CRE

CONFIDENTIAL

ALMATY AIR QUALITY STUDY (TA 2262-Kaz)

Prepared for the Asian Development Bank

Final Report

Your energy - Our business

August 1995

EXECUTIVE SUMMARY

Background and Aims

Following the Asian Development Bank country mission to Kazakhstan in October 1994, it was decided to accelerate a programme of possible power sector investments. This led to the letting of a small Technical Assistance study on air quality improvement in Almaty, the capital city of Kazakhstan. This study was carried out by CRE Group Ltd for the Asian Development Bank in the first half of 1995. The aims of the study were to provide the Bank with information on the environmental impact of fossil fuelled power generation in Almaty and to assess the environmental benefits of rehabilitation options for Power Plant No 1.

Work Carried Out

In order to achieve these aims, a computerised atmospheric dispersion model was developed. This model predicted the ground level concentrations of pollutants across the city and related these concentrations to the contributions from the major emitters. This environmental information was combined with information on the costs of the power plant rehabilitation options in order to determine which solution gave the best environmental improvement per dollar invested.

As reliable measurements of emissions to atmosphere at the three major power plants were not available, measurements of stack emissions were made. These data combined with information on emissions from other major emitters in the city and meteorological data were used as inputs for the dispersion model. The results of the monitoring exercise indicate that emissions of oxides of nitrogen (NO_x) were close to the Kazakh and EU limit values. Emissions of sulphur dioxide (SO_2) were generally higher than the Kazakh and EU limit values. Particulate emissions were up to 20 times the Kazakh and EU limit values.

An atmospheric dispersion model was developed and used to undertake a refined analysis of the contribution of pollutant discharges from the three power and district heating plants in Almaty to local ground level concentrations of SO_2, NO_x and particulates. The results of this exercise showed that the power plant (in particular Power Plant No 1) were contributing significantly to air pollution within the city. The model was then used to predict the environmental benefit which would accrue from each of the rehabilitation options for Power Plant No 1. Seven remedial strategy options were modelled, and six of these were costed. The costs of the environmental improvement for each strategy were expressed as a consistent value for the direct comparison of each option with the units: US dollar per annum per percentage point improvement in air quality at the point of maximum concentration for each pollutant ($/y/ % SO_2 improvement etc.)

Results

The breakdown of the specific costs of environmental improvement for each strategy is summarised below:

STRATEGY	COST('000$ per annum /% improvement)		
	SO_2	NO_x	Particulates
• CFBC Replacement of Boilers 7 & 8	6390	-	327
• PF Replacement of Boilers 7 & 8	-	-	408
• CFBC Replacement of all Boilers	2160	3024	585
• PF Replacement of all Boilers	3482	8269	640
• Closure and replacement Capacity at Nos 2 & 3 with PF	5573	7740	1380
• Increase Stack Height	135	68	10

Conclusions and Recommendations

Thus from the above calculations it can be deduced that the least cost strategy appears to be increasing the stack height at plant No. 1 to 150 m. This strategy, although having the biggest impact on ground level pollution in the urban areas does not actually reduce the total emissions from the city. The increased stack height merely leads to the emissions being distributed over a wider area, thus resulting in lower ground level concentrations at any particular point in the city. The local Aviation Authorities have rejected this strategy on the grounds that Power Plant No 1 is situated on the airport flightpath. Chimney heights at this location are limited to 90 m. Due to both these factors, this solution is rejected.

The biggest reduction in emissions is shown to occur with the strategy of replacing all the capacity at Almaty No 1 Power Plant with CFBC boilers. However, this strategy involves a high capital expenditure. The most realistic strategy to adopt is to start by replacing Boilers 7 and 8 at Almaty Power Plant No 1 with new capacity. The capital costs of this replacement are relatively low and real environmental gains can be achieved. Given the position of Almaty No 1 Power Plant in the city centre, the choice of boiler technology should be the cleanest in terms of emissions provided that this is not at excessive cost. This study has shown that the use of a CFBC boiler to replace capacity at Almaty No 1 Power Plant is cheaper than using a PF boiler and that it has greater environmental benefits. Following successful demonstration of the technology in Kazakhstan, replacement of further boilers could proceed in a step-wise approach.

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CRE

Your ref. TA 2262 - Kaz
Our ref. 554205

13 October 1995

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ASIAN DEVELOPMENT BANK
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19 OCT 1995
IED ENERGY (EAST)

Dear Mr Fernando

TA 2262 - Kaz: Almaty Air Quality Study

With reference to your communication of the 28 September 1995 regarding our Final Report on the above study. I am pleased to enclose 3 copies of the revised Final Report including clarification of the points raised in your fax and the amendments requested. We have addressed the issues raised as follows:

- The revised report has been reprinted to include all pages.

- Figure 1 has been revised to include the additional information requested including geographical features and boiler plant.

- The peak mazut boilers at plant TES1 were not included in the study. This decision arose from detailed discussions with Kazakhstanenergo regarding the extent and effects of the other major industrial and district heating sources in the city to be included in the model as required in the ToR. Kazakhstanenergo staff examined the most significant point sources in the study area (some 160 in total) and advised us that the 6 sources included in the model were by far the most significant. It can therefore be concluded that the omission of these district heating boilers reflects their peaking duty operation and correspondingly low annual load factor. Inclusion of these sources in the study is anticipated to have a minimal effect on the existing results.

- The effect on particulate control of emulsifiers relative to bag filters is discussed at various points in the report (page 8 Section 3.3, page 12 Section 4.1 and throughout section 6) and in Mr Summerfield's fax to Mr O'Sullivan responding to comments on the Draft Final Report. This discussion can be clarified as follows. Indicative emission measurements made on Boiler 11 at Almaty Plant No.1 showed that the installed emulsifiers had a predicted clean up efficiency of around 98 % compared to levels of 88 - 96% for the venturi scrubbers installed at other plants.

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These comments were made to highlight the possible improvements in particulate control that could be made by installing emulsifiers (a local Kazakh developmental technology) over Russian designed venturi scrubbers. The report did not comment on the obvious benefit of bag filtration technology (with removal efficiencies approaching 99.5%) which was assumed to be included in several of the remedial strategy options investigated. The strategy options considered were those agreed with Bank representatives during the April/May mission and did not include consideration of alternative particulate control technologies in conjunction with increased stack height strategies. This reflects the situation at the time of these discussions when the significance of particulate emissions was unknown.

- We appreciate your concerns regarding the changes in the Table presenting the ambient and predicted ground level concentrations. These changes have arisen from a combination of two factors. Firstly, the ambient data presented in the Final Report are based on detailed information from the monitoring stations in Almaty received from Kazakhstanenergo. These data were not made available in time for inclusion in the Draft Final Report. The ambient concentrations reported in the draft were based on rough averages for the city estimated in conjunction with the recipients. This situation was discussed with Mr O'Sullivan prior to delivery of the Draft Final Report. Secondly, changes in predicted ground level pollutant concentrations calculated by the model between the Draft and Final Reports have arisen from the inclusion of detailed meteorological data in the modelling runs incorporated into the Final Report. These data were again unavailable for inclusion in the Draft Report and the situation was communicated to Mr O'Sullivan. Knowing that a large follow-on TA was intended it was agreed that we should update the results using the best available data in order to facilitate performance of the next TA. I would stress that the changes in these results does in no way effect the ranking of the remedial strategy options and therefore the principal conclusions of the study

I hope that the above points clarify the issues raised in your fax but please do not hesitate to contact me if I can provide and further information. I must again thank you for the interest shown in our work and trust that we can now assume that the study is successfully completed.

Yours sincerely

Dr JM Topper
Commercial Manager

CONTENTS

1 INTRODUCTION

Following the Asian Development Bank country mission to Kazakhstan in October 1994, it was decided to accelerate a programme of possible power sector investments. This led to the letting of a small Technical Assistance study on air quality in Almaty, the capital city of Kazakhstan. This study was carried out by CRE Group for the Asian Development Bank in the first half of 1995. CRE Group were awarded this contract on the basis of their previous power sector work in Kazakhstan, their environmental capabilities and their knowledge of the Bank's requirements, having been involved, as consultants, in the October 1994 country mission. The aims of the study were to provide the Bank with information on the environmental impact of fossil fuelled power generation in Almaty and to assess the environmental benefits of rehabilitating Power Plant No 1.

In order to achieve these aims, a computerised atmospheric dispersion model was developed. This model predicted the ground level concentrations of pollutants across the city and related these concentrations to the contributions from the major emitters. The three major power plant and the large district heating boilers were included in the model as point sources. The model was then used to asses the environmental benefits that would accrue from modifying or rehabilitating Almaty Power Plant No 1. This environmental information was combined with information on the costs of the power plant modifications in order to determine which solution gave the best environmental improvement per dollar invested.

A great deal of input information was required to develop the atmospheric dispersion model. This included information on emissions from the major sources of pollution, meteorological data, and ambient measurements of ground level concentrations. This information was collected during two field missions to Almaty (February and April 1995). Some of these data were available from Kazakhstanenergo and the local Authorities such as the Ministry of Ecology and the Almaty Committee of Ecology. However, some information was not readily available and therefore measurements had to be made. In particular, measurements of atmospheric emissions were made at each of the three fossil fuelled power plants during the second mission. This was a substantial exercise involving a team to carry out the measurements and transportation of significant equipment in and out of Kazakhstan.

2. OBJECTIVES

The objective of the study was to assess the environmental impact of rehabilitating Almaty Power Plant No 1 and to relate this to the costs of the modifications. This overall objective was achieved by a completing a series of sub tasks:

1. Gather data on atmospheric emissions from the major power plants and district heating boilers in Almaty. This included measuring pollutant emissions from the three fossil fuelled power plants.
2. Gather data on meteorological conditions in Almaty.
3. Develop an atmospheric dispersion model of the emissions from these sources.
4. Compare the model output with ambient measurements to determine the contribution of the major emission sources to ground level pollutant concentrations.
5. Use the model to predict the environmental benefits of modifying or rehabilitating Almaty Power Plant No 1.
6. Gather indicative information on the costs of these improvements.
7. Compare the costs of the improvements with the environmental benefits to give a first estimate of which remedial strategy produces the greatest environmental benefit per dollar invested.

8. Develop a preliminary programme for further investment based on a least cost investment approach.

3. EMISSIONS MONITORING

As reliable measurements of emissions to atmosphere at the three major power plants were not available, measurements of stack emissions were made. During the first mission to Almaty, sampling positions were chosen and sampling sockets were supplied which were subsequently fitted by power plant personnel. The sampling positions were all chosen to be in long straight sections of duct after the induced draft fans. The positions were chosen to be as far away as possible from flow disruptions such as bends, fans etc. This ensured that the flue gas flow at the sampling positions was as fully developed as possible. During the second mission, the following measurements were made at each power plant:

1. Flue gas velocity using an "S" type pitot tube at positions across the duct at each sampling point. These velocity measurements were integrated across the duct cross section to give flue gas volumetric flow rate. One pitot scan was carried out in each duct during the sampling period.
2. Flue gas temperature using a thermocouple and digital readout. This was used to correct the flow measurements to standard conditions. The flue gas temperature was measured at the beginning and end of each sampling period.
3. Flue gas oxygen, carbon monoxide, sulphur dioxide and oxides of nitrogen contents using a "Testoterm" chemical cell analyser. The analyser's internal data logger was set to collect data every 30 seconds for a period of approximately 30 minutes. These data were averaged to produce a data set for that period. Three such averages were produced for each sampling period.
4. Flue gas water vapour by withdrawing a measured volume of flue gas through a pre-weighed tube containing a water absorbent (magnesium perchlorate). This was used to correct the other measurements to standard conditions. Three determinations of water vapour content were carried out during each sampling period and the results were averaged.
5. Flue gas particulate loading using the standard CEGB Mark IIIA isokinetic sampling equipment. One particulate determination was carried out in each duct during the sampling period. In general there were 4 sample ports on each duct and samples were collected at 3 positions across the duct, giving a total of 12 in-duct sampling positions. Samples were taken cumulatively for each sample port, resulting in (generally) 4 bulk samples per duct.
6. Atmospheric pressure using a barometer, ambient temperature using a thermocouple, duct dimensions, duct static pressure using a manometer, etc. These measurements were made to enable other measurements to be corrected to standard conditions.

These are the same techniques as CRE Group would use in the UK where emissions monitoring for the UK Government's Pollution Inspectorate and for industry is a significant part of their business. The measurement techniques are described in more detail in Appendix 1.

3.1 Plant Details

3.1.1 Almaty Power Plant No 1

Almaty Power Plant No 1 is located close to the city centre. It produces electricity and heat (for district heating) from 7, (6 x 160 t/h and 1 x 75 t/h steam) boilers firing pulverised coal, mazut, or gas (or combinations of these). Also on the site there are 7 hot water boilers which fire mazut and produce heat for the district heating system. These hot water boilers only operate in the winter.

The power boilers all operate using Karaganda coal which has an ash content of 25 to 35 %. This is higher than the boiler design figure (24 %). The boilers also generally burn mazut as a supplementary fuel to compensate for the variability of coal quality. Gas is used as a start up fuel.

The boilers each have 4 corner mounted burners incorporating secondary air injection. Particulate emission control is by venturi scrubbers on 4 boilers and emulsifiers on 2 boilers (Nos 11 and 12). The sulphur content of the coal is generally around 0.6 % , on an as-fired basis.

This is the station at which the Bank has been asked to consider the replacement of two ageing boilers with a single new unit. The boilers which would be replaced are Nos 7 and 8 (Steam ratings: No 7; 75 t/h, No 8; 160t/h). All the 160 t/h boilers (Nos 8 to 13) are of the same design, however boilers 11 and 12 have emulsifiers fitted for particulate cleanup whilst the others are fitted with venturi scrubbers. It was impossible to sample the flue gas from Boilers 7 and 8 due to the configuration of the ductwork. It was therefore decided to sample from Boiler 11 (to be representative of boilers with emulsifiers) and Boiler 13 (to represent boilers with scrubbers).

3.1.2 Almaty Power Plant No 2

Almaty Power Plant No 2 is located on the Western edge of the city. It produces electricity and heat (for district heating) from 7, (400 t/h steam) boilers firing pulverised coal. Mazut is used as a start up fuel and occasionally as a supplementary fuel to compensate for the variability of coal quality. The boilers all operate using a mixture of coals including Ekibastuz, Karaganda, and Borlinski which have ash contents of 30 to 35 %.

The boilers each have 4 corner mounted burners. Particulate emission control is by venturi scrubbers on 5 boilers and emulsifiers on 2 boilers (Nos 1 and 3). The sulphur content of the coal is generally around 0.6 %, on an as-fired basis. All the boilers are of the same design, it was decided to sample from Boiler 4 which was considered to be representative of all boilers on the Power Plant.

3.1.3 Almaty Power Plant GRES

The GRES power plant is situated about 20 km North of the city centre. It produces electricity and heat (for district heating) from 7, (160 t/h steam) boilers firing pulverised coal. Mazut is used as a start up fuel and occasionally as a supplementary fuel to compensate for the variability of coal quality. The boilers all operate using Ekibastuz coal which has an ash content of 30 to 40 %.

The boilers each have 4 corner mounted burners incorporating secondary air injection. Particulate emission control is by venturi scrubbers. The sulphur content of the coal is generally 0.6 to 0.8 % , on an as-fired basis. All the boilers are of the same design, it was decided to sample from Boiler 1 which was considered to be representative of all boilers on the Power Plant.

3.2 Plant Operation

During the test periods, the boiler operators were asked to run steadily at Maximum Continuous Rating (MCR). Plant data were collected throughout the tests by the power station staff to verify that the boilers were operating under steady state conditions. These data are presented in Tables 1 to 5 below.

Table 1 Plant Data Power Plant No 1, Boiler 11

Time	Steam Temperature, °C	Steam Pressure, kg/cm^2	Steam Flow, t/h	Flue Gas Temperature (after economisers), °C
12:15	529	88	130	154
12:45	527	89	135	153
13:15	527	89	135	155
13:45	540	87	145	155
14:15	528	86	142	151
14:45	528	84	133	151
15:15	535	87	140	151
15:45	528	88	142	150

MCR = 160 tph steam. Test carried out on 2 May 1995. Fuel 60 % coal, 40 % mazut.

Table 2 Plant Data Power Plant No 1, Boiler 13

Time	Steam Temperature, °C	Steam Pressure, kg/cm^2	Steam Flow, t/h	Flue Gas Temperature (after economisers), °C
15:30	506	91	165	152
16:00	531	87	165	153
16:30	529	90	170	153
17:00	509	94	155	152
17:30	517	92	158	152

MCR = 160 tph steam. Test carried out on 29 April 1995. Fuel 70 % coal, 30 % mazut.

Table 3 Plant Data Power Plant No 2, Boiler 4

Time	Steam Temperature, °C	Steam Pressure, kg/cm^2	Steam Flow, t/h	Flue Gas Temperature (after economisers), °C
12:00	525	135	405	270
13:00	520	130	395	270
14:00	505	140	370	270
15:00	520	140	375	270
16:00	510	140	385	270

MCR = 400 tph steam. Test carried out on 26 April 1995. Fuel 100 % coal.

Table 4 Plant Data Power Plant GRES, Boiler 1, Left Hand Duct

Time	Steam Temperature, °C	Steam Pressure, kg/cm^2	Steam Flow, t/h	Flue Gas Temperature (after economisers), °C
12:05	535	90	174	190
13:00	538	93	174	188
14:00	539	93	176	188
15:00	540	95	175	188
16:00	538	93	175	188
17:00	540	92	174	188

MCR = 160 tph steam. Test carried out on 27 April 1995. Fuel 100 % coal.

Table 5 Plant Data Power Plant GRES, Boiler 1, Right Hand Duct

Time	Steam Temperature, °C	Steam Pressure, kg/cm^2	Steam Flow, t/h	Flue Gas Temperature (after economisers), °C
09:00	540	101	170	189
10:00	540	103	172	189
11:00	540	103	170	189
12:00	540	104	170	189
13:00	540	100	170	193
14:00	540	100	170	193
15:00	540	100	170	198
16:00	540	103	170	198

MCR = 160 tph steam. Test carried out on 28 April 1995. Fuel 100 % coal.

From these tables it can be seen that the boilers were all operating under steady state conditions during the test periods. It can also be seen that all boilers except Power Plant No 1 Boiler 11 were operating at MCR during the test periods. Power Plant No 1 Boiler 11 was operating at approximately 85 % of full output.

3.3 Results of Emissions Testwork

The results of the emissions measurements carried out at each power plant are presented in detail in Appendices 3 to 5. These results are summarised in Tables 6 to 8 below. It should be noted that the figures in the summary tables have been rounded to reflect the accuracy of the measurements.

Table 6 Emissions Test Results Summary Power Plant No 1

As Measured			Boiler 11	Boiler 13
Particulates		kg/h	174	450
Moisture	(H_2O)	% (wet)	11.6	11.2
Oxygen	(O_2)	% (dry)	9.8	10.3
Carbon Dioxide	(CO_2)	% (dry)	9.8	9.3
Carbon Monoxide	(CO)	ppm (dry)	80	40
Oxides of Nitrogen	(NO_x)	ppm (dry)	260	260
Sulphur Dioxide	(SO_2)	ppm (dry)	360	290
Flue Gas Flow		m^3/h	370500	373500
Corrected to 6 % O_2,	dry	STP		
Particulates		mg/m^3	960	2580
Carbon Dioxide	(CO_2)	%	13.2	13.2
Carbon Monoxide	(CO)	mg/m^3	140	60
Oxides of Nitrogen	(NO_x)	mg/m^3	470	490
Sulphur Dioxide	(SO_2)	mg/m^3	1370	1160

Table 7 Emissions Test Results Summary Power Plant No 2

As Measured			One Duct	Total
Particulates		kg/h	312	624
Moisture	(H_2O)	% (wet)	8.0	8.0
Oxygen	(O_2)	% (dry)	11.7	11.7
Carbon Dioxide	(CO_2)	% (dry)	8.2	8.2
Carbon Monoxide	(CO)	ppm (dry)	60	60
Oxides of Nitrogen	(NO_x)	ppm (dry)	320	320
Sulphur Dioxide	(SO_2)	ppm (dry)	360	360
Flue Gas Flow		m^3/h	419500	839000
Corrected to 6 % O_2,	dry	STP		
Particulates		mg/m^3	1730	1730
Carbon Dioxide	(CO_2)	%	13.2	13.2
Carbon Monoxide	(CO)	mg/m^3	130	130
Oxides of Nitrogen	(NO_x)	mg/m^3	690	690
Sulphur Dioxide	(SO_2)	mg/m^3	1220	1220

Table 8 Emissions Test Results Summary Power Plant GRES

As Measured			Left Hand Duct	Right Hand Duct	Total
Particulates		kg/h	357	340	697
Moisture	(H_2O)	% (wet)	9.7	8.5	9.1
Oxygen	(O_2)	% (dry)	7.6	7.9	7.8
Carbon Dioxide	(CO_2)	% (dry)	11.7	11.4	11.5
Carbon Monoxide	(CO)	ppm (dry)	40	40	40
Oxides of Nitrogen	(NO_X)	ppm (dry)	320	330	330
Sulphur Dioxide	(SO_2)	ppm (dry)	480	500	490
Flue Gas Flow		m^3/h	166600	179000	345600
Corrected to 6 %O_2,	dry	STP			
Particulates		mg/m^3	3690	3330	3500
Carbon Dioxide	(CO_2)	%	13.2	13.2	13.2
Carbon Monoxide	(CO)	mg/m^3	50	50	50
Oxides of Nitrogen	(NO_X)	mg/m^3	490	500	500
Sulphur Dioxide	(SO_2)	mg/m^3	1550	1640	1600

In the following discussion, the figures quoted are corrected to 6 % oxygen in dry flue gas at Standard Temperature and Pressure (0 °C, 101.3 kPa).

