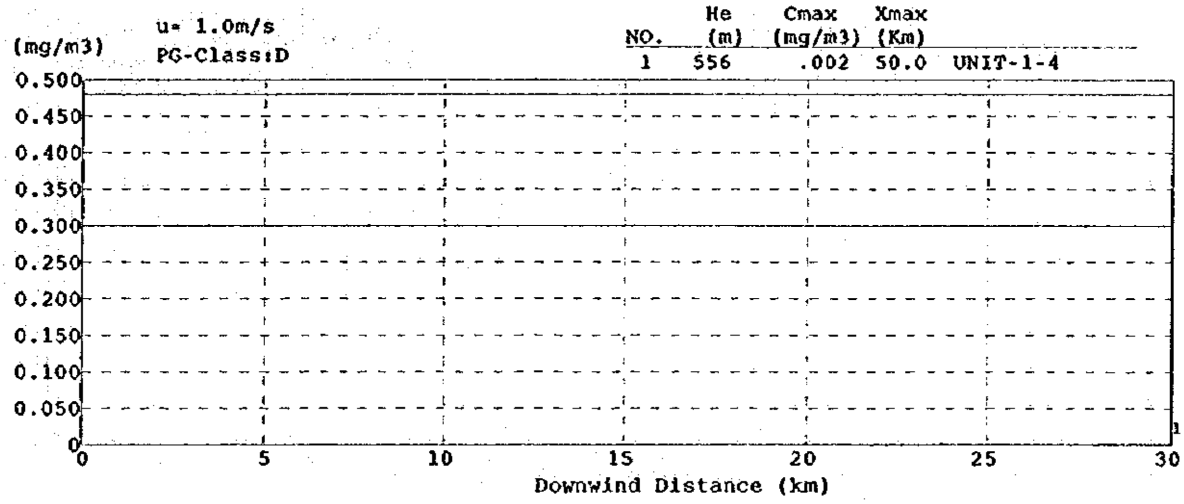
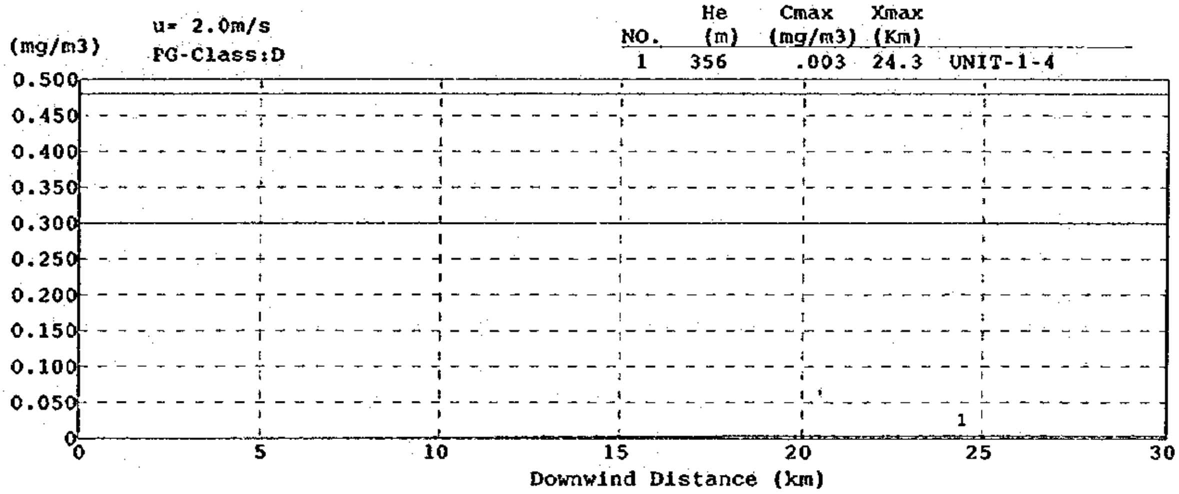
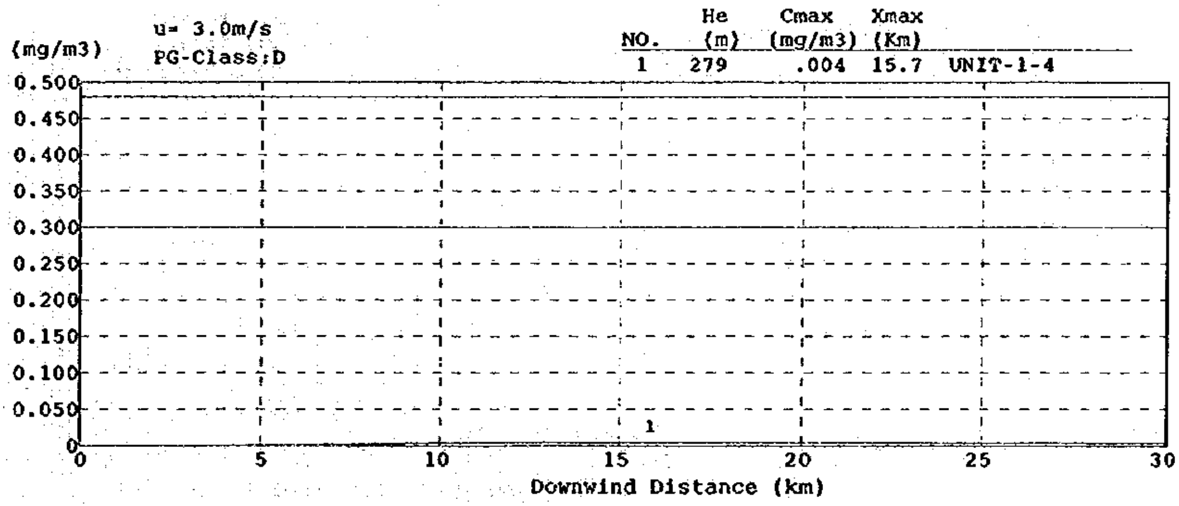
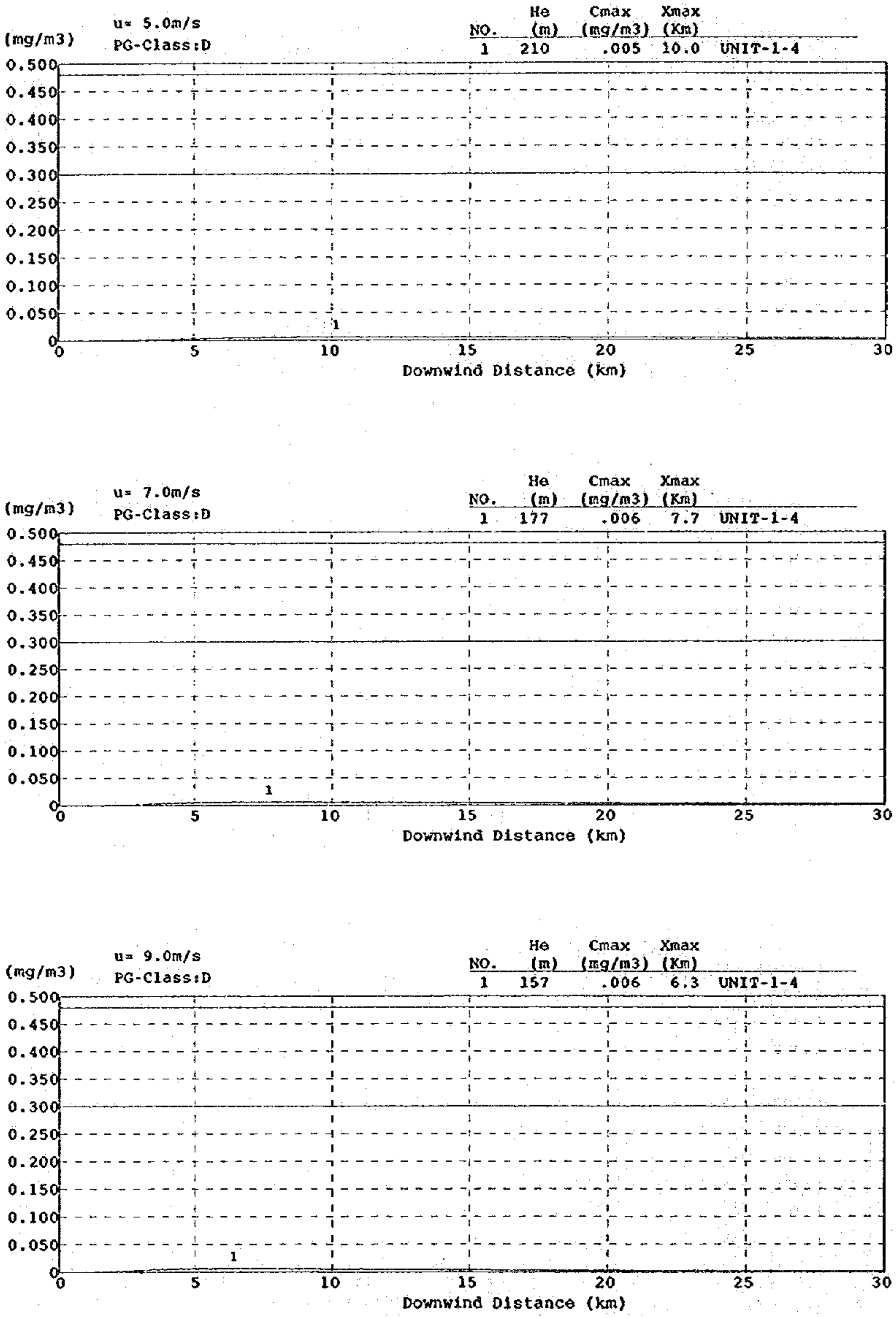






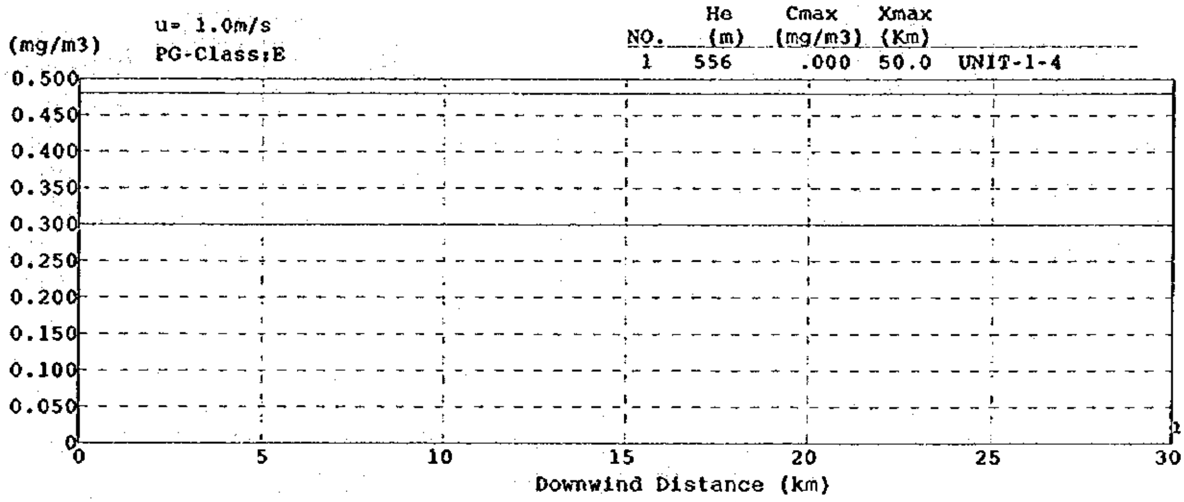
CONCAWE & Plume (Dust)

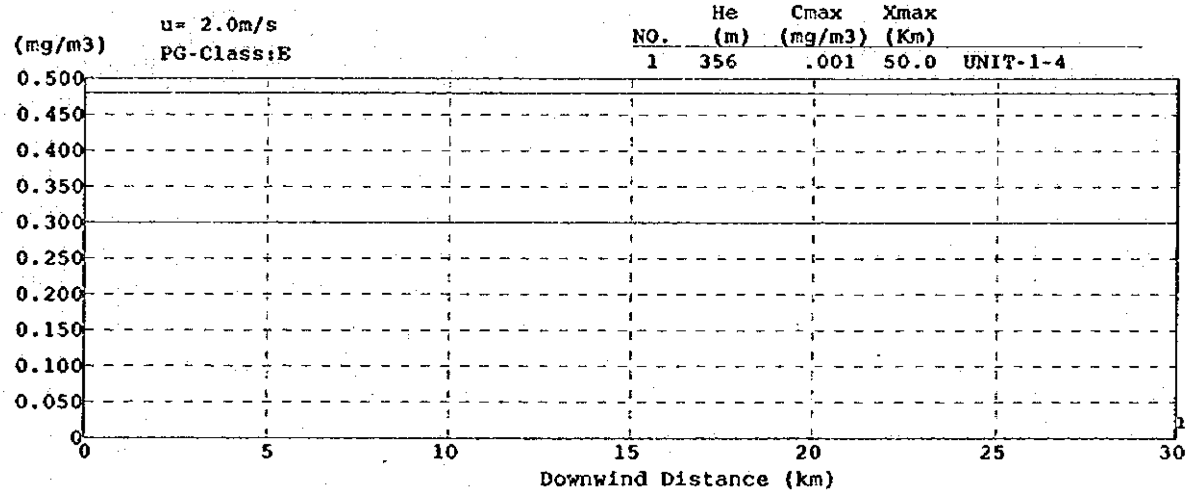
Charqueadas Power Station (Present)

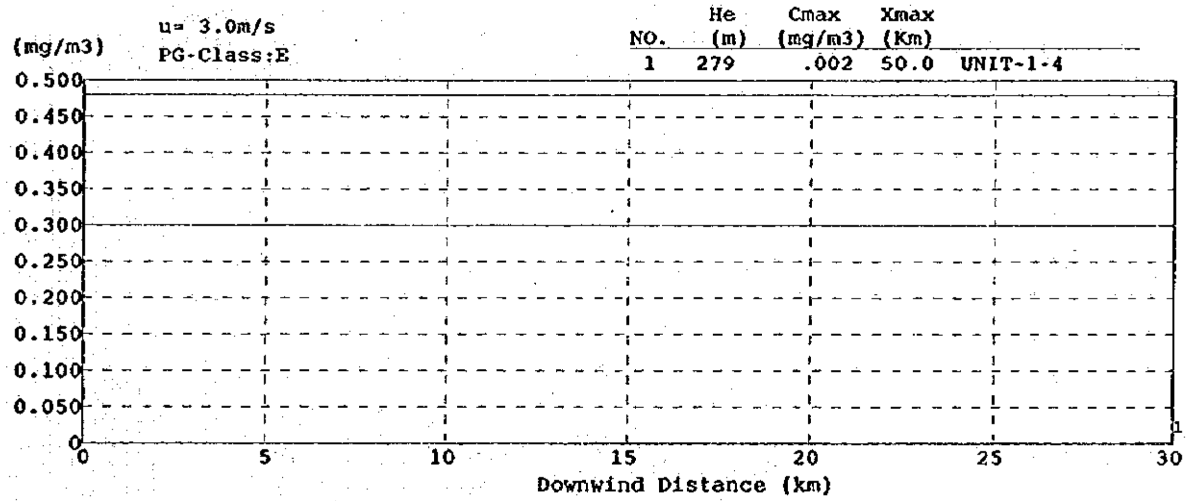


CONCAWE & Plume (Dust)

Charqueadas Power Station (Present)

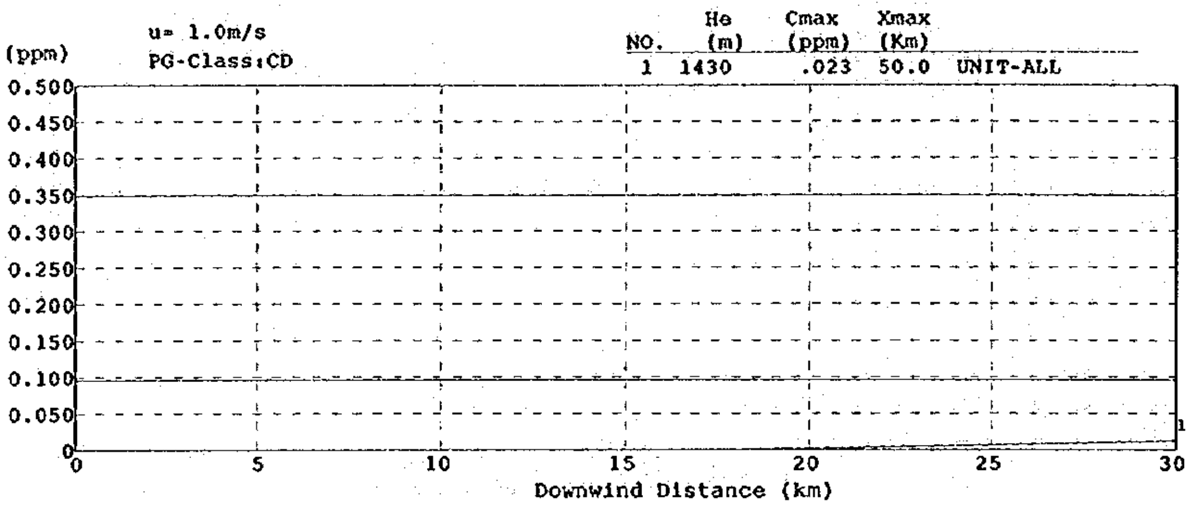


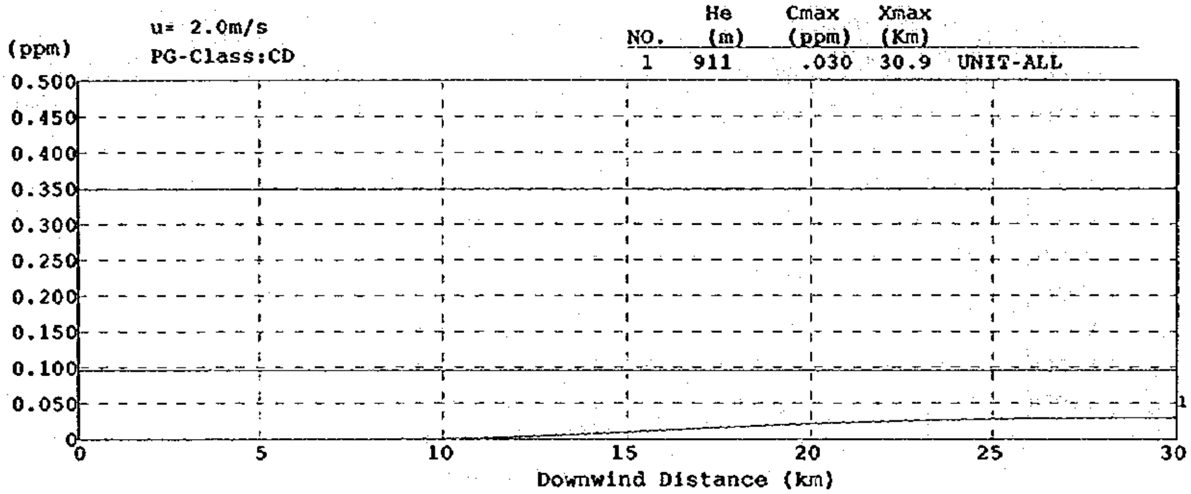


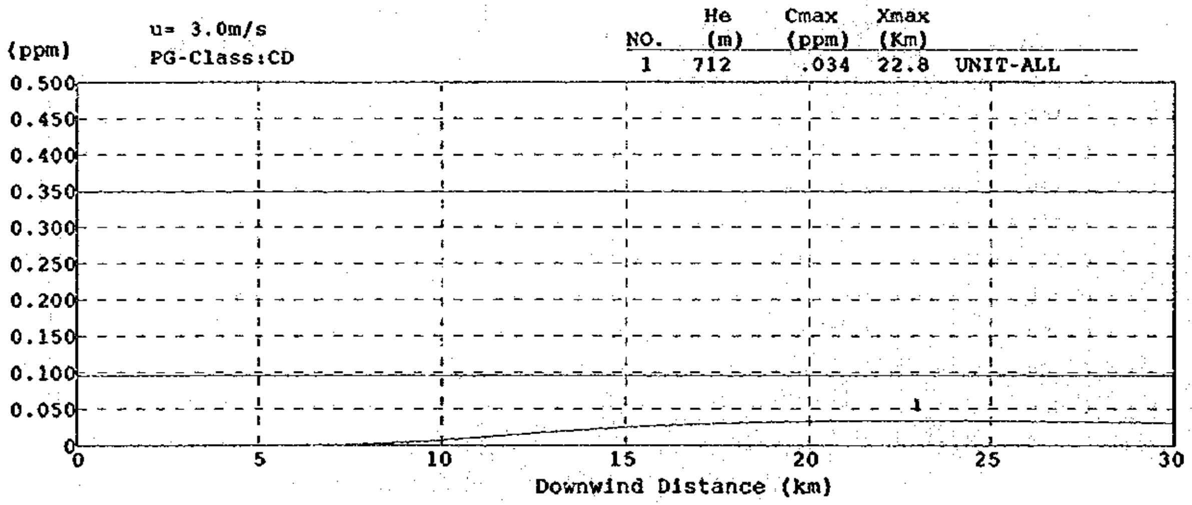


CONCAWE & Plume (Dust)

Charqueadas Power Station (Present)

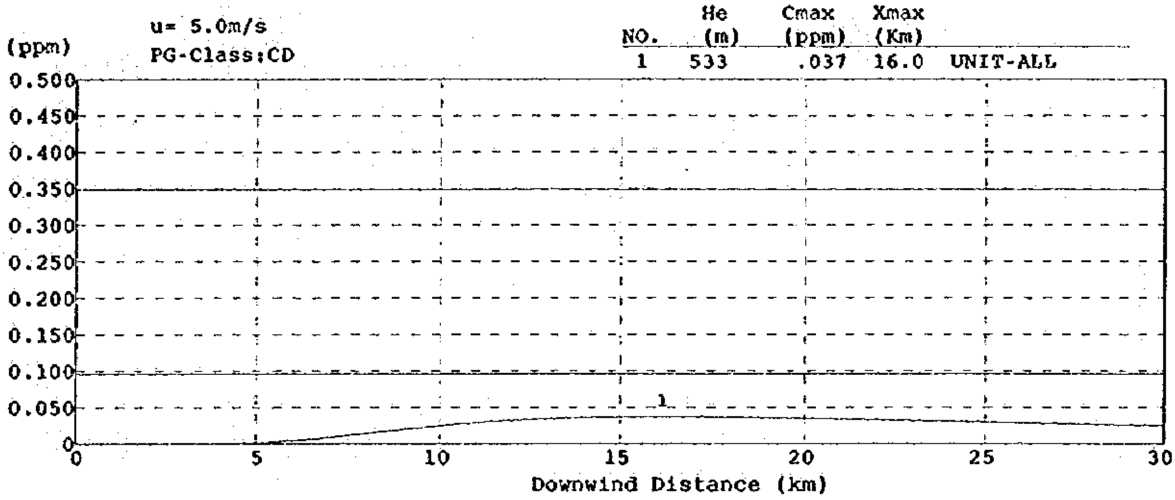


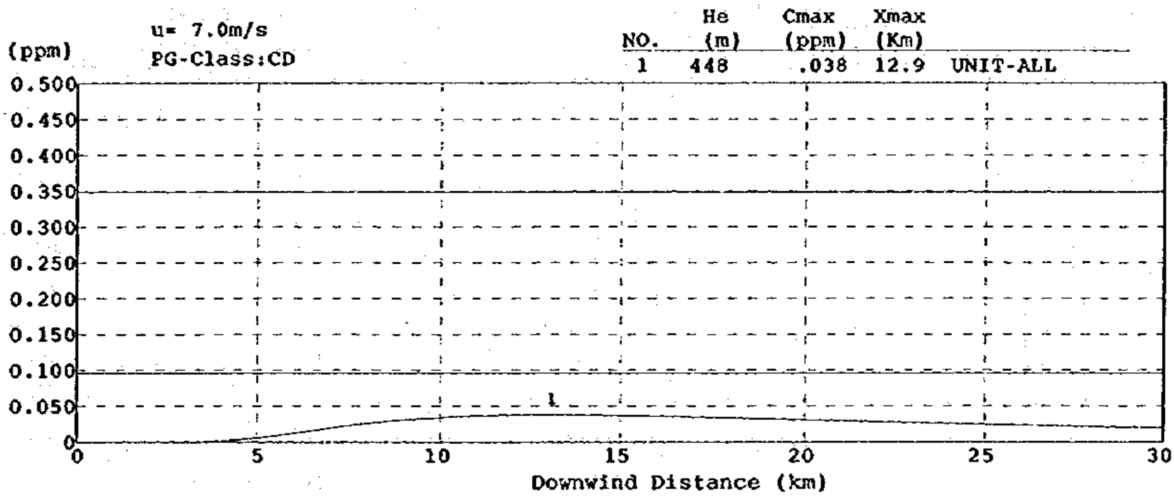


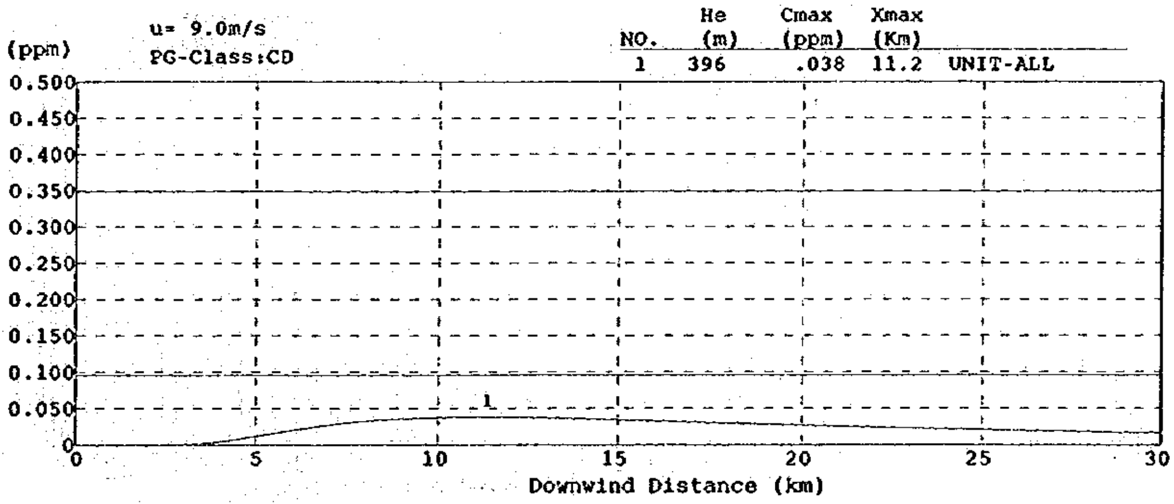


CONCAWE & Plume (SO2)

