier internals were inspected and repaired where necessary. This normally entails repairs to tiling that has come adrift and special attention was given to properly supporting the inverted cone (responsible for maintaining the correct vortex in the classifier).

- The PA control dampers were stroked separately and the pairs of dampers were checked symmetrically. The travel was checked internally as well as externally. This was found necessary since factors such as sheared keys could cause a deception; with the control arm moving outside but the damper remaining stationary inside.

4.2.4 BURNERS

- The secondary air registers or swirl generators (Figure 3.17) determine the length of flame and recirculating zone. The specification was adapted after the supplier BEC did tests on these swirl generator settings and forwarded a setting that would be used for all loads and conditions. These settings were taken as the present optimum and all burners were set similarly.

- The flow master dampers before the burner windboxes were set to balance the secondary air flow per burner according to the secondary aerofoil flow readings.

- Burner mouth defects were corrected and refractories repaired or renewed. The windbox door seals were renewed.

4.2.5 AIR HEATERS

- The secondary air heater seals were checked, adjusted or renewed where necessary. This applied to the radial, axial or circumferential seals. Concerning the radial seals the Guring gap censors were calibrated for the correct sector and seal gaps(15).

- The air heater packs were inspected for ash blockage. Fortunately no replacement or high pressure water washing was necessary.

- The primary air heater was pressure tested and all leaking tubes repaired or expanded in the end plates.

4.2.6 GAS PASSES

- A considerable gap was found in the rear gas pass skin casing at 41 m level and repaired.

- All ducting guide vanes were inspected and repaired where eroded or otherwise faulty.

- All ducting platework were inspected and repaired likewise.

- All sootblower lances, ports and nozzles were repaired. sootblower controls and the sootblowing program were checked. This was done for air heater, furnace walls and gas pass sootblowers.

- The flanges on the CO monitor ports on the ID fan discharge were removed, the infra-red CO monitor fitted and the alignment and calibration were done (clean air was required for this).

- The ports on the air heater outlet ducts (precipitator inlets) were prepared for fitting the flanges of the probes for the representative measuring points of oxygen and temperature. (As discussed in Chapter 4.7 and Appendix B).

- The sixteen point sampling matrix (Figure 3.30) that covers the area of each of the two economiser outlet ducts to measure representatively the oxygen and fly ash was checked, repaired and cleaned up of any ash blockage which the purging system could not remove.

4.2.7 AIR PASSES

- All dampers were stroked and checked internally and externally as with the gas pass dampers.

- All measuring points and ports were purged to clean up all impulse lines for clear pressure transducer signals. This was the case for all the primary aerofoil, duct ports, secondary aerofoils and the total aerofoils that measure the total combustion air. All associated transmitters and transducers were also calibrated by the Control and Instrumentation department.

4.2.8 FURNACE

The normal repairs on all pressure parts as well as those emanating from general furnace inspection were done. Special attention however was given to the water sealing trough at the bottom of the furnace. It was of utmost importance that the make-up water system to the boiler sealing trough was functioning well. If the water seal is too low air is allowed to be drawn into the furnace due to the negative furnace pressure maintained by the ID fans, which results in unmeasured quantities of air passing into the furnace. Special precautions were taken and additional make-up lines were installed since this problem has occurred in the past.

4.3 MILLING PLANT OPTIMISATION

4.3.1 LOAD LINE AND BYPASS DAMPER SETTING

In the discussions of section 4.1 it can be seen that the mill combinations needed for testing included four, five and six mill firing at the high loads. Four mill firing was outside the normal capability setting of the controls (124 MW per mill, UG based) and required a 155 MW per mill capability setting. The mill must also physically be able to comply to this demand. This was due to the varying coal qualities (see Tables C.3, D.3, E1 and E2). The mill performance should also accommodate the requirements of the combustion of high CV coals and still maintain pf fineness and not overgrind. The converse was also true for low grade coals. From these tables, where the mill combinations for the required pf fineness of the actual test coal received was calculated, it can also be seen that the spec. and high grade coal had total moisture values higher than average. This could also present a coal drying problem if the mill performance was not up to standard. Lethabo has a deficiency in this respect, in that the general experience shows the primary air heaters were under-designed.

In section 4.4 it was mentioned that unit optimisation prior to testing (e.g. load swings) was done. Mill optimisation must take place prior to unit optimisation. For some time at Lethabo, prior to testing, mill behaviour was erratic, especially on low loads. The boiler pressure was then difficult to control and the safety valves lifted often. A contributing reason towards this was the combination of the different heating values received at Lethabo and the minimum stops of 24 kg/s PA flow introduced after the unit three furnace explosion(13), to improve low load flame stability. All this of course proved an unacceptable state of affairs with testing of this nature in mind. Investigation into the matter and tests on units 1 - 4 since late October 1993 (Becht(16)) showed that the mills performed off the design load line. Factors that contributed towards this deficiency was:

- Seasoning of the grinding media that comes with ageing and causes a certain loss of grinding power. This occurred on unit one from 1985-1987.

- The compensating increased ball charge (87 to 97 tons) which was an interim remedy for the above problem, provided the required pf fineness at the range of PA flows, but in turn influenced other variables such as the percentage volumetric filling, now 24% of the mill, which impacts on e.g. the ratio of cascading to cateracting balls etc.

- Due to the above, there was an accompanying control system adaption needed. The power range of the mill moved from 1300-1500 kW to 1400-1600 kW etc.

- The mills were also charged with different grinding media, as opposed to the original. Intensive testing took place during