From these tables it can be seen that NO_x emissions are generally low at Power station No 1 and GRES, at approximately 500 mg/m^3, whilst at Power Plant No 2, NO_x emissions are slightly higher at around 700 mg/m^3. This is probably due to the design of burners at each power plant.

Coal samples were collected during the testwork and analysed by the Power Station staff. The results of these analyses are shown in Table 9 below. The measured emissions of SO_2 are in line with the expected value for power plant burning coals with these sulphur contents, with aqueous scrubbing equipment. It may be that the scrubbers are capturing some of the SO_2 which would otherwise be emitted to atmosphere, however further testwork would be required to confirm this.

Table 9 Coal Analyses

	Power Plant No 1		Power Plant No 2	Power Plant GRES	
Boiler No	11	13	4	1 LHS	1 RHS
Coal	Karaganda		Ekibastuz, Karaganda, Borlinski	Ekibastuz	
Moisture % as fired	7.4	8.1	4.8	5.4	5.0
Ash, % as fired	35.2	33.1	32.7	34.8	37.3
Sulphur, % as fired	0.58*	0.58*	0.59	0.8	1.1
Measured SO_2 concentration in flue gas, mg/m^3 @ 6 % O_2 and STP, dry	1370	1160	1220	1560	1640

* Calculated values

The emissions of particulates ranged from approximately 1000 mg/m^3 to 3500 mg/m^3. The uncleaned particulate emission from a pulverised coal fired boiler operating with 35 to 40 % ash coal could be in the range 30000 to 40000 mg/m^3. This suggests that the particulate removal equipment is operating at efficiencies ranging from 88 to 98 %. However, these figures should be treated with caution as measurements of the inlet dust loading were not made, this was merely estimated from experience.

The boiler with the lowest particulate emission was Power Plant No 1, Boiler 11 (960 mg/m^3 @ 6 % O_2 in dry flue gas at 0 °C, 101.3 kPa). The particulate removal equipment installed on this boiler is an emulsifier, all the other boilers tested were fitted with venturi scrubbers. It should be noted that this boiler was only operating at 85 % of Maximum Continuous Rating during the test period. It is difficult to predict how the particulate emission would change if the boiler was operating at full load. The inlet loading to the emulsifier would probably increase as the flue gas flow rate increased, however the emulsifier performance may improve with higher gas flow. The net effect may be that the particulate emission concentration would be similar at MCR to that measured during these tests. This suggests that the emulsifier had superior performance to the venturi scrubbers.

3.4 Comparison of Results with Emission Standards

Emission limits for large combustion plant in the European Union are based on Council Directive 88/609/EEC. These limits are treated as the minimum standard and several member states of the European Union have imposed more stringent limits.

Information was obtained from IEA Coal Research on emission limits for Kazakhstan. These limits are shown in Table 10.

Table 10 Emission Limits for Coal Fired Plants in Kazakhstan

Plant Type	Plant Size	Emission Limit, mg/m^3 @ 6 % O_2 in dry flue gas at 0 °C, 101.3 kPa	
		Hard Coal	Brown Coal
Oxides of Nitrogen			
Dry Bottom Boilers	<300 MW(th)	470	340
Dry Bottom Boilers	>300 MW(th)	240	225
Wet Bottom Boilers	<300 MW(th)	515	445
Wet Bottom Boilers	>300 MW(th)	480	225
Fluidised Bed Combustion	-	400	
Circulating Fluidised Bed Combustion	-	200	
Combustion Plants	<420 t/h steam	240	
Combustion Plants	>420 t/h steam	480	
Sulphur Dioxide			
Combustion Plants	<300 MW(th)	600	
Combustion Plants	>300 MW(th)	400	
Particulates			
Combustion Plants	<300 MW(th)	150	
Combustion Plants ash content<1%kg/MJ	>300 MW(th)	50	
Combustion Plants ash content1-4%kg/MJ	>300 MW(th)	100	
Combustion Plants ash content>4%kg/MJ	>300 MW(th)	150	

(Source IEA Coal Research Emission Standards Database)

The boilers at Power Plants No 1 and GRES each produce 160 t/h steam or less. 160 t/h steam is equivalent to approximately 130 MW(th). The boilers at Power Plant No 2 each produce 400 t/h of steam, which is equivalent to approximately 330 MW(th).

3.4.1 Oxides of Nitrogen

The emission limit to be applied for these boilers is not clear from Table 10. All the boilers produce less than 420 t/h of steam which would suggest that a limit of 240 mg/m^3 should be applied. However, the boilers at Power Plants No 1 and GRES are dry bottom boilers burning hard coal with a thermal input of less than 300 MW(th) which suggests that a limit of 470 mg/m^3 should be applied. None of the boilers tested meet the more stringent limit of 240 mg/m^3. However, the NO_x emission from the boilers at Power Plants No 1 and GRES is close to the less stringent limit of 470 mg/m^3. The corresponding limit for NO_x emissions in the EU is 650 mg/m^3 (for coal fired boilers with a thermal input of greater than 50 MW(th)).

3.4.2 Sulphur Dioxide

The emission limit for the boilers at Power Plants No 1 and GRES is 600 mg/m^3 and for the boilers at Power Plant No 2 it is 400 mg/m^3. None of the boilers tested met these limits. The corresponding limits for SO_2 emissions in the EU are approximately 1800 mg/m^3 for coal fired boilers with a thermal input of 130 MW(th) and approximately 900 mg/m^3 for coal fired boilers with a thermal input of 130 MW(th).

3.4.3 Particulates

The coal ash content was approximately 2 %kg/MJ. The emission limit for the boilers at Power Plants No 1 and GRES is 150 mg/m^3 and for the boilers at Power Plant No 2 it is 100 mg/m^3. None of the boilers tested met these limits. The corresponding limits for particulate emissions in the EU for existing coal fired boilers with a thermal input above 50 MW(th) is 140 mg/m^3.

4 MODELLING OF IMPACTS OF MAJOR AIR POLLUTION SOURCES

4.1 Model Development

Atmospheric dispersion modelling is a useful tool for estimating the contribution of pollutant emission sources to ambient air quality. The results from these dispersion modelling exercises provide a powerful tool for decision-makers in the selection of potential remedial strategies to overcome problems with poor air quality in urban areas. The objective of this study was to develop a simple atmospheric dispersion model of Almaty, to enable an estimate of the potential improvement in air quality resulting from implementation of various strategies to reduce pollutant emissions from No 1 Power Plant. The model concentrated on emissions of sulphur dioxide (SO_2), oxides of nitrogen (NO_x) and particulates (TSP) from major point sources. No attempt was made to include emissions from low level domestic sources, nor those from transportation. Emissions of SO_2, NO_x and TSP are of environmental concern as they are all associated with adverse health effects in exposed populations, and are frequently implicated with emissions from coal use. A detailed discussion of the important parameters associated with atmospheric pollutant dispersion modelling is given in Appendix 2.

The air quality model for Almaty was initially set up to estimate the contribution to ambient pollutant concentrations of emissions of SO_2, NO_x and TSP from the following major point sources within the city and its environs:

Almaty No 1 Power Plant;
Almaty No 2 Power Plant;
Almaty Power Plant GRES;
District Heating Plant No 1 (Western);
District Heating Plant No 2 (Western);
District Heating Plant No 3 (North Eastern).

The choice of these point sources was based on discussions with Kazakhstanenergo personnel during the first mission to Almaty in February 1995. The choice was based on inclusion of the major point sources for which emissions data could be accurately measured or estimated.

The pollutant emissions data for the three power plant used in the model were obtained during the mission by CRE Group Ltd personnel to Almaty during April and May 1995. Emissions data for the three district heating plant were provided by Kazakhstanenergo who assisted CRE during the mission to Almaty.

Meteorological data for Almaty were obtained from Trinity Consultants Incorporated. The meteorological data obtained were hourly measurements of atmospheric temperature, wind speed, wind direction, atmospheric stability category, and rural and urban mixing layer heights. These data were obtained as a computer file which contained hourly measurements made in Almaty throughout 1993. The computer file therefore contained more than 52500 data points.

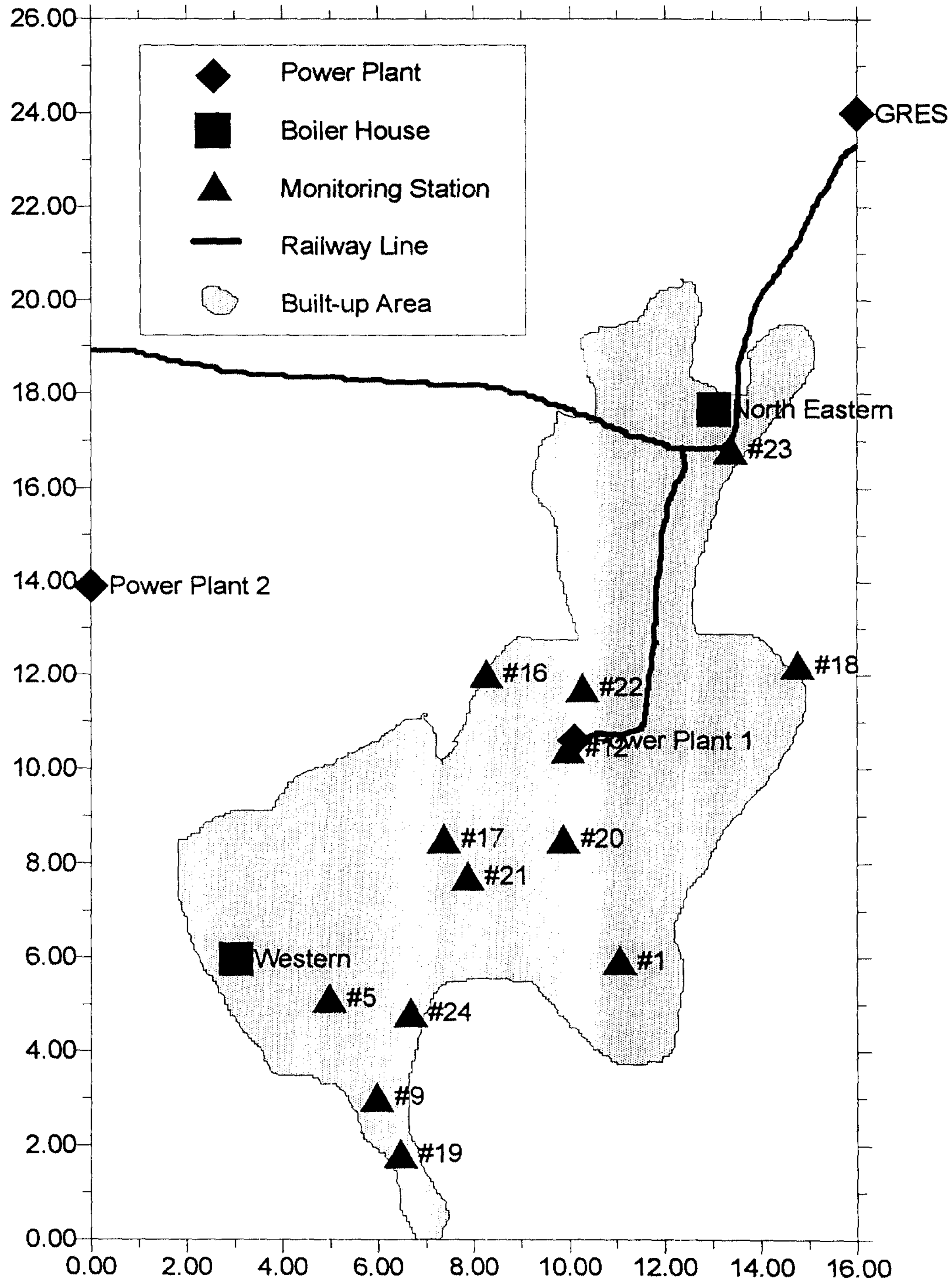
Due to the limited timescale of the study, it was not possible to make measurements of ground level concentrations of pollutants. However, Kazakhstanenergo assisted by providing ambient pollutant data for the monitoring stations within Almaty. These data were collected by the Almaty Committee of Ecology which is funded by the Ecology Ministry. The model predictions were compared with these measurements to assess the contributions of the major air pollution sources to ground level air pollution concentrations.

A detailed map of Almaty was also provided by Kazakhstanenergo. A Cartesian receptor grid, based on the co-ordinates of this detailed map was incorporated into the model to enable the relative positions of the major point sources to be located accurately. The receptor grid consisted of a 22 km East-West by 27 km North-South grid and the model calculated the ground level pollutant concentration at each intersection. In addition, ten discrete receptor points, corresponding to the ambient monitoring stations in Almaty, were also included in the model. This allowed a degree of validation of the model predictions, and permitted an estimate to be made of the contribution of emissions from the point sources to overall background concentrations at each location. The relative positions of the major point sources and the ambient monitoring stations are shown on Figure 1.

The first phase of the dispersion modelling study was to estimate the contribution to ambient air quality of pollutant emissions from the existing plant configurations. Subsequent modelling exercises were performed to simulate a range of remedial strategies, intended to improve air quality in the urban areas of Almaty. These strategies were agreed with the Asian Development Bank's Task Officer, Sean O'Sullivan, during his mission to Kazakhstan in April 1995. The remedial strategies which were modelled were:

1. Replacement of boilers 7 and 8 at Almaty No 1 Power Plant with a 230 MW(th) CFBC;
2. Replacement of boilers 7 and 8 at Almaty No 1 Power Plant with a 230 MW(th) PF-fired boiler with limestone addition;
3. Replacement of all of the boilers at Almaty No 1 Power Plant with 2 x 400 MW(th) CFBC boilers;

Figure 1 Positions of Major Point Sources and Ambient Monitoring Stations in Almaty



4. Replacement of all of the boilers at Almaty No 1 Power Plant with 2 x 400 MW(th) PF-fired boilers with limestone injection;
5. Complete closure of Almaty No 1 Power Plant and replacement with equivalent CHP plant at Almaty Nos 2 and 3 Power Plants;
6. Replacement of the chimneys at Almaty No 1 Power Plant with higher chimneys (150m compared with the existing 45m and 80m chimneys);
7. Replacement of all of the boilers at Almaty No 1 Power Plant with equivalent gas-fired capacity.

The potential benefits likely to accrue from the remedial strategies were compared against baseline conditions representing wintertime operation of the power plant and district heating plant. In winter it was assumed that all three power and district heating plant operated at full output for 24 hours per day. This would give the worst case scenario for emissions and ground level concentrations of pollutants.

The following assumptions were made concerning the pollutant emission characteristics of the proposed remedial options for boiler replacement at Almaty No 1 power plant, see Table 11.

Table 11 Effects of Remedial Strategies on Emissions

Remedial Strategy	Potential Pollutant Emission Reduction Relative to Base Case
CFBC	90 % reduction in SO_2: 50% reduction in NO_x: particulate emission concentration 100 mg/m^3 (bag filtration).
PF + Limestone Injection	50 % reduction in SO_2: no change to NO_x: particulate emission concentration 100 mg/m^3 (bag filtration).
New Capacity at Nos 2 & 3	50 % reduction in SO_2: no change to NO_x: Particulate emission concentration 100 mg/m^3 (bag filtration).
Gas Firing	Zero emissions of both SO_2 and particulates: NO_x emission concentration 350 mg/m^3.

The results from the dispersion modelling studies are presented in Section 5.

4.2 The Environmental Situation in Almaty

In common with many areas of the former Soviet Union, Kazakhstan suffers from a range of severe environmental problems. Major ecological issues in the region include the catastrophic desiccation of the Aral Sea basin, severe pollution of surface and ground waters with heavy metals and organic compounds and extreme levels of air pollution in many urban areas. In northern Kazakhstan, soil erosion is endemic; dust storms have become a regular feature of the area since the decision in the 1950's to turn this area of semi-arid steppe into a region of grain production.

The country is blessed with a wealth of natural resources including rare metals such as manganese, vanadium and chromium as well as coal, oil and gas. The exploitation of these resources has led to severe local and regional environmental problems. Urban air quality is also a severe problem in a number of cities. In 1988 eight Kazakh cities were included in a list of the most polluted cities in the USSR, including Almaty, Dzhambul, Leninogorsk and Temirtay.

The poor air quality situation is exacerbated by the climatic conditions. Kazakhstan is influenced by the central Asian high pressure system for much of the year, resulting in low wind speeds, poor atmospheric dispersion and frequent temperature inversions. The capital, Almaty, suffers particularly badly in this regard. The city is situated in a natural basin formed by the uplift of the Tien Shan mountain range. This topography, combined with the prevalence of continental high pressure systems inhibits the dispersion of atmospheric pollutants. The diurnal development of an inversion layer leads to increasing pollutant concentrations and the development of a smog which severely restricts visibility

4.3 Air Quality Data for Almaty

Copies of the ambient air quality data for the monitoring stations in the city were provided by the Almaty Committee of Ecology. The data for ten of the monitoring stations in the city is summarised in Table 12.

Table 12 Air Quality Monitoring Results for Almaty (Daily Average in $\mu g/m^3$)

Monitoring Station	TSP		SO_2		NO_x	
	January	July	January	July	January	July
1	240	105	30	15	68	44
5	225	75	20	15	64	32
9	420	165	40	20	124	120
12	330	225	40	20	116	172
16	150	90	30	15	80	72
18	270	150	20	15	76	64
19	210	105	20	15	84	44
20	15	-	10	10	76	72
22	465	330	45	5	72	96
23	390	-	35	-	144	-
Max recorded	465	180	45	20	144	172

The data for TSP and SO_2 show a marked seasonal variation, as might be expected if pollution is related to combustion of fossil fuels for heating in the winter. The absolute levels of particulates and SO_2 differ by virtually an order of magnitude. Winter concentrations of particulates are well in excess of WHO standards, with daily average levels reaching 465 $\mu g/m^3$ at monitoring station No. 22 in winter. Studies in other Asian cities have indicated that there are a number of sources of airborne particulates which contribute to the total atmospheric load. In certain areas contributions from natural sources far outweigh the emissions from combustion systems and industrial processes. This may be the situation in Almaty as much of Kazakhstan is affected by soil erosion due to over intensification of agriculture and poor land management during the Soviet period.

The data for sulphur dioxide concentrations in the city indicates that daily average levels of SO_2 are unexpectedly low. The reported values are not consistent with reports of poor air quality and are well below that which might be expected in the vicinity of coal fired power stations, even taking account of the low sulphur content of the coal which is used. Levels of 15-40 $\mu g/m^3$ are below background levels of SO_2 in most areas of the UK, where coal combustion is largely restricted to power generation purposes. In addition, measured emissions from the power stations indicate that the tonnage of SO_2 emitted is of similar magnitude to that of particulates. It is hard to reconcile this with a tenfold difference in ambient concentrations. These observations suggest that the data supplied for ambient SO_2 concentrations must be viewed with some scepticism, an observation which is supported by the output of the models, which are based on known emissions and stack heights and accurate meteorological data.

An additional comment on the air quality data is that daily average concentrations do not allow an accurate assessment of the environmental impact of Almaty power station No.1, located in the centre of the city. The principle environmental concern from this unit is the grounding of the plume, which leads to extremely high localised concentrations of SO_2 and particulates for short time periods. In an urban environment it is the human population which must be regarded as the most sensitive receptors for an assessment of environmental risk. Studies of the health effects of air pollution have indicated that exposure to high concentrations of SO_2 for as little as ten minutes can have an acute effect on individuals prone to respiratory disorders such as asthma. The available data does not allow this risk to be assessed accurately, but the results of the modelling study confirm that the low stack height and efflux velocity from power station No.1 is likely to lead to transient peaks in ground level concentrations of SO_2 in the vicinity of the plant. Full evaluation of this effect can only be achieved through continuous monitoring of air quality in the area; which is becoming common practice in the vicinity of many European power plants

Concentrations of NO_x show little seasonal variation, with breaches of air quality standards recorded at a number of monitoring sites. These levels are comparable with many cities around the world. In common with these cities, it is likely that the major contribution to NO_x pollution derives from mobile sources. However, the data available and the scope of study do not allow this to be assessed accurately. It is clear, however, that reduction in NO_x emissions from major sources are not likely to have a significant beneficial effect on local air quality unless they are linked to effective measures to control or reduce NO_x emissions from vehicles.

4.4 Air Quality Standards

The results from the dispersion modelling studies have been compared to air quality standards specified by the World health Organisation and the equivalent EC standards as applied in Member States of the European Union. The air quality standards, summarised in Tables 13 and 14, give limits for the total ground level concentrations of SO_2, smoke (total suspended particulates) and NO_2. These limits are based on concentrations which are known to cause health problems to vulnerable members of the population with a safety factor applied to limit the health problems within the exposed population. These limits can therefore be equally applied in Kazakhstan or elsewhere in the world.