Candiota Power Station (Present)

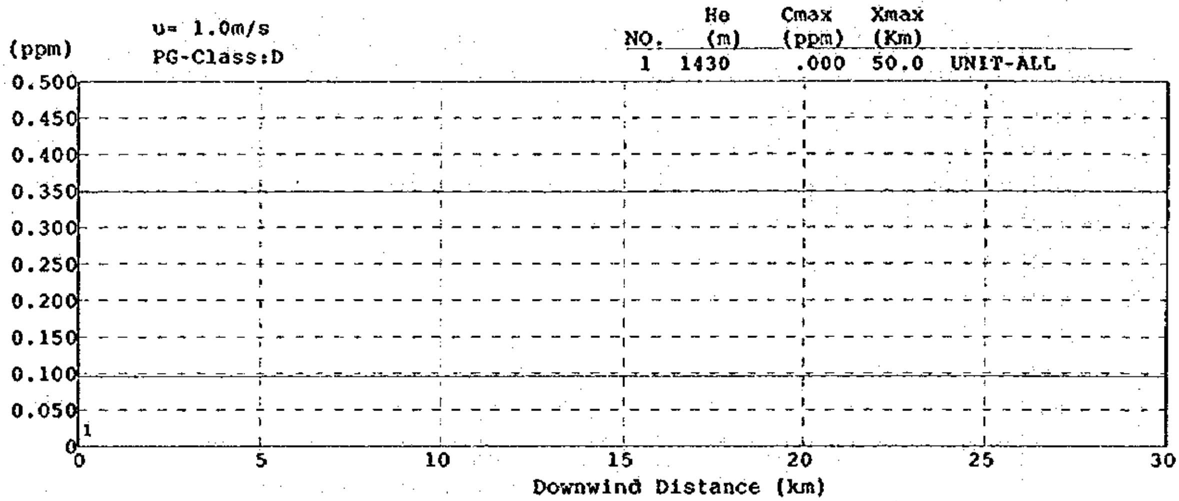


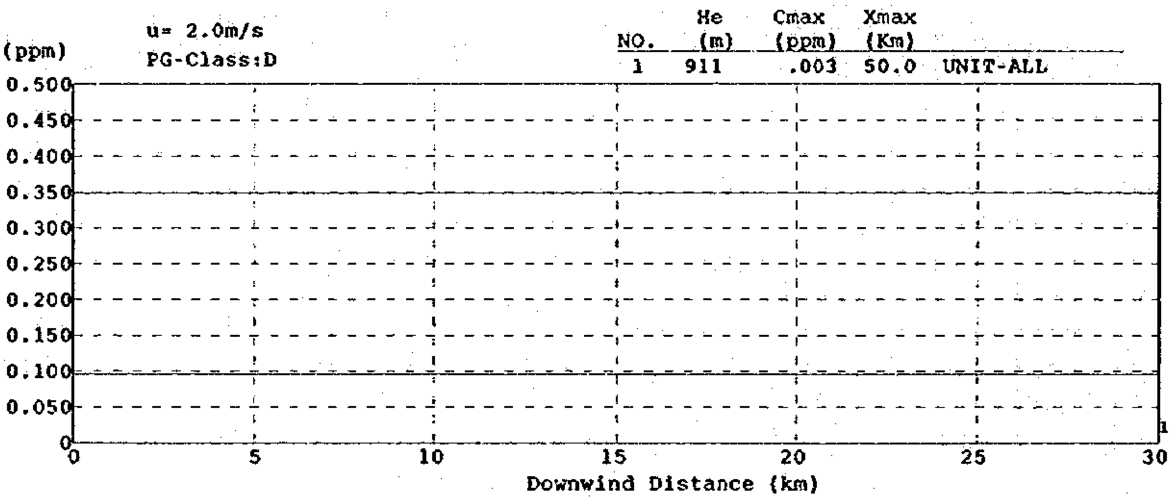


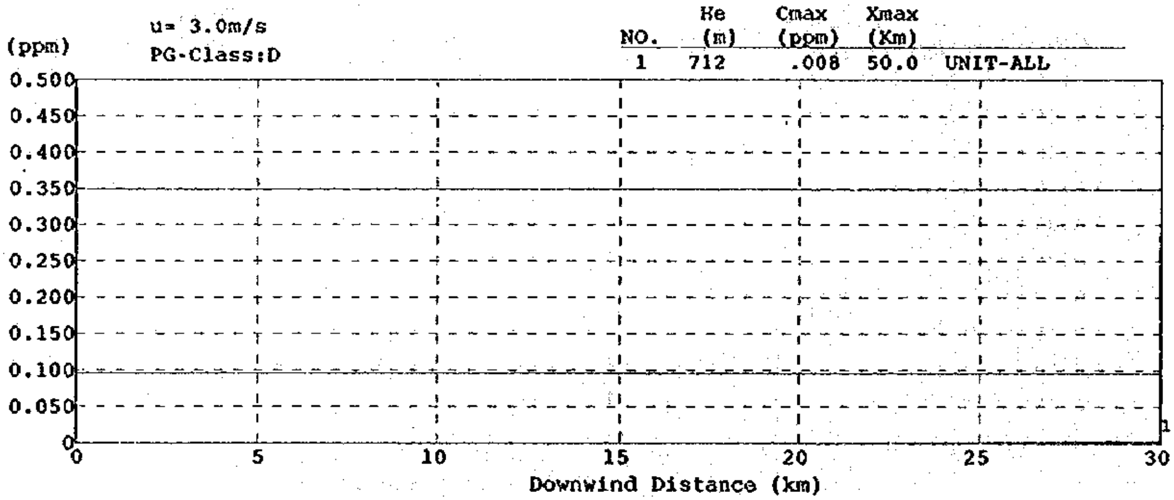


CONCAWE & Plume (SO2)

Candiota Power Station (Present)

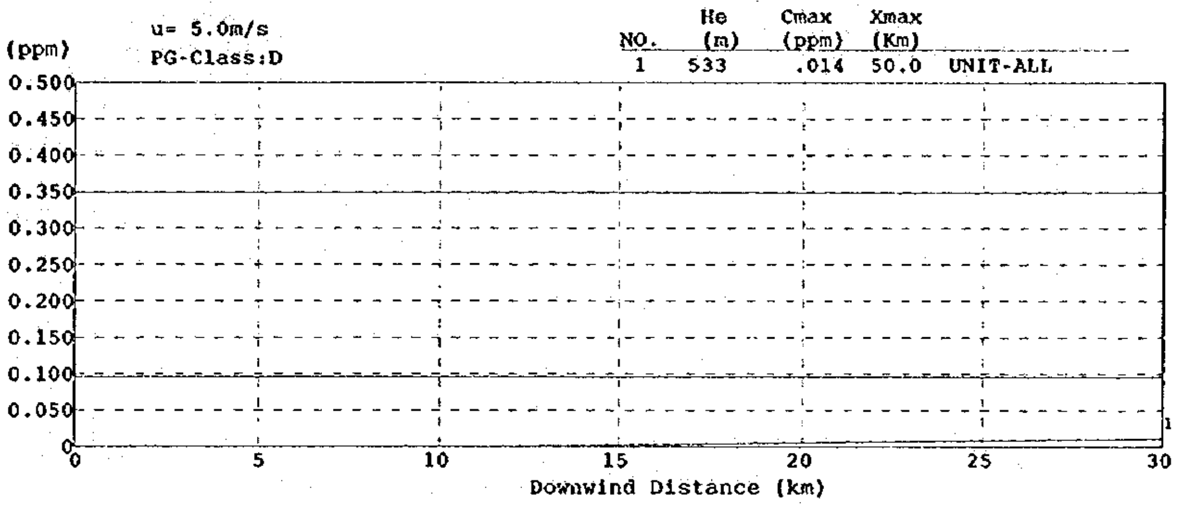


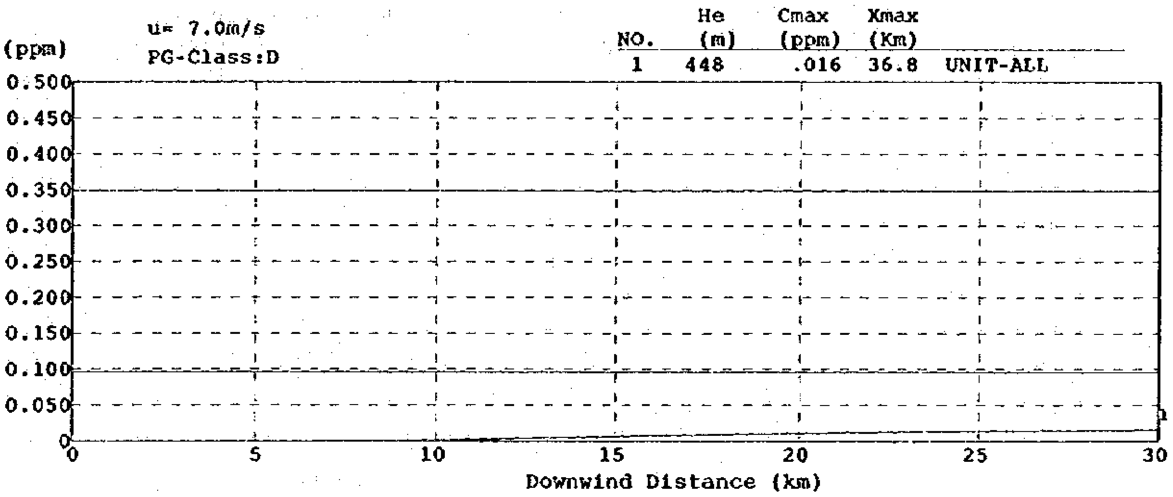


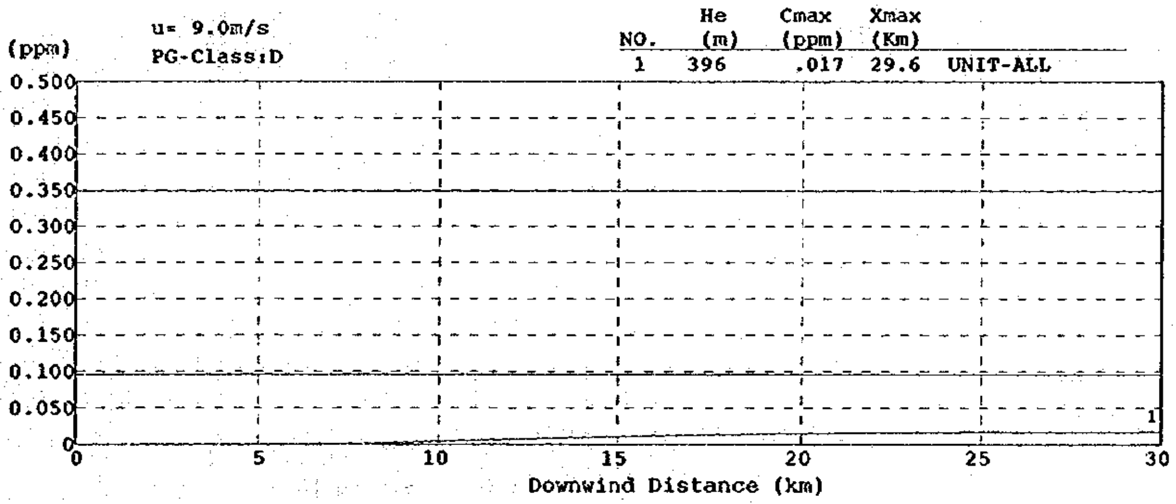


CONCAWE & Plume (SO2)

Candiota Power Station (Present)

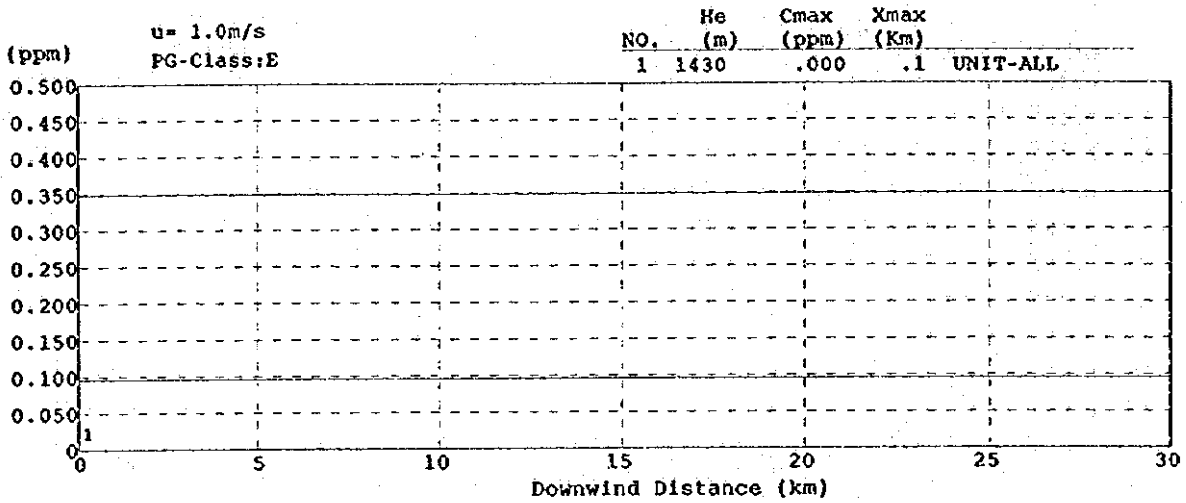


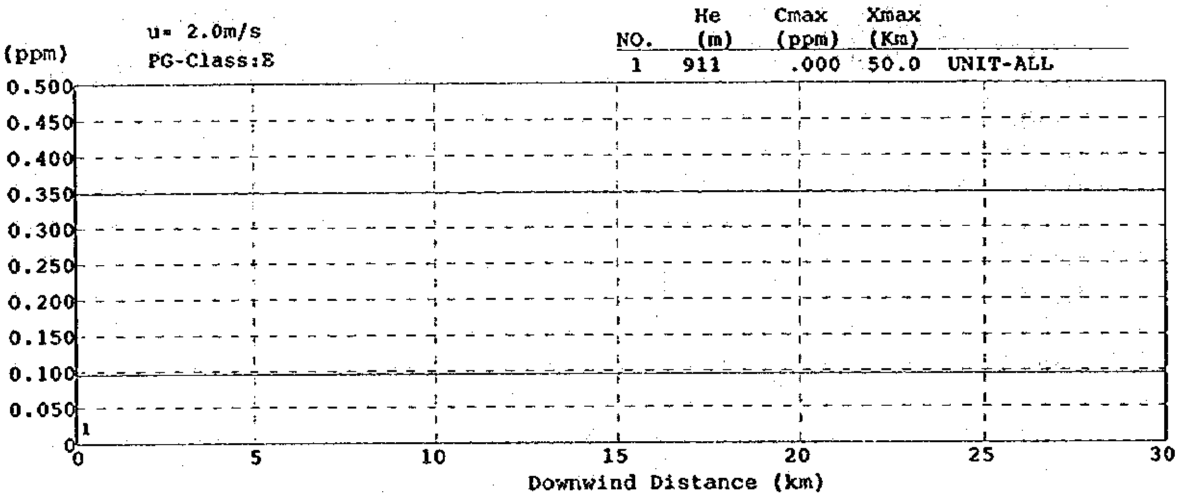


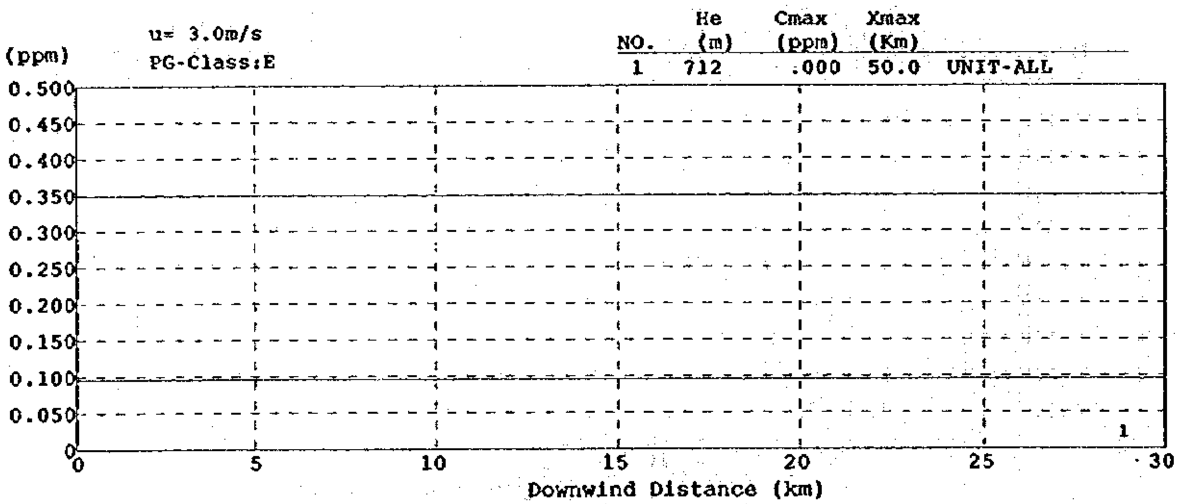


CONCAWE & Plume (SO2)

Candiota Power Station (Present)

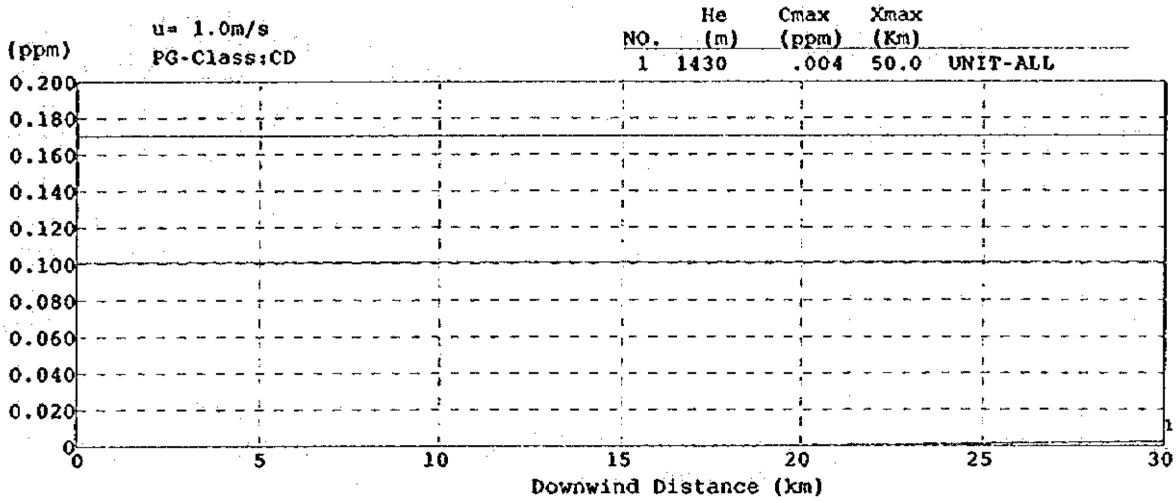


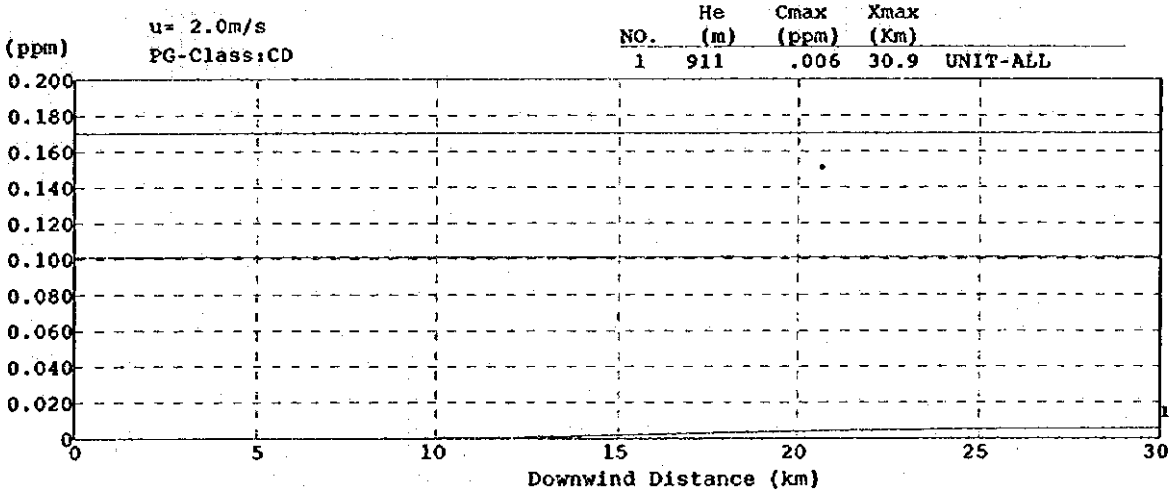


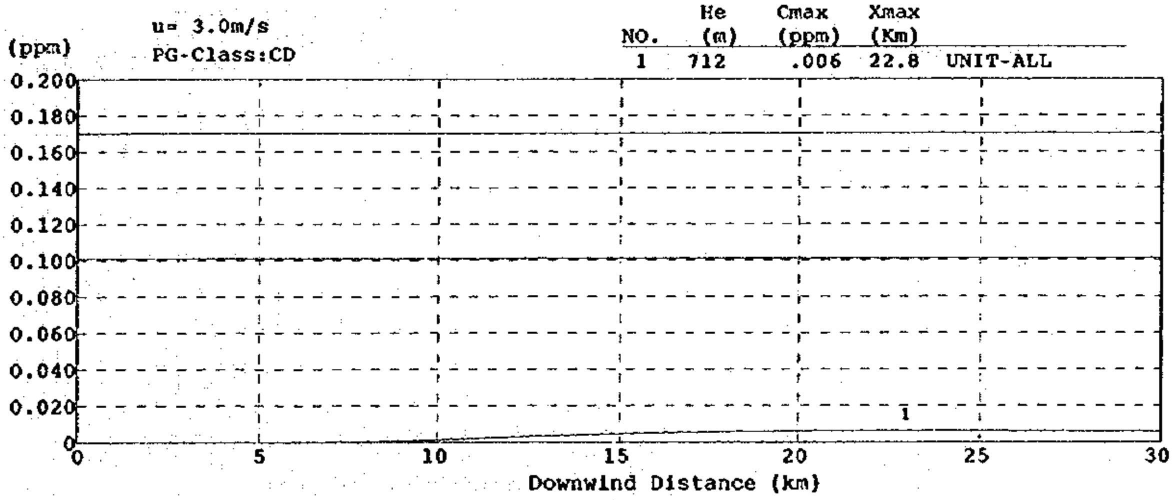


CONCAWE & Plume (SO2)

Candiota Power Station (Present)