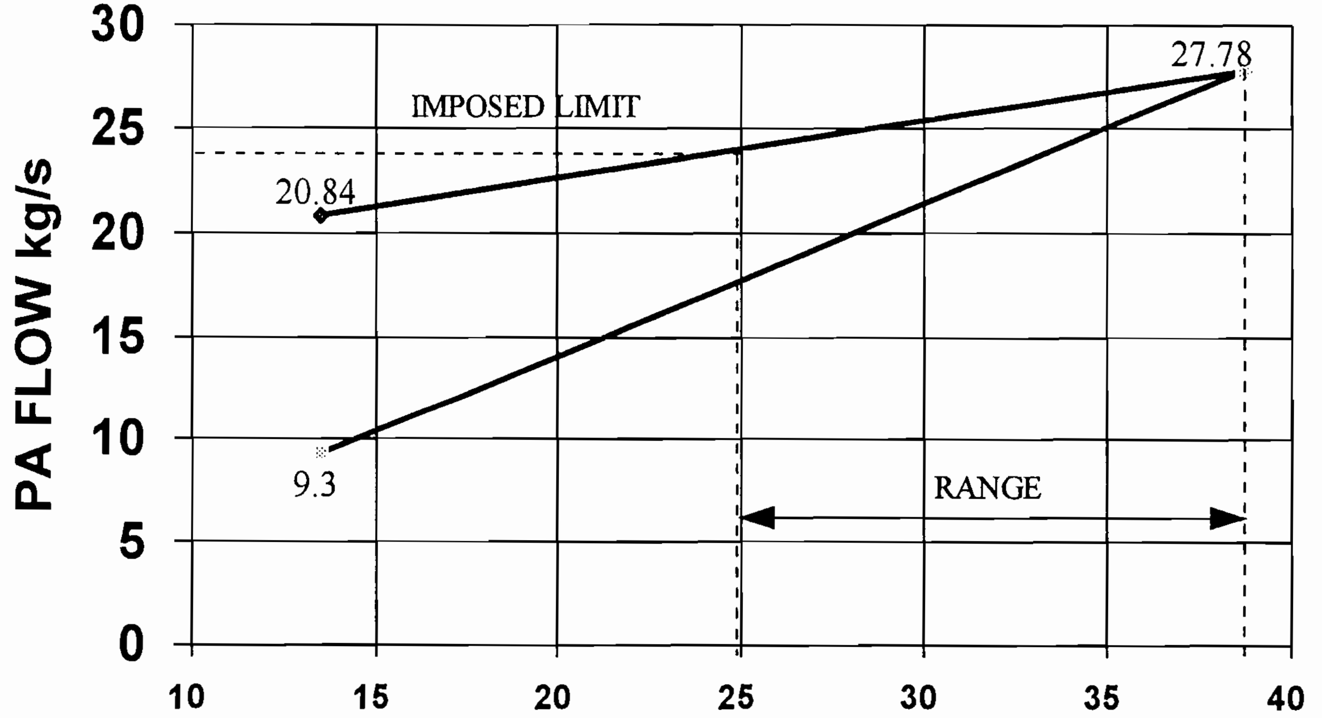
1987-1988, comparing the original SF55 and SF90 alloys (50 mm diameter) with 50 mm 12% Cr, 60 mm 12% Cr, Boulpebs and Cylpebs of a softer alloy. Units 1-4 on Lethabo were thereafter supplied with 50 mm 12% Cr and units 5-6 with Cylpebs.

- An important factor is that there was evidence of the control card and transducer hardware deteriorating which was proved by calibration problems.

- The minimum stops of the mill was increased from 21 to 24 kg/s, as mentioned above.

Adaptions or alterations thus had to be devised to get the mill performance back to the original load line, to again make the data and basis of calculation emanating from Figure 4.1, 4.2 and 4.3 valid. The capability limitation of the unit controls had to be changed to 4 mill firing and the mills must be capable of performing accordingly. The total and secondary air requirements also had to be complied with as explained in Chapter 3.5 and below. The initial load line and bypass damper setting can be seen in Figure 4.6. The following aspects should be noted:

- The low load point setting (without flame stability limit) is 20.84 kg/s PA flow with a bypass opening of 45% providing a mill pf air flow of ± 9.3 kg/s for a 13.5% feeder speed (coal flow of 28 tons/h).



FEEDER SPEED	%	13.5	20.0	25.0	32.3	38.7
COAL FLOW	t/h	28.0	41.5	52.0	67.0	80.0
BYPASS	%	45.0	33.0	25.0	11.0	0.0

Figure 4.6: INITIAL LOAD LINE AND BYPASS DAMPER SETTING

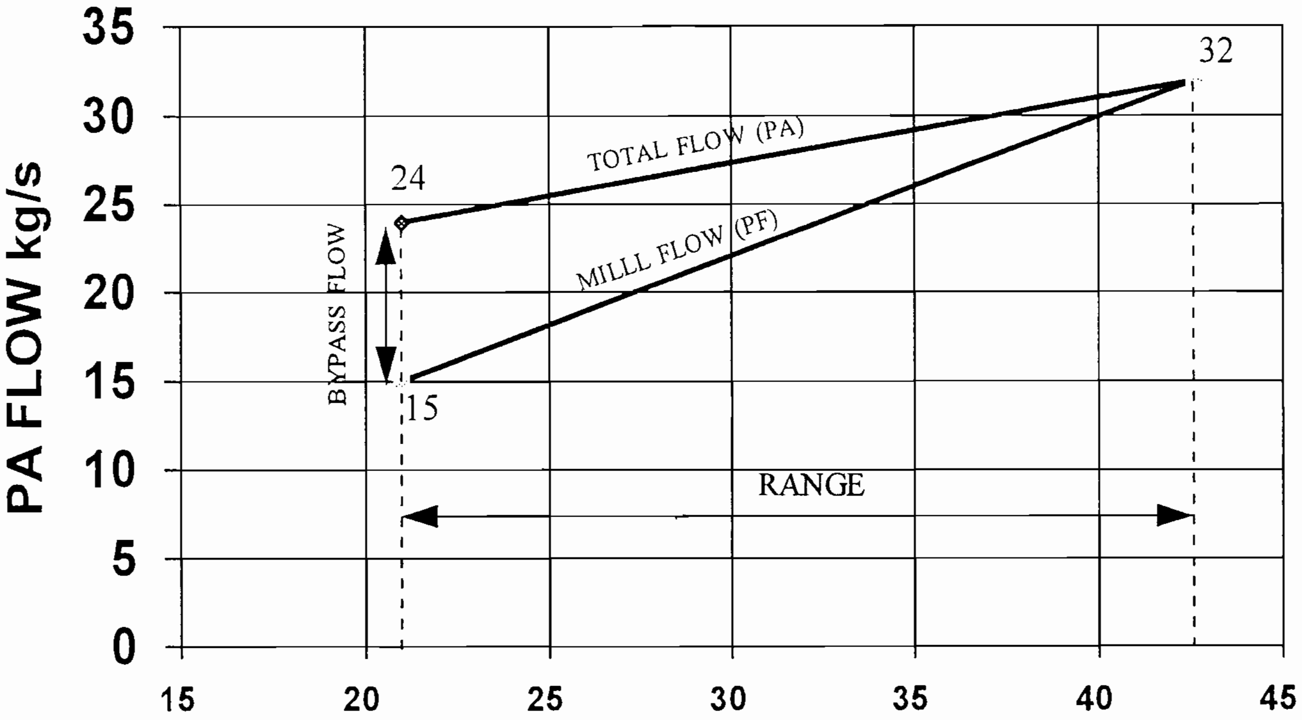
This minimum load point should provide adequate fuel pipe velocities (20.3 m/s) and air/fuel ratio at the burners (2.7:1). The burner thermal load when low CV coal is fired will be very low.