TABLE 13 EC Air Quality Standards

Reference Period	Concentration, μg/m³		
	Particulates (Smoke)	Sulphur Dioxide	Nitrogen Dioxide
LIMIT VALUES			
One Year (Median of Daily Values)	80	120 if smoke < 40 80 if smoke > 40	-
Winter (Median of Daily Values)	130	180 if smoke < 60 130 if smoke > 60	-
Year, Peak (98 Percentile of Daily Values)	250	350 if smoke < 150 250 if smoke > 150	-
Year (98 Percentile of 1 Hour Means)			200
GUIDE VALUES			
24 Hour Mean	-	100 - 150	-
1 Year Mean	-	40 - 60	-
1 Year (50 Percentile of 1 Hour Means)	-	-	50
1 Year (98 Percentile of 1 Hour Means)	-	-	135

EC Directive 80/779/EEC for particulates and SO_2; and EC Directive 85/203/EEC for NO_x

TABLE 14 World Health Organisation (WHO) Air Quality Guidelines for Europe

	Concentration, μg/m³			
	1 Hour	8 Hour	24 Hour	1 Year
Sulphur dioxide	350	-	125	50
Nitrogen oxides	400	-	150	-
Particulates (smoke)	-	125	-	-

Compliance with these standards for a specific location would be determined by measurement. The concentrations of any species at a specific location may well be attributable to several sources, some of which may be remote from the location. Plume dispersion modelling, such as that reported here, enables an estimate to be made of the contribution of a specific source to ground level concentrations of specific species at a specific location. It is not, however, possible to estimate the total ground level concentration without taking into account other sources likely to contribute to this concentration. The concentrations quoted in this report are therefore estimates of the maximum contribution of the Almaty power and district heating plant to ground level concentrations of SO_2, NO_x and particulates within the confines of the city and its environs.

5 DISPERSION MODELLING

The ATDM model was used to undertake a refined analysis of the contribution of pollutant discharges from the three power and district heating plants in Almaty to local ground level concentrations of SO_2, NO_x and particulates. The pollutant emission rates and operating characteristics (height, diameter, temperature, efflux velocity and volumetric flowrate) of the chimneys at each power plant and district heating plant are summarised in Appendix 6.

Table 15 summarises the results of the refined analysis of pollutant dispersion of the combined emissions from the various plant under winter operating conditions. Maximum contributions to ground level concentrations are presented in terms of maximum daily averages for SO_2, NO_x (expressed as NO_2) and particulates. It should be noted that these maximum values refer to the estimated highest contribution to ground level concentrations over the 432 receptors in the receptor grid. There will be, therefore, 431 receptors where the ground level concentrations are lower than this maximum value.

TABLE 15 Summary of Refined Analysis

Remedial Strategy	Maximum Ground Level Concentration (Maximum Daily Average), μg/m^3 WINTER		
	SO_2	NO_x	Particulates
BASE CASE	270	135	345
CFBC Replacement of Boilers 7 & 8	267	135	270
PF Replacement of Boilers 7 & 8	272	137	279
Full Replacement with CFBC	242	125	213
Full Replacement with PF	251	131	213
Closure and Replacement of Capacity at Nos 2 & 3	245	126	216
Increased Stack Height	268	133	309
Convert All Boilers to Gas	240	125	213

Nitrogen oxides are expressed as nitrogen dioxide.

5.1 Current Situation (Reference Case)

The dispersion model was run with input emissions data as shown in Appendix 6. The results are shown in Table 15 which shows the maximum ground level concentrations predicted anywhere within the modelled area. When the predictions are compared with the ambient measurements, it is clear that (for NO_x and particulates) the maximum predicted ground level concentrations anywhere in the city are very close to the maxima of the measurements made at the ambient monitoring stations. This suggests that the district heating and power plants modelled are major contributors to atmospheric pollution in Almaty.

The results of the modelling are shown as contour plots of pollutant concentrations ($\mu g/m^3$) for the modelled area in Figures 2 to 7 for winter and summer. It should be noted that the model only included emissions from the six major point sources in the modelled area of Almaty. Emissions from other sources and, in particular, from mobile sources were not modelled. Tables 16 to 18 show the maximum predicted ground level concentrations of SO_2, NO_x and particulates respectively and their positions within the modelled area for summer and winter under all the modelled scenarios.

Figure 2 Predicted Ground Level Concentrations of Sulphur Dioxide for Winter

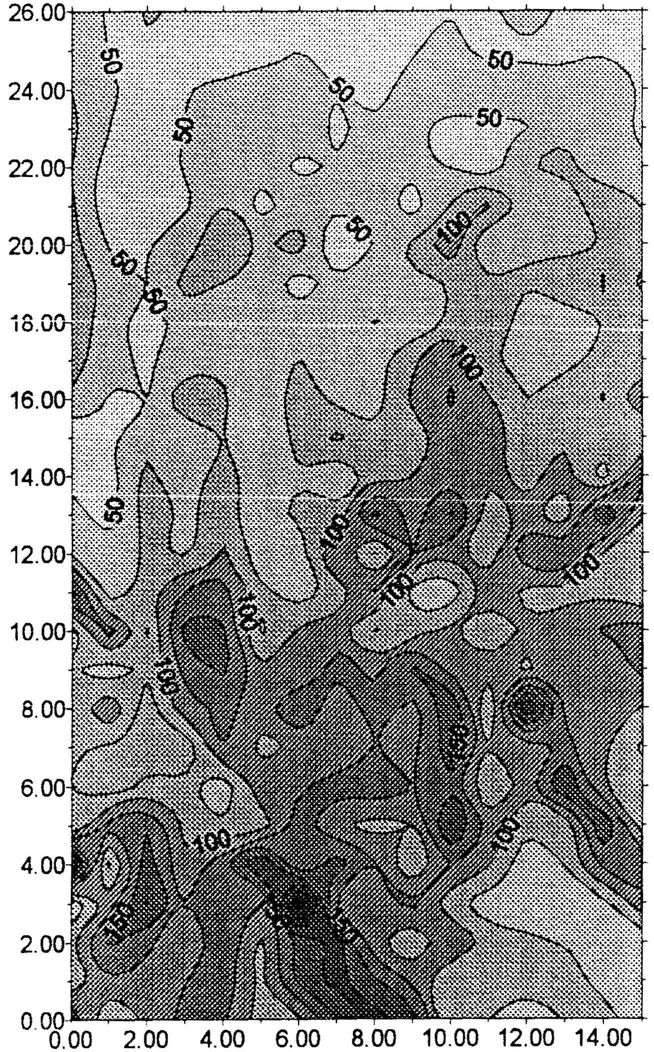


Figure 3 Predicted Ground Level Concentrations of Sulphur Dioxide for Summer

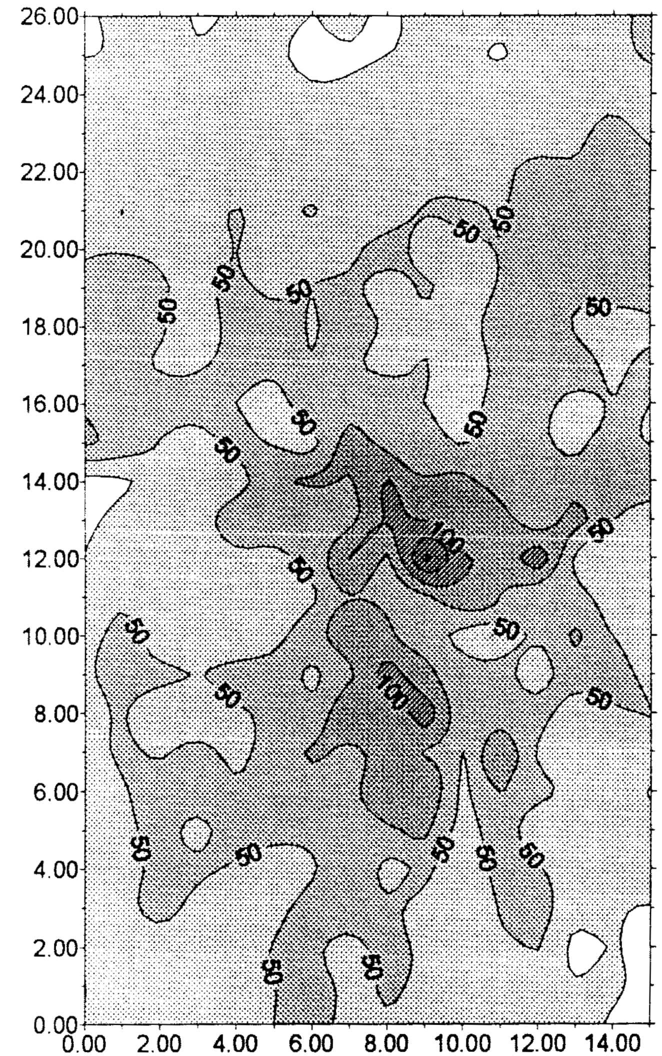
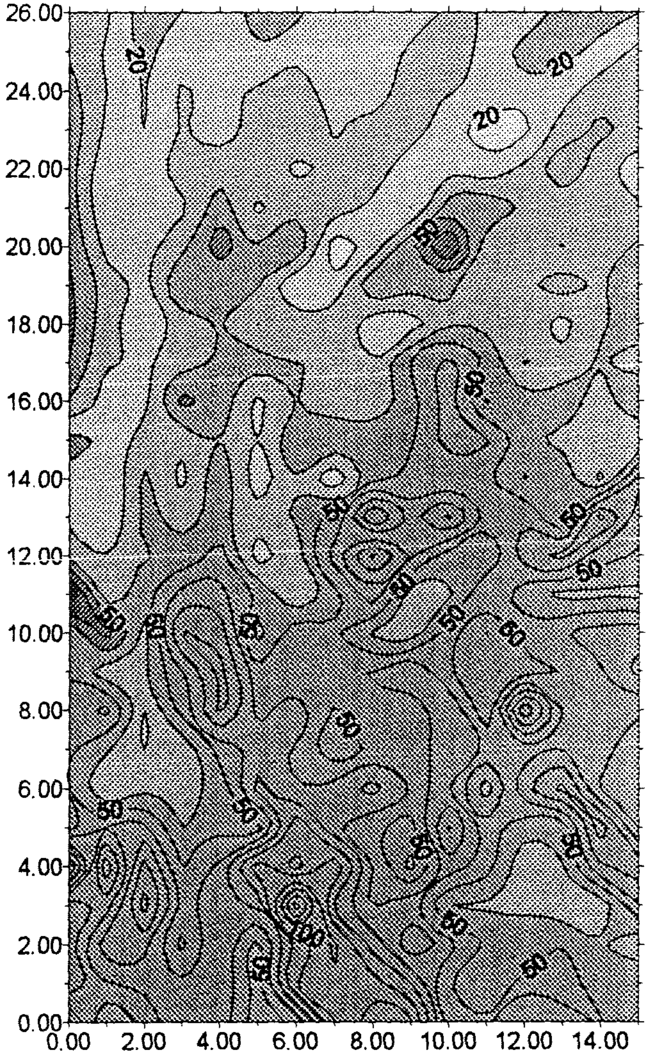


Figure 4 Predicted Ground Level Concentrations of Oxides of Nitrogen for Winter



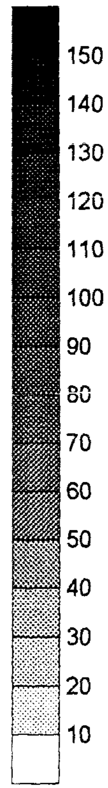


Figure 5 Predicted Ground Level Concentrations of Oxides of Nitrogen for Summer

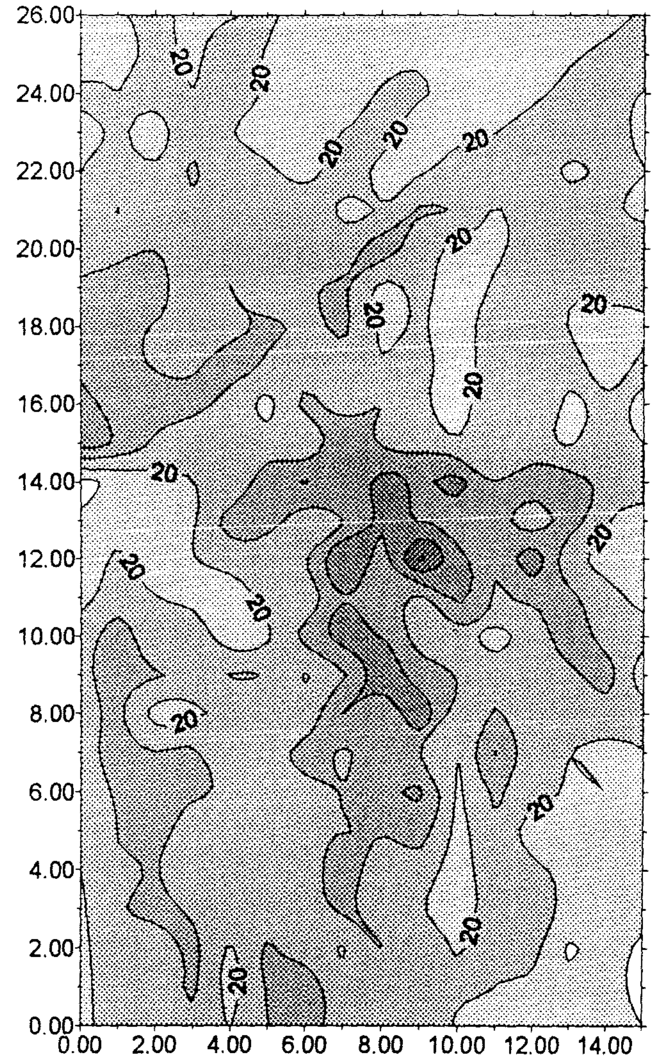


Figure 6 Predicted Ground Level Concentrations of Particulates for Winter

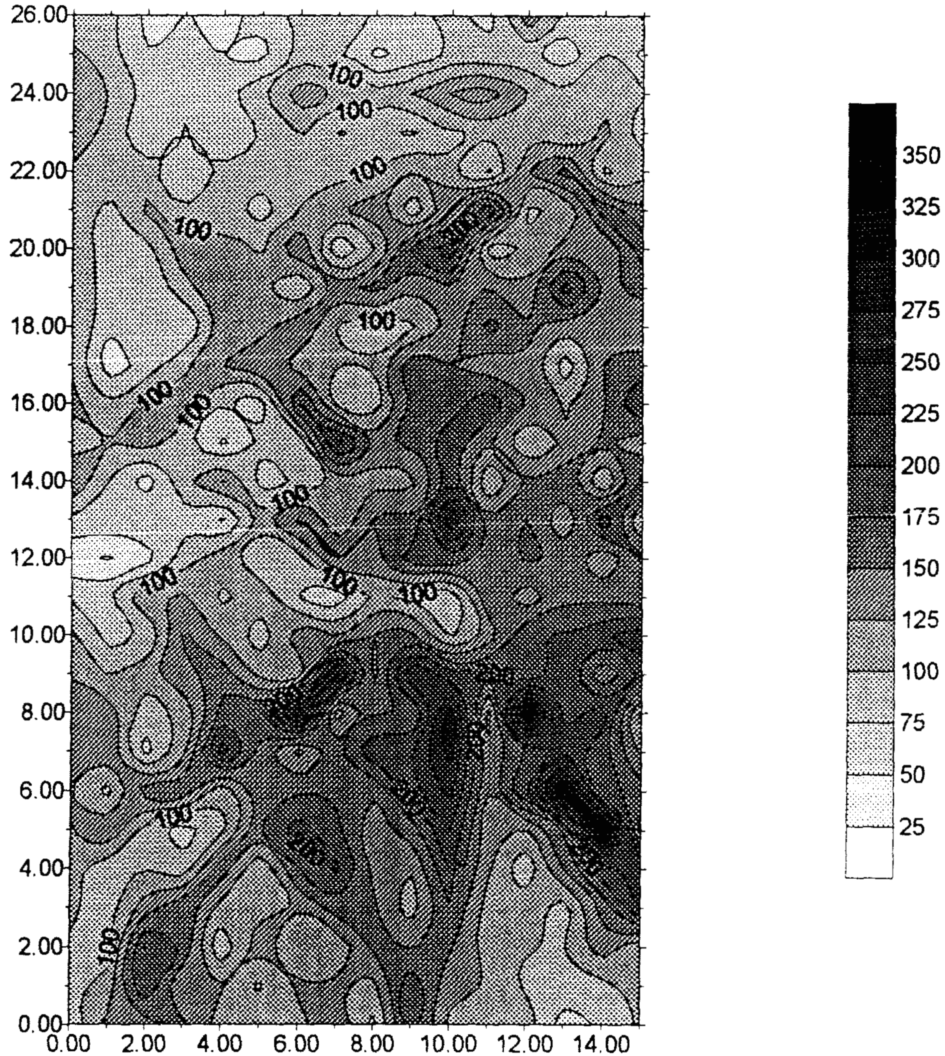


Figure 7 Predicted Ground Level Concentrations of Particulates for Summer

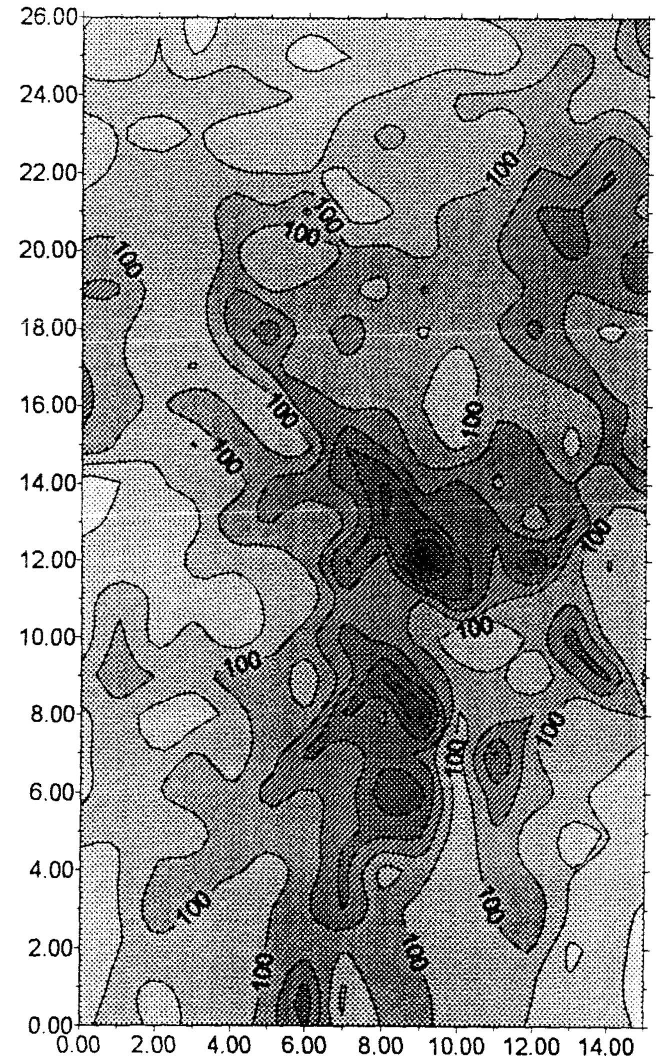


Table 16 Maximum Predicted Ground Level Concentrations of SO_2

Scenario	Summer			Winter		
	Maximum Concentration $\mu g/m^3$	Location		Maximum Concentration $\mu g/m^3$	Location	
		X	Y		X	Y
Base Case	156	9000	12000	270	6000	3000
CFBC Replacement of Boilers 7 & 8	113	10300	11700	267	6000	3000
PF Replacement of Boilers 7 & 8	135	10300	11700	272	6000	3000
CFBC Replacement of all Boilers	79	0	15000	242	6000	3000
PF Replacement of all Boilers	79	0	15000	251	6000	3000
Closure and replacement Capacity at Nos 2 & 3 with PF	97	0	15000	245	6000	3000
Increase Stack Height	120	10300	11700	268	6000	3000
Replacement of all Boilers with gas	79	0	15000	240	6000	3000

Table 17 Maximum Predicted Ground Level Concentrations of NO_x

Scenario	Summer			Winter		
	Maximum Concentration $\mu g/m^3$	Location		Maximum Concentration $\mu g/m^3$	Location	
		X	Y		X	Y
Base Case	62	9000	12000	135	6000	3000
CFBC Replacement of Boilers 7 & 8	49	10300	11700	135	6000	3000
PF Replacement of Boilers 7 & 8	59	10300	11700	137	6000	3000
CFBC Replacement of all Boilers	45	0	15000	125	6000	3000
PF Replacement of all Boilers	45	0	15000	131	6000	3000
Closure and replacement Capacity at Nos 2 & 3 with PF	59	0	15000	126	6000	3000
Increase Stack Height	48	10300	11700	133	6000	3000
Replacement of all Boilers with gas	45	0	15000	125	6000	3000

Table 18 Maximum Predicted Ground Level Concentrations of Particulates

Scenario	Summer			Winter		
	Maximum Concentration $\mu g/m^3$	Location		Maximum Concentration $\mu g/m^3$	Location	
		X	Y		X	Y
Base Case	285	9000	12000	345	14000	5000
CFBC Replacement of Boilers 7 & 8	171	10300	11700	270	14000	5000
PF Replacement of Boilers 7 & 8	186	10300	11700	279	14000	5000
CFBC Replacement of all Boilers	160	15000	20000	213	11000	21000
PF Replacement of all Boilers	160	15000	20000	213	1000	21000
Closure and replacement Capacity at Nos 2 & 3 with PF	160	15000	20000	216	6000	5000
Increase Stack Height	210	10300	11700	309	14000	5000
Replacement of all Boilers with gas	160	15000	20000	213	11000	21000

Table 18 Maximum Predicted Ground Level Concentrations of Particulates

Scenario	Summer			Winter		
	Maximum Concentration $\mu g/m^3$	Location		Maximum Concentration $\mu g/m^3$	Location	
		X	Y		X	Y
Base Case	285	9000	12000	345	14000	5000
CFBC Replacement of Boilers 7 & 8	171	10300	11700	270	14000	5000
PF Replacement of Boilers 7 & 8	186	10300	11700	279	14000	5000
CFBC Replacement of all Boilers	160	15000	20000	213	11000	21000
PF Replacement of all Boilers	160	15000	20000	213	1000	21000
Closure and replacement Capacity at Nos 2 & 3 with PF	160	15000	20000	216	6000	5000
Increase Stack Height	210	10300	11700	309	14000	5000
Replacement of all Boilers with gas	160	15000	20000	213	11000	21000

The model predictions and the ambient measurements show that the highest ground level pollutant concentrations generally occur close to Power Plant No 1, indicating that this plant is a major contributor to atmospheric pollution in Almaty.