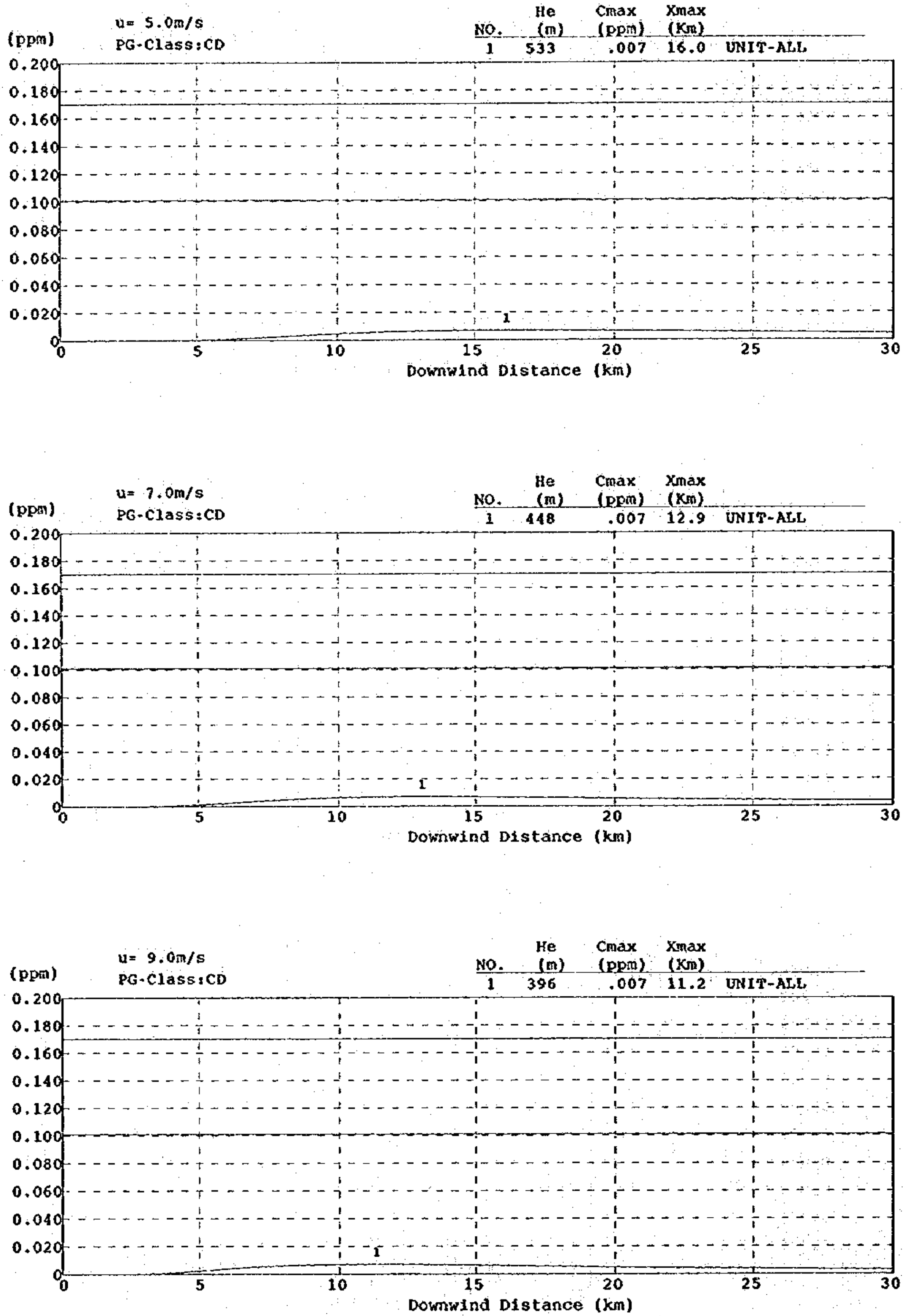






CONCAWE & Plume (NO2)

Candiota Power Station (Present)



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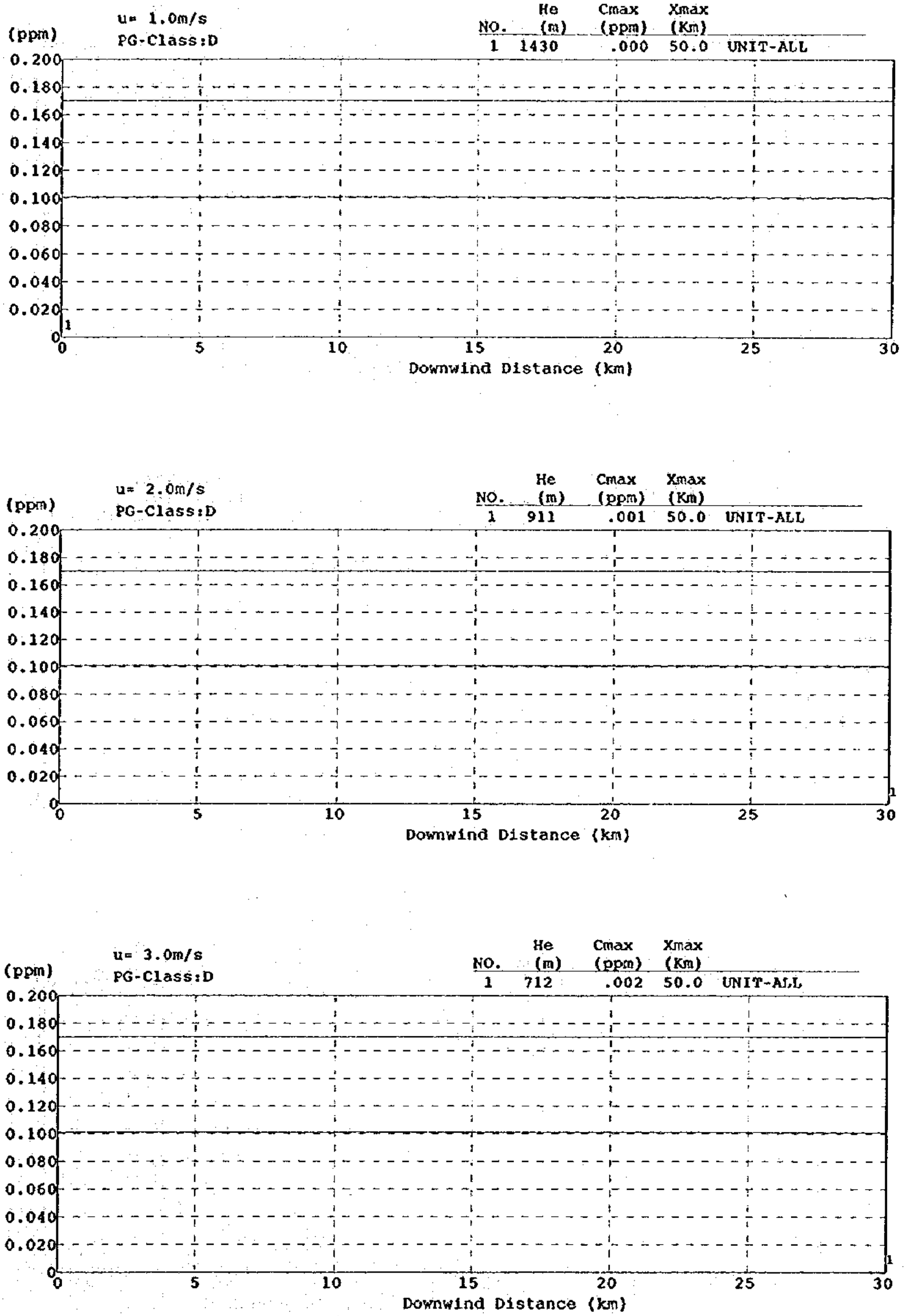
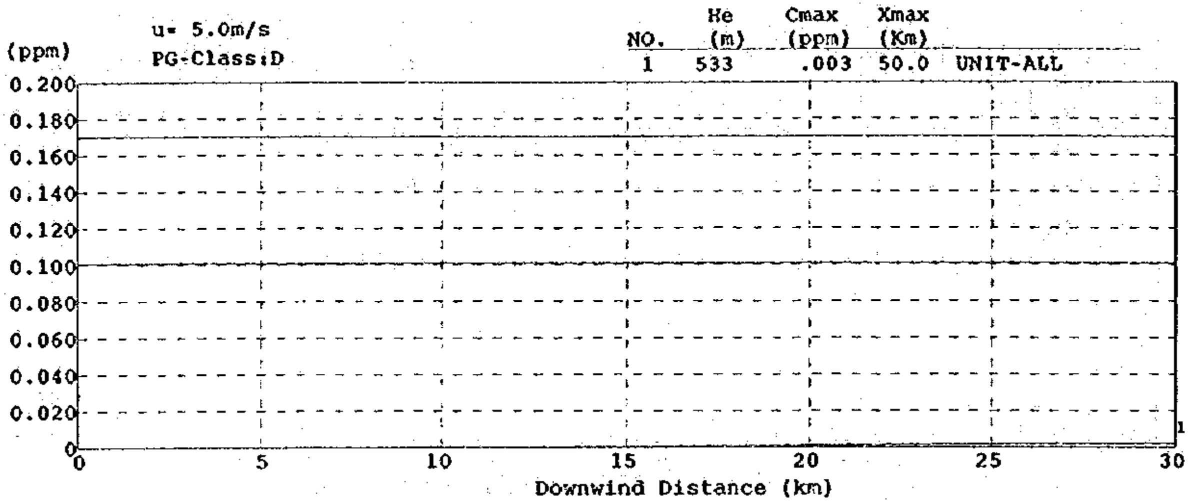
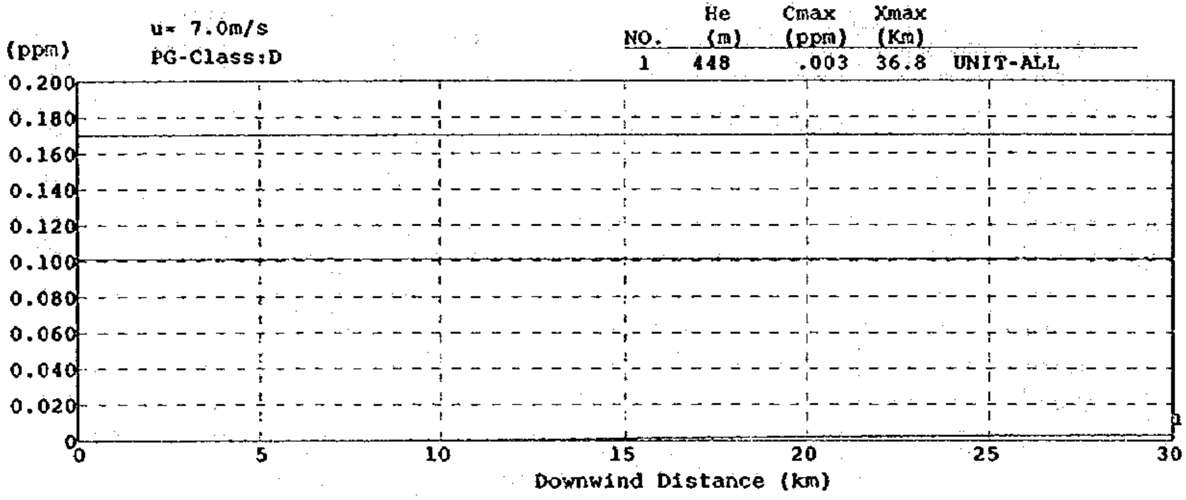
Candiota Power Station (Present)

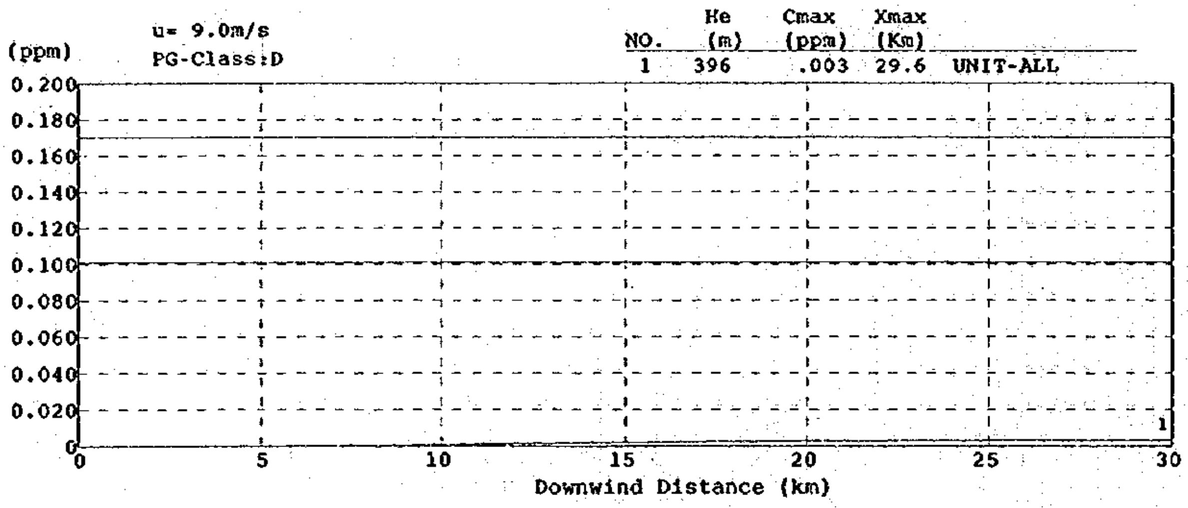


CONCAWE & Plume (NO2)

Candiota Power Station (Present)

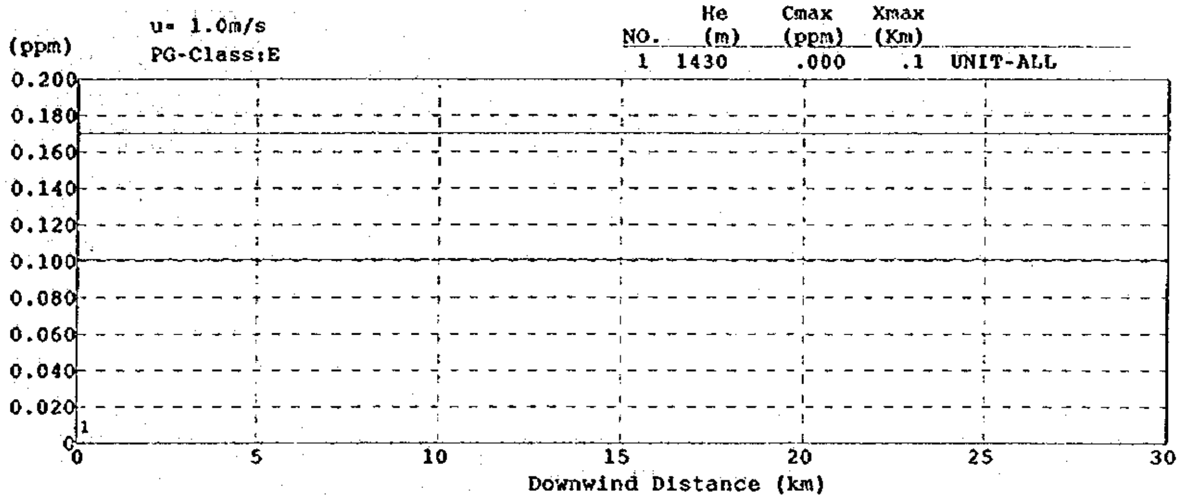


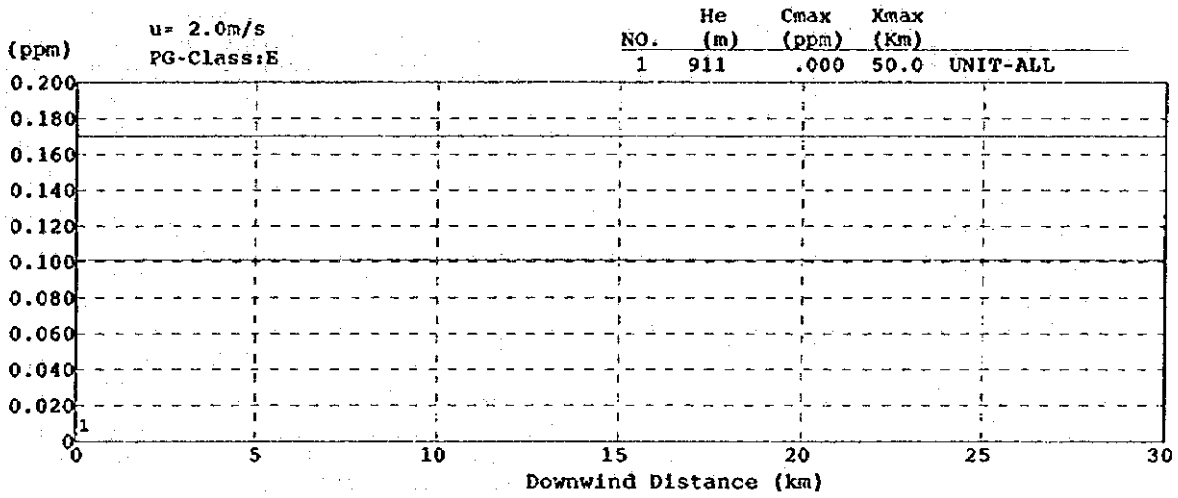


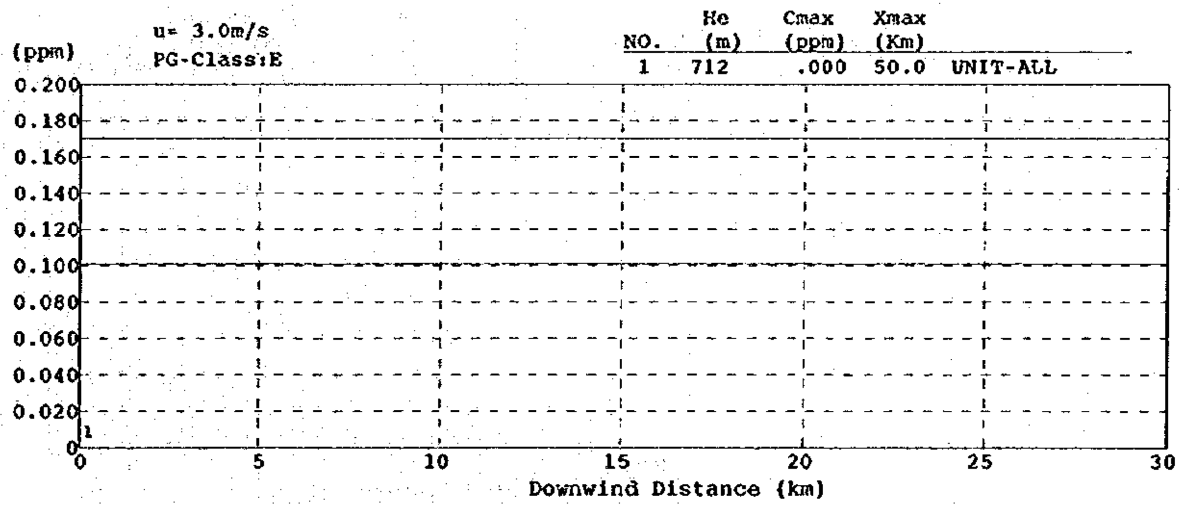


CONCAWE & Plume (NO2)

Candiota Power Station (Present)

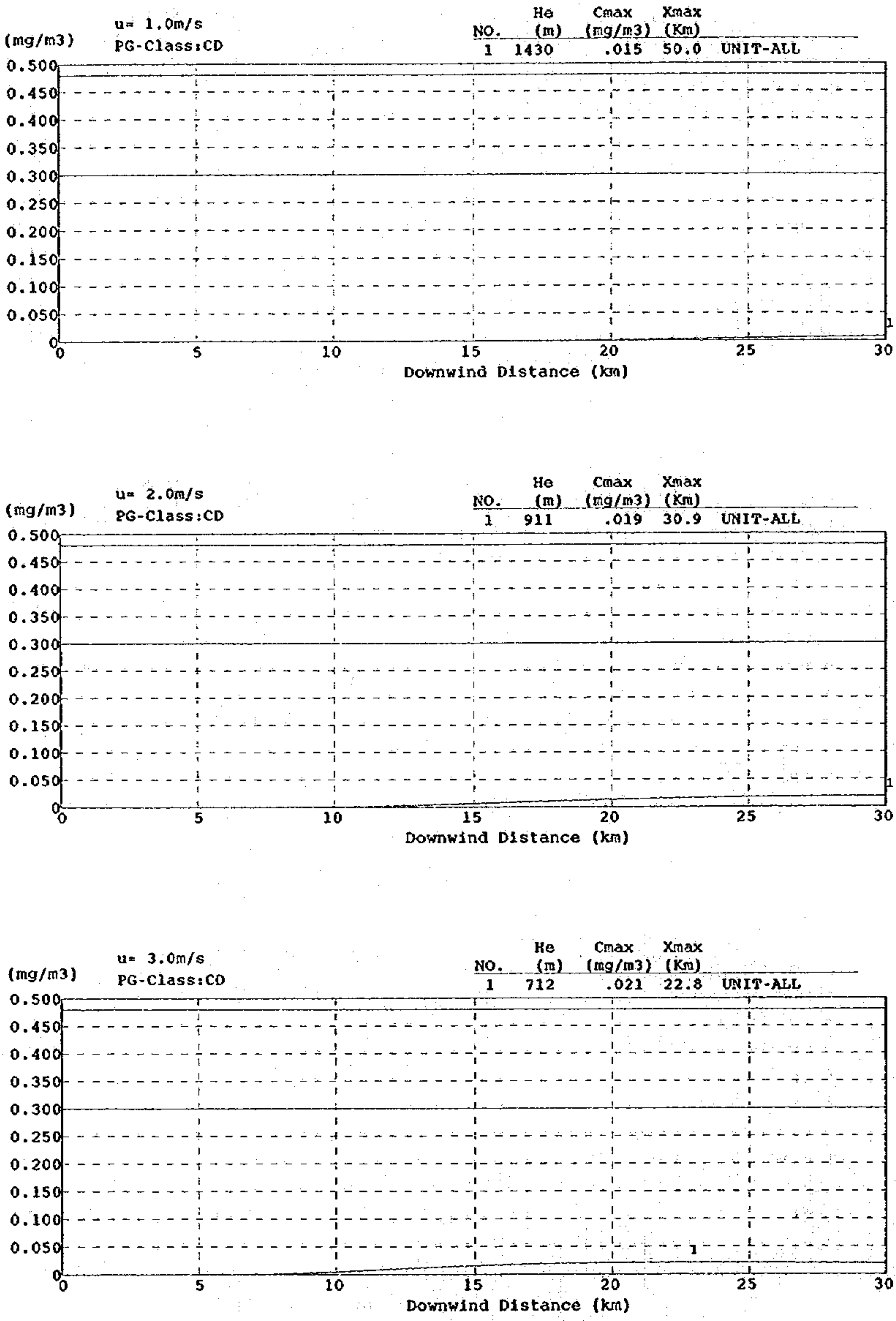






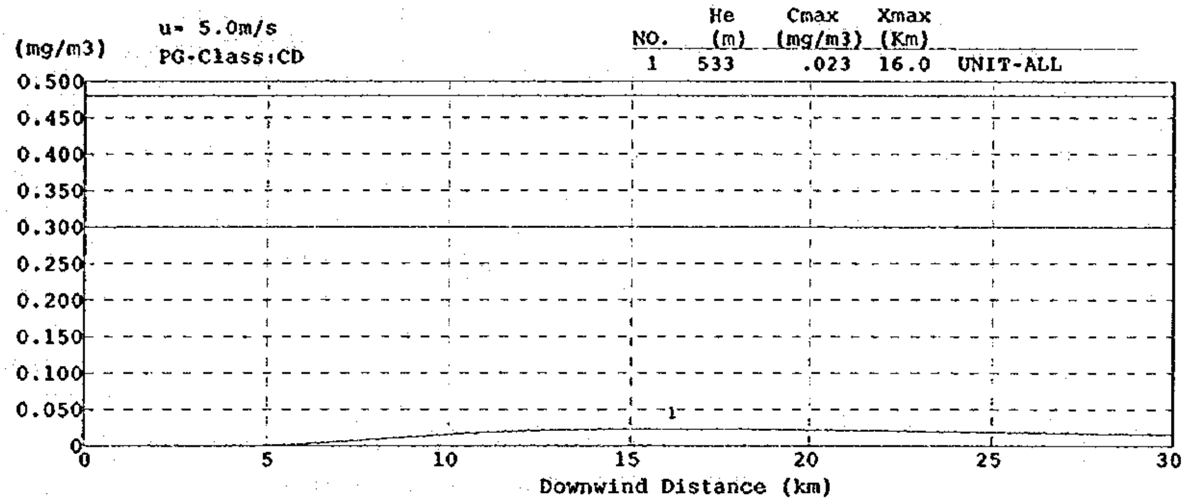
CONCAWE & Plume (NO2)

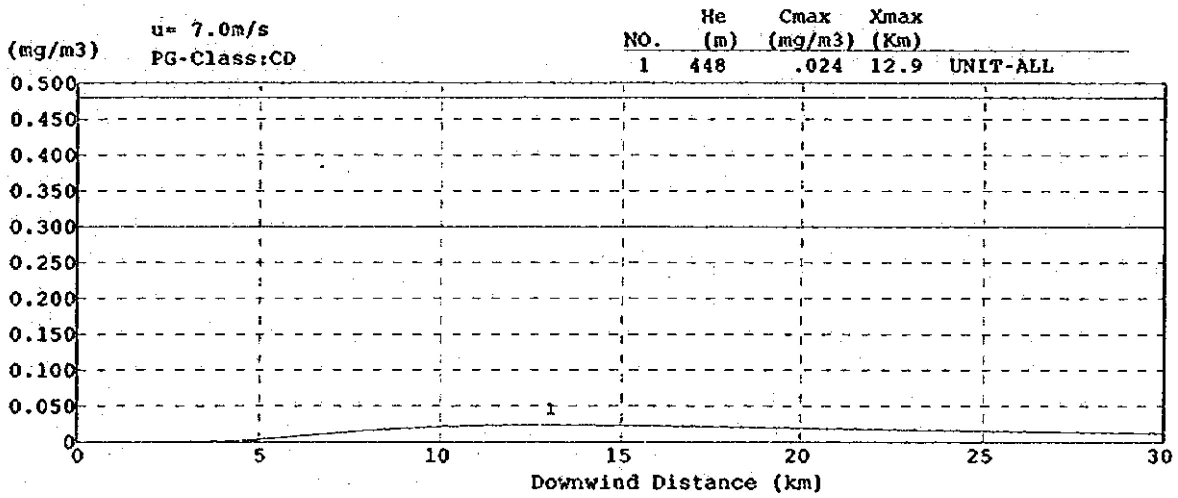
Candiota Power Station (Present)