- The high load point is at 27.78 kg/s PA flow, with the bypass fully closed (all the air flowing through the mill) and 80 tons/h coal flow. The fuel pipe velocities are 26.4 m/s and the fuel /air ratio 1.25:1.

- At the low limit stop imposed the PA flow is 24 kg/s, the coal flow is 52 tons/h and the bypass opening is 25%.

This resulted in a limited loading range for the mill (52 - 80 tons/h). Repeated fineness tests proved the mill performs adequately at least up to 32 kg/s and 88 tons/h due to the increased ball charge. This with other detail served as motivation to revise the load line by means of a changed bypass damper setting. This rendered the mill and boiler more flexible regarding loading and number of mills in service. The revised load line and bypass damper setting can be seen in Figure 4.7. Note the following:

- The high load point was raised to 32 kg/s PA flow, the bypass closed, the coal flow 88.6 tons/h with 30 m/s pipe velocity. Fuel system erosion was unlikely to be a problem if the fineness did not increase unduly. (see Appendix J).



FEEDER SPEED %	21.0	26.4	31.8	37.2	42.6
COAL FLOW t/h	44.0	55.0	66.3	77.5	88.6
BYPASS %	40.0	30.0	20.0	10.0	0.0

Figure 4.7: REVISED LOAD LINE AND BYPASS DAMPER SETTING

- The low load point became 24 kg/s PA flow, with a bypass opening of 40% corresponding to 10 kg/s, fuel pipe velocities of 24 m/s and a higher heat load per burner when burning low grade coal. This corresponds to 53% which would comply to the stability diagram limits (Figure 4.4) of 50% minimum. The coal flow was 44 tons/h.

Concerning the secondary air resulting from the PA flow (Figure 3.28) to form the total air requirement, the theory explained in Chapter 3.5 and Figures 3.24 through to 3.29 showed that with the new bypass setting, a higher PA flow was necessary for the same load. That was because there was more air on bypass due the greater damper opening and less mill air picking up pf. The SA resulting from the higher PA caused the total air to be greater, especially when low grade coal was burnt. The benefits or advantages of this was one of the aspects to be evaluated by the tests. The mill performance at the new setting in the form of pf fineness had to be tested prior to the main tests (see section 4.3.2).

During the outage as described in section 4.2, all the hardware components, controls, kW transducers and other electronic equipment associated with the mill were renewed, adjusted, or calibrated etc. according to the new bypass damper setting and load line. After the outage the running mill optimisation and evaluation of the above took place. It performed very well with the expected mill response and flexibility as described above.

In addition to the above advantages, the mill drying power improved due to the higher PA flow in the coal chute and thereafter in the pf pipes. The potential disadvantages anticipated from this adjustment included:

- boiler master needing adjustment due to the higher air/fuel ratio,
- possible higher pf pipe wear,
- higher PA flow requiring a higher fan pressure control set point which could result in increased pf leaks due to the higher duct pressure,
- higher mill and classifier recirculating load.

None of these proved to be significant deficiencies. A fact worth mentioning that became evident during the evaluation of the mills, was that the load line on the converted unit 1 mills actually did not change. In practice, the new bypass damper settings brought the actual PA vs % feeder speed relationship closer to original design load line. This was very reassuring because it meant that even with the changes that were done to the mills over the years (e.g. the increased ball charge, accompanying kW power range increase etc.) this new bypass damper setting enabled the tuning and optimisation process to result in the mills performing according to the design figures again.

4.3.2 PF SAMPLING

The final test for a mill was whether or not it could provide the required fineness of pulverised fuel product at the operating load of primary air flow. The mills of unit 1 were sampled prior to the test to verify this requirement (April 1994). The correct sampling, reworking, calculating and interpretation of a mill's product required great care and can not be discussed in detail in this report, although the mill performance (product delivered and automatic control behaviour) was of utmost importance. The isokinetic sampling of the pf product and all other actions such as the drying, sieving and weighing should be performed strictly according to procedure (Van Boorn(17)). The final criterion prescribed by the Rosin and Rammler graphs can be summarised as being that not more than 1% of the sampled and prepared mass should remain above the 300µm sieve and at least 70% should pass through the 75µm sieve.

Initially, the unit 1 mills were sampled prior to the test, after optimisation for final verification at ± 28 kg/s, which was the original high load point. These results of mills A, B, C, D and E can be viewed in Appendix J, pages J - 2 to J - 6 respectively. Each page consists of the sampled, dried and sieved masses and the calculated percentages, as well as the results plotted on a graph. At the time of sampling mill F was not operative but on stand-by, and therefore not sampled. All five running mills mentioned above comfortably passed the minimum requirements of the Rosin and Rammler standard.

The next step was to select a mill to be sampled during the main air flow optimisation tests. It would have been an impossible task to sample all the mills, both the drive (DE) and non-drive ends (NDE) during every test, so a representative mill was chosen and only one end was to be sampled during testing. In practice a top mill (A or F) is normally the first to be biased down or taken out of service when reducing load or to limit risk of metal temperature excursions. Conversely, the bottom mills (B and E, also referred to as the pressure mills) are normally the last to be taken out of service when given a choice, but they would normally be biased up when drum pressure was not adequate. The mills that would be operating at the most constant settings and virtually always be in service were is the two middle mills (D and C). Mill D (NDE) was ideal for sampling during testing also due to the pf sampling plug being most assessable. D mill DE was then chosen to be most representative of average of the performance for all the mills in service at all loads.

D mill was therefore sampled over the planned range of PA flows at intervals of 2 kg/s, from the 24 kg/s minimum to 32 kg/s, DE as well as NDE, as proof prior to testing. These results can be viewed on pages J - 8 to J - 12. These tests were also used to verify the equal degree of fineness between the DE and NDE of all the mills prior to the main tests. This was also an indication of the balance due to the equality of the trunnion division plate positioning, classifier vane setting and bypass damper opening between DE and NDE. Together with SA flow these were the main contributors to the even burner distribution and eventually the whole boiler balance. A summary of the above mentioned pf sampling results can be seen below:

Table 4.3: PF FINENESS: MILLS A - E, PRIOR TO TESTING

PERCENTAGE PASSING THROUGH 75 μm, 28 kg/s PA FLOW

MILL	DE	NDE
A	88	79
B	78	83
C	87	81
D	77	78
E	78	79

It will be noted that all the mills, both drive and non-drive ends conform to the Rosin and Rammler minimum criterion of 70% comfortably. This was at a PA flow of 28 kg/s which was more than the 25 - 26 kg/s that the mills were predicted to run on as calculated by the spreadsheets in Appendix C, D and E and explained in section 4.1.