When the model predictions and the ambient measurements are compared with the air quality standards shown in Tables 13 and 14, it is apparent that in parts of the city the air quality is poor. In particular, measured concentrations of suspended particulates exceed the WHO air quality guideline value by more than a factor of 2. Measured concentrations of NO_x are close to the WHO air quality guideline values. Measured concentrations of SO_2 are lower than the air quality guidelines, and they are also lower than the model predictions. In fact the measured concentrations of SO_2 are so low that there is doubt over the quality of the ambient SO_2 measurement data.

5.2 Replace Almaty Power Plant No 1 Boilers 7 and 8 with CFBC

The dispersion model was run with input emissions data as shown in Appendix 6. In this scenario, Boilers 7 and 8 at Power Plant No 1 are replaced with a CFBC which produces 280 t/h of steam. This allows the turbines at Power Plant No 1 to operate at full capacity. For this model run, it is assumed that a new chimney would be built at Power Plant No 1. The height of this chimney is limited to 90 m as this is the maximum height that the local Aviation Authorities will allow for a chimney at this location in Almaty.

It can be seen from Table 15 that this scenario results in improvements to air quality with respect to particulates.

5.3 Replace Almaty Power Plant No 1 Boilers 7 and 8 with PF with Limestone Injection

The dispersion model was run with input emissions data as shown in Appendix 6. In this scenario, Boilers 7 and 8 at Power Plant No 1 are replaced with a new PF boiler with in-furnace limestone injection which produces 280 t/h of steam. This allows the turbines at Power Plant No 1 to operate at full capacity.

It was decided to model a PF boiler with in-furnace limestone injection as this represents developed power generation technology with low cost SO_2 reduction equipment. In-furnace limestone injection can reduce sulphur emissions by around 50 % with relatively little capital investment or operating cost increase. The use of flue gas desulphurisation techniques such as the limestone-gypsum process can reduce sulphur emissions by 90 % but at substantially increased capital and operating costs. The sulphur emissions from the power plants in Almaty are relatively low due to the low sulphur contents of the coals burned. A 50 % reduction in emissions would meet European Community standards for SO_2 from this scale of plant. It was therefore considered appropriate to model a PF boiler with in-furnace limestone injection.

For this model run, it is assumed that a new chimney would be built at Power Plant No 1. The height of this chimney is limited to 90 m as this is the maximum height that the local Aviation Authorities will allow for a chimney at this location in Almaty.

It can be seen from Table 15 that this scenario results in improvements to air quality, particularly with respect to particulates. However, because of the technology used, the environmental performance of this plant is inferior to the CFBC. Indeed, ground level concentrations of NO_x increase marginally due to the slight increase in installed boiler capacity.

5.4 Replace Almaty Power Plant No 1 All Boilers with either CFBC or PF with Limestone Injection

The dispersion model was run with input emissions data as shown in Appendix 6. In this scenario, all the capacity at Almaty Power Plant No 1 is replaced with new boilers. For this model run, it is assumed that new chimneys would be built at Power Plant No 1. The height of these chimneys is limited to 90 m as this is the maximum height that the local Aviation Authorities will allow for a chimney at this location in Almaty.

This strategy results in improvements to air quality, particularly with respect to particulates where the predicted maximum ground level concentration falls by nearly 40 %.

5.5 Close Almaty Power Plant No 1 and Install Equivalent Heat and Power Capacity at Power Plants Nos 2 and 3

The dispersion model was run with input emissions data as shown in Appendix 6. In this scenario, it is assumed that Almaty Power Plant No 1 is closed completely and that a new PF boiler with in-furnace limestone injection is installed at each of Power Plants No 2 and GRES. This scenario leads to the best predicted air quality improvements, mainly because the pollutant emissions are moved to the outskirts of the city.

5.6 Increase Stack Height at Almaty Power Plant No 1

The dispersion model was run with input emissions data as shown in Appendix 6. In this scenario, new chimney stacks would be constructed at Power Plant No 1. These stacks would be 150 m tall in place of the existing stacks which are 45 m and 80 m tall. Table 15 shows that this scenario results in improved air quality. This is because the taller stacks lead to better dispersion of the pollutant emissions. It should be noted that the actual emissions from the power station do not change, they are merely dispersed over a wider area.

It should also be noted that there may be a limitation on the stack height at Power Plant No 1 as the plant is sited on the flight-path for the airport. This means that this strategy is only of academic interest.

5.7 Convert Almaty Power Plant No 1 All Boilers to Gas Firing

The dispersion model was run with input emissions data as shown in Appendix 6. In this scenario, all the boilers at Power Plant No 1 are assumed to be fired with natural gas. Table 15 shows that this scenario results in improved air quality. This is due to the reduced emissions from the plant. It should be noted that the availability of gas for power generation is thought to be limited. This results in high gas prices which would distort the economics of this strategy. No information was available on gas prices and how these might change if a large user such as this power plant were to enter the market. For this reason no attempt has been made to cost this option.

6. COSTS OF REMEDIAL STRATEGIES

Section 5 outlined the alternative remedial strategies. In this section, preliminary estimates of the differential costs of these options are developed. The modified plant configurations, and in particular the sizes and numbers of boiler units, etc., were selected on the basis of achieving economies of scale while minimising technical risks. Brief commentaries on some of the implications of these choices are included within the subsections below.

The methodology adopted for each alternative strategy was as follows. The new or revised major plant equipment areas were initially defined and the principal mass and energy flows of the major equipment areas estimated. The flows were then used in conjunction with in-house data to determine the capital costs of the equipment.

Note that in a preliminary study of this nature the estimation of capital requirements is inevitably subject to considerable uncertainty. In general, such costs should not be relied upon to better than plus or minus 25%. This was considered to be the minimum level of accuracy which would allow meaningful comparison of the differences between cases. It would be possible to improve the accuracy of the cost estimates, however this would require much more detailed engineering and design work than could be carried out within the budget for this study. The level of design work is that conventionally done to achieve a budget authorisation estimate; two of the key components of which are nomination of a specific site location to set site conditions and preliminary flowsheets with material and energy balances to ensure that there are no significant omissions from the project scope. The next level of project cost control estimate which conventionally aims at an accuracy of ± 10% is neither feasible nor warranted within the context of this study. Project cost estimates require much of the detailed engineering to have been done and quoted equipment prices received; the cost of doing such an estimate is substantially greater than the cost of this study. The cost estimates here assume a degree of sourcing of materials and labour from within Kazakhstan.

Annual capital repayment costs (assuming a 25 year term) were then calculated, using the estimated capital costs at a test discount rate of 10%, real.

The components of differential annual costs, including fixed and variable operating costs and fuel costs, were estimated and aggregated. Because of a lack of detailed operating cost data on the Almaty No 1 Power Plant, the estimated operating cost changes should also be regarded as subject to uncertainty. Estimated contributions to these are both positive and negative, but the balance is likely to be negative. These operating cost savings are however small compared with the repayments on the capital raised to fund the works. The various components of differential operating costs are discussed further later.

Costs are expressed in US $ at a (nominal) reference date of January, 1995.

6.1 Replace Almaty Power Plant No 1 Boilers 7 and 8 with CFBC

All of the boilers at Almaty Power Plant No 1 are of non-reheat design. Boilers 7 and 8 are rated, respectively, at 75 t/h and 160 t/h of superheated steam at around 90 bar/540°C. These correspond to thermal inputs of approximately 60 MW and 125 MW thermal, respectively. All the 160 t/h boilers on the site are limited to 140 t/h output by the Local Authorities to reduce pollutant emissions in the city centre. As a result of this the turbines are under-utilised. It is therefore logical to replace these two units with a single CFBC, with a combined size of 280 t/h steam (230 MW(th)). This is well within the experience range for commercial CFBCs from various manufacturers and will minimise cost through economies of scale and reduction in the number of subsystems.

Replacement of the boilers with a single CFBC will entail installation of the following new/replacement sub-systems (balance of plant assumed to be retained):

Coal preparation:	new coal grinders to provide a feed coal size of around 6 - 8 mm.
Limestone systems:	reception, preparation to <1 mm, handling.
CFBC:	boiler, feed systems, heat recovery steam generator, forced draught fans, air heater and economiser, boiler control system.
Flue gas systems:	baghouse, induced draught fans, ducting, stack.
Ash handling:	for boiler ash and bag filter ash.
Miscellaneous:	modifications to pipework.

The estimated total cost of the above modifications is $58 million. Note that the boiler market worldwide is increasingly competitive and prices of CFBCs have fallen since the costing study for a CFBC at Power Plant GRES was carried out under UK Government funding.

Based on the Consultants' experience of operating costs at plant in Kazakhstan, it is likely that operating costs are likely to be reduced slightly for the following reasons. On the positive side, there are likely to be fuel efficiency (from a lower stack temperature) and availability gains and avoidance of support fuel (mazut), also savings in labour to operate the new plant and a reduction in emissions tax. There will also be some increase in power output. Partially balancing these, on the negative side, will be additional feedstock costs (for limestone) and slightly higher auxiliary power requirements and solid waste disposal costs. Table 19 in section 6.6, which gathers together all the cost information from section 6, gives the estimated total operating cost saving per year, assuming a capacity factor of 80%.

6.2 Replace Almaty Power Plant No 1 Boilers 7 and 8 with PF with Limestone Injection

In this case, the two boiler units would be replaced by a single PF unit with furnace limestone injection.

Replacement of the boilers with a single PF with limestone injection will entail installation of the following new/replacement sub-systems (balance of plant assumed to be retained):

Coal preparation:	new PF mills to cope with current coal quality.
Limestone systems:	reception, preparation and feed system.
PF boiler:	boiler to cope with current coal quality, feed and sorbent handling, forced draught fans, air heater and economiser, boiler control system.
Flue gas systems:	baghouse, induced draught fans, ducting, stack.
Ash handling:	for boiler ash and bag filter ash.
Miscellaneous:	Modifications to pipework.

The estimated total cost of the above modifications is $64 million. The PF system is expected to be more expensive than the CFBC because its cost is penalised more by fuels of high ash content, as encountered in the coals to be fired.

Fuel efficiency and other gains are again expected to result in an overall operating cost saving, although this is not expected to be as large as for CFBC because of a greater limestone requirement and smaller emissions tax and fuel savings.

6.3 Replace Almaty Power Plant No 1 All Boilers with CFBC or with PF with Limestone Injection

If all existing boiler units at the plant were to be replaced by two CFBC boilers, this would imply using CFBCs of 400 MW(th) input each. This arrangement would allow a greater economy of scale than the two earlier options but integration with the existing turbines would be less simple. Larger CFBCs can be ordered, but the scale implied by twin units would permit adequate economy of scale while maximising availability. Having two identical boilers, although not affording as great an economy of scale as using a single, double-rated unit, would permit about a 5% saving in costs compared with twice the price of a single one.

The new sub-systems that would be required would be broadly analogous to those listed in section 6.1. The two boilers would each be served by a separate stack.

The estimated total cost of the two-boiler CFBC system is $185 million.

Alternatively, all the existing boiler units at the plant could be replaced by two new PF boilers fitted with furnace limestone injection, each again of around 400 MW(th) input each. This would also allow a greater economy of scale than the first two options at the expense of less simple integration with the existing turbines. PF technology is available at up to far larger boiler sizes and it would be possible to order a single boiler unit to provide the steam demand. However, world experience with furnace limestone injection has largely been confined to maximum boiler sizes of around 400 MW(th) because of the potential difficulties in achieving adequate mixing with the hot combustion gases at larger boiler sizes. Use of two identical boilers, as for CFBC, should in any case again permit some savings in costs compared with twice the price of a single unit.

The new sub-systems that would be required would be broadly analogous to those listed in section 6.2. The two boilers would each be served by a separate stack.

The estimated total cost of the above modifications based on PF is $200 million.

The simplification of the plant and cost savings of the generic types discussed earlier would result in a net reduction in operating costs in either case, but this is likely to be better for CFBC than for PF.

6.4 Close Almaty Power Plant No 1 and Install Equivalent Heat and Power Capacity at Power Plants Nos 2 and 3

Complete closure of Almaty Power Plant No 1 with installation of an equivalent heat and power capacity at Power Plants Nos 2 and 3 (50% at each) would require a single 400 MW(th) boiler at each, together with the sub-systems listed in section 6.2. These would be totally new installations and so coal reception and handling systems, extraction/condensing or backpressure steam turbogenerators, feedwater heating systems, CHP heat exchangers, additional water treatment and wastewater systems, cooling towers, additional district heating distribution capacity, power line reinforcement, etc would also be required. This option would offer the opportunity for higher steam conditions and the use of reheat, which would provide a benefit in thermal efficiency and operating costs. Availability would also be higher because of the use of modern systems throughout, along with proper training in modern maintenance procedures.

Because so much new equipment would be needed, the cost of this option is estimated to be high, at $400 million for PF with limestone injection. Naturally, because there would be total flexibility in plant design for these options, as completely new self-contained boiler/turbine units would be installed, the range in uncertainty in these particular capital cost estimates is likely to be higher than for the other cases. The cost of power line and district heating main reinforcements would also have to be added. Provision for another $20 million to cover these would appear prudent.

There is clearly scope for operating cost savings over and above those for the previous two strategies because of the complete freedom available in setting plant design criteria. The savings given in Table 19 are conservative estimates and could probably easily be exceeded.

6.5 Increase Stack Height at Almaty Power Plant No 1

This would necessitate demolition of the existing stacks and replacement with two new ones of 150 m height.

Although difficult to estimate, the cost is likely to be low because all required materials and labour could be sourced locally. The cost is expected to be no more than $1 million.

There would be no significant effect on operating costs.

6.6 Summary of Capital and Annual Costs of the Options

Table 19 below summarises the capital and differential operating cost data from the above sections. The operating cost data are based on plant average annual capacity factors of 80%. In addition, estimated annualised capital repayments (including an allowance for interest during construction), at a real discount rate of 10% and repayment period of 25 years are given. This approach to comparing project options is entirely adequate for the purpose of the current study.

Table 19 Estimated Capital Costs and Incremental Operating Costs for the Alternative Remedial Strategies

	CFBC Replacement of Boilers 7 & 8	PF Replacement of Boilers 7 & 8	Full Replacement with CFBC	Full Replacement with PF	Closure and Replacement Capacity at Nos 2 & 3 (PF)	Increase stack height
Capital cost, $m	58	64	185	200	420	1
Annualised capital payments, $m	7.2	7.9	23.0	24.9	52.1	0.1
Incremental annual operating cost, $m	-0.1	-0.1	-0.6	-0.4	-0.5	0

These data are presented again in section 7 alongside the predicted air quality improvements but two comments on the relative costs themselves are given below.

Firstly, all of the remedial strategies except for the change in stack height involve significant capital expenditure. There is nevertheless a wide range of requirements and in determining the strategy to adopt, the developers will clearly need to establish the availability of capital.

Secondly, operating cost changes are likely to be dwarfed by the repayments on the loans. This conclusion is robust to assumptions on the real cost of capital. For instance, a 5% test discount rate reduces the annualised capital repayments for CFBC replacement of boilers 7 and 8 to $4.4 million/annum which is still four orders of magnitude greater than the annual operating cost savings.

7. LEAST COST INVESTMENT PROGRAMME

The following sections outline the analysis of the least cost investment strategy for the improvement of air quality in the city of Almaty, Kazakhstan. The analysis has been subdivided into the component parts that are integral in the consideration of a least cost investment approach. The approach comprises a comparison of the costs and environmental benefits of each of the major remedial strategies for air quality improvement in the City as detailed in Section 5 and 6. This will attempt to determine the least cost option for investment in terms of air quality improvement by analysis of the costs, suitability, projected emission reduction and associated air quality benefits of each major proposal. This will include calculations of specific improvements to air quality expressed as a cost per unit enhancement in air quality.

7.1 Comparison of Each Remedial Strategy

The detailed costs and environmental impact of each remedial strategy are presented in Sections 5 and 6. A summary of the findings are presented in Table 20.

TABLE 20 Summary of Costs and Environmental Benefit of Each Remedial Strategy

STUDY FINDINGS	BASE CASE	CFBC Replacement of Boilers. 7 & 8	PF Replacement of Boilers. 7 & 8	Full Replacement with CFBC	Full Replacement with PF	Closure and Replacement of Capacity at Nos 2 & 3	Increased Stack Height
Capital (Jan. 1995 US $m)	0	58	64	185	200	420	1
Annualised Capital Repayment (Jan. 1995 US $m)	0	7.2	7.9	23.0	24.9	52.1	0.1
Differential Operating Costs (Jan. 1995 US $m)	0	-0.1	-0.1	-0.6	-0.4	-0.5	0
Emissions Reduction (% of base case)							
SO_2	100	96.8	99.3	85.0	91.5	91.5	100
NO_x	100	99.4	100	92.5	99.5	99.5	100
Particulates	100	94.9	94.9	79.0	79.0	79.0	100
Air Quality Improvement (% improvement of value at point of maximum concentration)							
SO_2	0	1	-1*	10	7	9	1
NO_x	0	0	-1*	7	3	7	1
Particulates	0	22	19	38	38	37	10
Specific Costs of Air quality Improvement (1995 US k$/% improvement at point of max. concentration)							
SO_2	-	6390	*	2160	3482	5573	135
NO_x	-	-	*	3024	8269	7740	68
Particulates	-	327	408	585	640	1380	10

* denotes an increase in predicted ground level concentrations

7.2 Specific Costs of Improvements to Air Quality

Although the environmental improvement in terms of emissions avoided and the corresponding effect on air quality in the city can be measured (and has been estimated in the technical part of this study), the financial effect is difficult to present in conventional terms. Estimates of the costs of environmental impacts are controversial and judgmental but are often used as part of powerful political and macro-economic arguments. Within this study every effort has been made to present sensible and meaningful specific costs of environmental benefits of the proposed projects. However, as with all calculations of this type, the results are open to reinterpretation and debate. Other issues that can be raised in this context are the cost and environmentally-effective development of the use of coal as a valuable natural resource in the country. Similarly, there are likely to be associated welfare benefits in terms of improved health of the population leading to fewer lost working days and reductions in the costs of the provision of health care.

The following calculation method to attribute the costs of environmental improvement has been adopted. The annual operating costs and annualised capital repayments of each strategy were summed. The total annual cost was then divided by the percentage reduction in the concentration of each pollutant at the point of maximum concentration (note that the location of the point of maximum concentration varied from case to case).

Thus the cost of the environmental improvement for each strategy can be expressed as a consistent value for the direct comparison of each option with the units: $ per annum per percentage point improvement in air quality at the point of maximum concentration for each pollutant($ /y / % SO_2 improvement etc.)

The breakdown of the specific costs of environmental improvement for each strategy is summarised below:

STRATEGY	COST('000$ per annum /% improvement)			
	SO_2	NO_x	Particulates	
• CFBC Replacement of Boilers 7 & 8		6390	-	327
• PF Replacement of Boilers 7 & 8	-	-	408	
• CFBC Replacement of all Boilers	2160	3024	585	
• PF Replacement of all Boilers	3482	8269	640	
• Closure and replacement Capacity at Nos 2 & 3 with PF	5573	7740	1380	
• Increase Stack Height	135	68	10	

Thus from the above calculations it can be deduced that the least cost strategy appears to be increasing the stack height at plant No. 1 to 150 m. This strategy, although having the biggest impact on ground level pollution in the urban areas does not actually reduce the total emissions from the city. The increased stack height merely leads to the emissions being distributed over a wider area, thus resulting in lower ground level concentrations at any particular point in the city. The local Aviation Authorities have rejected this strategy on the grounds that Power Plant No 1 is situated on the airport flightpath. Chimney heights at this location are limited to 90 m. Due to both these factors, this solution is rejected.