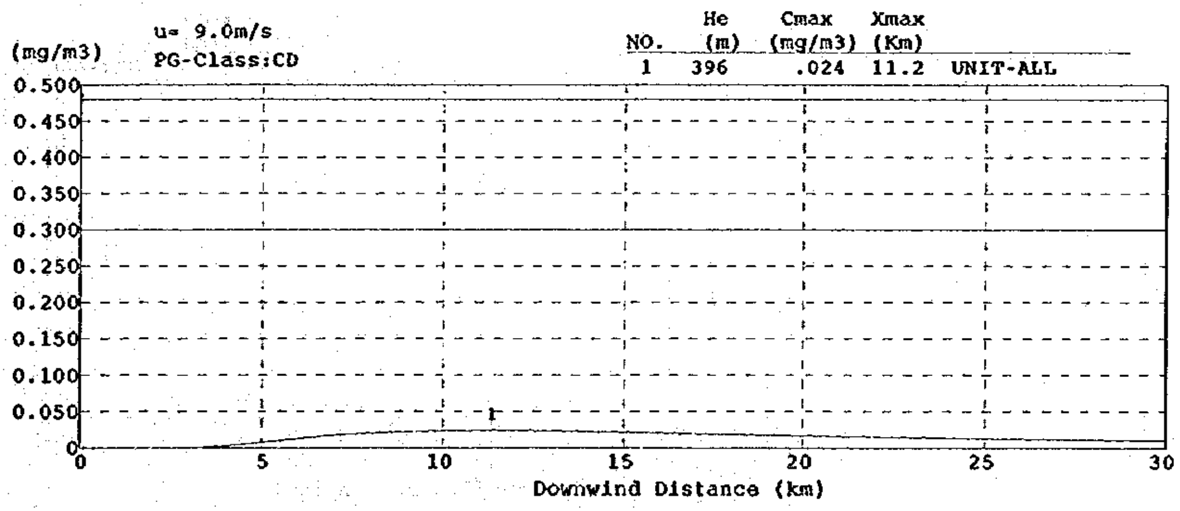


CONCAWE & Plume (Dust)

Candiota Power Station (Present)

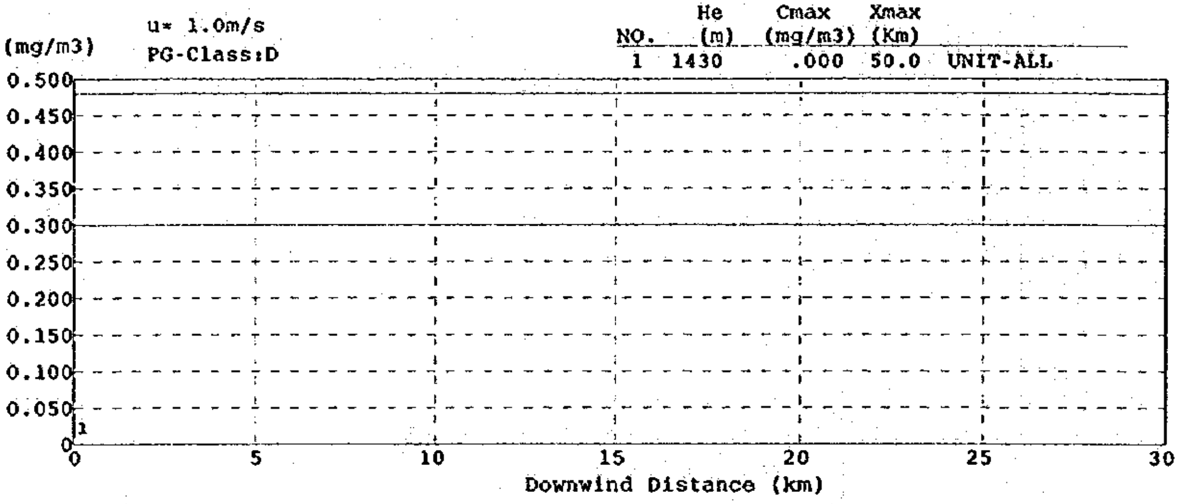


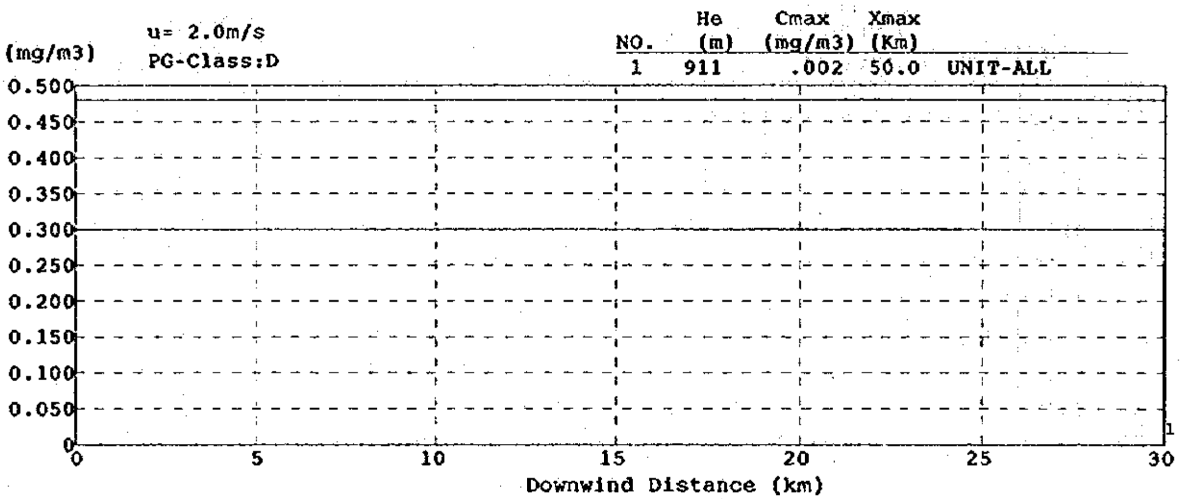


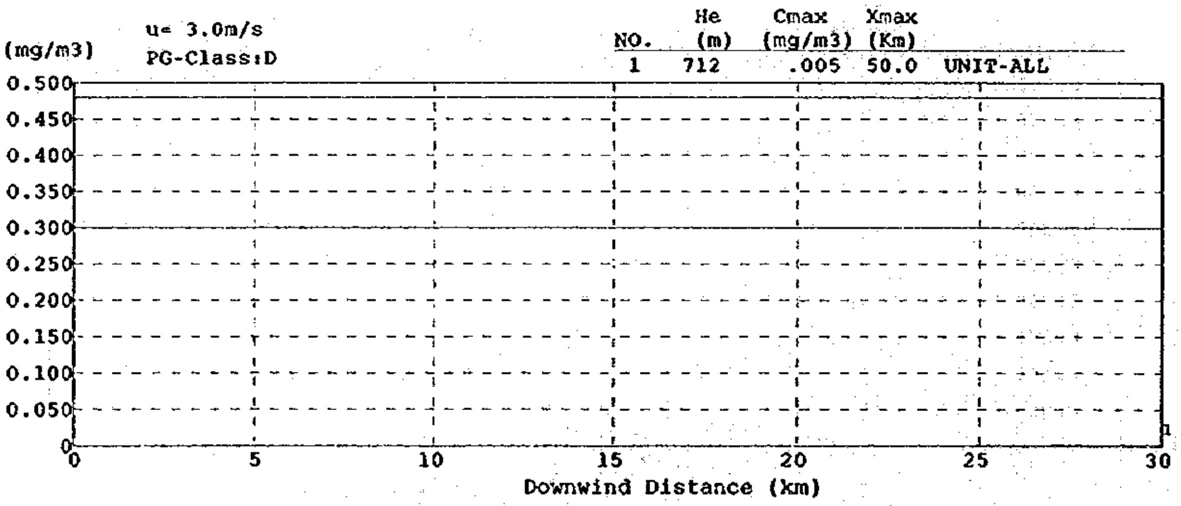


CONCAWE & Plume (Dust)

Candiota Power Station (Present)

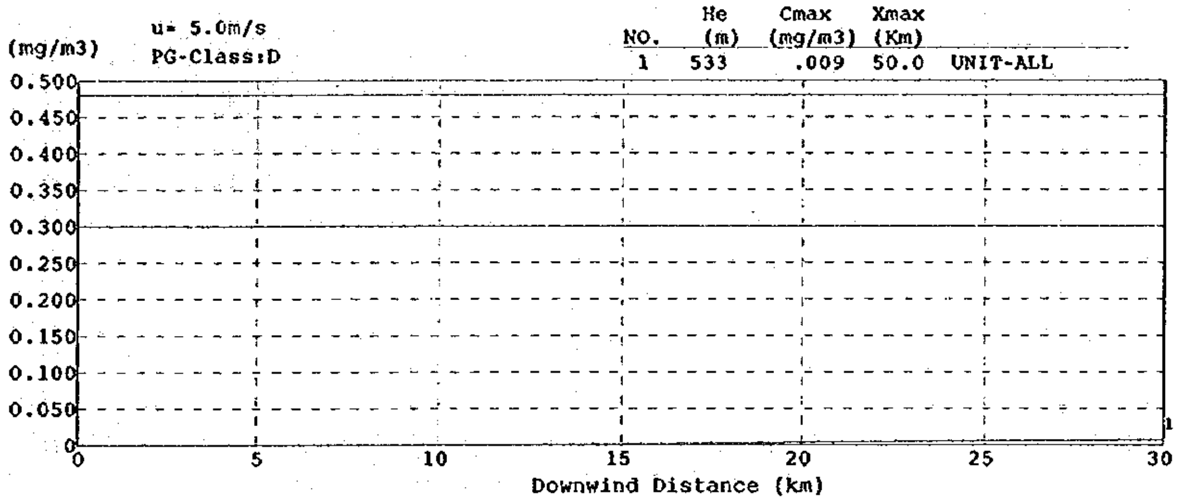


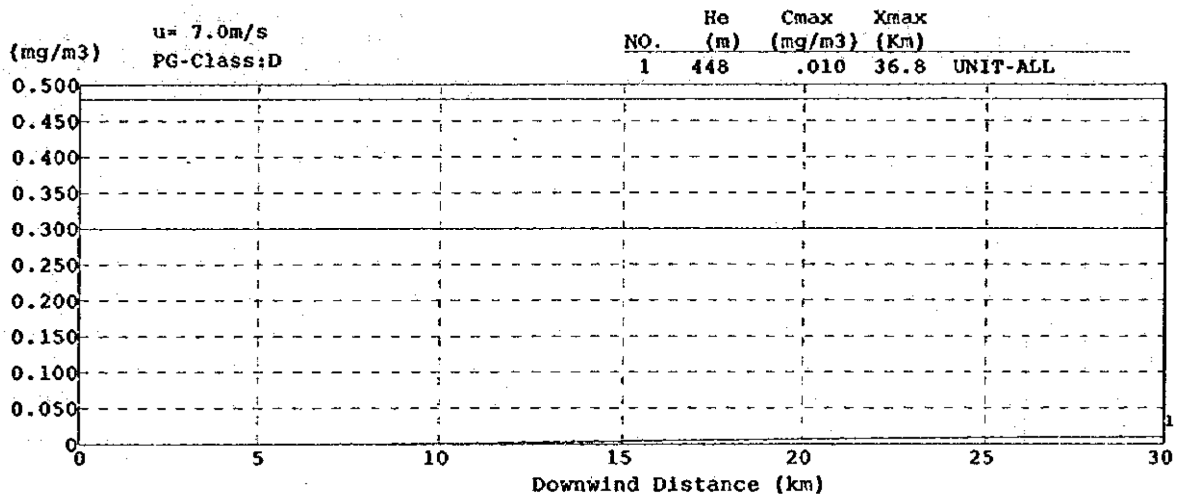


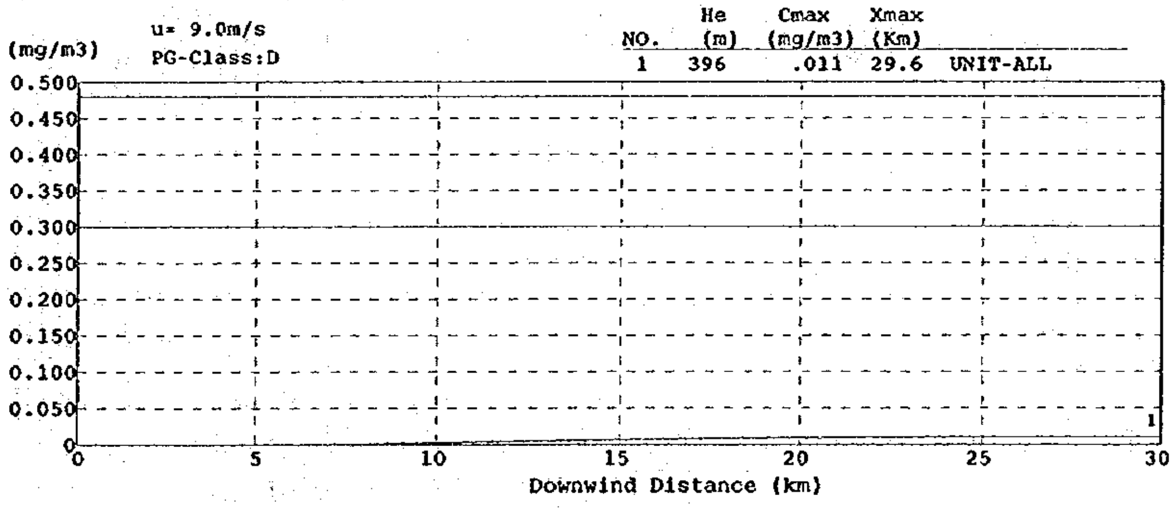


CONCAWE & Plume (Dust)

Candiota Power Station (Present)

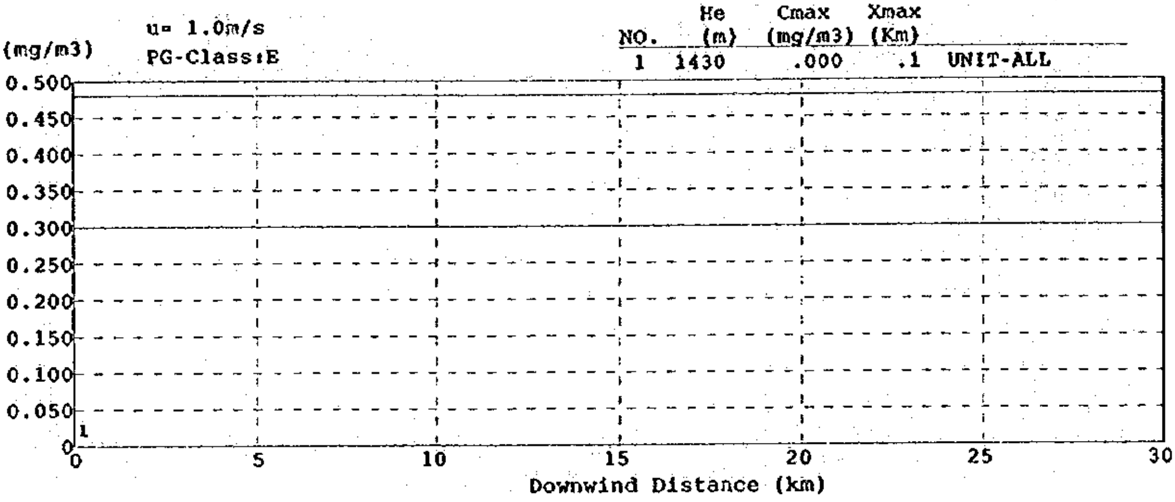




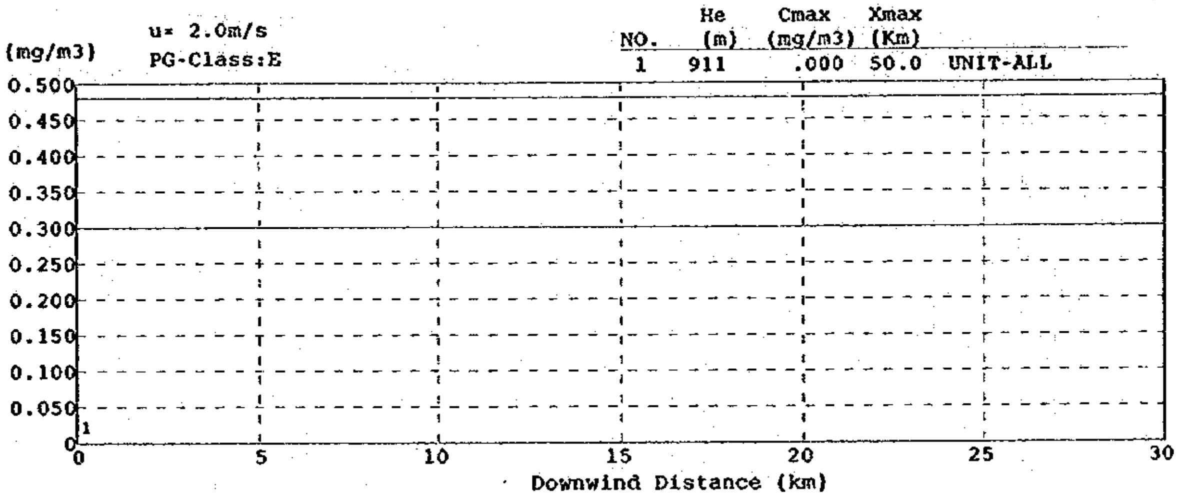


CONCAWE & Plume (Dust)

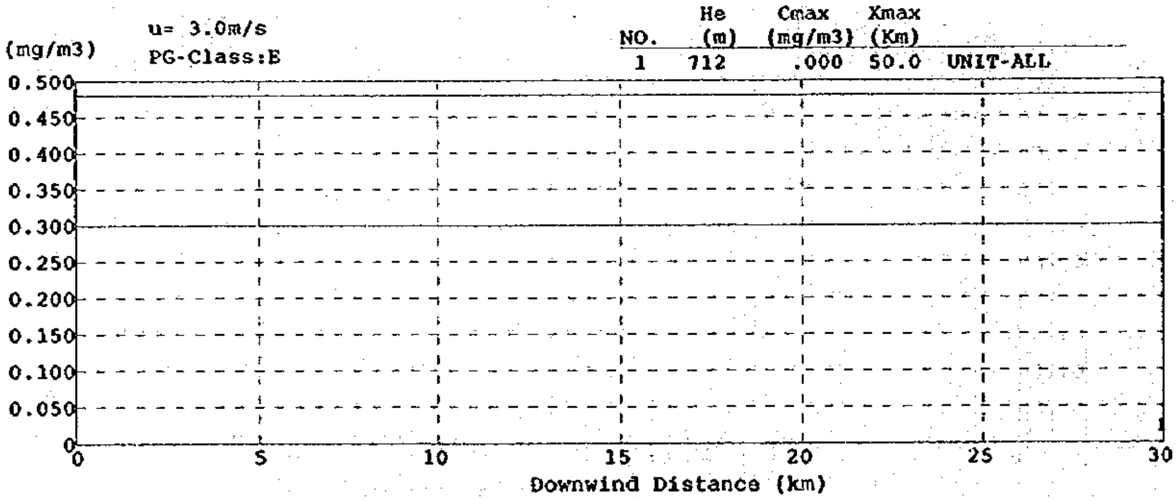
Candiota Power Station (Present)



NO.	He (m)	Cmax (mg/m3)	Xmax (Km)	
1	1430	.000	.1	UNIT-ALL



NO.	He (m)	Cmax (mg/m3)	Xmax (Km)	
1	911	.000	50.0	UNIT-ALL



NO.	He (m)	Cmax (mg/m3)	Xmax (Km)	
1	712	.000	50.0	UNIT-ALL

CONCAWE & Plume (Dust)

Candiota Power Station (Present)

Appendix 6-3 Setting of Diffusion Parameter

Diffusion parameters can be established with a reasonable adjustment to make calculated concentration agreeable with actual values in the air pollution simulation model, if data of most emission sources in the target area are available, in order to have good reproducibility of the simulation.

In the Study, other pollutant sources besides the targeted power plant(s) were out of the scope of work, and no information was tried to obtain. Typical parameters used and confirmed in Japan were adopted to simulate the impact from the power plants.

Generally, air pollution models on environmental impact assessments of power plants adopt parameters established by regional simulation conducted by local governments etc. previously.

Another project has to be originated to allow more detailed calibration. For example, the question raised at the DF/R meeting for setting up of different parameters for 62 meter stack and 150 meter stack become probable.

Appendix 7-1 Emission Parameters under the Future Condition

Emission Conditions
Charqueadas in the Future

Dust		UNIT-1	UNIT-2	UNIT-3	UNIT-4	
Dust Reg.	(mg/m3N)	80	80	80	80	
02 %	(%)	6	6	6	6	
Dust Reg.	(mg/m3N)	70.9	74.1	64.5	60.3	<=
Actual 02	(%)	7.7	7.1	8.9	9.7	

SOx		UNIT-1	UNIT-2	UNIT-3	UNIT-4	
SOx Reg.	(mg/m3N)	400	400	400	400	
02 %	(%)	6	6	6	6	
SOx Reg.	(mg/m3N)	354.7	370.7	322.7	301.3	
SOx Reg.	**(ppm)**	**124.1**	**129.7**	**112.9**	**105.5**	<=
Actual 02	(%)	7.7	7.1	8.9	9.7	

NOx		UNIT-1	UNIT-2	UNIT-3	UNIT-4
NOx Reg.	(mg/m3N)	400	400	400	400
02 %	(%)	6	6	6	6
NOx Reg.	(mg/m3N)	354.7	370.7	322.7	301.3
As NO	(ppm)	264.8	276.8	240.9	225.0
As NO2	(ppm)	172.7	180.5	157.1	146.7
Actual 02	(%)	7.7	7.1	8.9	9.7
NOx Present	(ppm)	207.7	147.8	200.3	180.4

↑ Present Values are used because they are below regulations as NO.

		UNIT-1	UNIT-2	UNIT-3	UNIT-4	Unit 1-4	
Capacity	(MW)	18.0	18.0	18.0	18.0	72.0	
Electricity	(MW)	15.5	15.4	14.3	16.1	61.2	
Gas Dry	(m3N/h)	99800.0	101200.0	108200.0	128550.0	437750.0	
Gas Wet	(m3N/h)	110450.0	111850.0	118100.0	137850.0	478250.0	Wet
Dust	(mg/m3N)	70.9	74.1	64.5	60.3		
	(Kg/h)	7.1	7.5	7.0	7.7	29.3	Dust
SOx	(ppm)	**124.1**	**129.7**	**112.9**	**105.5**		
	(m3N/h)	12.4	13.1	12.2	13.6	51.3	SOx
NOx	(ppm)	207.7	147.8	200.3	180.4		
	(m3N/h)	20.7	15.0	21.7	23.2	80.5	NOx
Temperature	(C.deg.)	188.0	181.5	179.7	169.5	100.0	
Loading Factor		0.858	0.853	0.794	0.894	0.850	
						62	

Jacui in the Future

Dust		UNIT-X	
Dust Reg.	(mg/m3N)	140	at 280 MW
02 %	(%)	6	
Dust Reg.	(mg/m3N)	**140.0**	<=
Actual O2	(%)	6.0	

SOx		UNIT-X	
SOx Reg.	(mg/m3N)	1500	
02 %	(%)	6	
SOx Reg.	(mg/m3N)	1500.0	
SOx Reg.	**(ppm)**	**525.0**	<=
Actual O2	(%)	6.0	

NOx		UNIT-X	
NOx Reg.	(mg/m3N)	680	
02 %	(%)	6	
NOx Reg.	(mg/m3N)	680.0	
As NO	**(ppm)**	**507.7**	<=
As NO2	(ppm)	331.1	
Actual O2	(%)	6.0	

		UNIT-1
Capacity	(MW)	350.0
Electricity	(MW)	350.0
Gas Dry	(m3N/h)	1130148.3
Gas Wet	(m3N/h)	1234708.0
Dust	(mg/m3N)	140.0
	(Kg/h)	158.2
SOx	(ppm)	525.0
	(m3N/h)	593.3
NOx	(ppm)	507.7
	(m3N/h)	573.8
Temperatur	(C.deg.)	100.0
Loading Factor		1.000

Candiota in the Future

Dust		UNIT-A1	UNIT-A2	UNIT-B1	UNIT-B2	UNIT-III	
Dust Reg.	(mg/m3N)	80	80	1204.0	700.0	265.0	at 280 MW
O2 %	(%)	6	6	12.2	12.3	6	
Dust Reg.	(mg/m3N)	52.8	43.7	1,204.0	700.0	265.0	<=
Actual O2	(%)	11.1	12.8	12.2	12.3	6	

SOx		UNIT-A1	UNIT-A2	UNIT-B1	UNIT-B2	UNIT-III	
SOx Reg.	(mg/m3N)	400	400	2100.0	2100	2000	
O2 %	(%)	6	6	6	6	6	
SOx Reg.	(mg/m3N)	264.0	218.7	1232.0	1218.0	2000.0	
SOx Reg.	(ppm)	92.4	76.5	431.2	426.3	700.0	<=
Actual O2	(%)	11.1	12.8	12.2	12.3	6.0	

NOx		UNIT-A1	UNIT-A2	UNIT-B1	UNIT-B2		UNIT-III	
NOx Reg.	(mg/m3N)	400	400	680	680	(ppm)	259.4	
O2 %	(%)	6	6	6	6	(%)	12.3	
NOx Reg.	(mg/m3N)	264.0	218.7	398.9	394.4	(ppm)	447.2	from Unit-B2
As NO	(ppm)	197.1	163.3	297.9	294.5	(ppm)	447.2	<=
As NO2	(ppm)	128.6	106.5	194.3	192.1			
Actual O2	(%)	11.1	12.8	12.2	12.3		6.0	
NOx Present	(ppm)	182.5	200.6	290.6	259.4			

↑Most of present values below regulation.