Table 4.4: PF FINENESS: MILL D, PRIOR TO TESTING

PERCENTAGE PASSING THROUGH 75 μm

PA flow (kg/s)	DE	NDE
24	87	86
26	80	85
28	74	85
30	71	80
32	70	79

In Table 4.4 it can be seen that D mill exceeded the minimum Rosin and Rammler standard at all PA flows for both DE and NDE. Most comforting was the fact that the required fineness of ± 82 % passing 75 µm, which the predictions in Appendices C, D and E are based on, occurred at a PA flow of 26 kg/s. That was the best average of PA flow that was calculated by the spreadsheets as a target. This also confirmed that the mills would run closer to the original load line, due to the new bypass damper setting and the general optimisation.

Concerning the balance of the mill, (DE compared to NDE), it appeared that some of the mills, including D mill at the various PA flows, were not equal. This may have been deceiving, because the feeder speeds, DE vs. NDE, should be taken into account. The feeders were left on auto control during sampling and not separately forced to equal speed, so controlled for the mill as a whole. The balance between DE and NDE were acceptable when the feeder speed inequalities are taken into account. The pf fineness results taken during testing are given in Appendix J, page J - 14 and onward.

4.3.3 MILL POWER AND BALL CHARGE

At any selected load with a set total air flow during a test, the boiler should run very steadily and the functions of the boiler controls that remain on automatic and able to change are the pressure controller (including feed flow, etc.) and the primary air (mills). This can be derived from the explanation in sections 3.5 and 4.6. The boiler must be able to react to achieve a heat balance with resulting efficiency by means of more or less fuel (primary air flow and feeder speed). Care was taken to ensure optimum operation. (The remainder of section 4.3 is intended for the reader unfamiliar with standard conditions of this specific plant):

To ensure that the mills are running steadily and not oscillating, the feeder set point must be accurately correlated with the power consumption of the mill. The mill power versus the tonnage of its charge can be seen in Figure 4.8. From the figure it can be seen that the mill will absorb approximately 1400 kW with balls only. As it is filled with coal the power will increase until it peaks at 1600 kW, whereafter it will decrease due to the counter balance that is caused by the additional coal in the rotating mill. The mill is operated in the range that follows the kW set point (± 93% at Lethabo). A stripping peak procedure is followed to determine the charge of grinding media in the mill and the amount of make-up necessary. It is also performed to calculate the feeder set point, i.e. to match the kW absorbed at the specific kW set point (e.g. 93%) with the amount of coal fed into the mill by the feeder. If the feeder set point is not correct, the mill could either be deprived of coal or be choked with coal, or it could be oscillating between the two possibilities. An air optimisation test cannot be performed under these unsteady conditions.

The determination of the ball charge and feeder set point is ensured by following a stripping peak and filling peak procedure on the mill.

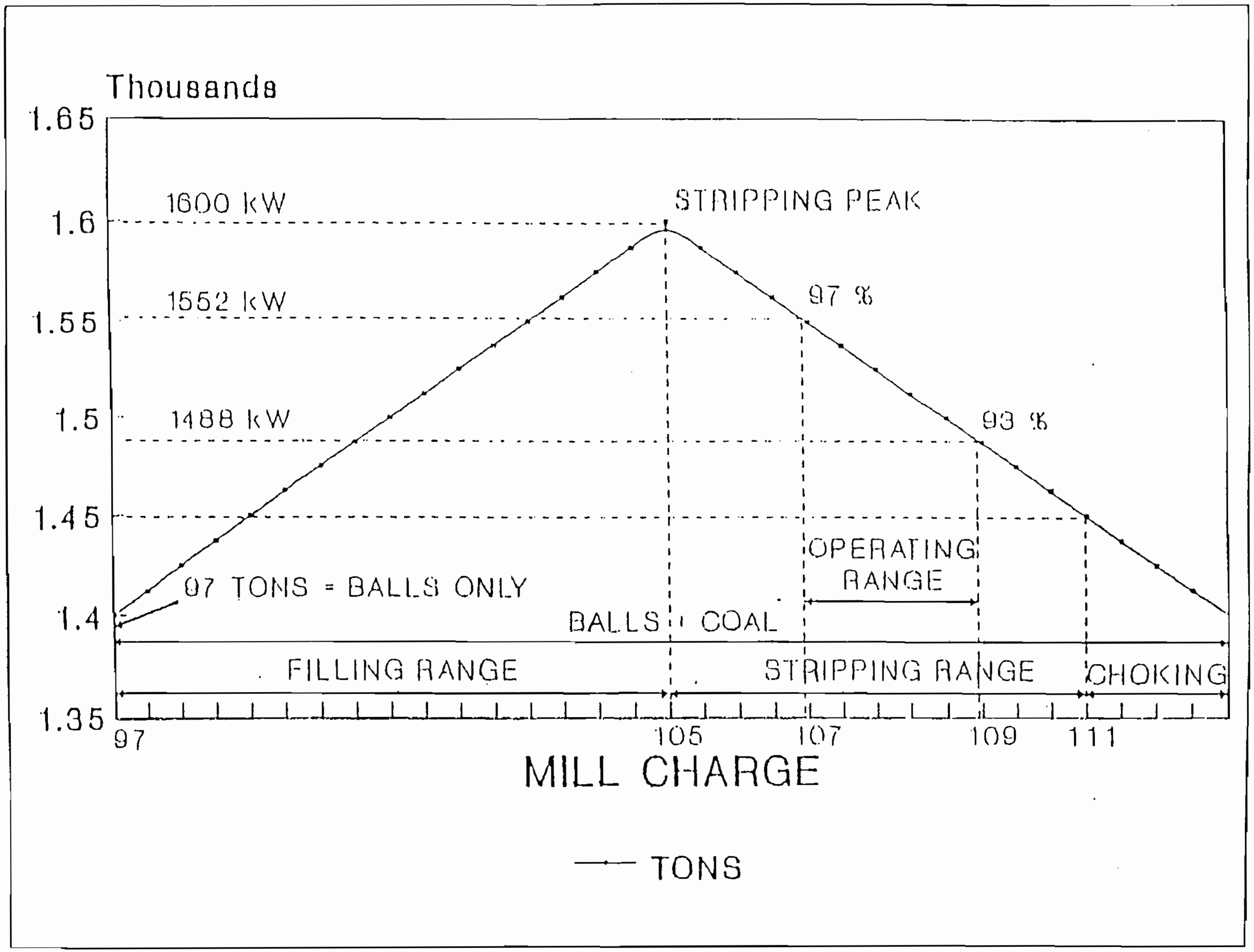


Figure 4.8: MILL POWER CURVE

This action too is performed to a specific procedure. It is done by retracting the feeder manually to a portion of its percentage feed, approximately 10-15 %, depending on the type of mill. This will cause the mill to run leaner by gradually depriving it of coal feed. The mill power will gradually increase up the slope of the curve until the apex at maximum power is reached, where the power will start decreasing again down the filling range of the curve (see figure 4.8).