The biggest reduction in emissions is shown to occur with the strategy of replacing all the capacity at Almaty No 1 Power Plant with CFBC boilers. However, this strategy involves a high capital expenditure. The most realistic strategy to adopt is to start by replacing Boilers 7 and 8 at Almaty Power Plant No 1 with new capacity. The capital costs of this replacement are relatively low and real environmental gains can be achieved. Given the position of Almaty No 1 Power Plant in the city centre, the choice of boiler technology should be the cleanest in terms of emissions provided that this is not at excessive cost. This study has shown that the use of a CFBC boiler to replace capacity at Almaty No 1 Power Plant is cheaper than using a PF boiler and that it has greater environmental benefits. Following successful demonstration of the technology in Kazakhstan, replacement of further boilers could proceed in a step-wise approach.

8 CONCLUSIONS AND RECOMMENDATIONS

A computerised atmospheric dispersion model of the city of Almaty was developed. The model predicted the ground level concentrations of pollutants across the city and these concentrations were related to the contributions from the major emitters.

As reliable measurements of emissions to the atmosphere at the three major power plants were not available, measurements of stack emissions were made. These data combined with information on emissions from other major emitters in the city and meteorological data were used as inputs for the dispersion model.

The results of the emissions monitoring exercise indicate that emissions of oxides of nitrogen (NO_x) were close to the Kazakh and EU limit values. Emissions of sulphur dioxide (SO_2) were generally higher than the Kazakh and EU limit values. Particulate emissions were up to 20 times the Kazakh and EU limit values.

An atmospheric dispersion model was developed and used to undertake a refined analysis of the contribution of pollutant discharges from the three power and district heating plants in Almaty to local ground level concentrations of SO_2, NO_x and particulates. The results of this exercise showed that the power plant (in particular Power Plant No 1) were contributing significantly to air pollution within the city.

When the model predictions and the ambient measurements are compared with the air quality standards, it is apparent that in parts of the city the air quality is poor. In particular, concentrations of suspended particulates exceed the WHO air quality guideline value by more than a factor of 2. Concentrations of NO_x are close to the WHO air quality guideline values.

The model was then used to predict the environmental benefit which would accrue from each of the rehabilitation options for Power Plant No 1. Seven remedial strategy options were modelled, and six of these were costed. This environmental information was combined with information on the costs of the power plant rehabilitation options in order to determine which solution gave the best environmental improvement per dollar invested. All of the strategies studied resulted in air quality improvements although there was a wide variation in costs to achieve the same improvement.

The least cost strategy appears to be increasing the stack height at plant No. 1. This strategy, although having the biggest impact on ground level pollution in the urban area does not actually reduce the total emissions from the city. The increased stack height merely leads to the emissions being distributed over a wider area, thus resulting in lower ground level concentrations at any particular point in the city. It is not possible to implement this strategy as the power plant is sited on the flight-path to the airport. This strategy is therefore rejected.

The biggest reduction in emissions is predicted to occur with the strategy of replacing all the capacity at Almaty No 1 Power Plant with CFBC boilers. However, this strategy involves a high capital expenditure. It is concluded that the most realistic strategy to adopt is to start by replacing Boilers 7 and 8 at Almaty Power Plant No 1 with new capacity. The use of a CFBC boiler to replace capacity at Almaty No 1 Power Plant is cheaper than using a PF boiler and it has greater environmental benefits. It has proved difficult to assign costs to the use of gas in place of coal at Power Plant No 1 although this is predicted to result in air quality improvements. It is recommended that further work is carried out to assess the costs of a range rehabilitation options at Power Plant No 1.

The estimates of capital requirements developed in this study are inevitably subject to uncertainty. In general, such costs should not be relied upon to better than plus or minus 25%. It is recommended that a more extensive costing study be carried out which would have a higher degree of certainty associated with the cost estimates. This would involve the preparation of tender documents for the chosen rehabilitation option.

The atmospheric dispersion model developed in this study was limited to a few point sources. It is recommended that the model is extended to include estimates of emissions from more sources. This would allow the model to be validated against ambient measurements. This would enable the model to be used as an environmental management tool.

what about model's assumption of flat terrain? Is it justified?

APPENDIX 1 EMISSIONS MONITORING PROCEDURES

APPENDIX 1 EMISSIONS MONITORING PROCEDURES

A1.1 DETERMINATION OF THE PARTICULATE CONCENTRATION IN FLUE GASES

The Central Electricity Generating Board (CEGB) Mk IIIA particulate sampling equipment is illustrated in Figure A.1.1.

Gas velocity within the duct or chimney is first determined using a Pitot-static tube (designed to BS 1042:Part 2a) and the duct area and gas temperature are measured. From these parameters a velocity profile of the gas stream is plotted and the sample positions chosen. The number and location of these sampling positions is dependent on:

i) Duct size
ii) Access to sampling positions
iii) Accuracy required

It is necessary to maintain the same gas sampling velocity at entry to the nozzle of the sampling probe as exists within the flue gas duct at each of the chosen sampling positions i.e maintain isokinetic conditions. This is achieved by multiplying the duct gas velocity by the nozzle entry area and arriving at an appropriate sample gas volume flow rate. This volume flow is translated into a pressure drop reading across the down-stream orifice meter. By changing the sampling area using detachable nozzles, a full range of flue gas velocities can be sampled.

The particulates are captured on a pre-weighed filter bag. The weight of dust collected is determined by comparing the weight of the filter bag at the beginning and end of the test period, and, from the sampling time at each point, an emission rate per unit area is then calculated. The total emission rate is then calculated from the average of these values and the duct area.

The particulates can be analysed for chemical composition and size distribution.

The procedure for particulate determination and all equipment employed complies fully with the requirements of BS 3405:1983.

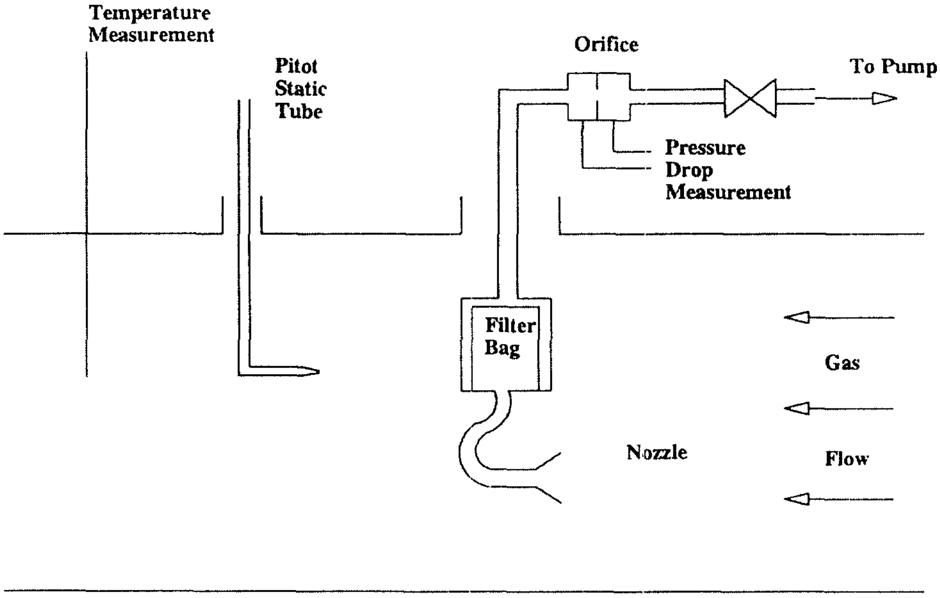


Figure A1.1 CEGB Mk IIIA Particulate Sampling Apparatus

A1.2 DETERMINATION OF WATER VAPOUR CONTENT BY A GRAVIMETRIC METHOD

Waste gas is withdrawn from the sample location through a stainless steel tube and passed through three pre-weighed drying tubes in series. The drying tubes contain magnesium perchlorate, a recognised drying agent. The resulting dry gas is then passed through a pump to a pre-calibrated gas meter which measures the volume of gas sampled. The dry gas sampling rate is generally around 1 litre/min. Each determination is typically of 20 minutes duration in which time around 20 litres of gas is sampled. At the end of the sampling period the drying tubes are weighed and the mass of water removed from the sampled gas calculated. The aim is to detect zero weight gain in the third drying tube, indicating full removal of water from the sampled gas in the first two tubes.

Based on the volume of gas sampled and measured weight of water removed from the sampled gas its water vapour content can be calculated.

A1.3 MEASUREMENT OF FLUE GAS SPECIES USING THE TESTOTERM ELECTROCHEMICAL CELL CONTINUOUS ANALYSER

The flue gas concentration of selected species was continuously monitored using a Testo Term 33 electrochemical continuous gas analyser. Waste gases were withdrawn from the outlet duct via a stainless steel probe and passed through a heated line to a gas preparation unit. Within the unit the flue gas is cooled rapidly within a Peltier element to remove condensate whilst preventing absorption, and hence loss, of NO2 or SO2. The gas is then passed to the analyser which uses specific electrochemical cells for the detection and measurement of the required species.

To ensure reliable and accurate measurement it is CRE practice to calibrate the analyser against certificated bottled gases both before commencement of measurements and at the end of the measurement period. In addition, all such analysers are serviced and calibrated by a qualified service agent at least every four months and calibration certificates are available for inspection.

APPENDIX 2 DEVELOPMENT OF ATMOSPHERIC DISPERSION MODEL OF ALMATY

APPENDIX 2 DEVELOPMENT OF ATMOSPHERIC DISPERSION MODEL OF ALMATY

A2.1 INTRODUCTION

An atmospheric dispersion model is a useful tool for assessing the effects of air pollution and guiding the choice of remedial strategies. The objective in developing an atmospheric dispersion model of Almaty was to use the model to predict the effect of various strategies to reduce emissions on the ground level concentration of specific air pollutants, sulphur dioxide (SO_2), oxides of nitrogen (NO_x), and particulates. In this Appendix the assumptions and approach to atmospheric dispersion modelling are discussed.

A2.2 PLUME HEIGHT

Chimneys and stacks are used to disperse exhaust gases to the atmosphere, and are designed to give acceptable ground level concentrations both locally and further afield. The principal parameters affecting the rate of dispersion are stack height, gas exit velocity (or efflux velocity) and gas temperature. The latter two determine the effective increased height of the gas plume, resulting from momentum and buoyancy.

Mathematically, this extra height can be estimated by the expression:

$$H = V_s\, d/U \{1.5 + 0.00268\, p\, d\, (T_s - T_a)/T_s\}$$

where	H	=	extra height	(m)
	V_s	=	stack gas velocity	(m/s)
	d	=	stack diameter	(m)
	U	=	wind speed	(m/s)
	p	=	atmospheric pressure	(mb)
	T_s	=	stack gas temperature	(K)
	T_a	=	ambient temperature	(K)

Thus, the extra height achieved by the plume is inversely proportional to wind speed.

A2.3 COMPUTER MODEL SELECTION

The United States Environmental Protection Agency (US EPA) has controlled the development and validation of air quality models for over a decade and make recommendations (US Environmental Protection Agency, "Guideline on Air Quality Models", Report No. EPA-450/2-78-027R, July 1986.) on the selection of the most suitable model to evaluate the impact of specific pollution sources. Modelling procedures are classified as Gaussian, numerical, statistical and physical. They can be applied at different levels of sophistication. The first level consists of generally, relatively simple estimation techniques that provide `worst case' estimates of the air quality impact of a specific source. These are "screening techniques" or "screening models". Satisfactory screening results avoid the need for further detailed modelling for those sources that clearly will not cause unacceptable ground level concentrations of pollutants. The second more complex level provides more accurate concentration estimates and involves analytical techniques which consider detailed treatment of physical and chemical atmospheric processes and require more detailed and precise input data relating to meteorological conditions and local topography.

The US EPA computer programme selected for this application was the All Terrain Dispersion Model (ATDM). This model is recommended for stationary source applications by the US EPA. It incorporates the ISCST2 and COMPLEX dispersion algorithm for simple terrain, (ie where the height of the local terrain is below the height of discharge of the pollutants under consideration), and complex terrain (ie where the height of the local terrain is above the height of discharge of the pollutants under consideration). The model automatically determines each receptor's terrain regime relative to each source. Based on this assessment, the ISCST2 algorithm is used for those receptors in simple terrain, and the COMPLEX algorithm is used for receptors in complex terrain. Both algorithms are used for receptors in intermediate terrain, and ATDM reports the higher of the two calculated concentrations.

The ATDM model is a steady state Gaussian model which can be used to assess pollutant concentrations from a wide variety of sources associated with an industrial source complex. It can be used for initial screening or more refined determination of ground level pollutant concentrations on either a short term basis (up to 24 hour averages) or longer term (monthly, quarterly or annual averages).

A2.4 GAUSSIAN PLUME MODELS

Gaussian plume models assume that the spatial distribution of concentration can be expressed in terms of the shape of the lateral and vertical wind distributions, the wind speed, and the source strength. The distributions are assumed to be normal and the concentrations of pollutants are predicted by equations of the following form:

$$C(x,y,z) = Q/(Pi\ U\ sig_y\ sig_z)\ exp\ (-0.5\{y/sig_y\}^2)\ (vertical\ term)$$

where	Q	=	pollutant emission rate
	U	=	wind speed
	sig_y, sig_z	=	dispersion coefficients

The latter are determined experimentally and depend on stability conditions and on terrain, which is categorised as `rural' or `urban'. Thus, it is found that a plume spreads out more rapidly in urban than in rural terrain.

A2.5 METEOROLOGICAL DATA

As discussed above, wind speed has an important effect on the effective height of a plume and the dilution of the plume by the surrounding air is also affected by weather conditions. For example, in stable conditions, the dilution of the plume will be limited and the maximum ground level concentration of a contaminant may occur a substantial distance downwind from the source. Conversely, in unstable conditions the plume will increase in cross-sectional area more quickly giving maximum ground level concentrations nearer to the source.

When modelling plume dispersion, the following meteorological data are required:

- wind speed
- stability conditions
- wind direction
- mixing height

The meteorological information used in this study is detailed in Section 4.

A2.6 LOCAL TOPOGRAPHY AND CONDITIONS

There are factors, specific to the location of the source of discharge, which have a bearing on the atmospheric dispersion of pollutants and their ground level concentrations:

- Topography
- Area classification
- Adjacent structures

The local topography or terrain will have an impact on plume dispersion. The US EPA consider simple terrain to be an area where terrain features are all lower in elevation than the top of the source of discharge, ie stack. Complex terrain is defined as terrain exceeding the height of the source. Almaty is situated on the edge of a broad plain to the North of a range of mountains. The area under consideration in this study concentrates on the flat plain where most of the industry and population is situated. For simplicity, the area was initially modelled as simple terrain. It was decided that topography would only be included in the model if the validation exercise suggested that this was necessary.

The type of area, ie urban or rural, will have an effect on the stability of the lowest layers of the atmosphere. The wind near the earth's surface is retarded by obstacles ranging from blades of grass to tall buildings due to surface friction. Not only will the height of the particular surface roughness elements affect the degree of slowing of the wind and the vertical extent to which this will reach, but also the horizontal spacing of these elements will have an influence. Large surface roughness elements cause an influence of the ground through a deeper layer of the atmosphere than small surface roughness elements. The wind that no longer "feels" the effect of the ground is known as the gradient wind. The gradient wind is nearer the ground for a surface having small roughness elements than for one having large surface roughness elements. Along with the greater retardation of the wind speed by the larger roughness elements there is a greater directional turning towards low pressure which affects local wind direction. The US EPA define area classifications based on land use or population density. On the basis of land use, the area considered within this study is assumed to be urban, ie more than 50% of land use inside a circle of radius 3 km around each source can be considered heavy or medium industrial, commercial or multi-family residential.

When buildings or structures interrupt wind flow, an area of turbulence, termed building downwash, is created. Discharged pollutants can be caught in this turbulence and their dispersion will be affected. Modelling which includes calculations for building downwash gives a more accurate representation of pollutant dispersion than modelling which omits consideration of downwash. The US EPA recommend that downwash be considered for buildings which have a maximum height equivalent to at least 40% of the source height and which are within a distance defined as five times the lesser of the height or maximum projected width of the building.

Due to the complexity of the structures within Almaty city and a lack of detailed information, the effects of buildings on dispersion have not been considered in this study. To include the effects of buildings would be a very major exercise.

Is this acceptable?

APPENDIX 3 EMISSIONS MONITORING RESULTS AT POWER PLANT No 1

GAS ANALYSIS USING TESTOTERM ANALYSER (chemical cells)

Site:	Almaty Power Plant No 1
test No:	1 Boiler 13
conditions :	100 % Output
date:	29.04.95
start time :	13:26:26
end time :	13:53:26
log interval(sec) :	30
scans :	55

	dry basis							6.0 % O2 dry basis									
	gas temp	NO2	NO	SO2	CO	CO2	O2	NO2		NO		SO2		CO		CO2
	deg C	ppm	ppm	ppm	ppm	%	%	ppm	mg/m3	ppm	mg/m3	ppm	mg/m3	ppm	mg/m3	%
Maximum	–	3	260	278	45	9.7	10.9	4	9	386	517	397	1135	65	81	13.2
Minimum	–	2	239	231	28	8.8	9.9	3	6	324	434	336	960	40	50	13.1
Average	–	2	252	265	34	9.2	10.4	3	6	359	481	377	1079	49	61	13.2
Std Dev	–	0.1	5	11.6	3	0.3	0.3	0.2	0.5	16	21	13	37	6	7	0.0
Std Error	–	0.02	0.68	1.56	0.46	0.03	0.04	0.03	0.06	2.14	2.87	1.72	4.93	0.76	0.95	0.01

GAS ANALYSIS USING TESTOTERM ANALYSER (chemical cells)

Site:	Almaty Power Plant No 1
test No:	2 Boiler 13
conditions :	100 % Output
date:	29.04.95
start time :	14:00:35
end time :	14:42:05
log interval(sec) :	30
scans :	84

	dry basis							6.0 % O2 dry basis									
	gas temp	NO2	NO	SO2	CO	CO2	O2	NO2		NO		SO2		CO		CO2
	deg C	ppm	ppm	ppm	ppm	%	%	ppm	mg/m3	ppm	mg/m3	ppm	mg/m3	ppm	mg/m3	%
Maximum	–	3	263	305	43	9.6	11.2	4	9	401	537	435	1243	64	80	13.2
Minimum	–	2	250	265	29	8.6	10.1	3	6	345	462	391	1118	42	52	13.1
Average	–	2	257	288	35	9.2	10.5	3	6	370	496	414	1184	51	63	13.2
Std Dev	–	0.1	3	9.2	3	0.2	0.2	0.2	0.4	10	13	12	33	4	6	0.0
Std Error	–	0.01	0.32	1.00	0.32	0.02	0.02	0.02	0.04	1.07	1.43	1.25	3.59	0.49	0.61	0.00

GAS ANALYSIS USING TESTOTERM ANALYSER (chemical cells)

Site:	Almaty Power Plant No 1
test No:	3 Boiler 13
conditions :	100 % Output
date:	29.04.95
start time :	14:51:55
end time :	15:22:25
log interval(sec) :	30
scans :	62

dry basis

	gas temp	NO2	NO	SO2	CO	CO2	O2
	deg C	ppm	ppm	ppm	ppm	%	%
Maximum	–	2	266	335	42	10.0	10.6
Minimum	–	1	238	294	32	9.1	9.6
Average	–	2	257	309	38	9.6	10.1
Std Dev	–	0.1	6	9.2	3	0.2	0.2
Std Error	–	0.02	0.81	1.17	0.35	0.02	0.03

6.0 % O2 dry basis

	NO2		NO		SO2		CO		CO2
	ppm	mg/m3	ppm	mg/m3	ppm	mg/m3	ppm	mg/m3	%
Maximum	3	6	385	516	450	1286	58	73	13.2
Minimum	1	3	314	421	405	1157	43	53	13.1
Average	3	6	354	474	425	1216	52	65	13.2
Std Dev	0.2	0.4	15	20	11	32	4	5	0.0
Std Error	0.02	0.05	1.90	2.55	1.44	4.12	0.51	0.64	0.01

MOISTURE ANALYSIS PROGRAMME

SITE: Almaty No. 1
DATE: 29 April 1995
TEST: 1
BOILER: 13
Barometric: 958 mbar

Sample No.	After Weight g	Before Weight g	Weight Gain g	Volume Sampled Litres	Temp. C	Corrected Volume Sampled (l)	Water in Gas %
1	51.600	50.708	0.892	10.00	28	9.59	11.58
2	58.831	58.000	0.831	10.00	28	9.59	10.79
3	50.488	49.618	0.870	10.00	28	9.59	11.29
Average							11.22

GAS FLOW CALCULATION - VOLFLOW4.WK1 (Version 2.00)

Compiled by:
Date:

Project No.: 554205 Site: Almaty No. 1 Test Date: 29-Apr-95
File No.: Test: Test 1 Boiler 13

Checked by:
Date:

Scale Factor	0.07		Dry	Wet	
Calib. Temp.	22.0 dgC	02	10.30 %	9.14 %	
Flue Gas Temp.	76.0 dgC	C02	9.30 %	8.26 %	
Ambient Temp.	28.0 dgC	CO	36.00	0.00 %	
Static Pressure	135.00 Pa	H20		11.22 %	
Temp.Cor Factor	-0.0057	N2	80.40 %	71.38 %	
Atmos Pressure	958 mb				
		S.G.	1.036	0.990	

Correct to : 6 % Oxygen

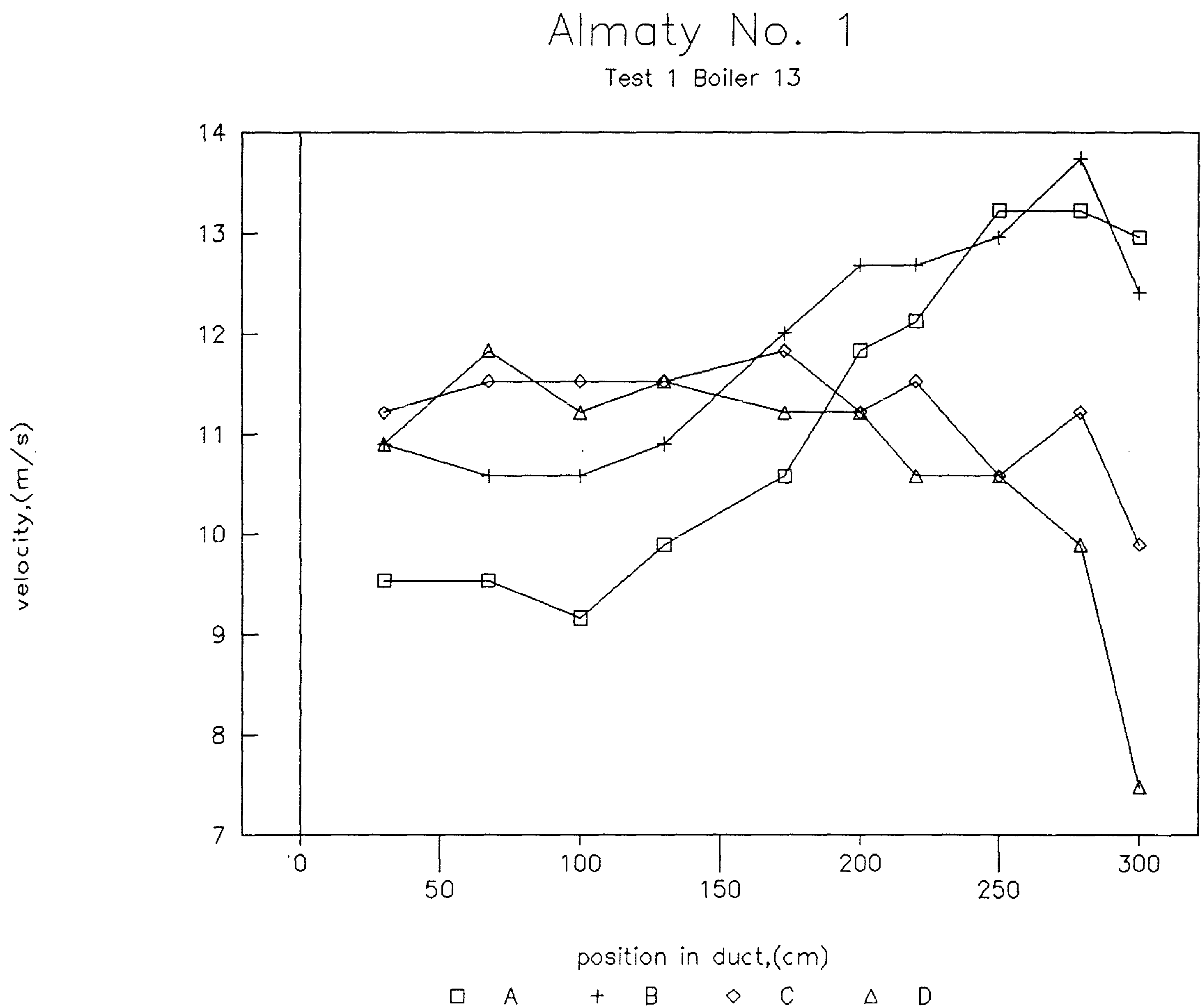
Position in duct (cm)	Access Port A scale reading (kPa)	h (Pa)	Velocity (m/s)	Access Port B scale reading 0.200	h (Pa)	Velocity (m/s)	Access Port C scale reading (kPa)	h (Pa)	Velocity (m/s)	Access Port D scale reading (kPa)	h (Pa)	Velocity (m/s)
NW	0.00	0.0	0.000	0.00	0.0	0.000	0.00	0.0	0.000	0.00	0.0	0.000
30.00	0.65	43.1	9.535	0.85	56.3	10.904	0.90	59.7	11.220	0.85	56.3	10.904
67.00	0.65	43.1	9.535	0.80	53.0	10.578	0.95	63.0	11.527	1.00	66.3	11.827
100.00	0.60	39.8	9.161	0.80	53.0	10.578	0.95	63.0	11.527	0.90	59.7	11.220
130.00	0.70	46.4	9.895	0.85	56.3	10.904	0.95	63.0	11.527	0.95	63.0	11.527
173.00	0.80	53.0	10.578	1.03	68.3	12.003	1.00	66.3	11.827	0.90	59.7	11.220
200.00	1.00	66.3	11.827	1.15	76.2	12.683	0.90	59.7	11.220	0.90	59.7	11.220
220.00	1.05	69.6	12.119	1.15	76.2	12.683	0.95	63.0	11.527	0.80	53.0	10.578
250.00	1.25	82.9	13.222	1.20	79.5	12.955	0.80	53.0	10.578	0.80	53.0	10.578
279.00	1.25	82.9	13.222	1.35	89.5	13.741	0.90	59.7	11.220	0.70	46.4	9.895
300.00	1.20	79.5	12.955	1.10	72.9	12.404	0.70	46.4	9.895	0.40	26.5	7.480
FW	0.00	0.0	0.000	0.00	0.0	0.000	0.00	0.0	0.000	0.00	0.0	0.000

Duct Dimensions

Width	125.20 ins		
Depth	114.17 ins	11.205 m/s (mean A)	11.943 m/s (mean B)
Area	99.262 sq.ft	11.207 m/s (mean C)	10.645 m/s (mean D)
	9.221 m2		

SQUARE DUCT APPROXIMATIONS

	Volume Flow	Volume Flow at 6 % Oxygen	Mass Flow (as measured)
Actual	373462 m3/h	265901 m3/h	
Standard (0 dgC 1 atm)	276595 m3/h	196933 m3/h	353978.02 kg/h
Standard (dry)	245561 m3/h	174837 m3/h	329059.23 kg/h



Almaty No. 1
Test 1 Boiler 13
velocity,(m/s)
14
13
12
11
10
9
8
7
0
50
100
150
200
250
300
position in duct,(cm)
A
B
C
D

SOLIDS EMISSION TO ATMOSPHERE FROM A SQUARE DUCT (Version 1.00)

Date: 29–Apr–95

Site: Almaty No. 1
Test: 1 Boiler 13

Duct Dimensions
Width 125.2 ins
Depth 114.2 ins
Useable Area 100 %
" " 9.22 m2

Sample No	Filter Weights (grammes) No	After	Before	Collected	Rate of Emission kg/m2	Total rate Of Emission kg/h	Nozzle Area 1/m2	Duration mins
1	G12	25.8966	24.3762	1.5204	45.61	420.63	5000	10
2	G13	26.2943	24.1047	2.1896	43.79	403.85	5000	15
3	G14	26.9812	24.1219	2.8593	57.19	527.37	5000	15

Avg Rate Of Emission: 450.62 kg/h

PARTICULATES CONCENTRATION

At Duct Conditions	Corrected to 6 % [O2], dry, at STP
Volume Flowrate: 373462 m3/h	Volume Flowrate: 174837 m3/h
Dust Concentration: 1207 mg/m3	Dust Concentration: 2577 mg/m3

GAS ANALYSIS USING TESTOTERM ANALYSER (chemical cells)

Site: Almaty Power Plant No 1
test No: 1 Boiler 11
conditions : 85 % Output
date: 02.05.95
start time : 11:44:55
end time : 12:33:55
log interval(sec) : 30
scans : 99

	dry basis							6.0 % O2 dry basis									
	gas temp	NO2	NO	SO2	CO	CO2	O2	NO2		NO		SO2		CO		CO2
	deg C	ppm	ppm	ppm	ppm	%	%	ppm	mg/m3	ppm	mg/m3	ppm	mg/m3	ppm	mg/m3	%
Maximum	–	3	285	365	89	10.1	10.5	4	9	407	545	481	1376	119	149	13.2
Minimum	–	2	243	322	70	9.2	9.5	3	5	319	427	454	1298	95	119	13.1
Average	–	3	268	339	79	9.6	10.0	4	7	368	494	465	1331	108	135	13.2
Std Dev	–	0.5	12	12.1	4	0.2	0.3	0.7	1.5	25	33	7	20	6	7	0.0
Std Error	–	0.05	1.19	1.22	0.40	0.02	0.03	0.08	0.15	2.49	3.34	0.69	1.97	0.59	0.74	0.00

GAS ANALYSIS USING TESTOTERM ANALYSER (chemical cells)

Site:	Almaty Power Plant No 1
test No:	2 Boiler 11
conditions :	85 % Output
date:	02.05.95
start time :	12:57:05
end time :	13:29:05
log interval(sec) :	30
scans :	65

dry basis

	gas temp	NO2	NO	SO2	CO	CO2	O2
	deg C	ppm	ppm	ppm	ppm	%	%
Maximum	–	2	260	374	97	10.1	9.9
Minimum	–	2	230	357	77	9.7	9.5
Average	–	2	246	364	84	9.9	9.7
Std Dev	–	0.0	6	4.0	3	0.1	0.1
Std Error	–	0.00	0.79	0.50	0.36	0.01	0.01

6.0 % O2 dry basis

	NO2		NO		SO2		CO		CO2
	ppm	mg/m3	ppm	mg/m3	ppm	mg/m3	ppm	mg/m3	%
Maximum	3	6	348	466	494	1412	128	160	13.2
Minimum	3	5	301	403	473	1354	102	127	13.1
Average	3	5	326	437	483	1380	111	139	13.2
Std Dev	0.0	0.0	11	14	4	12	4	5	0.0
Std Error	0.00	0.01	1.32	1.77	0.52	1.50	0.48	0.60	0.00

GAS ANALYSIS USING TESTOTERM ANALYSER (chemical cells)

Site: Almaty Power Plant No 1
test No: 3 Boiler 11
conditions : 85 % Output
date: 02.05.95
start time : 14:37:17
end time : 14:56:17
log interval(sec) : 30
scans : 39

	dry basis						6.0 % O2 dry basis									
	gas temp	NO2	NO	SO2	CO	CO2	O2	NO2		NO		SO2		CO		CO2
	deg C	ppm	ppm	ppm	ppm	%	%	ppm	mg/m3	ppm	mg/m3	ppm	mg/m3	ppm	mg/m3	%
Maximum	–	3	287	383	181	10.3	10.2	4	9	396	531	494	1412	231	288	13.2
Minimum	–	2	227	341	75	9.5	9.2	3	5	289	387	470	1345	100	125	13.1
Average	–	2	260	363	87	9.9	9.7	3	7	348	466	484	1385	116	145	13.2
Std Dev	–	0.5	17	13.1	20	0.3	0.3	0.7	1.5	31	41	6	19	24	30	0.0
Std Error	–	0.08	2.67	2.10	3.17	0.04	0.05	0.12	0.24	4.91	6.58	1.04	2.98	3.78	4.73	0.01

MOISTURE ANALYSIS PROGRAMME

SITE: ALMATY No. 1
DATE: 2 May 95
TEST: 2
BOILER: 11
Barometric: 960.00

Sample No.	After Weight g	Before Weight g	Weight Gain g	Volume Sampled Litres	Temp. C	Corrected Volume Sampled (l)	Water in Gas %
1	57.678	56.809	0.869	10.00	30.00	9.51	11.38
2	51.906	51.004	0.902	10.00	30.00	9.51	11.81
3	53.664	52.961	0.703	10.00	30.00	9.51	9.21
Average							11.60

Note: Sample 3 NOT included in average

GAS FLOW CALCULATION - VOLFLOW4.WK1 (Version 2.00)

Compiled by:
Date:

Project No.: 554205 Site: Almaty No. 1 Test Date:02-May-95
File No.: Test: Test 2 Boiler 11

Checked by:
Date:

				Dry	Wet
Scale Factor	0.07				
Calib. Temp.	22.0 dgC		O2	9.80 %	8.66 %
Flue Gas Temp.	75.0 dgC		CO2	9.80 %	8.66 %
Ambient Temp.	30.0 dgC		CO	85.00	0.01 %
Static Pressure	250.00 Pa		H2O		11.60 %
Temp.Cor Factor	-0.0076		N2	80.39 %	71.07 %
Atmos Pressure	960 mb				
			S.G.	1.038	0.990

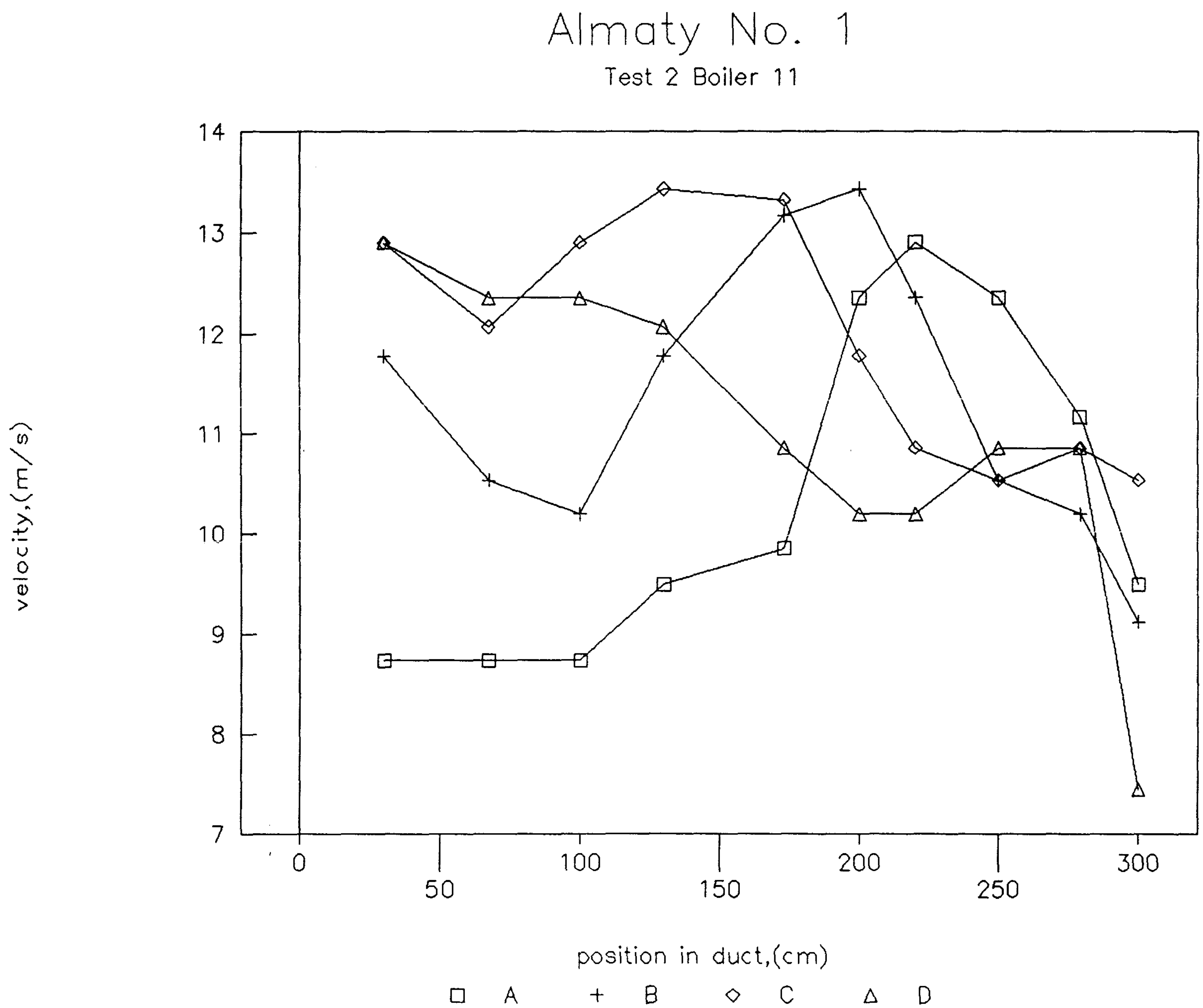
Correct to : 6 % Oxygen

Position in duct (cm)	Access Port A scale reading (kPa)	h (Pa)	Velocity (m/s)	Access Port B scale reading 0.200	h (Pa)	Velocity (m/s)	Access Port C scale reading (kPa)	h (Pa)	Velocity (m/s)	Access Port D scale reading (kPa)	h (Pa)	Velocity (m/s)
NW	0.00	0.0	0.000	0.00	0.0	0.000	0.00	0.0	0.000	0.00	0.0	0.000
30.00	0.55	36.4	8.734	1.00	66.2	11.777	1.20	79.4	12.902	1.20	79.4	12.902
67.00	0.55	36.4	8.734	0.80	52.9	10.534	1.05	69.5	12.068	1.10	72.8	12.352
100.00	0.55	36.4	8.734	0.75	49.6	10.200	1.20	79.4	12.902	1.10	72.8	12.352
130.00	0.65	43.0	9.495	1.00	66.2	11.777	1.30	86.0	13.428	1.05	69.5	12.068
173.00	0.70	46.3	9.854	1.25	82.7	13.168	1.28	84.7	13.325	0.85	56.2	10.858
200.00	1.10	72.8	12.352	1.30	86.0	13.428	1.00	66.2	11.777	0.75	49.6	10.200
220.00	1.20	79.4	12.902	1.10	72.8	12.352	0.85	56.2	10.858	0.75	49.6	10.200
250.00	1.10	72.8	12.352	0.80	52.9	10.534	0.80	52.9	10.534	0.85	56.2	10.858
279.00	0.90	59.5	11.173	0.75	49.6	10.200	0.85	56.2	10.858	0.85	56.2	10.858
300.00	0.65	43.0	9.495	0.60	39.7	9.123	0.80	52.9	10.534	0.40	26.5	7.449
FW	0.00	0.0	0.000	0.00	0.0	0.000	0.00	0.0	0.000	0.00	0.0	0.000

Duct Dimensions

		SQUARE DUCT APPROXIMATIONS	
Width	125.20 ins		
Depth	114.17 ins	10.383 m/s (mean A)	11.309 m/s (mean B)
Area	99.265 sq.ft	11.919 m/s (mean C)	11.010 m/s (mean D)
	9.222 m2		

	Volume Flow	Volume Flow at 6 % Oxygen	Mass Flow (as measured)
Actual	370328 m3/h	276072 m3/h	
Standard (0 dgC 1 atm)	275965 m3/h	205726 m3/h	353262.07 kg/h
Standard (dry)	243953 m3/h	181862 m3/h	327557.96 kg/h



Almaty No. 1
Test 2 Boiler 11
14
13
12
11
10
9
8
7
velocity,(m/s)
0
50
100
150
200
250
300
position in duct,(cm)
A
B
C
D

SOLIDS EMISSION TO ATMOSPHERE FROM A SQUARE DUCT (Version 1.00)

Date: 02–May–95

Site: Almaty No. 1

Test: 2 Boiler 11

Duct Dimensions

Width	125.2 ins
Depth	114.2 ins
Useable Area	100 %
" "	9.22 m2

Sample No	Filter Weights (grammes) No	After	Before	Collected	Rate of Emission kg/m2	Total rate Of Emission kg/h	Nozzle Area 1/m2	Duration mins
1	g16	25.4349	24.9340	0.5009	18.03	166.29	9000	15
2	g17	24.4564	23.9103	0.5461	19.66	181.30	9000	15
3	g18				0.00	0.00	9000	15

Avg Rate Of Emission: 173.80 kg/h

PARTICULATES CONCENTRATION

At Duct Conditions	Corrected to 6 % [O2], dry, at STP
Volume Flowrate: 370328 m3/h	Volume Flowrate: 181862 m3/h
Dust Concentration: 469 mg/m3	Dust Concentration: 956 mg/m3

APPENDIX 4 EMISSIONS MONITORING RESULTS AT POWER PLANT No 2

GAS ANALYSIS USING TESTOTERM ANALYSER (chemical cells)