		UNIT-A1	UNIT-A2	UNIT-B1	UNIT-B2	UNIT all	UNIT-III
Capacity	(MW)	63.0	63.0	160.0	160.0	446.0	350
Electricity	(MW)	25.0	23.5	81.7	88.0	218.2	350
Gas Dry	(m3N/h)	247000.0	254000.0	842000.0	860000.0	2203000.0	1263067
Gas Wet	(m3N/h)	269000.0	275000.0	898000.0	926000.0	2368000.0	1360000
Dust	(mg/m3N)	52.8	43.7	1204.0	700.0		265.0
	(Kg/h)	13.0	11.1	1013.8	602.0	1639.9	334.7
SOx	(ppm)	92.4	76.5	431.2	426.3		700.0
	(m3N/h)	22.8	19.4	363.1	366.6	772.0	884.1
NOx	(ppm)	182.5	163.3	290.6	259.4		447.2
	(m3N/h)	45.1	41.5	244.7	223.1	554.3	564.9
Temperature	(C.deg.)	127.0	110.5	148.0	158.0	100.0	100
Loading Factor		0.397	0.373	0.511	0.550	0.489	1.000
		11.1	12.8	12.2	12.3	150	230

↑Dry/Wet ratio from UNIT-B2

Appendix 7-2 Gas Volume and Pollutant Emission under Maximum Loading in the Future

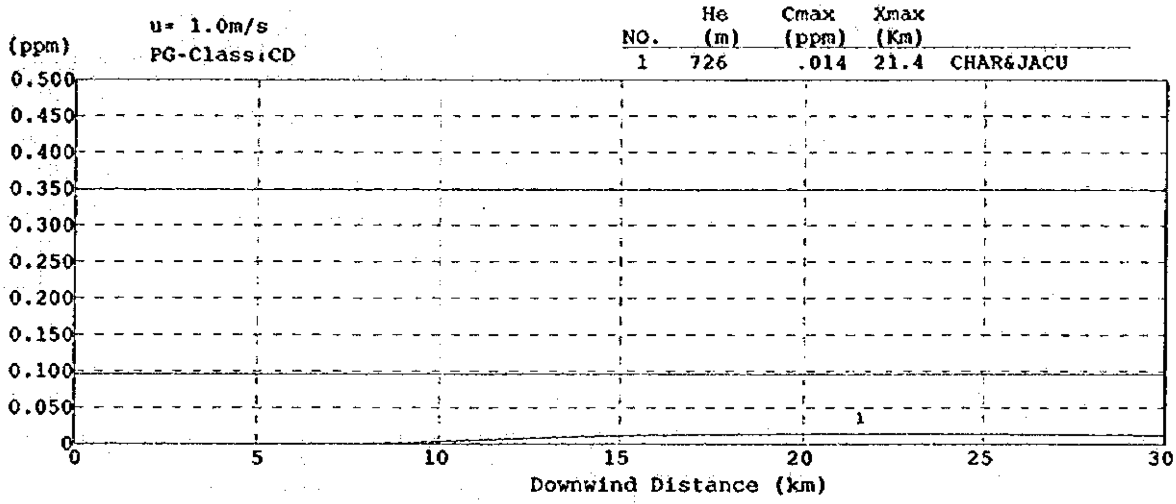
Charqueadas & Jacui

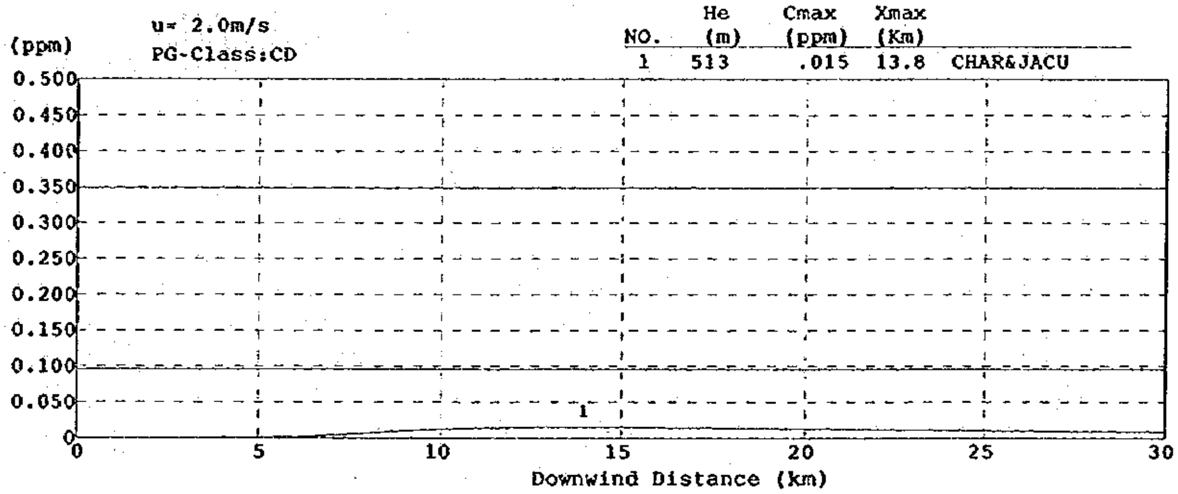
Power Plant Stack Code Connected UNIT	Unit	Charqueadas 1 1-4	Jacui 2 X
Electricity Generation	(MWh)	72	350
Wet Gas Volume	(Km^{3}N/h)	562.7	1234.7
Dust	(Kg/h)	34.5	158.2
SO_x	(m^{3}N/h)	60.4	593.1
NO_x	(m^{3}N/h)	94.9	573.6

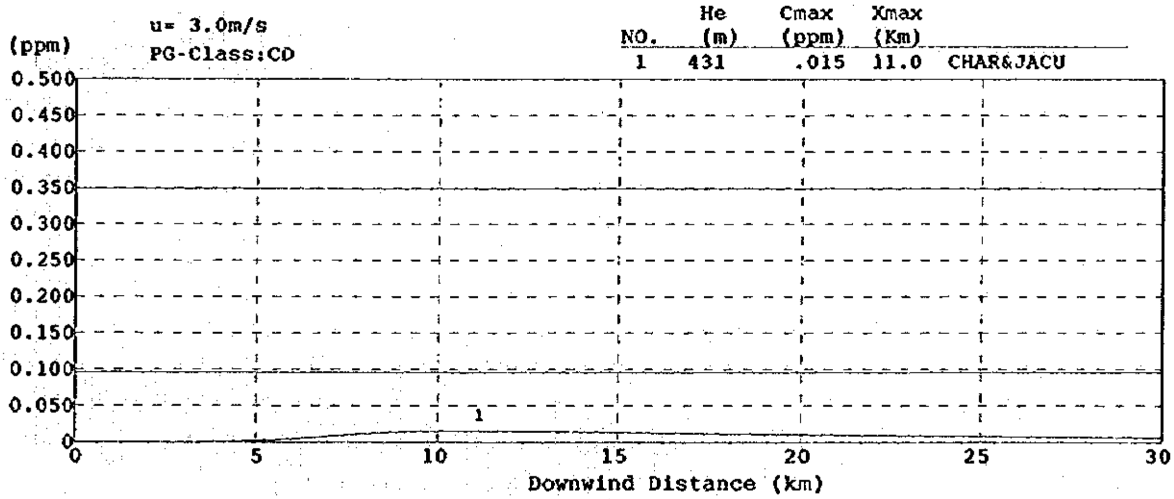
Candiota

Power Plant Stack Code Connected UNIT	Unit	Candiota 1 1-4	Candiota 2 5
Electricity Generation	(MWh)	446	350
Wet Gas Volume	(Km^{3}N/h)	4859.5	1360
Dust	(Kg/h)	3142.6	334.7
SO_x	(m^{3}N/h)	1487.4	884.1
NO_x	(m^{3}N/h)	1109.9	564.9

Appendix 7-3 Hourly Concentration Profile under the Future Condition

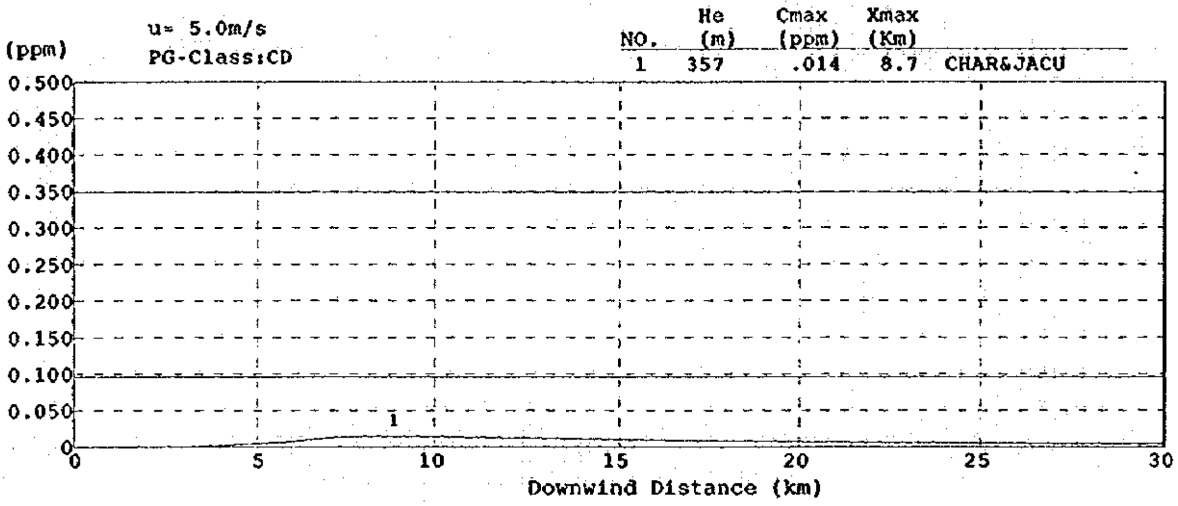


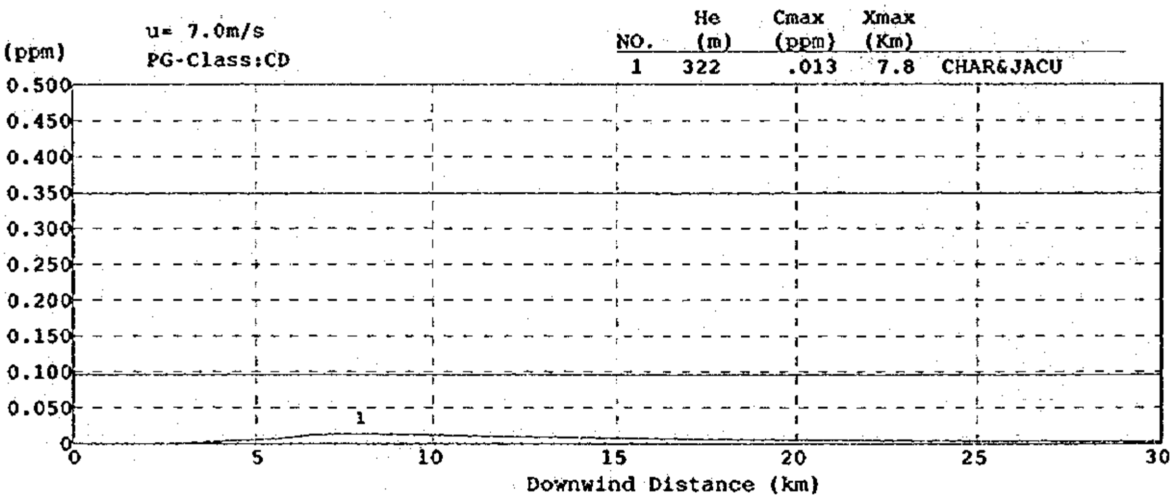


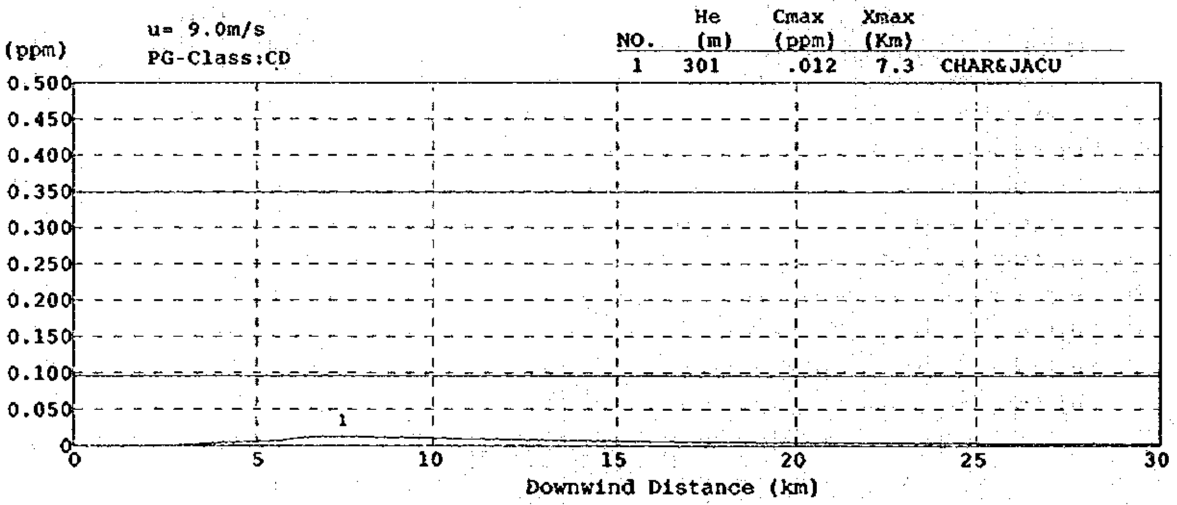


CONCAWE & Plume (SO2)

Charqueadas & Jacui Power Station (Future)

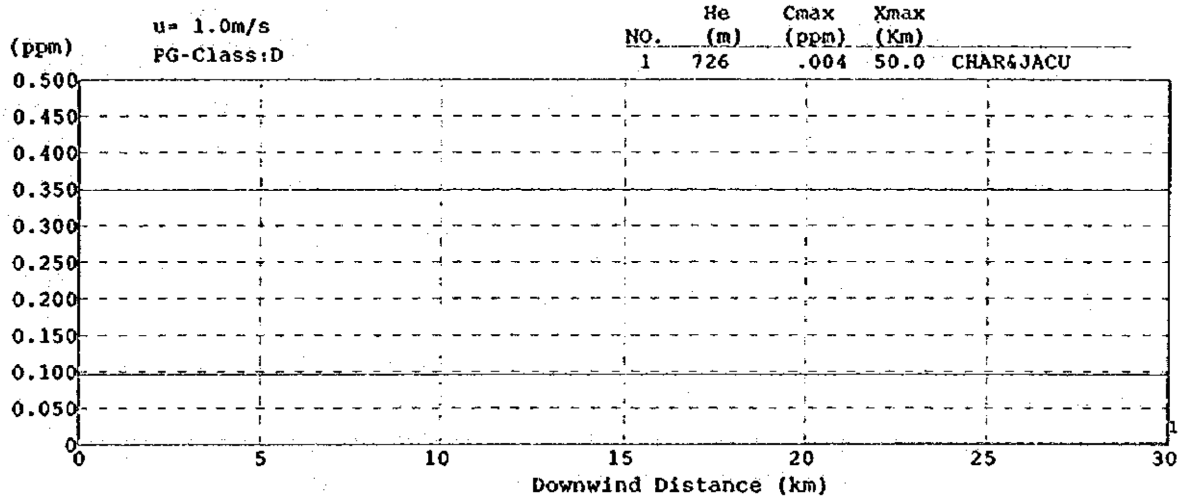


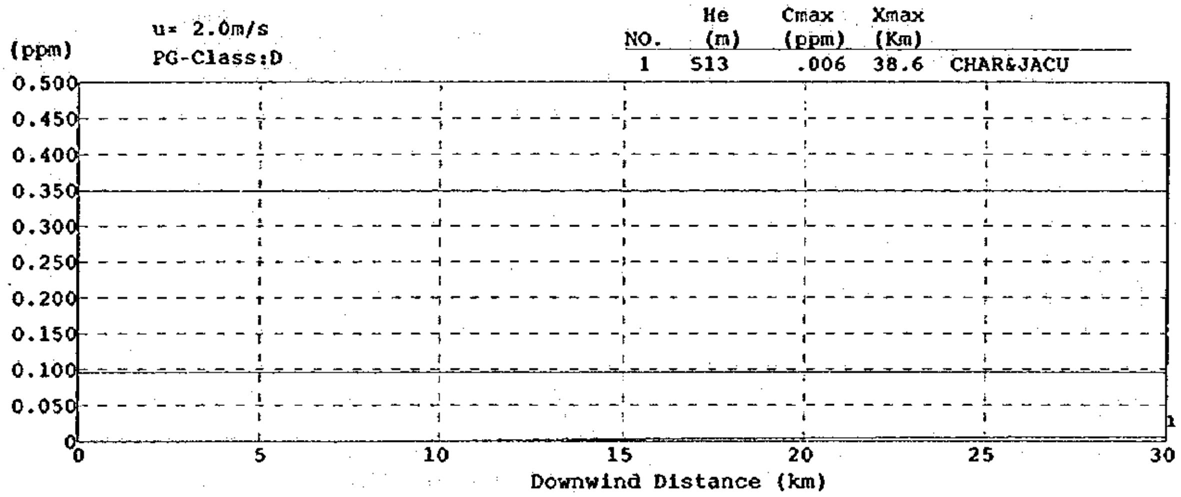


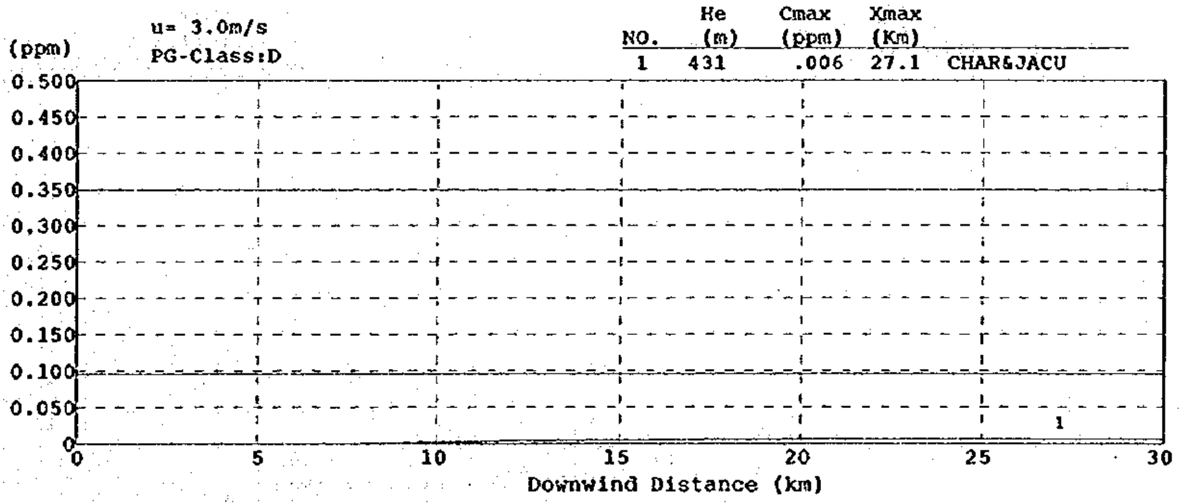


CONCAWE & Plume (SO2)

Charqueadas & Jacui Power Station (Future)

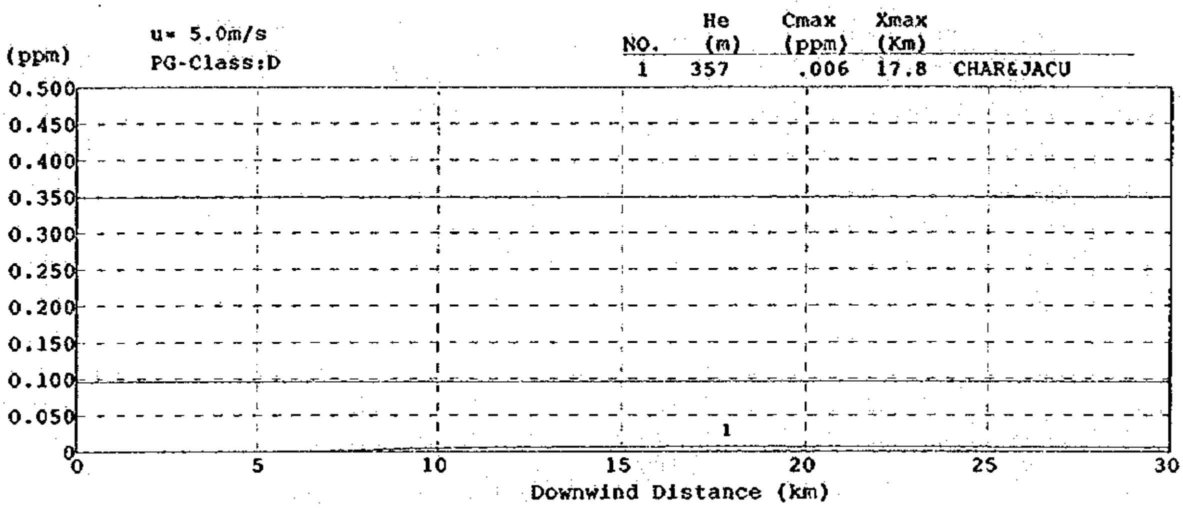


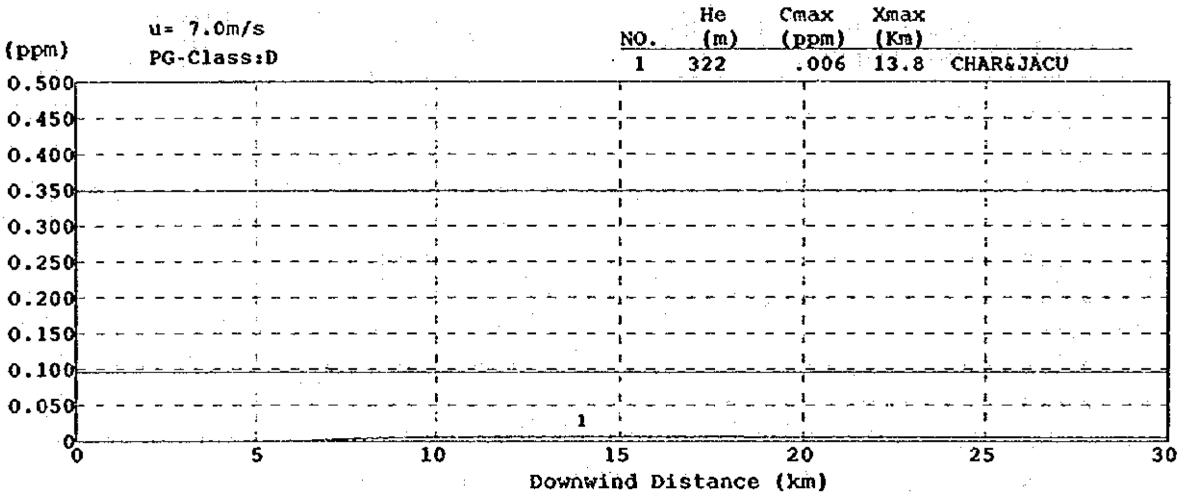


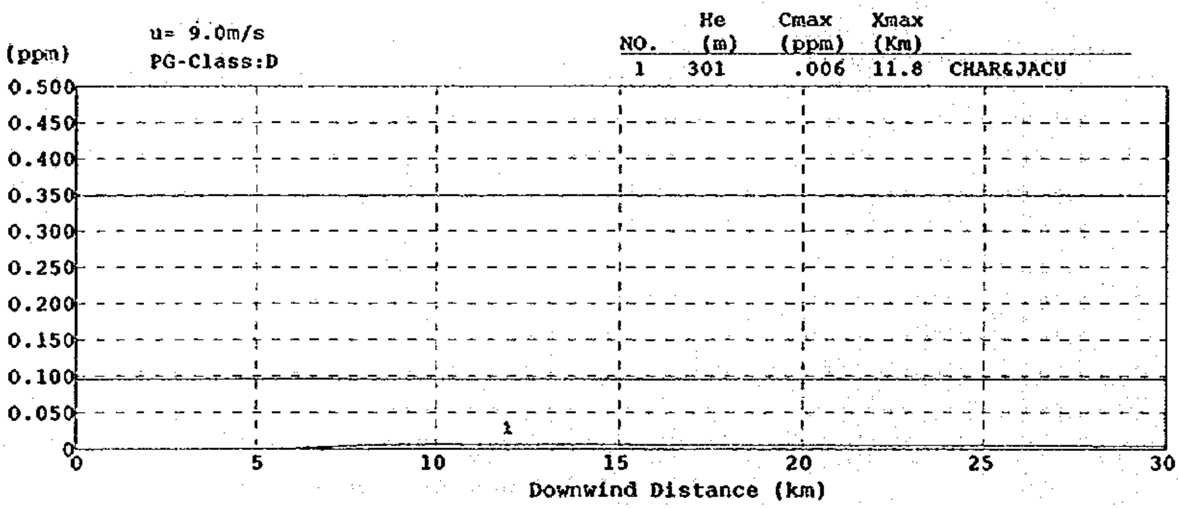


CONCAWE & Plume (SO2)

Charqueadas & Jacui Power Station (Future)