The ball charge is obtained from tables which are empirically compiled from the corresponding power while the ball charge is increased. The feeder set point is adjusted after the ball make-up is made with a fixed kW set point according to the following formula:

$$\text{Feeder set point \%} = \frac{(\text{Stripping peak kW} \quad 0{,}93) - 1400}{2}$$

There are two feeders per mill (therefore the division by 2) and 1400 kW is the base power of the control system range and the power absorption of the mill with 97 tons of balls only. If a mill strips, for example at 1590 kW, the ball charge from the tables would read ± 95 tons of grinding media and the make-up should thus be ±2 tons. If the power set point is run at 93 %, the feeder set point would be:

$$\text{Feeder set point \%} = \frac{(1590 \times 0{,}93) - 1400}{2}$$

$$= 39 \ \%$$

The feeder would then be set at 39% (each feeder is capable of 50%) not to choke the mill or deprive it of coal, but to control in a steady mode of loading. The performing of this procedure on a routine basis during testing a special operational procedure is essential (see Chapter 4.8.)

4.4 UNIT OPTIMISATION

After the unit one outage, where the repairs, correction of deficiencies and the static calibration of mechanical and electronic components took place (see section 4.2), the optimisation was done. Most of these activities are specialised actions, thus only a summary of the activities are given in sequential order:

- The mill optimisation as described in Chapter 4.3 had to be done before the overall unit optimisation could commence. This included the new bypass damper setting and implementation of the new load line. Calibration checks on feeders and the mill level control system were also done in the two days needed for this exercise. Operating department was requested to "strip" each mill as the optimisation of the mill's control and instrumentation side was completed. This is necessary to evaluate and have visibility on the final fine tuning as well as being able to derive the make-up grinding media mass. This was done on all the mills A, B, C, D, E and F.

- The overall unit optimisation consisted mainly of load swings and a stability test which took one day.

- The fine tuning thereafter involved the evaluation of the overall unit performance with the new mill load line and bypass damper setting and correctly topped up ball charge. This entailed the fine tuning of the turbine load controller, boiler master and pressure controller, CV correction, air/fuel correction and the critical pressure deviation. This took another one day.

- The boiler capability was set to also accommodate four mill firing on full load (from 124 - 155 MW per mill). This was to accommodate the high grade coal requiring only four mills on full load (see Chapter 4.1 and Table C.3, D.3, E.1 and E.2.) and avoid overgrinding or the boiler safeties lifting with the mills at the imposed 24 kg/s PA flow minimum stops.

4.5 MONITORING AND GENERAL ARRANGEMENTS

The measurements to be taken during testing for this project, were selected to enable the display of data or the calculation of the main parameters at:

- Various total combustion air flows,
- at selected loads,
- for different coal qualities,
- with overall thermal efficiency as main criterion.

The first step in accomplishing the above was to identify all the parameters to be measured to enable the calculation of these main entities. For this project it would also mainly be all the measurements to support the inputs to perform a STEP (Station Thermal Efficiency Program) run. Table 4.5 shows a summary of the measuring points, their source and approximate amount of manpower needed.

Table 4.5: TEST MEASURING POINTS

No.	MEASUREMENT	UNITS	SOURCE	MANPOWER
1	Generating time	hours	MIDAS	0
2	Steaming time	hours	SICOMP 70	0
3	EFP running hours	hours	OPS Log	0
4	Mill running hours	hours	OPS Log	0
5	Units generated	MW	MIDAS	0
6	Unit auxiliaries	MW	MIDAS	0
7	Reactive load generated	MVAr	MIDAS	0
8	Feed water flow to boiler	kl	SICOMP 70	0
9	Final feed water temperature	°C	SICOMP 70	0
10	Demin make up water to boiler	kl	SICOMP 70	0
11	Steam flow	kg/s	SICOMP 70	0
12	Main steam temperature	°C	SICOMP 70	0
13	Reheat steam temperature	°C	SICOMP 70	0
14	Cold condenser inlet temperature	°C	SICOMP 70	0
15	Hot condenser inlet temperature	°C	SICOMP 70	0
16	Hot condenser outlet temperature	°C	SICOMP 70	0
17	Hotwell condensate temperature	°C	SICOMP 70	0

No.	MEASUREMENT	UNITS	SOURCE	MANPOWER
18	Condenser back pressure	kPa	SICOMP 70	0
19	CV of coal as fired	MJ/kg	Laboratory	0
20	Total moisture in coal	%	Laboratory	0
21	Ash content of coal	%	Laboratory	0
22	Volatile matter in coal	%	Laboratory	0
23	Fixed carbon in coal	%	Laboratory	0
24	Sulphur in coal	%	Laboratory	0
25	Coal Hardgrove index	no.	Laboratory	0
25	Coal abrasiveness	mg	Laboratory	0
26	Coal mass flow (feeder integrator)	t/h	Manual	2
27	Fuel oil burnt	%	Laboratory	0
28	Total air flow to boiler	%	Manual	2
29	Burner core air in-leakage	kg/s	Manual	1
30	Seal air fan in-leakage	kg/s	Manual	see no. 29
31	Opacity	mg/sm^3	SICOMP 70	0
32	Carbon in fly ash	%	Manual	1
33	Carbon in course ash	%	Manual	see no. 30
34	Barometric pressure	kPa	Manual	see no. 36
35	Ambient air temperature	°C	SICOMP 70	0
36	FD air inlet temperature (T_{db})	°C	Manual	1
37	FD air inlet temperature (T_{wb})	°C	Manual	see no. 36
38	Total air flow to boiler	kg/s	Manual	see no. 36
39	Air heater gas inlet temperature	°C	SICOMP 70	0
40	Air heater gas outlet temperature	°C	Manual	2
41	ID fan discharge temperature	°C	Caravan	2

No.	MEASUREMENT	UNITS	SOURCE	MANPOWER
42	Dew point temperature	°C	Caravan	see no. 41
43	Economiser outlet O_2	vol %	SICOMP 70	0
44	Air heater outlet O_2	vol %	Manual	see no. 40
45	ID fan discharge O_2	vol %	Caravan	see no. 41
46	ID fan discharge CO	ppm	Caravan	see no. 41
47	ID fan discharge CO	ppm	Manual	1
48	ID fan discharge SO_2	ppm	Caravan	see no. 41
49	ID fan outlet NO_x	ppm	Caravan	see no. 41
50	ID fan outlet CO_2	ppm	Caravan	see no. 41
51	Coal sampling		Manual	2

Due to automation by means of the unit process computer and the equipment in the mobile caravan facility, approximately fifteen people were needed to monitor and accumulate the data. This excluded the personnel in the laboratories who performed coal analysis and the numerical calculations which followed after the test. In addition there were certain operational and instrumentation personnel necessary to set up and man the unit controls and do instrument calibration beforehand, as will be explained in sections 4.6 and 4.7. There was however a condition attached to relying on certain data from the process computer. The monitoring instruments feeding the process computer, namely transducers and other electro-mechanical equipment, had to be calibrated to specified accuracy and the appropriate correction factors and correlations had to be determined. The SICOMP and MIDAS computers with their printers were also to be serviced prior to the tests, since a failure could not be tolerated during testing.