Site: Almaty Power Plant No 2
test No: 1
conditions : 100 % Output
date: 26.04.95
start time : 12:31:18
end time : 12:41:03
log interval(sec) : 15
scans : 39

	dry basis						6.0 % O2 dry basis									
	gas temp	NO2	NO	SO2	CO	CO2	O2	NO2		NO		SO2		CO		CO2
	deg C	ppm	ppm	ppm	ppm	%	%	ppm	mg/m3	ppm	mg/m3	ppm	mg/m3	ppm	mg/m3	%
Maximum	–	4	320	271	65	8.4	12.0	7	14	521	698	444	1269	105	132	13.3
Minimum	–	4	303	202	37	7.9	11.4	6	13	485	651	324	926	59	74	13.1
Average	–	4	314	263	54	8.2	11.7	6	13	507	679	423	1211	87	109	13.2
Std Dev	–	0.0	4	12.4	7	0.1	0.1	0.1	0.2	7	9	20	58	11	14	0.0
Std Error	–	0.00	0.61	1.98	1.14	0.02	0.02	0.01	0.03	1.07	1.44	3.24	9.27	1.83	2.29	0.01

GAS ANALYSIS USING TESTOTERM ANALYSER (chemical cells)

Site: Almaty Power Plant No 2
test No: 2
conditions : 100 % Output
date: 26.04.95
start time : 12:52:04
end time : 13:01:04
log interval(sec) : 15
scans : 36

dry basis

	gas temp	NO2	NO	SO2	CO	CO2	O2
	deg C	ppm	ppm	ppm	ppm	%	%
Maximum	–	5	325	279	76	8.5	12.0
Minimum	–	4	302	246	52	7.9	11.3
Average	–	4	314	267	65	8.2	11.7
Std Dev	–	0.2	6	7.2	7	0.1	0.2
Std Error	–	0.03	1.08	1.21	1.14	0.02	0.03

6.0 % O2 dry basis

	NO2		NO		SO2		CO		CO2
	ppm	mg/m3	ppm	mg/m3	ppm	mg/m3	ppm	mg/m3	%
Maximum	8	17	523	701	445	1274	120	151	13.3
Minimum	6	13	494	662	403	1152	85	106	13.1
Average	7	13	509	682	431	1234	104	130	13.2
Std Dev	0.3	0.6	7	10	8	23	10	13	0.1
Std Error	0.05	0.10	1.21	1.62	1.34	3.83	1.70	2.12	0.01

GAS ANALYSIS USING TESTOTERM ANALYSER (chemical cells)

Site: Almaty Power Plant No 2
test No: 3
conditions : 100 % Output
date: 26.04.95
start time : 13:11:15
end time : 13:24:30
log interval(sec) : 15
scans : 39

dry basis

	gas temp	NO2	NO	SO2	CO	CO2	O2
	deg C	ppm	ppm	ppm	ppm	%	%
Maximum	–	4	321	276	81	8.3	12.0
Minimum	–	3	293	190	50	7.9	11.5
Average	–	4	309	263	68	8.1	11.7
Std Dev	–	0.2	7	14.9	8	0.1	0.1
Std Error	–	0.04	1.09	2.39	1.31	0.01	0.02

6.0 % O2 dry basis

NO2		NO		SO2		CO		CO2
ppm	mg/m3	ppm	mg/m3	ppm	mg/m3	ppm	mg/m3	%
7	14	522	700	452	1293	130	162	13.3
5	10	475	636	308	880	81	101	13.1
6	13	501	671	427	1221	111	139	13.2
0.3	0.7	9	13	24	68	13	16	0.1
0.06	0.11	1.51	2.02	3.82	10.92	2.10	2.62	0.01

MOISTURE ANALYSIS PROGRAMME

SITE: Almaty No. 2
DATE: 26 April 1995
TEST: 1
BOILER: 4
Barometric: 965 mbar

Sample No.	After Weight g	Before Weight g	Weight Gain g	Volume Sampled Litres	Temp. C	Corrected Volume Sampled (l)	Water in Gas %
1	55.797	55.166	0.631	10.00	21	9.75	8.06
2	57.765	57.145	0.620	10.00	21	9.75	7.92
Average							7.99

GAS FLOW CALCULATION - VOLFLOW4.WK1 (Version 2.00)

Compiled by:
Date:

Project No.: 554205 Site: Almaty No. 2 Test Date:26-Apr-95
File No.: Test: Test 1

Checked by:
Date:

			Dry	Wet
Scale Factor	0.13			
Calib. Temp.	22.0 dgC	O2	11.70 %	10.77 %
Flue Gas Temp.	72.0 dgC	CO2	8.20 %	7.54 %
Ambient Temp.	21.0 dgC	CO	59.00	0.01 %
Static Pressure	280.00 Pa	H2O		7.99 %
Temp.Cor Factor	0.0010	N2	80.09 %	73.69 %
Atmos Pressure	965 mb			
		S.G.	1.032	0.999

Correct to : 6 % Oxygen

	Access Port A			Access Port B			Access Port C			Access Port D		
Position in duct (cm)	scale reading (kPa)	h (Pa)	Velocity (m/s)	scale reading 0.200	h (Pa)	Velocity (m/s)	scale reading (kPa)	h (Pa)	Velocity (m/s)	scale reading (kPa)	h (Pa)	Velocity (m/s)
NW	0.25	33.4	8.266	0.55	73.4	12.260	0.40	53.4	10.456	0.05	6.7	3.697
20.00	0.80	106.8	14.786	0.70	93.4	13.831	0.45	60.1	11.090	0.10	13.3	5.228
37.50	0.75	100.1	14.317	0.70	93.4	13.831	0.50	66.7	11.690	0.15	20.0	6.403
60.00	0.80	106.8	14.786	0.50	66.7	11.690	0.45	60.1	11.090	0.15	20.0	6.403
80.00	0.85	113.4	15.241	0.55	73.4	12.260	0.45	60.1	11.090	0.20	26.7	7.393
112.50	0.80	106.8	14.786	0.60	80.1	12.805	0.45	60.1	11.090	0.20	26.7	7.393
130.00	0.75	100.1	14.317	0.60	80.1	12.805	0.42	56.1	10.714	0.20	26.7	7.393
150.00	0.75	100.1	14.317	0.65	86.7	13.328	0.30	40.0	9.055	0.15	20.0	6.403
187.50	0.80	106.8	14.786	0.60	80.1	12.805	0.25	33.4	8.266	0.15	20.0	6.403
200.00	0.70	93.4	13.831	0.55	73.4	12.260	0.25	33.4	8.266	0.15	20.0	6.403
FW	0.35	46.7	9.780	0.25	33.4	8.266	0.10	13.3	5.228	0.05	6.7	3.697

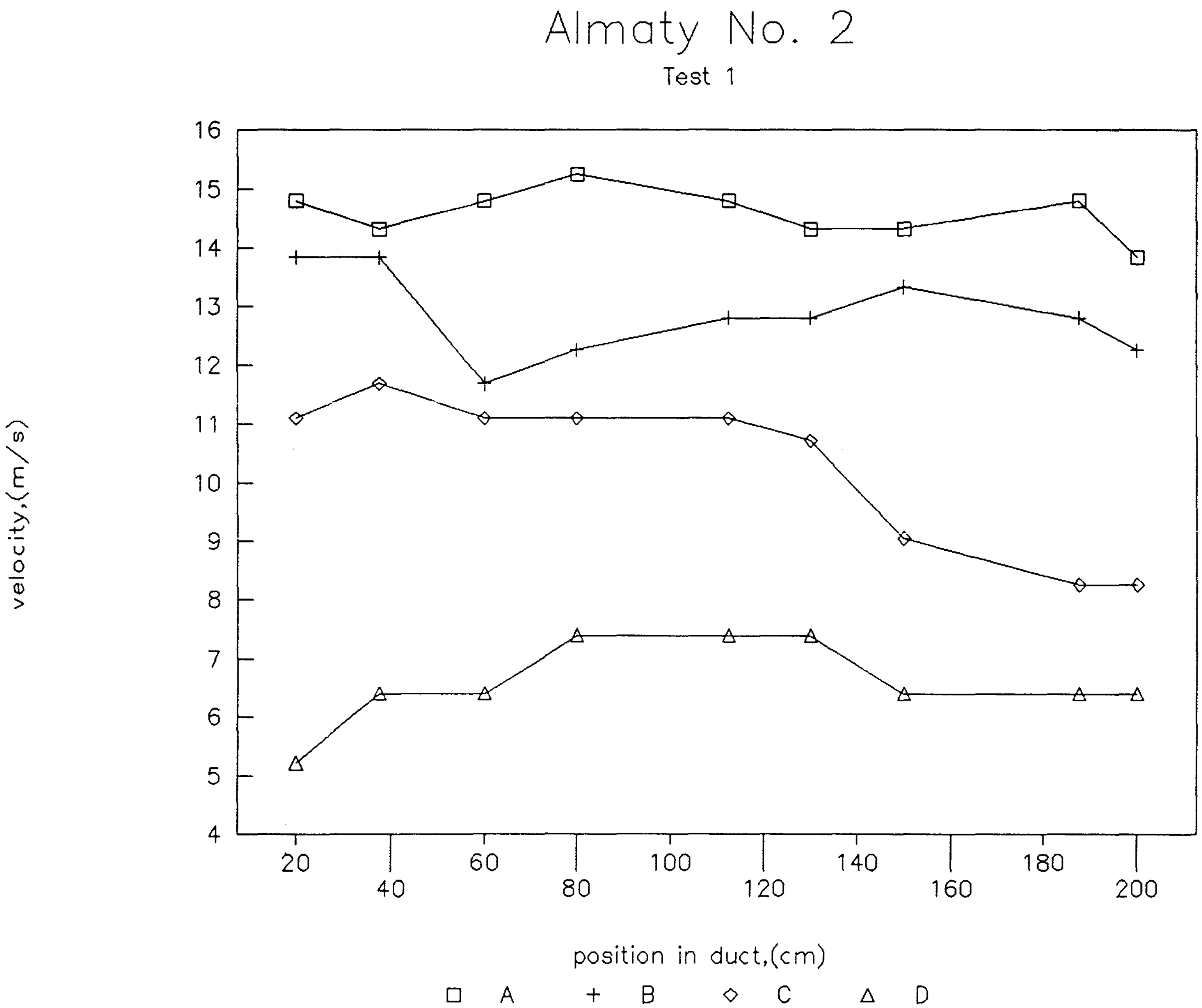
Duct Dimensions

Width 88.58 ins
Depth 184.25 ins
Area 113.344 sq.ft
10.530 m2

SQUARE DUCT APPROXIMATIONS

14.574 m/s (mean A)
12.846 m/s (mean B)
10.261 m/s (mean C)
6.602 m/s (mean D)

	Volume Flow	Volume Flow at 6 % Oxygen	Mass Flow (as measured)
Actual	419667 m3/h	259446 m3/h	
Standard (0 dgC 1 atm)	317188 m3/h	196092 m3/h	409862.05 kg/h
Standard (dry)	291845 m3/h	180424 m3/h	389512.52 kg/h


Almaty No. 2
Test 1
velocity,(m/s)
16
15
14
13
12
11
10
9
8
7
6
5
4
20
40
60
80
100
120
140
160
180
200
position in duct,(cm)
A
B
C
D

SOLIDS EMISSION TO ATMOSPHERE FROM A SQUARE DUCT (Version 1.00)

Date: 26–Apr–95

Site: Almaty No. 2
Test: 1

Duct Dimensions

Width	88.6 ins
Depth	184.3 ins
Useable Area	100 %
" "	10.53 m2

Sample No	Filter Weights (grammes) No	After	Before	Collected	Rate of Emission kg/m2	Total rate Of Emission kg/h	Nozzle Area 1/m2	Duration mins
1	G2	27.1746	25.1516	2.0230	36.41	383.44	9000	30
2	G3	25.9805	23.9967	1.9838	35.71	376.01	9000	30
3	G4	25.6730	24.1153	1.5577	27.82	292.90	5000	17
4	G5	26.3121	25.2845	1.0276	18.52	194.97	3000	10

Avg Rate Of Emission: 311.83 kg/h

PARTICULATES CONCENTRATION

At Duct Conditions	Corrected to 6 % [O2], dry, at STP
Volume Flowrate: 419667 m3/h	Volume Flowrate: 180424 m3/h
Dust Concentration: 743 mg/m3	Dust Concentration: 1728 mg/m3

APPENDIX 5 EMISSIONS MONITORING RESULTS AT POWER PLANT GRES

GAS ANALYSIS USING TESTOTERM ANALYSER (chemical cells)

Site: Almaty Power Plant No 3
test No: 1 Left Duct
conditions : 100 % Output
date: 27.04.95
start time : 12:21:43
end time : 12:52:13
log interval(sec) : 30
scans : 62

dry basis

	gas temp	NO_2	NO	SO_2	CO	CO_2	O_2
	deg C	ppm	ppm	ppm	ppm	%	%
Maximum	–	3	334	516	52	12.7	8.2
Minimum	–	1	306	422	27	11.2	6.5
Average	–	2	323	466	34	11.7	7.7
Std Dev	–	0.3	6	17.3	5	0.3	0.3
Std Error	–	0.04	0.72	2.19	0.69	0.04	0.04

6.0 % O_2 dry basis

	NO_2		NO		SO_2		CO		CO_2
	ppm	mg/m3	ppm	mg/m3	ppm	mg/m3	ppm	mg/m3	%
Maximum	4	7	388	520	553	1582	59	74	13.2
Minimum	1	2	317	424	480	1373	28	35	13.1
Average	2	5	363	487	524	1499	38	47	13.2
Std Dev	0.4	0.8	14	19	15	43	6	8	0.0
Std Error	0.05	0.11	1.84	2.46	1.90	5.42	0.78	0.97	0.00

GAS ANALYSIS USING TESTOTERM ANALYSER (chemical cells)

Site: Almaty Power Plant No 3
test No: 2 Left Duct
conditions : 100 % Output
date: 27.04.95
start time : 13:01:32
end time : 13:47:02
log interval(sec) : 30
scans : 92

dry basis

	gas temp	NO2	NO	SO2	CO	CO2	O2
	deg C	ppm	ppm	ppm	ppm	%	%
Maximum	–	3	335	517	40	12.7	8.1
Minimum	–	1	300	466	28	11.3	6.5
Average	–	2	320	488	34	11.7	7.6
Std Dev	–	0.3	6	10.4	2	0.3	0.3
Std Error	–	0.03	0.68	1.09	0.25	0.03	0.03

6.0 % O2 dry basis

	NO2		NO		SO2		CO		CO2
	ppm	mg/m3	ppm	mg/m3	ppm	mg/m3	ppm	mg/m3	%
Maximum	3	7	387	518	563	1609	44	55	13.2
Minimum	1	2	312	419	527	1508	31	39	13.1
Average	2	5	359	482	547	1564	38	48	13.2
Std Dev	0.4	0.8	14	19	7	20	3	4	0.0
Std Error	0.04	0.08	1.45	1.94	0.71	2.04	0.29	0.37	0.00

GAS ANALYSIS USING TESTOTERM ANALYSER (chemical cells)

Site:	Almaty Power Plant No 3
test No:	3 Left Duct
conditions :	100 % Output
date:	27.04.95
start time :	13:53:35
end time :	14:24:35
log interval(sec) :	30
scans :	63

	dry basis							6.0 % O2 dry basis										
	gas temp	NO2	NO	SO2	CO	CO2	O2	NO2		NO		SO2		CO		CO2
	deg C	ppm	ppm	ppm	ppm	%	%	ppm	mg/m3	ppm	mg/m3	ppm	mg/m3	ppm	mg/m3	%
Maximum	–	2	325	512	42	12.4	8.1	2	5	378	507	566	1617	48	60	13.2
Minimum	–	1	301	471	34	11.3	6.9	1	2	324	434	538	1538	38	48	13.1
Average	–	2	314	491	38	11.7	7.6	2	5	352	471	550	1573	43	54	13.2
Std Dev	–	0.2	5	8.1	2	0.2	0.3	0.2	0.4	11	15	6	17	3	3	0.0
Std Error	–	0.02	0.64	1.02	0.27	0.03	0.03	0.03	0.05	1.40	1.88	0.74	2.12	0.32	0.40	0.00

MOISTURE ANALYSIS PROGRAMME

SITE: Almaty No. 3
DATE: 27 April 1995
TEST: 1 (LHS)
BOILER: 1
Barometric: 959 mbar

Sample No.	After Weight g	Before Weight g	Weight Gain g	Volume Sampled Litres	Temp. C	Corrected Volume Sampled (l)	Water in Gas %
1	56.456	55.696	0.760	10.00	28	9.58	9.88
2	57.457	56.735	0.722	10.00	28	9.58	9.38
3	56.922	56.156	0.766	10.00	28	9.58	9.95
Average							9.74

GAS FLOW CALCULATION - VOLFLOW3.WK1 (Version 2.00)

Compiled by:
Date:

Project No.: 554205 Site: Almaty No. 3 Test Date:27-Apr-95
File No.: Test: Test 1 Left Hand Side

Checked by:
Date:

Scale Factor	0.03			Dry	Wet
Calib. Temp.	22.0 dgC		O2	7.60 %	6.86 %
Flue Gas Temp.	85.0 dgC		CO2	11.70 %	10.56 %
Ambient Temp.	28.0 dgC		CO	36.00	0.00 %
Static Pressure	-83.0 Pa		H2O		9.74 %
Temp.Cor Factor	-0.0057		N2	80.70 %	72.84 %
Atmos. Pressure	959 mb				
			S.G.	1.046	1.005

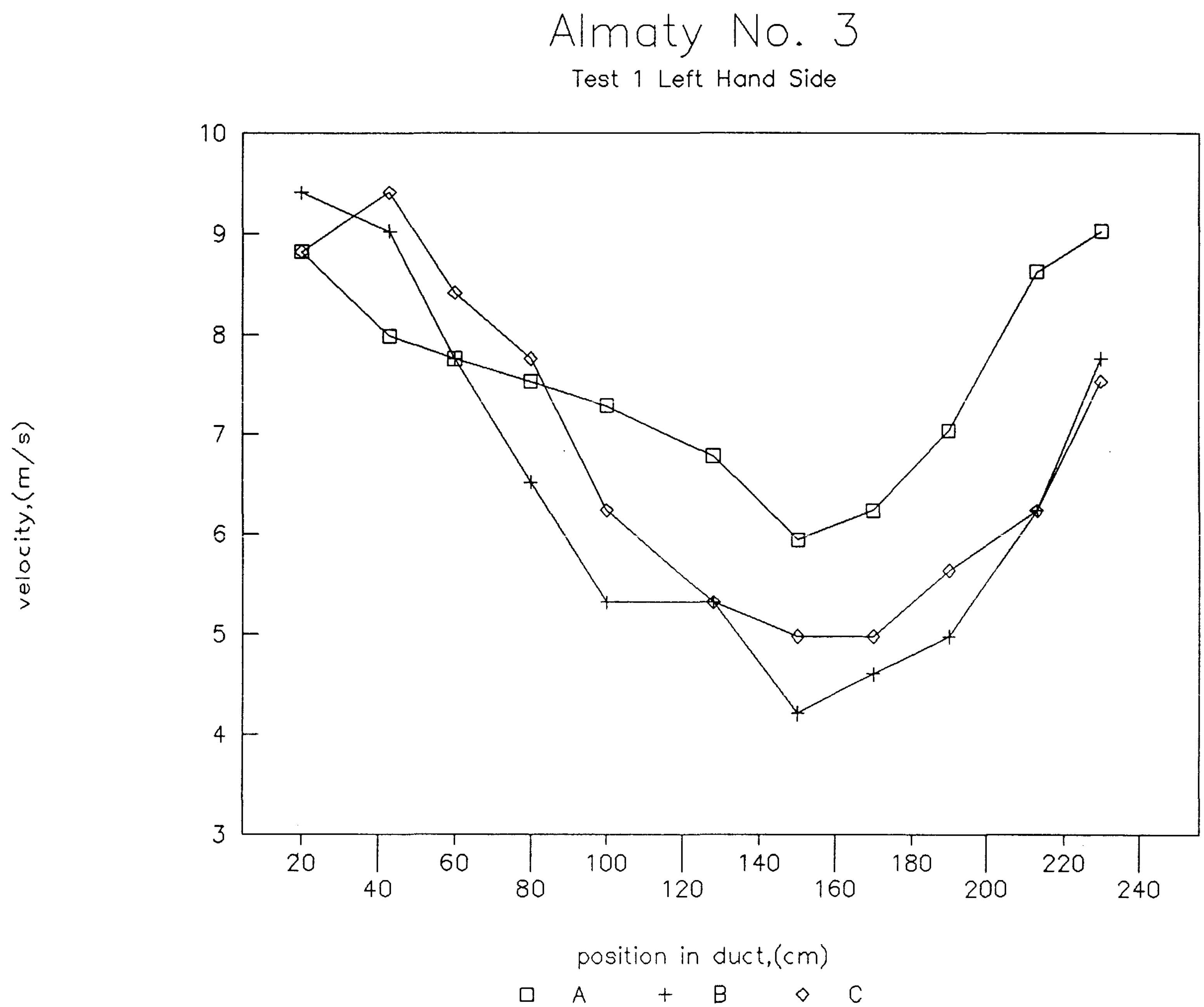
Correct to : 6 % O2

	Access Port A			Access Port B			Access Port C		
Position in duct (cm)	scale reading (kPa)	h (Pa)	Velocity (m/s)	scale reading (kPa)	h (Pa)	Velocity (m/s)	scale reading (kPa)	h (Pa)	Velocity (m/s)
N/W	0.00	0.0	0.000	0.00	0.0	0.000	0.00	0.0	0.000
20.00	1.10	36.5	8.823	1.25	41.4	9.405	1.10	36.5	8.823
43.00	0.90	29.8	7.981	1.15	38.1	9.021	1.25	41.4	9.405
60.00	0.85	28.2	7.756	0.85	28.2	7.756	1.00	33.1	8.412
80.00	0.80	26.5	7.524	0.60	19.9	6.516	0.85	28.2	7.756
100.00	0.75	24.9	7.285	0.40	13.3	5.321	0.55	18.2	6.239
128.00	0.65	21.5	6.782	0.40	13.3	5.321	0.40	13.3	5.321
150.00	0.50	16.6	5.949	0.25	8.3	4.206	0.35	11.6	4.977
170.00	0.55	18.2	6.239	0.30	9.9	4.608	0.35	11.6	4.977
190.00	0.70	23.2	7.038	0.35	11.6	4.977	0.45	14.9	5.643
213.00	1.05	34.8	8.620	0.55	18.2	6.239	0.55	18.2	6.239
230.00	1.15	38.1	9.021	0.85	28.2	7.756	0.80	26.5	7.524
FW	0.00	0.0	0.000	0.00	0.0	0.000	0.00	0.0	0.000