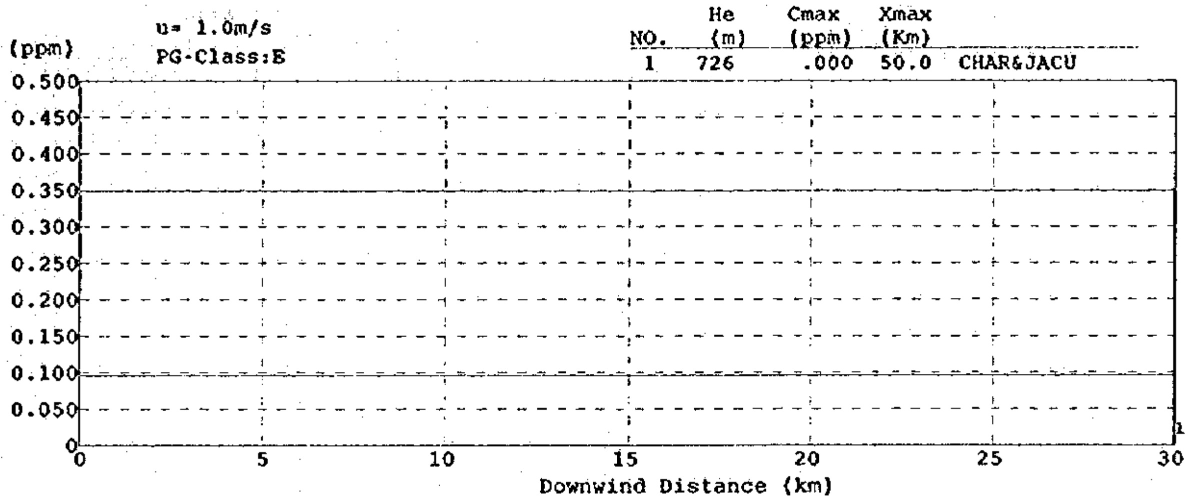


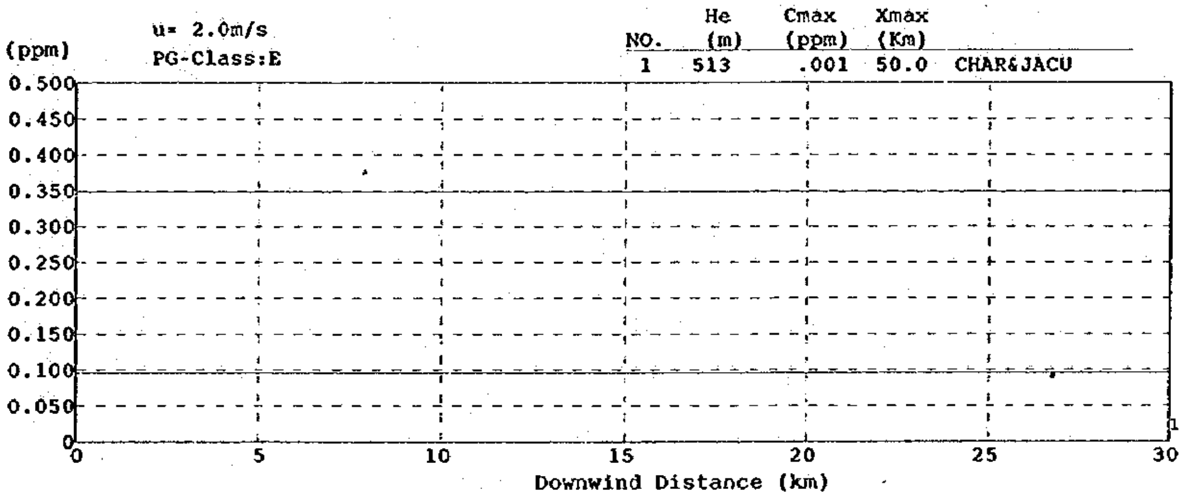


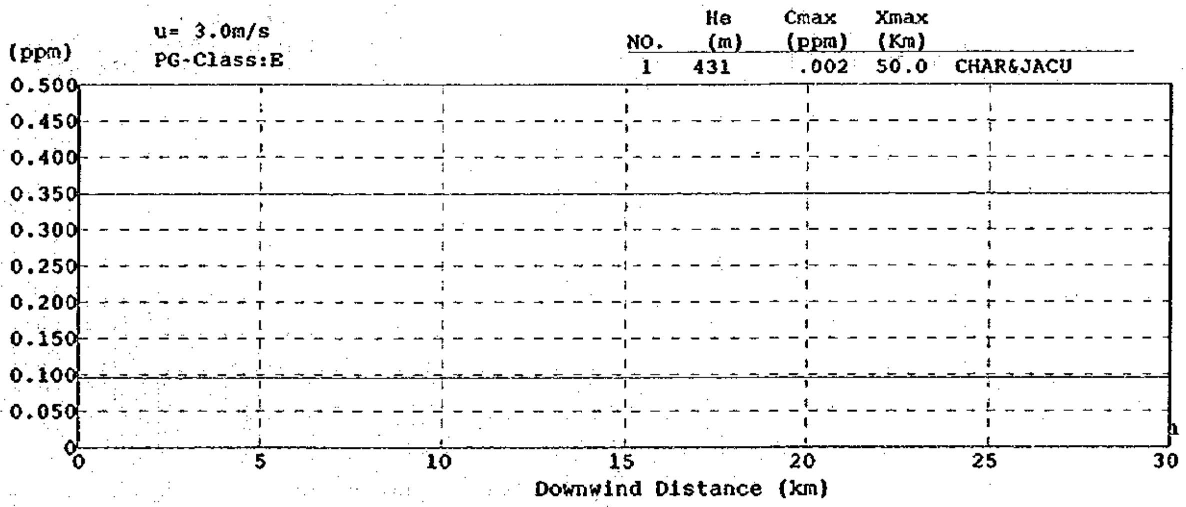


CONCAWE & Plume (SO2)

Charqueadas & Jacui Power Station (Future)

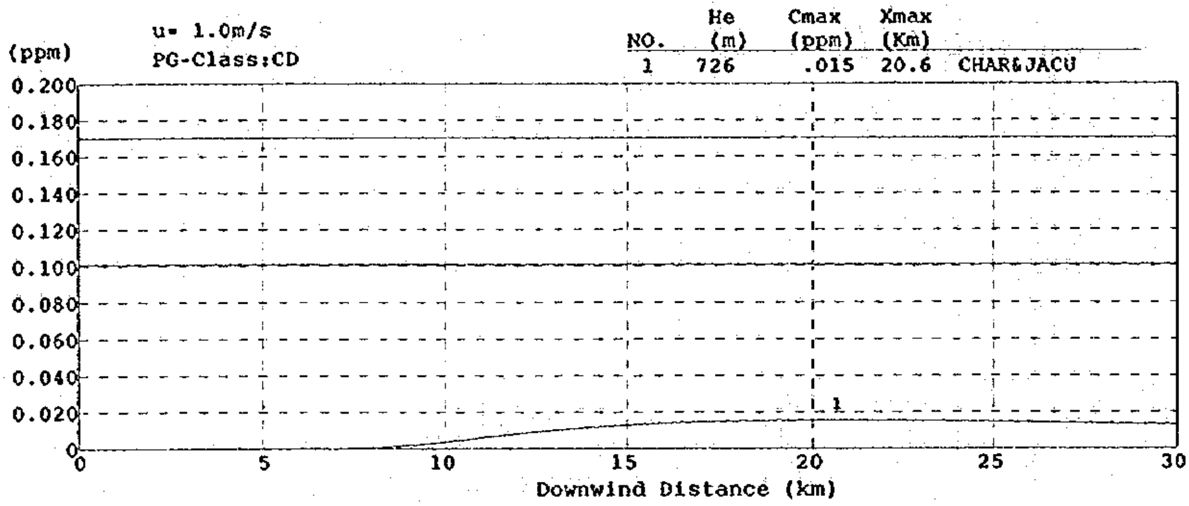


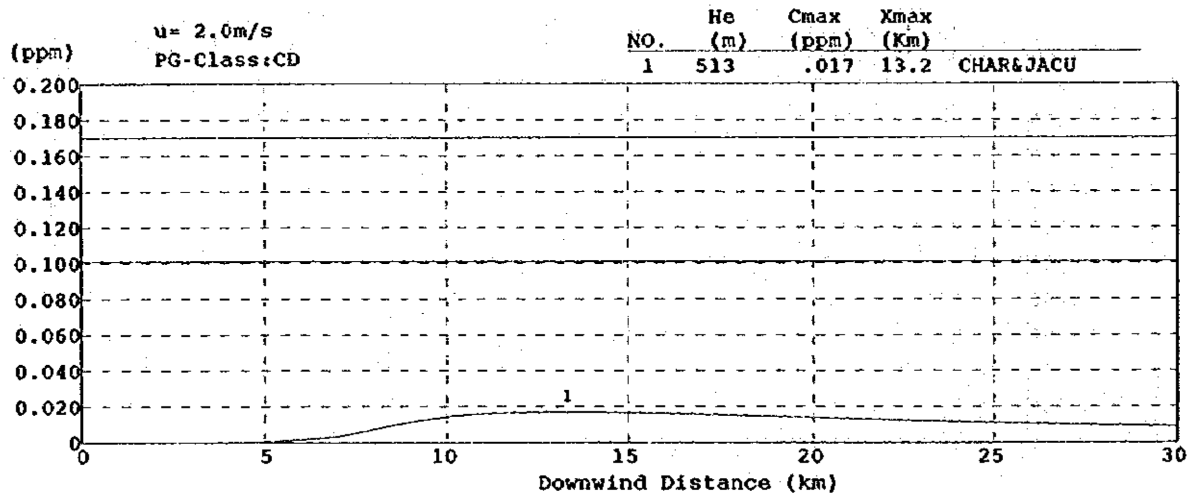


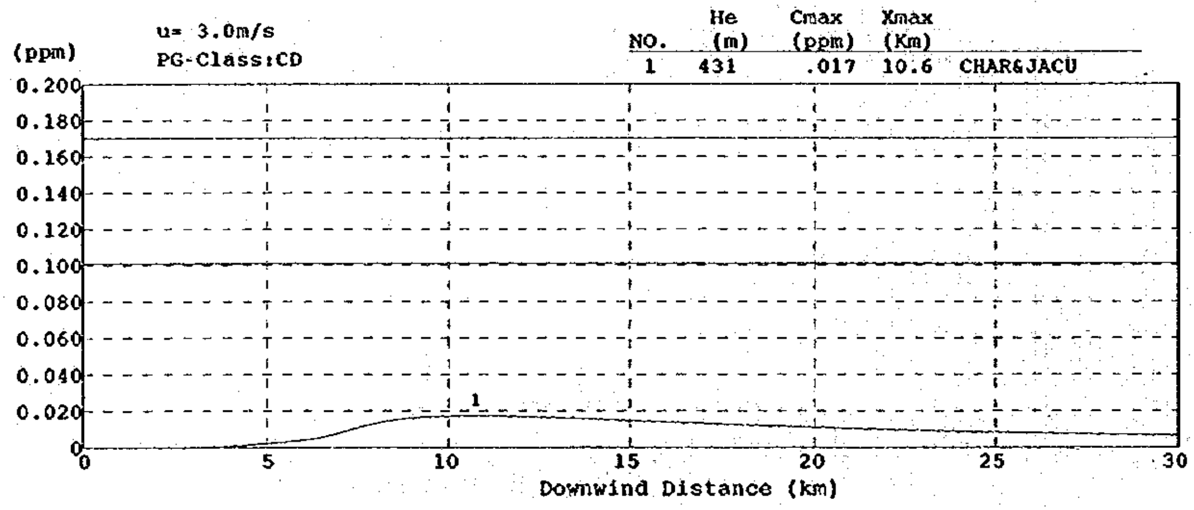


CONCAWE & Plume (SO2)

Charqueadas & Jacui Power Station (Future)

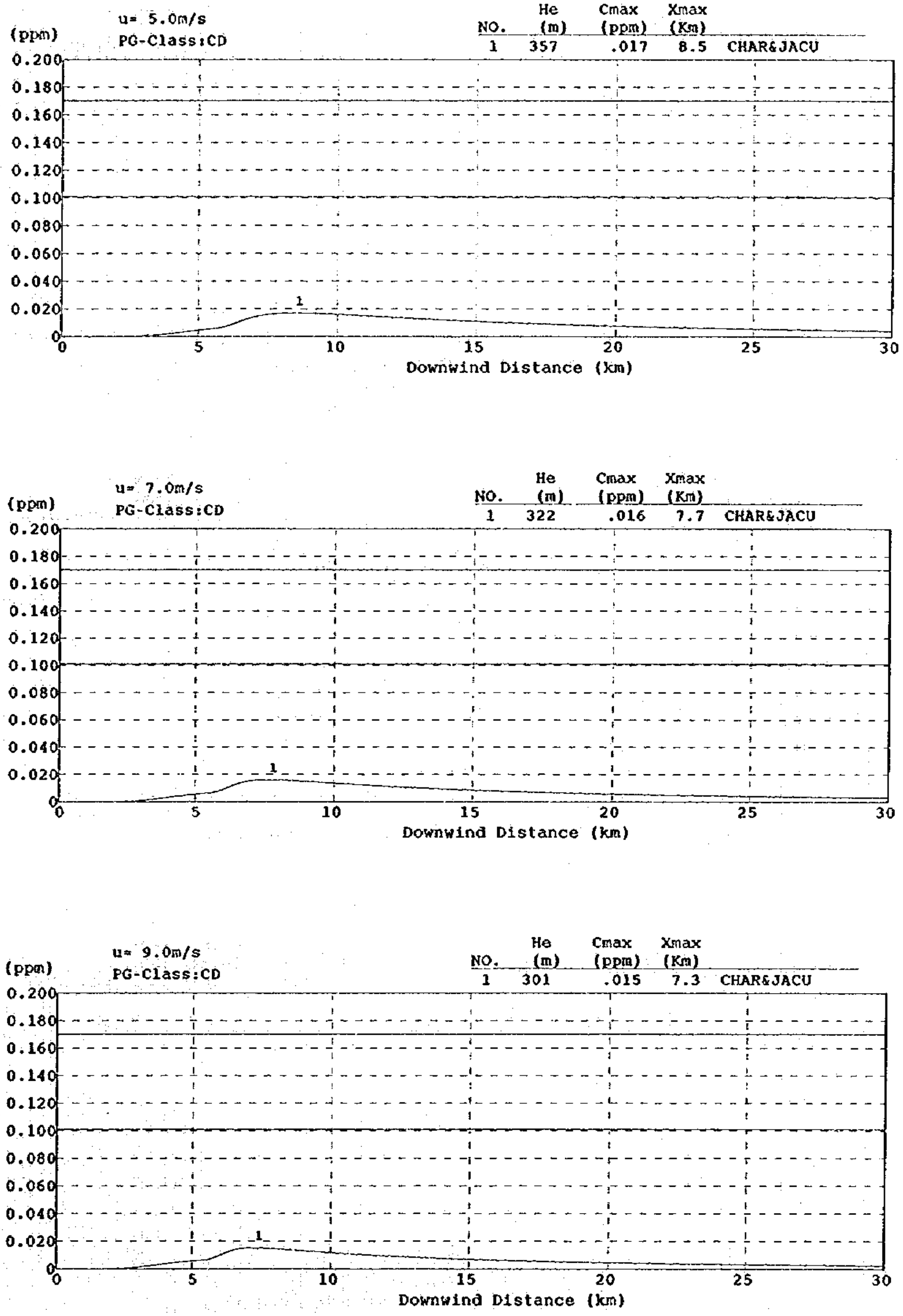






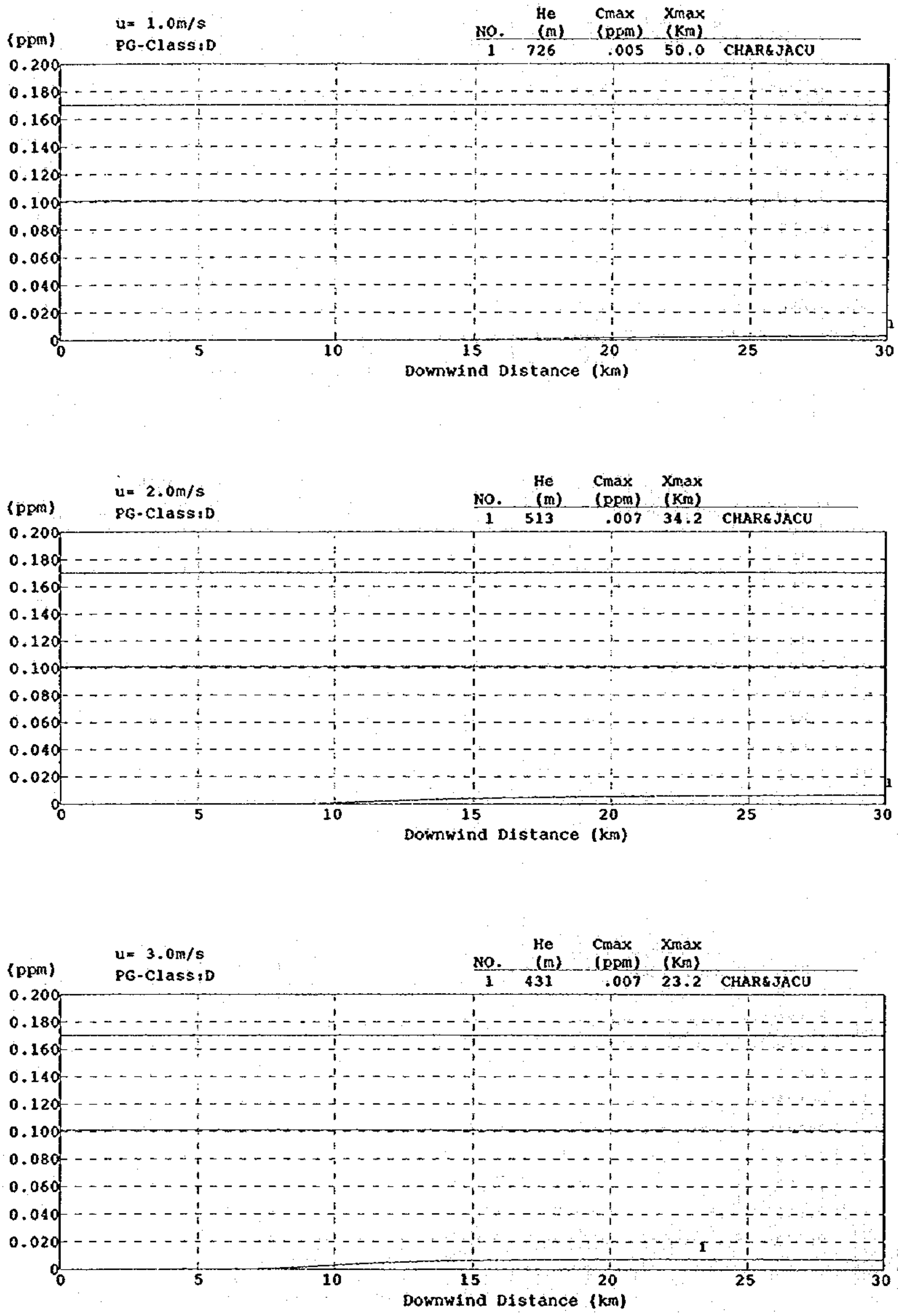
CONCAWE & Plume (NO2)

Charqueadas & Jacui Power Station (Future)



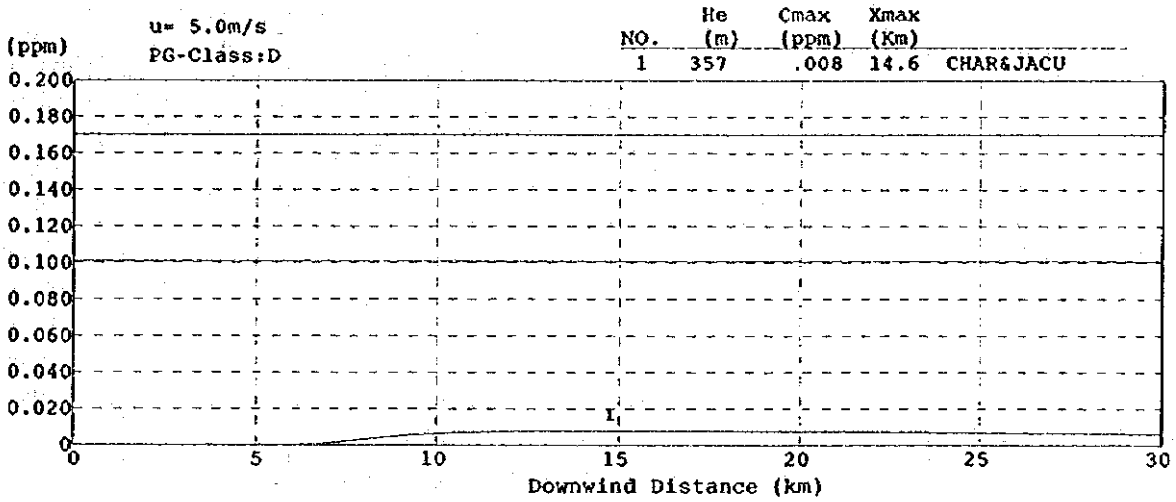
CONCAWE & Plume (NO2)

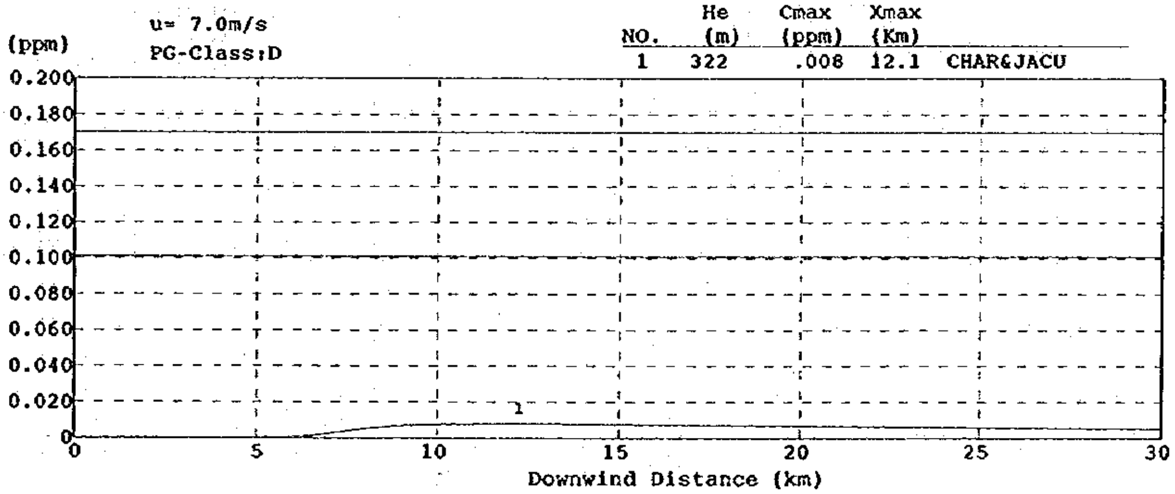
Charqueadas & Jacui Power Station (Future)

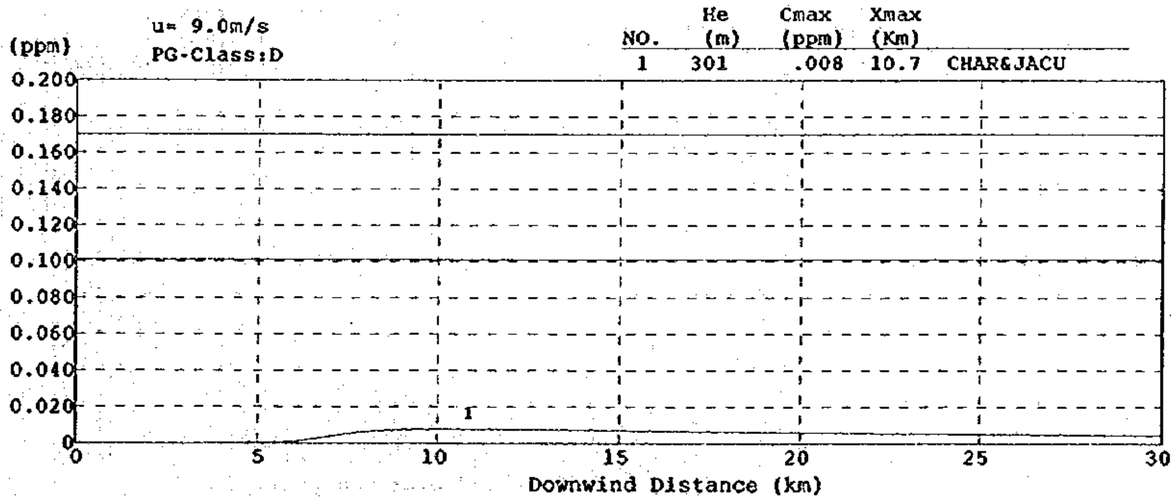


CONCAWE & Plume (NO2)

Charqueadas & Jacui Power Station (Future)