The back-end gas analysis caravan facility was booked in advance since it is the only one of its kind available here. Radios with a pre-arranged channel for communication were arranged since the co-ordination of starting and ending times of a specific test, the safety of the plant and the indicators for starting a test (CO ppm at back-end) could only effectively be communicated by this means.

The labelling of samples was also very important. A numbering system was devised to distinguish any sample, reading or test performed unambiguously. A total of ninety tests were to be performed. The reason was to cover the full loading range of the unit adequately, with sufficient air flows at each load for each coal quality to produce a smooth curve of efficiency (or any other parameter). Another very important reason was to have a wide enough range of readings covered to obtain any turning point in the plotted parameter that indicates an optimum. The three coal batches as calculated in section 4.1 and Appendices C, D and E were designated as Low, Spec. and High grade coals. These were abbreviated using the letters "L", "S" and "H" to form the first letter in the code of the labelling system.

The maximum short term loading at which the Lethabo turbo-alternators can be operated is slightly above the rated 618 MW. The minimum on auto control is just below 400 MW, since Lethabo was primarily designed as a base load station (because of its drum boiler, it is not able to change load as speedily as a once-through Benson type boiler). Five loads were selected:

630 MW
550 MW
500 MW
450 MW
400 MW

This was used as the second figure in the coding of a sample. The next figure, all separated by a "/" from the preceding letter or figure, was the approximate percentage excess air at which the test was conducted. The last of the four figures separated by a "/", was the time at which the test was performed, since it could then easily be correlated to the chart recorders of the unit, which recorded many of the important parameters as a back-up. A typical code appearing on a label of a sample or a set of readings would be:

L/550 / 20 / 16h00

which would mean it was a 550 MW test, with the total air flow such that it produced 20% excess air, the test commenced at 4:00 pm and low grade coal was burnt. Another example could be:

S/400 / 4,5 / 17h30

This would imply a 400 MW test, with an excess air percentage of 4,5% at 5:30 pm and spec. grade coal was tested.

The training of staff was also important in this type of testing. The interpretation of readings taken and the ability to monitor was very important. If for example a test had a duration of forty five minutes and for the first five minutes the value of a certain parameter monitored decreased exponentially, to level out at a more constant value for the rest of the forty five minutes of the particular test, the first five minutes' values were ignored since the plant or associated process was not yet stable, but in transient condition. A plant of this magnitude has a tremendous thermal inertia and behaviour of this kind is not uncommon.

Tests had to be carried out under stable conditions. If on the other hand a value monitored oscillated with a relatively small amplitude but the trend seems constant, the values were be averaged out for the period of testing and used for calculation. The main criterion in preparing the staff to assist with monitoring was that readings with "integrity" would be those reflecting the most representative image of the process at that time and equally important, consistency had to be maintained with the "integrity" of readings taken during tests performed. The aim was to be able to evaluate the difference in, for example thermal efficiency between all the tests while non-conformances in integrity of measurement were excluded.

4.6 UNIT LOADING AND CONTROL SETUP

4.6.1 UNIT LOADING

The loading that the unit would be subjected to for an anticipated three weeks, consisted of a different coal quality per week, at five constant loads per week, stretching over the first five days of the week, with six air flows per load, totalling ninety tests. The planned time phase was from 2nd - 27th May 1994, the anticipated test loading was as follows:

WEEK 1:

Monday, 2nd May 1994 - ± 100% MCR - (± 618 MW UG / 593 MW USO)
Tuesday, 3rd May 1994 - ± 90% MCR - (± 550 MW UG / 525 MW USO)
Wednesday, 4th May 1994 - ± 80% MCR - (± 500 MW UG / 475 MW USO)
Thursday, 5th May 1994 - ± 72% MCR - (± 450 MW UG / 425 MW USO)
Friday, 6th May 1994 - ± 65% MCR - (± 400 MW UG / 375 MW USO)

WEEK 2:

Monday, 9th May 1994 - ± 100% MCR - (± 618 MW UG / 593 MW USO)
Tuesday, 10th May 1994 - ± 90% MCR - (± 550 MW UG / 525 MW USO)
Wednesday, 11th May 1994 - ± 80% MCR - (± 500 MW UG / 475 MW USO)
Thursday, 12th May 1994 - ± 72% MCR - (± 450 MW UG / 425 MW USO)
Friday, 13th May 1994 - ± 65% MCR - (± 400 MW UG / 375 MW USO)

WEEK 3:

Monday, 16th May 1994 - ± 100% MCR - (± 618 MW UG / 593 MW USO)
Tuesday, 17th May 1994 - ± 90% MCR - (± 550 MW UG / 525 MW USO)
Wednesday, 18th May 1994 - ± 80% MCR - (± 500 MW UG / 475 MW USO)
Thursday, 19th May 1994 - ± 72% MCR - (± 450 MW UG / 425 MW USO)
Friday, 20th May 1994 - ± 65% MCR - (± 400 MW UG / 375 MW USO)

WEEK 4:

Monday, 23rd May 1994
Tuesday, 24th May 1994
Wednesday, 25th May 1994 Loads to be announced.
Thursday, 26th May 1994
Friday, 27th May 1994

The above stated loads could not be forecast exactly, and could vary slightly during the day due to the following:

- The ratio of UG to USO changes dependant on whether the SFP or EFP's are in service.
- The condenser vacuum will change due to varying CW inlet temperature as the day progresses.
- The coal quality will influence the mill combination and the subsequent plant behaviour will only be known at the time of testing.

Week 4 was reserved for "special tests" since the TRI caravan was also provisionally available for that extra week if necessary. These days were only to catch up the tests which could not be performed due to unforeseen incidents such as failure of certain vital components of plant causing the testing schedule to fall behind. The expectance was that none of these days would be utilised and the request for special loading would be cancelled accordingly. It was therefore not possible to specify the required load.