SQUARE DUCT APPROXIMATIONS

Duct Dimensions 7.547 m/s (mean A) 6.466 m/s (mean B)
Width 100.79 ins 6.847 m/s (mean C)
Depth 102.36 ins
Area 71.645 sq.ft
6.656 m2

	Volume Flow	Volume Flow at 6 % Oxygen	Mass Flow
Actual	166609 m3/h	148754 m3/h	(as measured)
Standard (0 dgC 1 atm)	120144 m3/h	107269 m3/h	156050 kg/h
Standard (dry)	108442 m3/h	96821 m3/h	146654 kg/h


Almaty No. 3
Test 1 Left Hand Side
velocity,(m/s)
10
9
8
7
6
5
4
3
20
40
60
80
100
120
140
160
180
200
220
240
position in duct,(cm)
A
B
C

SOLIDS EMISSION TO ATMOSPHERE FROM A SQUARE DUCT (Version 1.00)

Date: 27-Apr-95

Site: Almaty No. 3

Test: 1 Left Hand Side

Duct Dimensions

Width	100.8 ins
Depth	102.4 ins
Useable Area	100 %
" "	6.66 m2

Sample No	Filter Weights (grammes) No	After	Before	Collected	Rate of Emission kg/m2	Total rate Of Emission kg/h	Nozzle Area 1/m2	Duration mins
1	G6	27.5317	24.6144	2.9173	58.35	388.35	5000	15
2	G7	27.4761	25.0175	2.4586	49.17	327.29	5000	15
3	G8	26.8287	24.1668	2.6619	53.24	354.35	5000	15

Avg Rate Of Emission: 356.66 kg/h

PARTICULATES CONCENTRATION

At Duct Conditions	Corrected to 6 % [O2], dry, at STP
Volume Flowrate: 166609 m3/h	Volume Flowrate: 96821 m3/h
Dust Concentration: 2141 mg/m3	Dust Concentration: 3684 mg/m3

GAS ANALYSIS USING TESTOTERM ANALYSER (chemical cells)

Site:	Almaty Power Plant No 3
test No:	1 Right Duct
conditions :	100 % Output
date:	28.04.95
start time :	10:27:47
end time :	10:58:17
log interval(sec) :	30
scans :	62

dry basis

	gas temp	NO2	NO	SO2	CO	CO2	O2
	deg C	ppm	ppm	ppm	ppm	%	%
Maximum	–	4	353	535	46	11.8	9.0
Minimum	–	2	314	479	29	10.5	7.5
Average	–	3	329	504	35	11.2	8.2
Std Dev	–	0.5	9	14.0	4	0.3	0.4
Std Error	–	0.07	1.19	1.78	0.49	0.04	0.05

6.0 % O2 dry basis

	NO2		NO		SO2		CO		CO2
	ppm	mg/m3	ppm	mg/m3	ppm	mg/m3	ppm	mg/m3	%
Maximum	5	10	431	578	618	1766	54	67	13.2
Minimum	2	5	349	468	559	1600	34	42	13.1
Average	3	6	388	520	594	1698	42	52	13.2
Std Dev	0.7	1.4	22	29	15	42	4	5	0.0
Std Error	0.09	0.18	2.74	3.67	1.86	5.33	0.53	0.66	0.00

GAS ANALYSIS USING TESTOTERM ANALYSER (chemical cells)

Site: Almaty Power Plant No 3
test No: 2 Right Duct
conditions : 100 % Output
date: 28.04.95
start time : 11:02:21
end time : 11:45:21
log interval(sec) : 30
scans : 87

	dry basis							6.0 % O2 dry basis									
	gas temp	NO2	NO	SO2	CO	CO2	O2	NO2		NO		SO2		CO		CO2
	deg C	ppm	ppm	ppm	ppm	%	%	ppm	mg/m3	ppm	mg/m3	ppm	mg/m3	ppm	mg/m3	%
Maximum	–	3	337	566	40	12.0	8.5	4	7	403	539	638	1823	47	59	13.2
Minimum	–	2	305	477	30	11.0	7.3	2	5	334	448	555	1588	33	41	13.1
Average	–	3	320	514	36	11.4	7.9	3	6	369	494	591	1690	41	51	13.2
Std Dev	–	0.5	8	18.7	2	0.2	0.2	0.6	1.2	15	20	21	59	2	3	0.0
Std Error	–	0.05	0.83	2.01	0.21	0.02	0.03	0.06	0.13	1.57	2.10	2.21	6.32	0.26	0.33	0.00

GAS ANALYSIS USING TESTOTERM ANALYSER (chemical cells)

Site: Almaty Power Plant No 3
test No: 3 Right Duct
conditions : 100 % Output
date: 28.04.95
start time : 11:51:12
end time : 12:17:12
log interval(sec) : 30
scans : 53

	dry basis						
	gas temp	NO2	NO	SO2	CO	CO2	O2
	deg C	ppm	ppm	ppm	ppm	%	%
Maximum	–	3	333	497	41	12.3	8.2
Minimum	–	2	308	449	33	11.2	7.0
Average	–	3	322	477	38	11.6	7.7
Std Dev	–	0.4	5	12.8	2	0.2	0.2
Std Error	–	0.05	0.75	1.76	0.23	0.03	0.03

	6.0 % O2 dry basis								
	NO2		NO		SO2		CO		CO2
	ppm	mg/m3	ppm	mg/m3	ppm	mg/m3	ppm	mg/m3	%
Maximum	4	7	382	511	556	1589	48	60	13.2
Minimum	2	4	336	450	507	1451	38	48	13.1
Average	3	7	364	488	539	1542	43	53	13.2
Std Dev	0.4	0.9	11	14	11	31	2	3	0.0
Std Error	0.06	0.12	1.47	1.97	1.48	4.24	0.28	0.35	0.00

MOISTURE ANALYSIS PROGRAMME

SITE: Almaty No. 3
DATE: 28 April 1995
TEST: 2 (RHS)
BOILER: 1
Barometric: 959 mbar

Sample No.	After Weight g	Before Weight g	Weight Gain g	Volume Sampled Litres	Temp. C	Corrected Volume Sampled (l)	Water in Gas %
1	54.524	53.987	0.537	10.00	28	9.58	6.98
2	53.016	52.352	0.664	10.00	28	9.58	8.63
3	56.725	55.969	0.756	10.00	28	9.58	9.82
Average							8.48

GAS FLOW CALCULATION - VOLFLOW3.WK1 (Version 2.00)

Compiled by:
Date:

Project No.: 554205 Site: Almaty No. 3 Test Date:28-Apr-95
File No.: Test: Test 2 Right Hand Side

Checked by:
Date:

				Dry	Wet
Scale Factor	0.03			Dry	Wet
Calib. Temp.	22.0 dgC		O2	7.90 %	7.23 %
Flue Gas Temp.	89.0 dgC		CO2	11.40 %	10.43 %
Ambient Temp.	28.0 dgC		CO	36.00	0.00 %
Static Pressure	-50.0 Pa		H2O		8.48 %
Temp.Cor Factor	-0.0057		N2	80.70 %	73.85 %
Atmos. Pressure	959 mb				
			S.G.	1.045	1.009

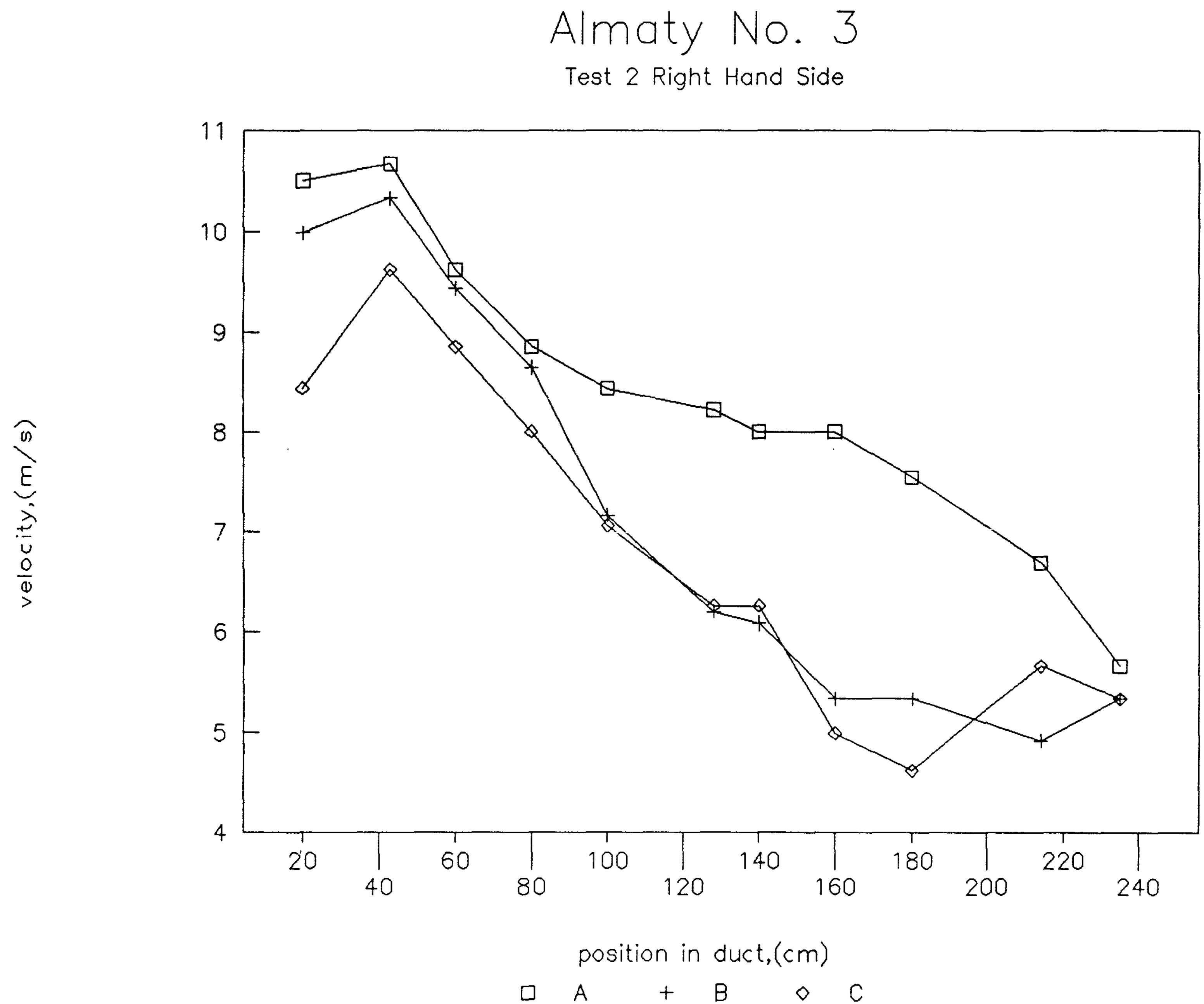
Correct to : 6 % O2

Position in duct (cm)	Access Port A scale reading (kPa)	h (Pa)	Velocity (m/s)	Access Port B scale reading (kPa)	h (Pa)	Velocity (m/s)	Access Port C scale reading (kPa)	h (Pa)	Velocity (m/s)
N/W	0.00	0.0	0.000	0.00	0.0	0.000	0.00	0.0	0.000
20.00	1.55	51.4	10.508	1.40	46.4	9.987	1.00	33.1	8.440
43.00	1.60	53.0	10.676	1.50	49.7	10.337	1.30	43.1	9.623
60.00	1.30	43.1	9.623	1.25	41.4	9.436	1.10	36.5	8.852
80.00	1.10	36.5	8.852	1.05	34.8	8.649	0.90	29.8	8.007
100.00	1.00	33.1	8.440	0.72	23.9	7.162	0.70	23.2	7.062
128.00	0.95	31.5	8.226	0.54	17.9	6.202	0.55	18.2	6.259
140.00	0.90	29.8	8.007	0.52	17.2	6.086	0.55	18.2	6.259
160.00	0.90	29.8	8.007	0.40	13.3	5.338	0.35	11.6	4.993
180.00	0.80	26.5	7.549	0.40	13.3	5.338	0.30	9.9	4.623
214.00	0.63	20.9	6.699	0.34	11.3	4.921	0.45	14.9	5.662
235.00	0.45	14.9	5.662	0.40	13.3	5.338	0.40	13.3	5.338
FW	0.00	0.0	0.000	0.00	0.0	0.000	0.10	3.3	2.669

SQUARE DUCT APPROXIMATIONS

Duct Dimensions 8.386 m/s (mean A) 7.163 m/s (mean B)
Width 100.79 ins 6.829 m/s (mean C)
Depth 102.36 ins
Area 71.645 sq.ft
6.656 m2

	Volume Flow	Volume Flow at 6 % Oxygen	Mass Flow (as measured)
Actual	178736 m3/h	155990 m3/h	
Standard (0 dgC 1 atm)	127509 m3/h	111283 m3/h	166311 kg/h
Standard (dry)	116697 m3/h	101846 m3/h	157629 kg/h


Almaty No. 3
Test 2 Right Hand Side
11
10
9
8
7
6
5
4
velocity,(m/s)
20
40
60
80
100
120
140
160
180
200
220
240
position in duct,(cm)
A
B
C

APPENDIX 6 DISPERSION MODEL EMISSIONS INPUTS

Table A6.1 Almaty No 1 Power Plant

Boiler No.	Chimney No.	Chimney Ht. (m)	Chimney Dia. (m)	Temperature (K)	Flowrate (m^3/min)	SO_2 Emission Rate (g/s)	NO_x Emission Rate (g/s)	TSP Emission Rate (g/s)
7	1	45	3	348	2905	45	17	63
8, 9, 10	2	80	4.3	348	18595	287	109	400
11, 12, 13	2	80	4.3	348	18595	287	109	400

Table A6.2 Almaty No 2 Power Plant

Boiler No.	Chimney No.	Chimney Ht. (m)	Chimney Dia. (m)	Temperature (K)	Flowrate (m^3/min)	SO_2 Emission Rate (g/s)	NO_x Emission Rate (g/s)	TSP Emission Rate (g/s)
1,2,3,4	1	129	6.0	345	55933	702	397	996
5,6,7	2	129	6.6	345	41950	527	298	747

Table A6.3 Almaty Power Plant GRES

Boiler No.	Chimney No.	Chimney Ht. (m)	Chimney Dia. (m)	Temperature (K)	Flowrate (m^3/min)	SO_2 Emission Rate (g/s)	NO_x Emission Rate (g/s)	TSP Emission Rate (g/s)
1	1	60	4.0	358	5760	97	30	213
2,3,4,5,6	2	100	5.1	358	28800	483	150	1063

Table A6.4 District Heating Plant No 1

Boiler No.	Chimney No.	Chimney Ht. (m)	Chimney Dia. (m)	Temperature (K)	Flowrate (m^3/min)	SO_2 Emission Rate (g/s)	NO_x Emission Rate (g/s)	TSP Emission Rate (g/s)
1 - 3	1	45	2.6	463	5370	133	47	-
4 - 7	2	80	4.2	463	15294	378	135	-
8 - 13	3	80	4.2	463	20406	505	180	-

Table A6.5 District Heating Plant No 2

Boiler No.	Chimney No.	Chimney Ht. (m)	Chimney Dia. (m)	Temperature (K)	Flowrate (m^3/min)	SO_2 Emission Rate (g/s)	NO_x Emission Rate (g/s)	TSP Emission Rate (g/s)
1 - 6	1	96	4.2	448	18216	197	109	-

Table A6.6 District Heating Plant No 3

Boiler No.	Chimney No.	Chimney Ht. (m)	Chimney Dia. (m)	Temperature (K)	Flowrate (m^3/min)	SO_2 Emission Rate (g/s)	NO_x Emission Rate (g/s)	TSP Emission Rate (g/s)
1 - 3	1	45	2.5	453	3924	56	20	-
4 - 7	2	30	1.5	453	1231	18	6	-
8 - 10	3	43	2.2	453	1495	21	8	-

Table A6.7 Replace Boilers 7 & 8 at No 1 with CFBC

Boiler No.	Chimney No.	Chimney Ht. (m)	Chimney Dia. (m)	Temperature (K)	Flowrate (m^3/min)	SO_2 Emission Rate (g/s)	NO_x Emission Rate (g/s)	TSP Emission Rate (g/s)
New CFBC	1	90	4.3	450	14756	23	43	18
9, 10	2	80	4.3	358	12400	191	73	261
11 - 13	3	80	4.3	358	18600	287	109	391

Table A6.8 Replace Boilers 7 & 8 at No 1 with PF + Injection

Boiler No.	Chimney No.	Chimney Ht. (m)	Chimney Dia. (m)	Temperature (K)	Flowrate (m^3/min)	SO_2 Emission Rate (g/s)	NO_x Emission Rate (g/s)	TSP Emission Rate (g/s)
New PF	1	90	4.3	450	14756	114	86	18
9, 10	2	80	4.3	358	12400	191	73	261
11 - 13	3	80	4.3	358	18600	287	109	391

Table A6.9 Replace All Boilers at No 1 with CFBC

Boiler No.	Chimney No.	Chimney Ht. (m)	Chimney Dia. (m)	Temperature (K)	Flowrate (m^3/min)	SO_2 Emission Rate (g/s)	NO_x Emission Rate (g/s)	TSP Emission Rate (g/s)
New CFBC	1	90	5	450	19375	30	57	24
New CFBC	2	90	5	450	19375	30	57	24

Table A6.10 Replace All Boilers at No 1 with PF + Injection

Boiler No.	Chimney No.	Chimney Ht. (m)	Chimney Dia. (m)	Temperature (K)	Flowrate (m^3/min)	SO_2 Emission Rate (g/s)	NO_x Emission Rate (g/s)	TSP Emission Rate (g/s)
New PF	1	90	5	450	19375	149	113	24
New PF	2	90	5	450	19375	149	113	24

Table A6.11 Close No 1, Install Equivalent PF + Injection at Nos 2 & 3

Boiler No.	Chimney No.	Chimney Ht. (m)	Chimney Dia. (m)	Temperature (K)	Flowrate (m^3/min)	SO_2 Emission Rate (g/s)	NO_x Emission Rate (g/s)	TSP Emission Rate (g/s)
1 - 4	1	129	6	345	55933	702	398	996
5 - 7	2	129	6.6	345	41950	527	298	747
No 2	A	150	5	450	19375	149	113	24
No 3	B	150	5	450	19375	149	113	24

Table A6.12 Increase Stack Height at No 1

Boiler No.	Chimney No.	Chimney Ht. (m)	Chimney Dia. (m)	Temperature (K)	Flowrate (m^3/min)	SO_2 Emission Rate (g/s)	NO_x Emission Rate (g/s)	TSP Emission Rate (g/s)
7 - 10	1	150	4.3	450	21500	332	126	463
11 - 13	2	150	4.3	450	18595	287	109	400

Table A6.13 Convert Power Plant No 1 to Gas

Boiler No.	Chimney No.	Chimney Ht. (m)	Chimney Dia. (m)	Temperature (K)	Flowrate (m^3/min)	SO_2 Emission Rate (g/s)	NO_x Emission Rate (g/s)	TSP Emission Rate (g/s)
7 - 13	1	90	4.3	450	40106	0	109	0

APPENDIX 7 GLOSSARY OF TERMS

Glossary of Terms

ADB	Asian Development Bank
ATDM	All Terrain Dispersion Model
CEGB	Central Electricity Generating Board
CFBC	Circulating Fluidised Bed Combustor
CRE	CRE Group Ltd
mg/m^3	Milligram per cubic metre (one thousandth of a gram per cubic metre)
NO_x	Oxides of nitrogen
O_2	Oxygen
PF	Pulverised Fuel
"S" type pitot	Device for measuring flow velocity in a duct
SO_2	Sulphur dioxide
STP	Standard Temperature and Pressure (0 °C, 101.3 kPa)
TSP	Total Suspended Particulates
$\mu g/m^3$	Microgram per cubic metre (one millionth of a gram per cubic metre)