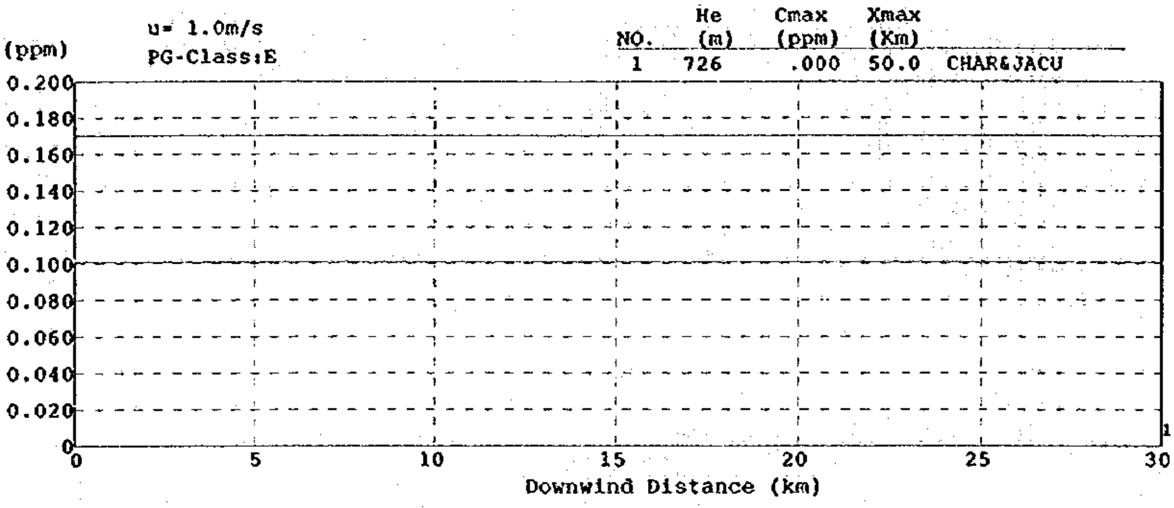


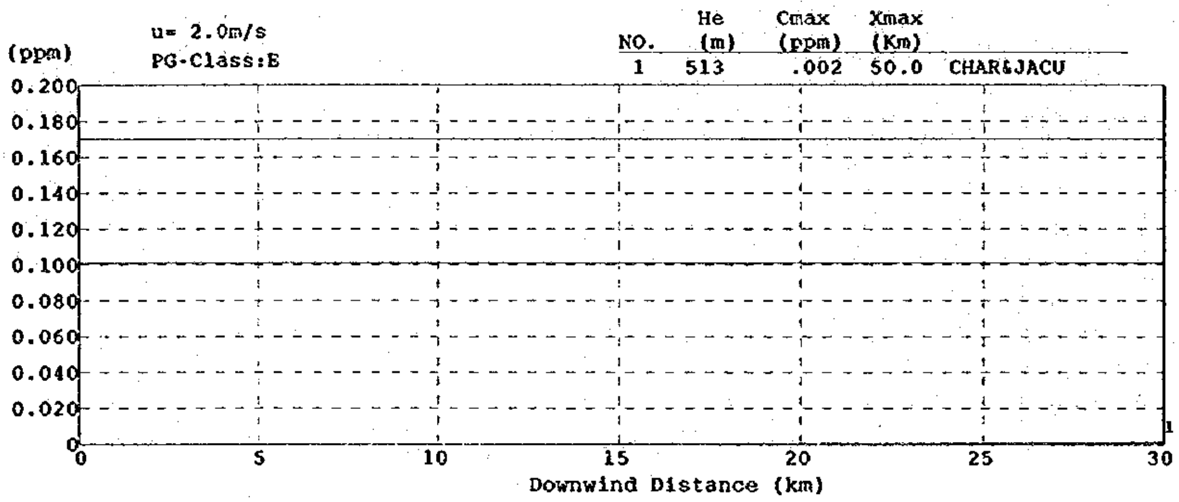


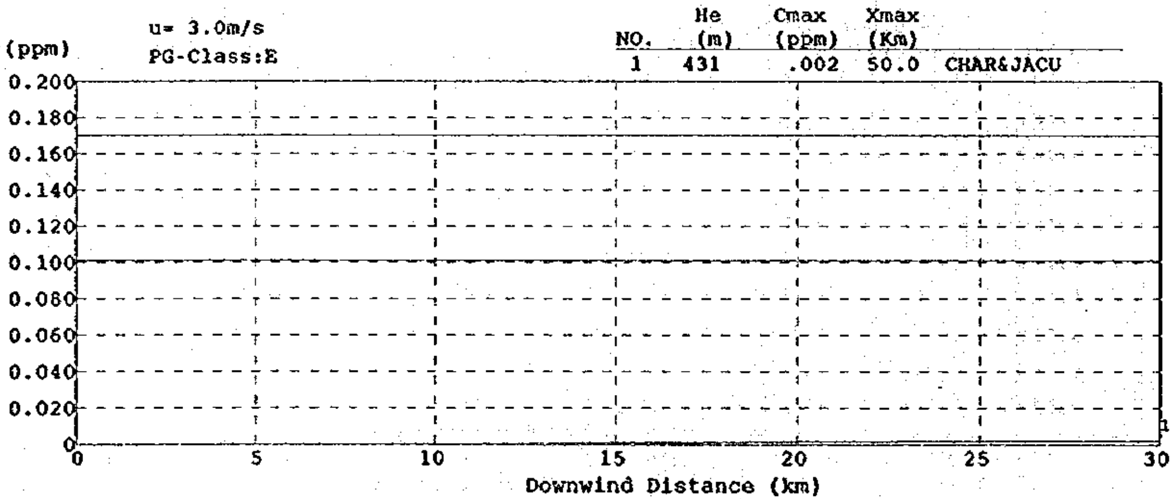


CONCAWE & Plume (NO2)

Charqueadas & Jacui Power Station (Future)

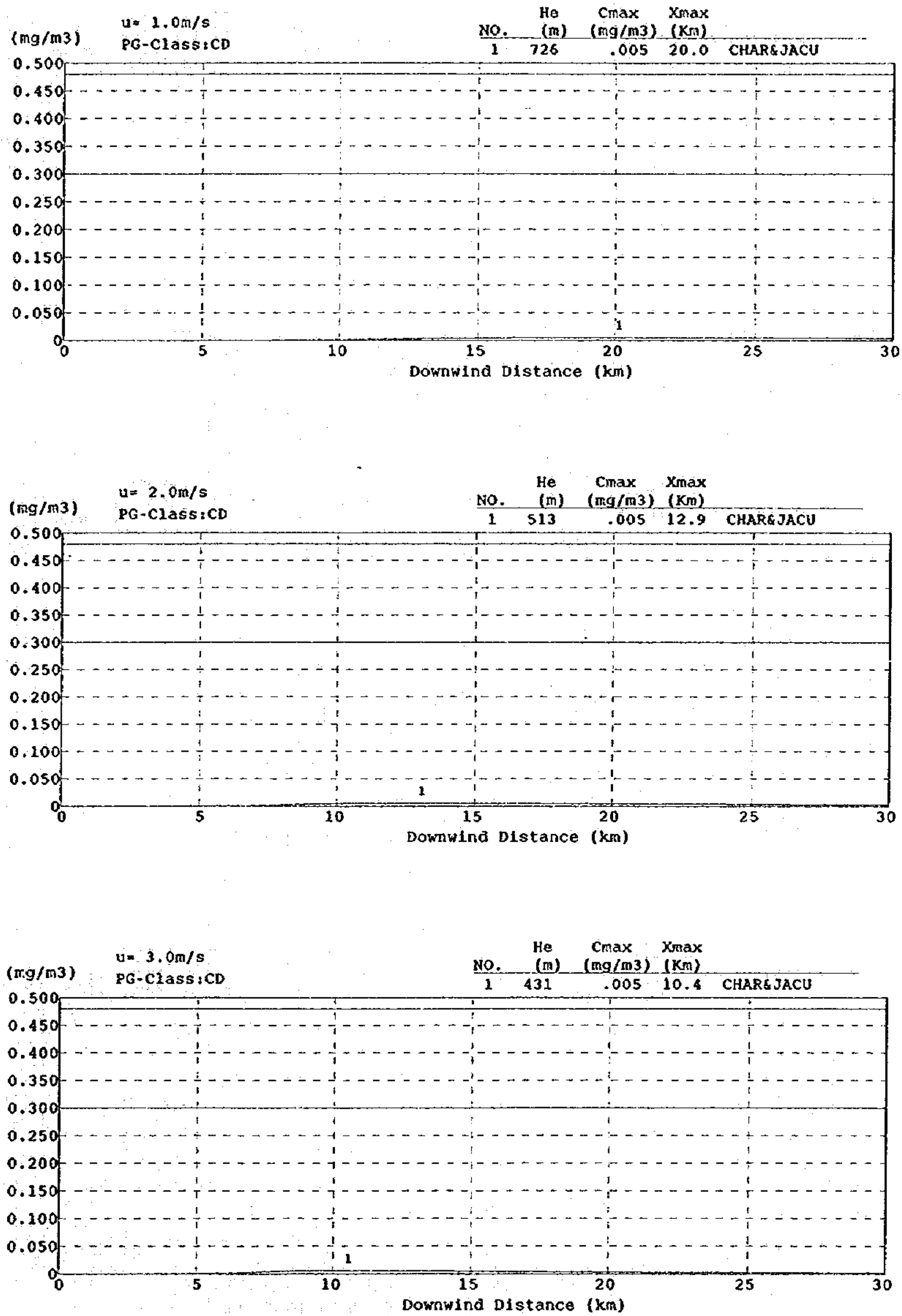






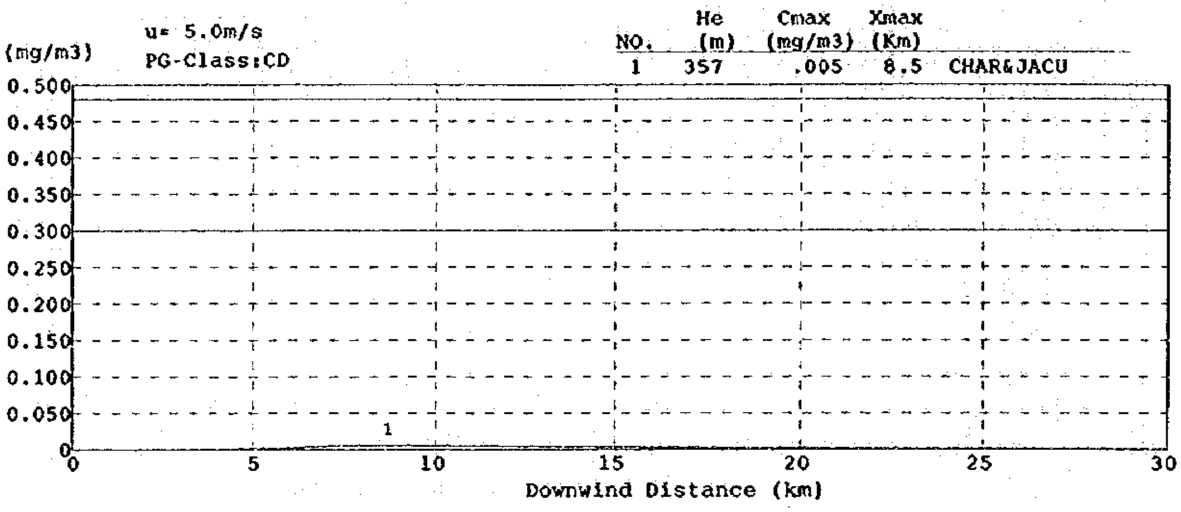
CONCAWE & Plume (NO2)

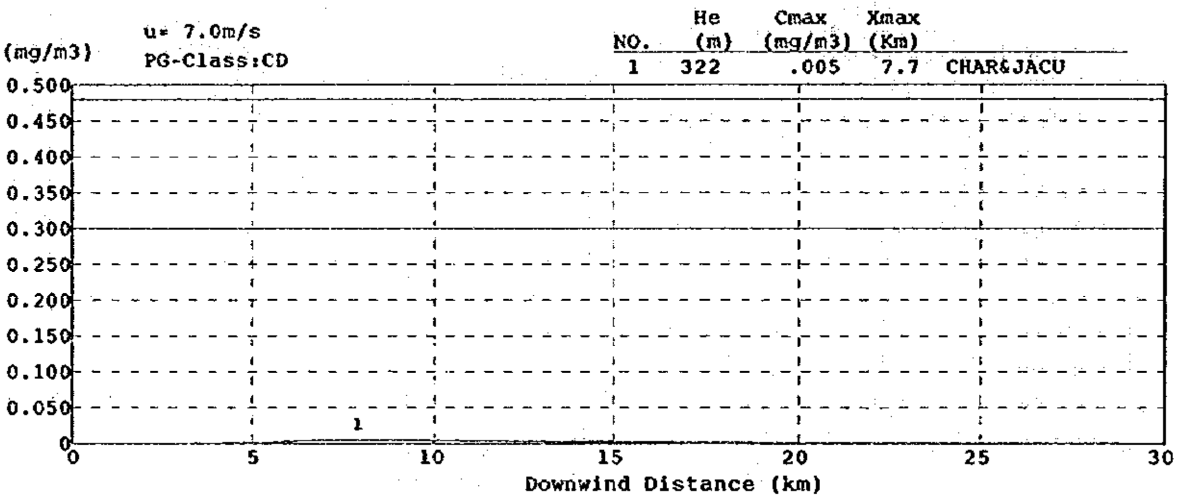
Charqueadas & Jacui Power Station (Future)

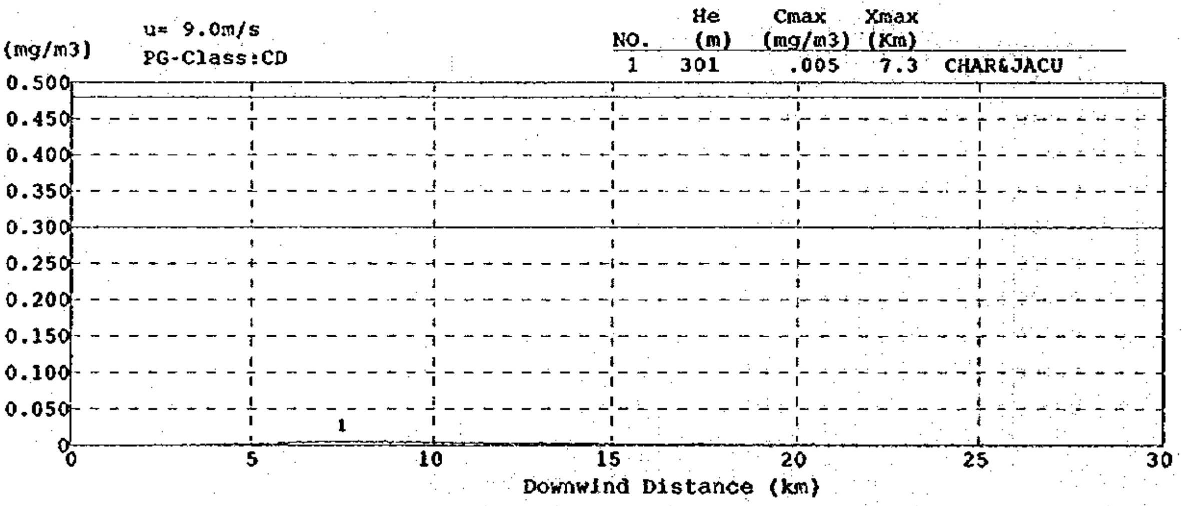


CONCAWE & Plume (Dust)

Charqueadas & Jacui Power Station (Future)

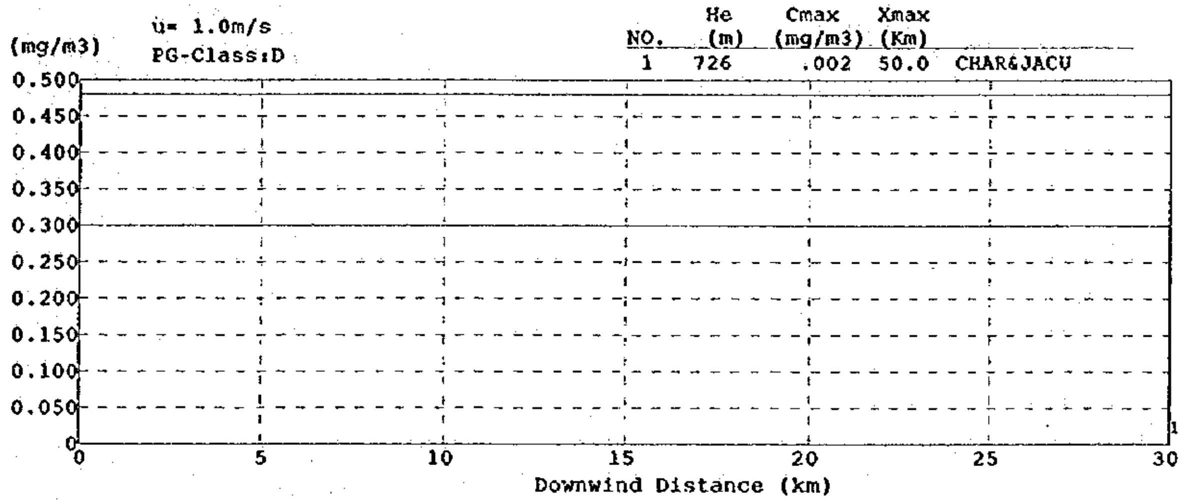


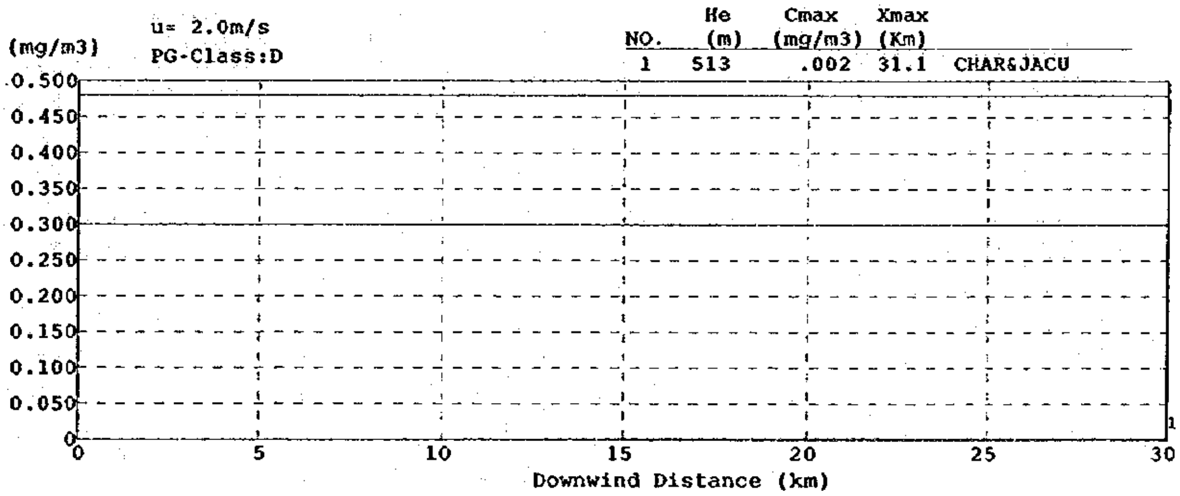


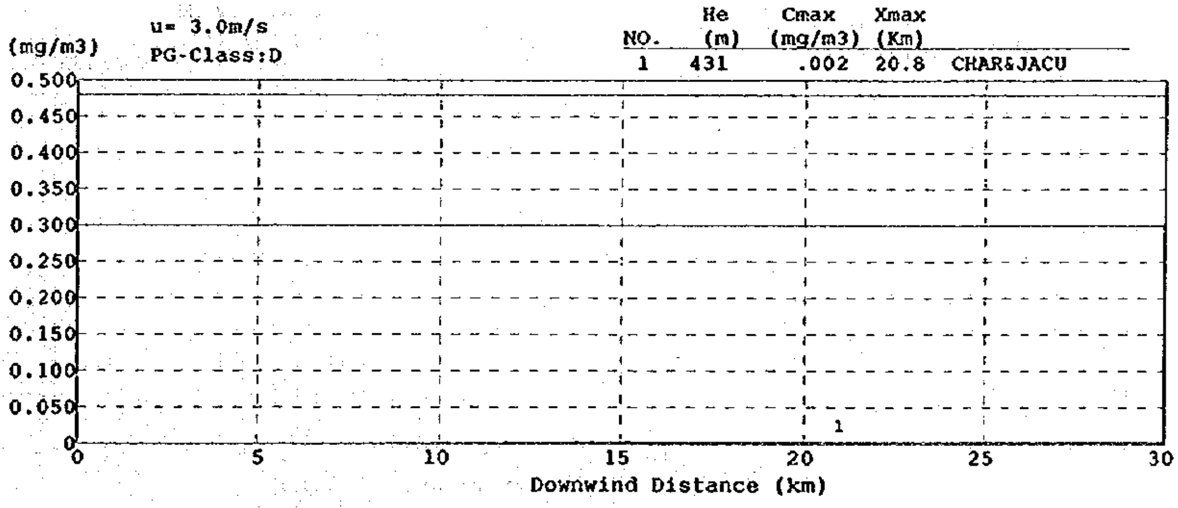


CONCAWE & Plume (Dust)

Charqueadas & Jacui Power Station (Future)

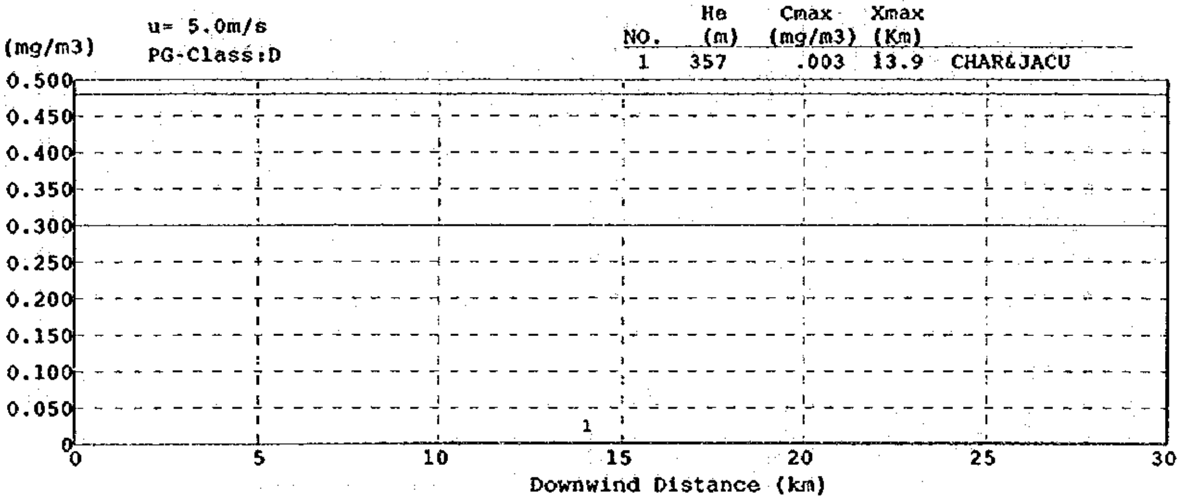


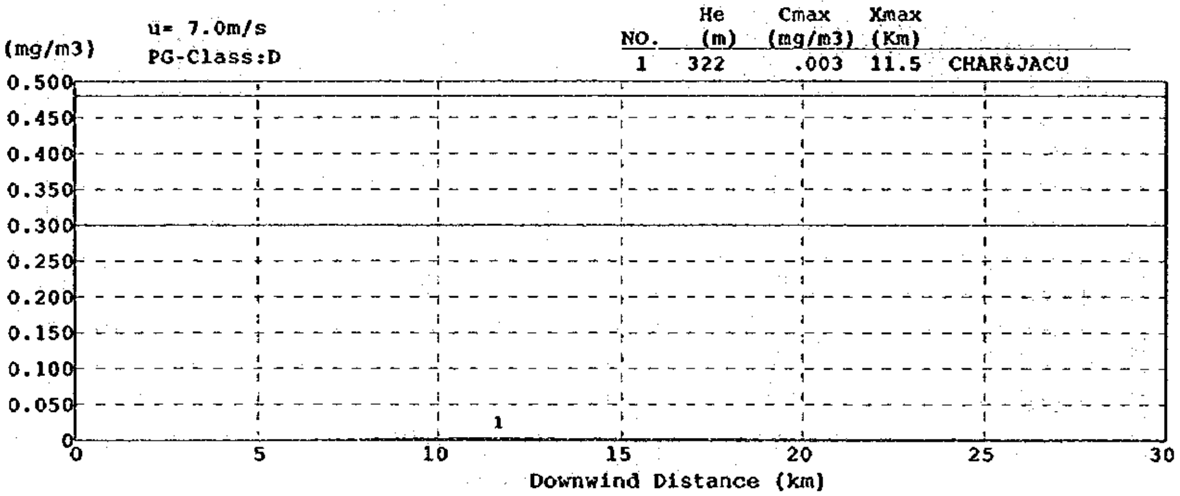


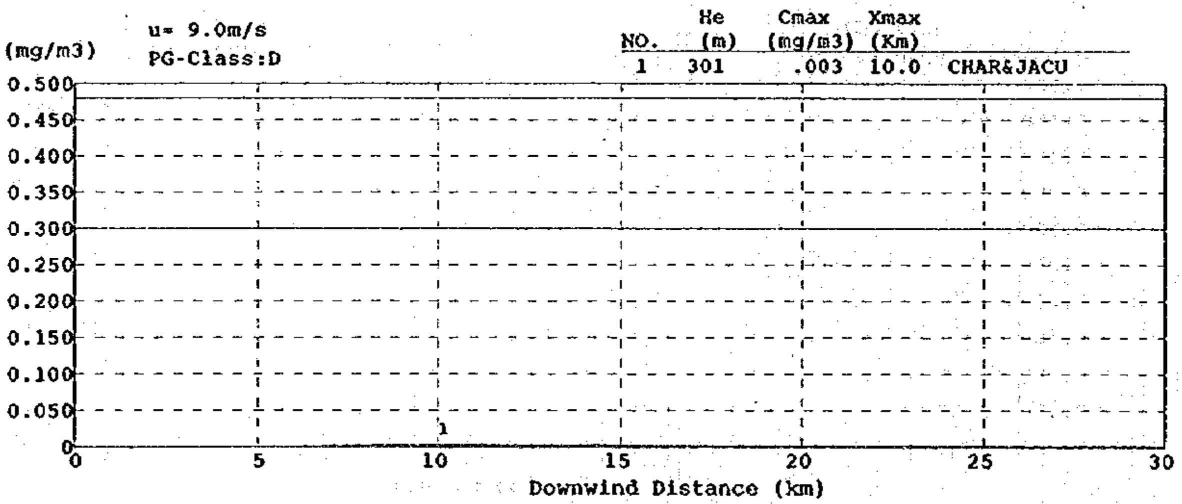


CONCAWE & Plume (Dust)