The unit was required to operate off ENCOR and frequency bias with MHC/EHC in operation on the turbine governing and the boiler on pressure support mode. Many other parameters such as secondary air flow were run on manual. Although the loading of the unit on each day of the week appeared identical to the corresponding day of the other weeks, the unit was run on different coal each week:

- Low grade coal for week one
- Spec. grade coal for week two
- High grade coal for week three

During each day the unit was submitted to ± six different air flows per load per coal type, each lasting ± 2 hours. This implies that the unit had to be available for stabilising at the required load for the day, at 06h00 on each of the days. After each day's testing the unit was put back on ENCOR and frequency bias for the night. Other specific operational instructions were given for the night (milling combinations etc.) especially for the week of low grade testing (see section 4.8).

4.6.2 COAL SUPPLY:

In order to achieve the required unit loading, detailed planning was conducted to ensure the supply of the coal feedstock at the correct time and in the correct order. As mentioned in section 4.1, the correct coal grade had to be supplied for the proposed five days of testing, starting on each Monday, with the weekends for clearing of bunkers and silos for the change over.

Good communication between the outside plant control room (OPCR) and the stockyard was of utmost importance. The low grade coal was stored on Live Pile A1, on the far Western side of the stockyard, which was reserved for the purpose (see Chapter 3.8). Although 70000 tons of low grade coal was ordered, 80000 tons arrived and was available for testing, change over and clearing of bunkers and silos. Coal supply belts to the station is by means of two parallel 100% capacity conveyor belts designated "A" and "B". The A belt was reserved for the test coal supply for the month of May, in order to eliminate confusion and mistakes. Silo 1 (serving unit one) low level trip was disabled during the test month to enable more thorough flushing. Detailed coal supply plans were drawn up to support the air flow tests on the unit and these succeeded in achieving the desired uninterrupted flow of the tests.

The remainder of this section (4.6.2) contains detail of the coal supply plan which was executed as such, and is intended for production inclined readers, interested in the logistic detail thereof:

WEEK 1: Low grade coal tests:

Friday, 29th April 1994, afternoon shift: They had to ensure that the stand-by mill bunker had been run empty and Silo 1 level lowered to 40% before 22h00.

Friday, 29th April 1994, night shift: Silo 1 had been emptied by ± 02h00. All bunkers were above 95% at that time (except the stand-by mill which was empty). All other silos were put in service, as well as the bunkers on other units filled by 07h00, on Saturday 30th May 1994.

Saturday, 30th April 1994, 06h00: The Coal stockyard moved Stacker-reclaimer no. 1 into position, i.e. A1 far Western side.

Saturday, 30th April 1994, 07h00: The reclaiming of the A line into Silo 1 commenced. The silo was filled to 40% by 08h00.

Unit 1 bunker levels were reduced to 40%, then the topping up of the in-service bunkers progressed for 30 minutes each, whilst the TH13-A mass meter was loaded to 800 tons/h throughout. This action increased the bunker levels to 75%. Meanwhile the other units' silos were filled by the B conveyor line. After the 25% bunker levels were reached on Unit 1 without any ignition and combustion problems, Stacker 1 once more reclaimed from the A1 West pile into the selected Silo 1. The A line was again started and Silo 1 as well as the five bunkers in service filled. The stand-by bunker was then filled to only 40% since the sixth mill was only to be used for limited periods. After initially filling Silo 1 and bunkers coaling was done from the stockyard during morning shift. The same coal was used to replenish coal burnt during the week.

Saturday, 7th May 1994, 07h00 - Afternoon shift ran Silo 1 empty by 18h00 after the A line was completely emptied to clear all low grade coal. The stand-by mill bunker was run empty as well.

WEEK 2: Spec. grade coal tests:
This coal was stored and reclaimed from live pile A1 East section.

Saturday, 7th May 1994, 07h00 - As soon as Silo 1 was empty and Stacker 1 was repositioned to the Eastern side of A1 live pile, Silo 1 was filled to 100%. The coal level in the unit 1 bunkers was allowed to reduce to 20% before coaling was restarted. The coaling rate of Belt A was increased to 950 tons/h. The stand-by mill bunker was filled to 40% for reasons already mentioned. Coal was replenished from A1 East by using A line for the rest of the week.

Saturday, 14th May 1994, 04h00 - Night shift ran silo 1 empty. The bunkers on the running mills were kept above 90% and the stand-by mill bunker empty.

<u>WEEK 3</u>: High grade coal tests:

The coal (from Vaal stockpile as explained in Chapter 4.1) was piled close to two inloaders and was supplied to the silo using four front end loaders initially and thereafter two, to keep up with the burn rate.

Sunday, 15th May 1994, 07h00, morning shift: The A line was on load, selected to Silo 1, when loading started with four front end loaders. The bunker levels were allowed to lower to 30 % before filling was started. The stand-by mill bunker was once more filled to 40%, for reasons as above.

After the bunkers were filled and the silo level was above 60%, only two front end loaders were used to replenish coal levels until all the test coal (± 50000 tons) had been moved. After this, Silo 1 was filled with normal ROM coal. Bunker levels were reduced to 30% prior to filling. Coaling was then continued in the normal manner.

4.6.3 CONTROL SETUP:

The air flow was varied for each load from an absolute maximum to a minimum. During the previous unit 2 tests(2) the process was reversed, because the lower limits were not known. Since these had consequently been established, it was better to start at the highest air flow a furnace can tolerate. The reason for this was to avoid contamination of fly ash samples by deposits from a previous test run being disturbed by the higher air flow of a subsequent test, that should produce a lower carbon in ash figure. The upper limit of air mass flow to the boiler was governed by metal temperature excursions and the lower limit by the combustion stability indicated by the pyrometers and witnessed by rising CO in flue gas.

The unit was thus stabilised on the required load for the specific day, and gradually the total air flow was increased manually (as explained in Chapter 5) until metal temperatures stabilised just below limit value, which permitted the start of the first test for the day. The approximate minimum, which was derived from previous test experience as explained above, was used as the other extreme and the range of air flow in between was divided into six arithmetically equal portions. This is explained in more detail in Chapter 5. There were however some other indicators that also served as guidelines:

- There was no positive scientific evidence that it would be beneficial to deliberately go sub-stoichiometric on the amount of air flow but it could be dangerous (see Sample Calculation 1, Appendix A).

- The most readily available indicator is the flue gas O_2 content. The O_2 % value approaching zero should be the bottom limit. While it is not precise, since furnace leakage can make this value to differ from the actual combustion O_2 %, it can serve as a guideline.

- The CO (ppm) content of the flue gas is another indicator that the excess air is getting low, but relies on a well balanced furnace. A distorted burner, or fuel maldistribution may produce CO long before a limiting overall excess air quantity is reached.

Since the planned tests intended to cover values of excess air above and below the ESKOM standard values defined in the Pf Code of Practice(8), "sanction for test" had to be obtained. Loading restrictions dictated by the programme had also to be approved to ensure that no capability loss was debited against Lethabo by the National Control Centre.

A very important aspect was the way the unit controls were set up for this test. Two possibilities existed. The first is where the generator output is fixed at a specific load, by taking the unit off automatic generation control and disabling the governor. The unit would then run reasonably steady, but National Control should rather lock the specific unit on base load for this method of control setup to be effective. The turbine load controller should also be fixed with the boiler pressure controller on automatic. This is the method to use when the grid frequency is not very stable.

The other method is when the boiler pressure controller is selected to a fixed value and the turbine automatic load controller is switched off, to generate according to the fixed boiler output even if it results in varying generator output due to factors such as changing condenser vacuum.

Simply setting the unit to turbine-follow mode could not quite produce the required effect for reasons associated with slight fluctuations in main steam pressure, causing the boiler load to oscillate slightly. The desired effect could be obtained by fixing the steam governor valve opening to the turbine while leaving the boiler on automatic control to maintain a constant steam pressure. With the fixed valve opening ensuring a constant throughput area and with the boiler pressure controller maintaining a constant steam pressure, the mass flow of steam demanded by the turbine and produced by the boiler should remain constant.

If the mass flow, pressure and temperature of steam (total enthalpy) remain constant, the boiler load would remain constant. This desired effect could have been achieved by means of a manual setting on either of the turbine valve control systems, termed MHC and EHC (see nomenclature), respectively. Since EHC provided a more sensitive valve control, it was proposed to be the valve control mode to use. This methods of control setup can be used if grid demand and frequency is quite stable.

With the boiler pressure controller on automatic and manual setting of the secondary air to produce the desired total air, the primary air side (including mills and feeders) remains the only variable capable of responding to fuel demand to settle at a different coal flow, resulting in a different thermal efficiency. If all other variables are constant and the boiler burns a different amount of coal, there is a corresponding change in thermal efficiency. This would however not be possible if the whole boiler control were to be fixed on manual (i.e. primary air and mills as well).

4.7 SPECIAL CALIBRATIONS AND SETTINGS

As mentioned previously in Chapter 4.5, there are conditions attached to relying on certain of the SICOMP 70 monitoring values. Here follow some calibrations made for extra accuracy, with correction factors determined where necessary:

4.7.1 CONDENSER

The thermocouples and/or transducers of the following temperatures were recalibrated: CW inlet temperature (T_1) and CW outlet temperature (T_2), hotwell condensate temperature (T_c), the condenser vacuum saturation pressure (P_s).

4.7.2 FEED WATER FLOW

Concerning the steam side (Rankine cycle) the accuracy of the mass flow of the working fluid is very important. Since the STEP calculations are also accordingly sensitive to this feed water flow to the boiler a special laboratory calibrated orifice plate was installed in a Sempell block that is specifically designed to accommodate the plate. (See Figure 3.32). Special high pressure transducers were employed with appropriate conversion and correlation factors to produce accurate flow values. See Sample Calculation 4, Appendix A.

4.7.3 COAL FEEDERS

On the combustion side the coal flow is very important. The coal flow was measured by means of volumetric feeder-integrators. The feeder bars were set according to the required measurements and a correction factor was determined for the coal mass flow from the feeder integrator. See Sample Calculation 5, Appendix A.

4.7.4 AIR HEATERS

The influence of the S/A/HTR seals leaking air to gas creates a false impression of dfg temperature and loss due to the dilution effect. Although a compensating calculation (Sample Calculation 3, Appendix A) was built into STEP, the A/HTR leakage must be limited to the minimum for the sake of heat transfer. The air heater packs were inspected on the outage and the seals set according to specification.

4.7.5 AIR FLOW TO FURNACE

The other important measurement on the combustion side was the total air flow. This was the main parameter to be optimised, as explained previously. The measurements were taken by manometer with temperature and relative humidity compensations as described in Sample calculation 2, Appendix A.

4.7.6 ECONOMISER OUTLET OXYGEN

This is the important value addressed in the pf code of practice(8). At Lethabo the sixteen point sampling matrix that covers the cross-sectional area of each of the two economiser outlet ducts was built and installed to obtain a representative sample (see Figure 3.30). The on-line instrumentation was checked with a specially calibrated O_2 analyser(22) (utilising specially prepared test gas with a percentage O_2 in the range of actual operation) and a correction factors determined.

4.7.7 AIR HEATER OUTLET OXYGEN AND TEMPERATURE

Since no such matrix exists in any of the air heater outlet ducts, a traverse with a pitot-static tube was carried out on each duct in order to determine the most representative measuring point, where the main stream of flow pass through. A thermocouple was attached to the pitot tube to incorporate the influence of temperature as well. The four precipitator inlet ducts were chosen since that is the most representative and practical measuring point where sufficient mixing of the secondary and the primary air heater outlet gas takes place. For detail on the determination hereof, see Appendix B.

4.7.8 CO, NO_x AND SO_2

The TRI mobile caravan facility enables the measurements of these gases and was calibrated very accurately. In addition Lethabo Power Station also had stack mounted SO_2 and NO_x analysers fitted, as well as ID fan discharge mounted CO measuring instruments. The SO_2 works on an extracted sample principle whereas the NO_x and CO are of the infra-red cross duct scanner type which proved very accurate and reliable. All these instruments were calibrated prior to the test according to manufacturers specifications.

4.8 SPECIAL OPERATIONAL ROUTINES AND PRECAUTIONS

The following were additional testing requirements, information and safety precautions, especially applied during operation of the unit while testing:

- The testing involved operation outside the pf code of practice.

- No 3000h mill services were be scheduled during the test period on unit one, since six mill operation were required often as discussed in Chapter 4.1. The weekends and nights were the only time available for emergency repair work and other servicing.

- All the tests were performed with either the SFP or the EFP's in service, but not a random changing of both.

- Constant CW flow was required for testing and CW pump combinations on the West side were not to be changed during a test, especially without prior warning.

- Boiler drum blowdowns were only to be done during night time if necessary, but not during testing.

- Sootblowing was carried out extensively according to an enhanced method and philosophy as described in Chapter 5, prior to testing.

- Mill stripping was carried out early morning on night shifts (see section 4.3.3) prior to testing. In many instances it was performed under the supervision of testing staff. The calculated media make-up was controlled very strictly and no make-up was made without the knowledge of appointed testing staff.

- O_2 calibrations were performed every morning for the day's correction factor according to procedure(22).

- It was of utmost importance that the make-up water to the boiler sealing trough was maintained, as explained in section 4.2.8.

- The ID fan balance and furnace pressure impulse lines were treated equally important.

- Finally the eight pyrometers on 51 m level (four on each side) monitoring the flame were cleaned on a routine basis at least daily. Normally this precaution was carried out prior to the low air flow tests (see Chapter 5) every day.