Charqueadas & Jacui Power Station (Future)

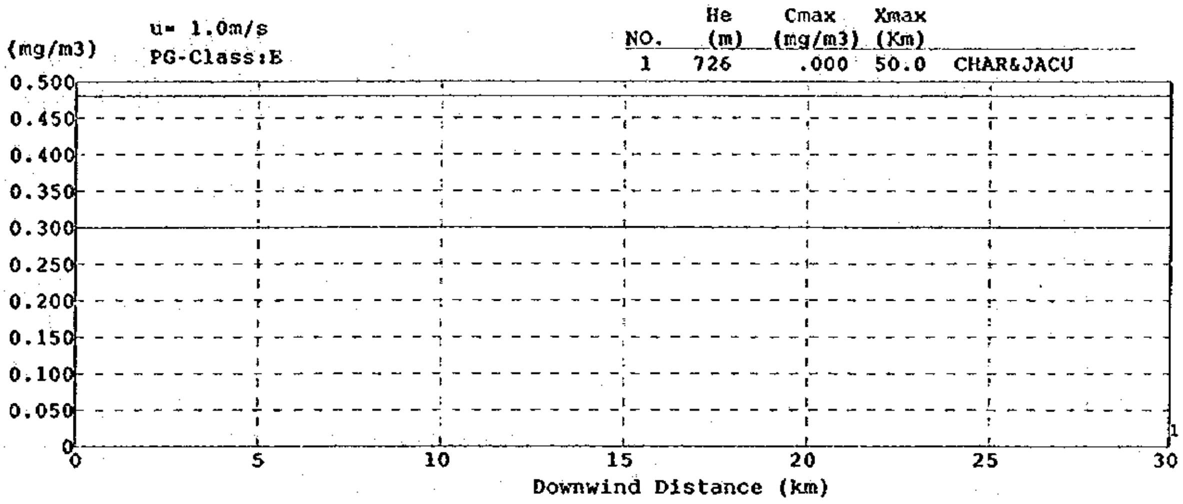


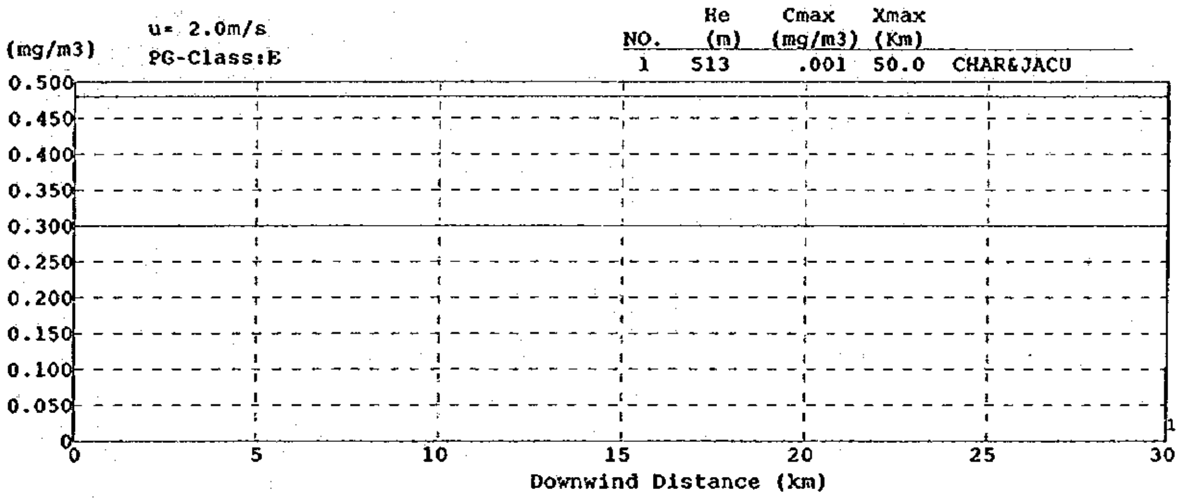


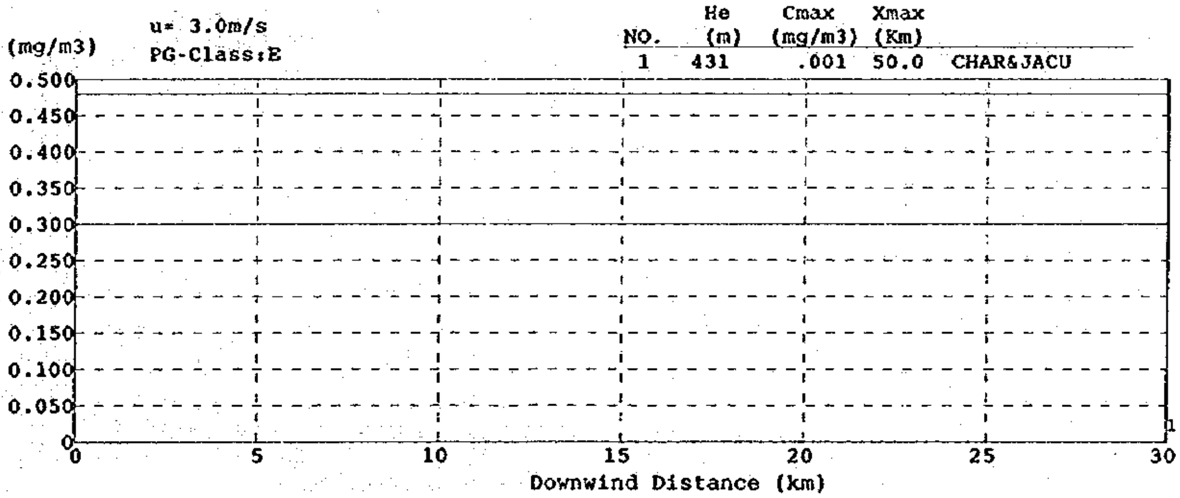


CONCAWE & Plume (Dust)

Charqueadas & Jacui Power Station (Future)

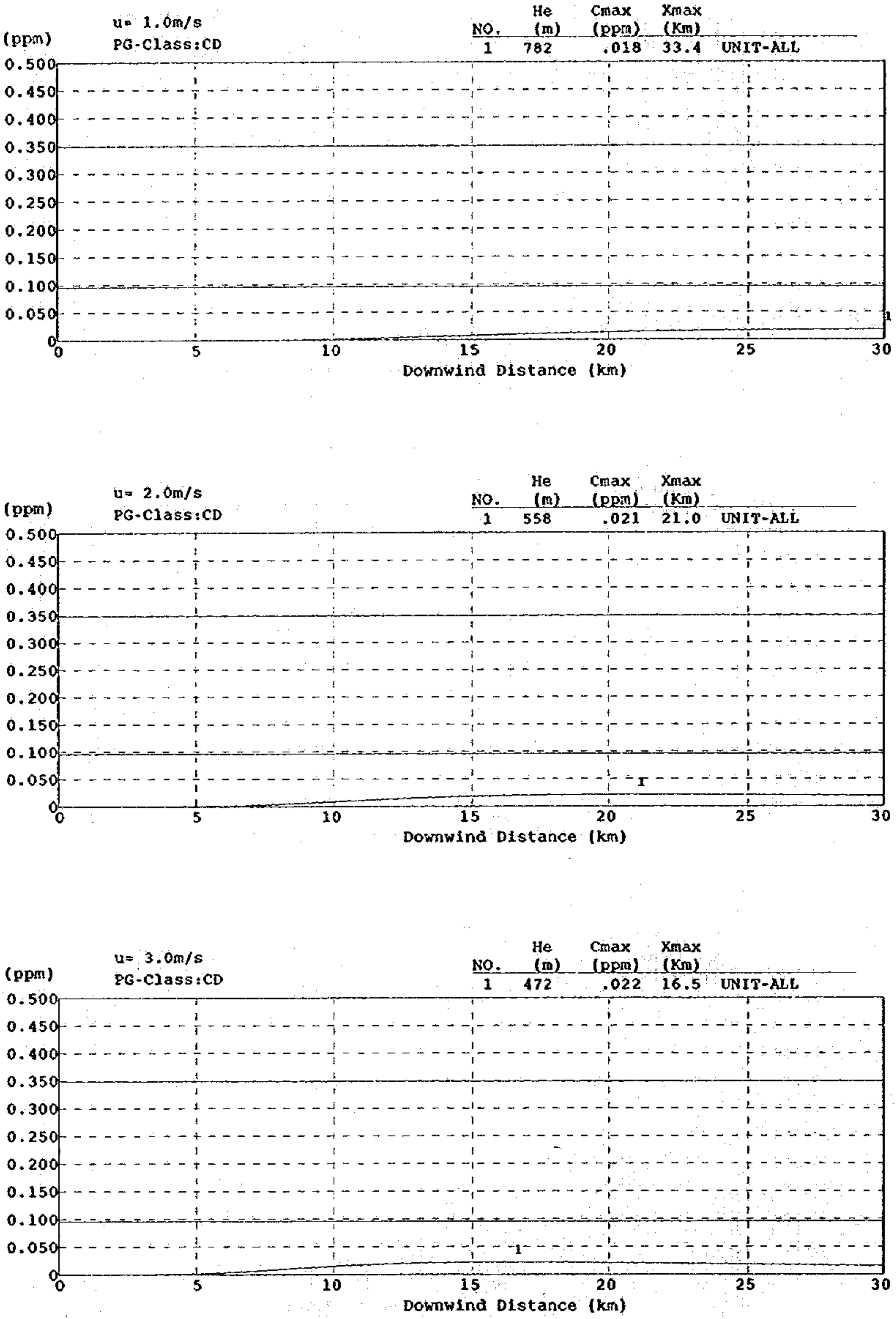






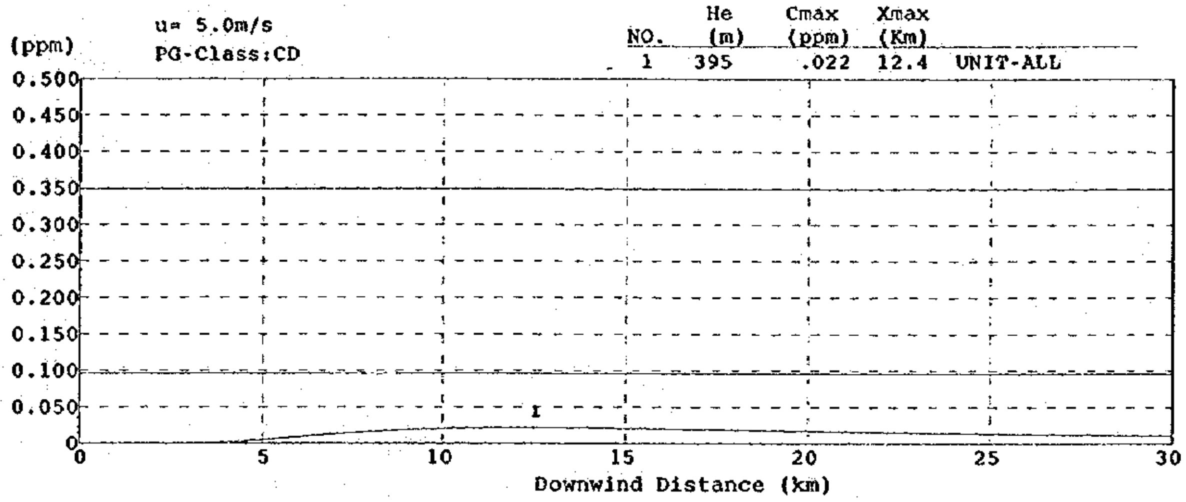
CONCAWE & Plume (Dust)

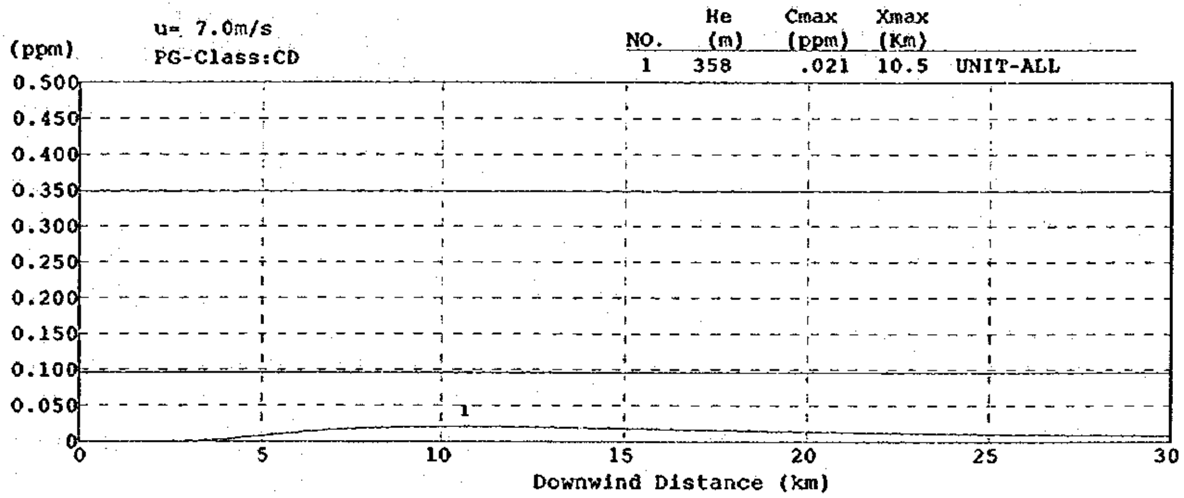
Charqueadas & Jacui Power Station (Future)

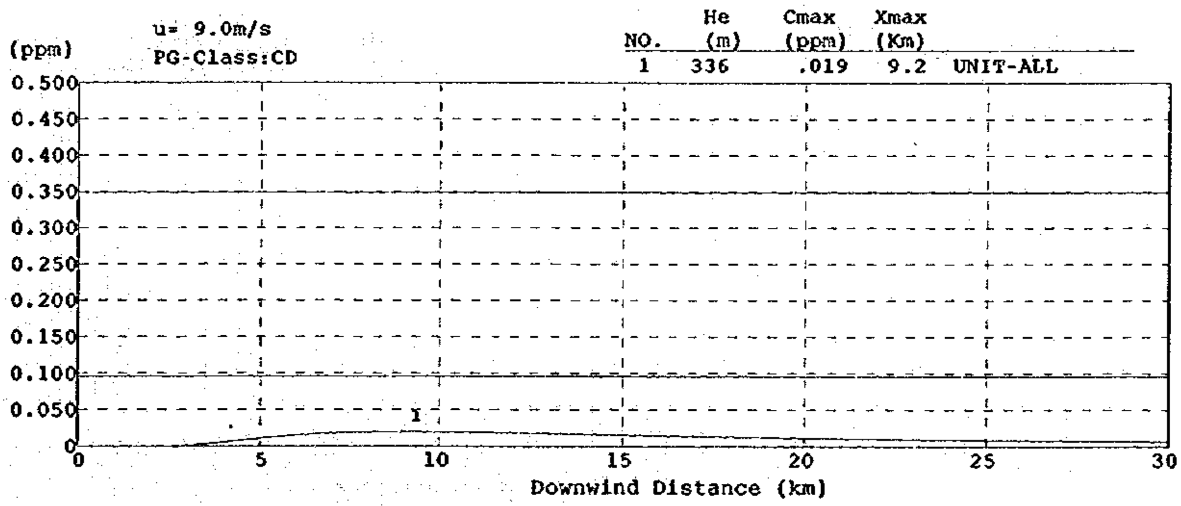


CONCAWE & Plume (SO2)

Candiota Power Station (Future)

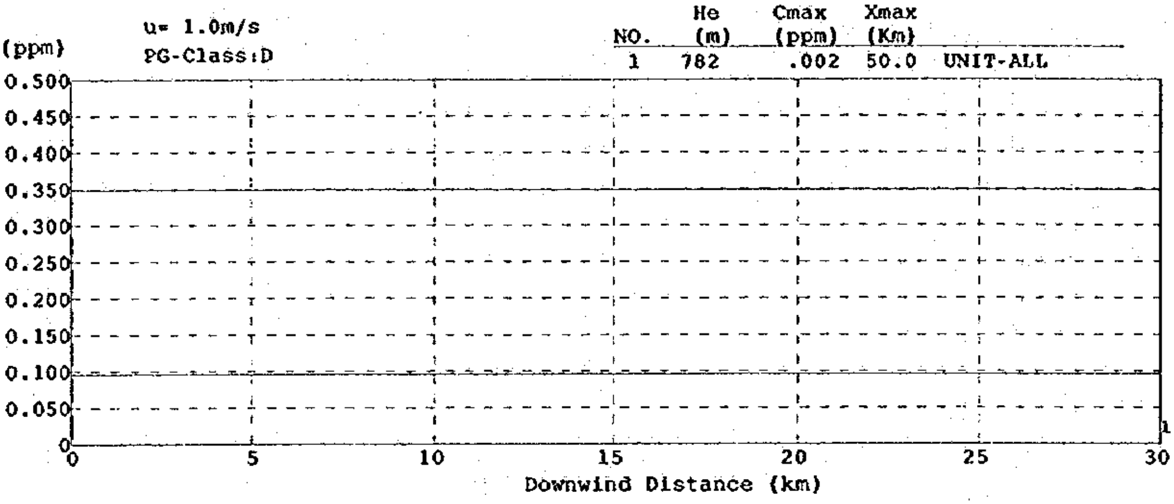


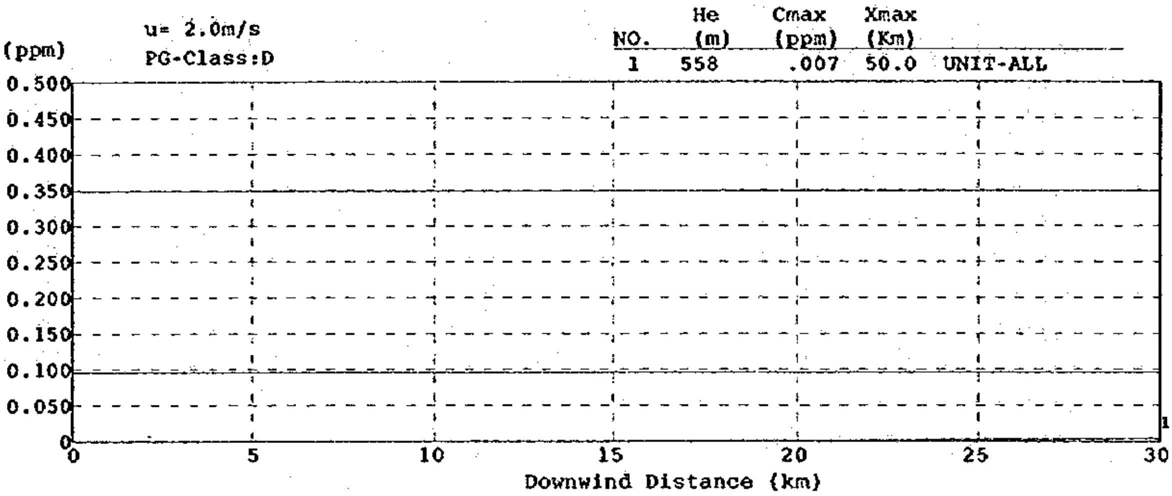


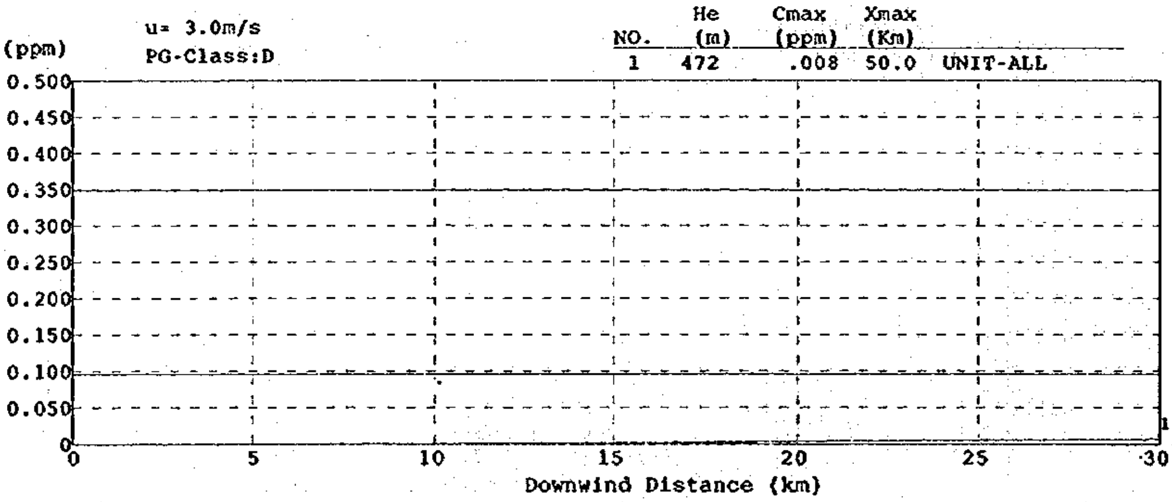


CONCAWE & Plume (SO2)

Candiota Power Station (Future)

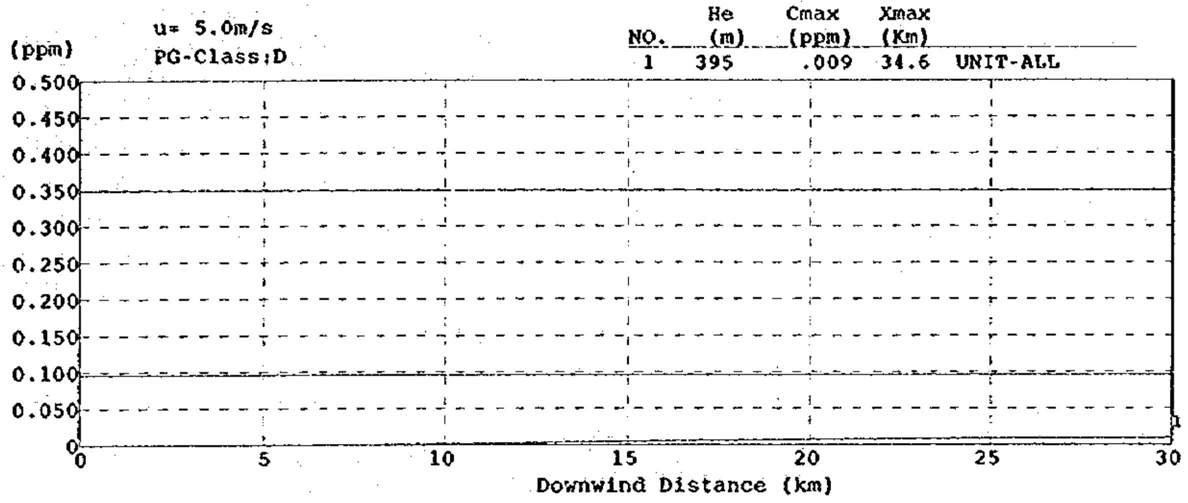


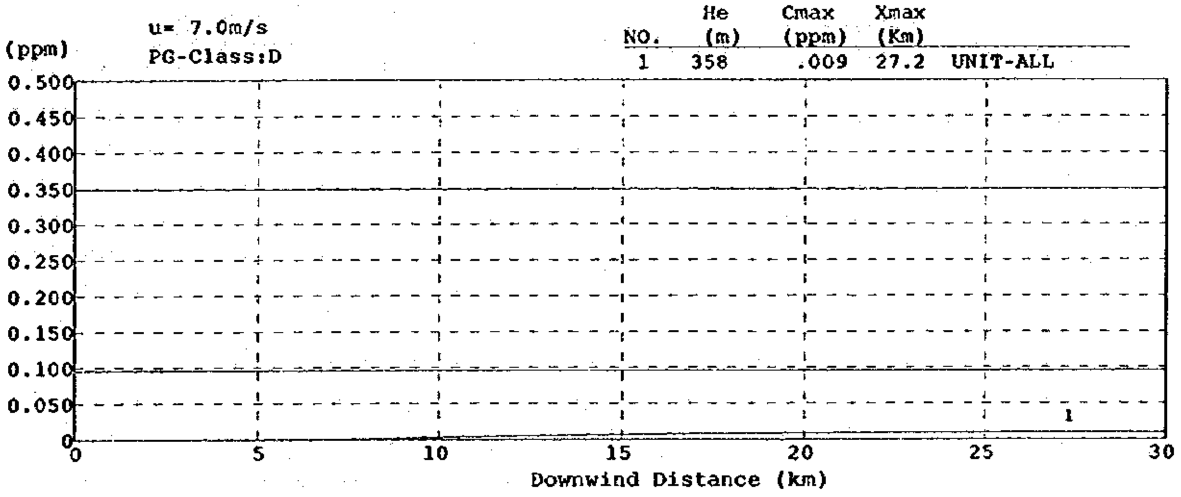


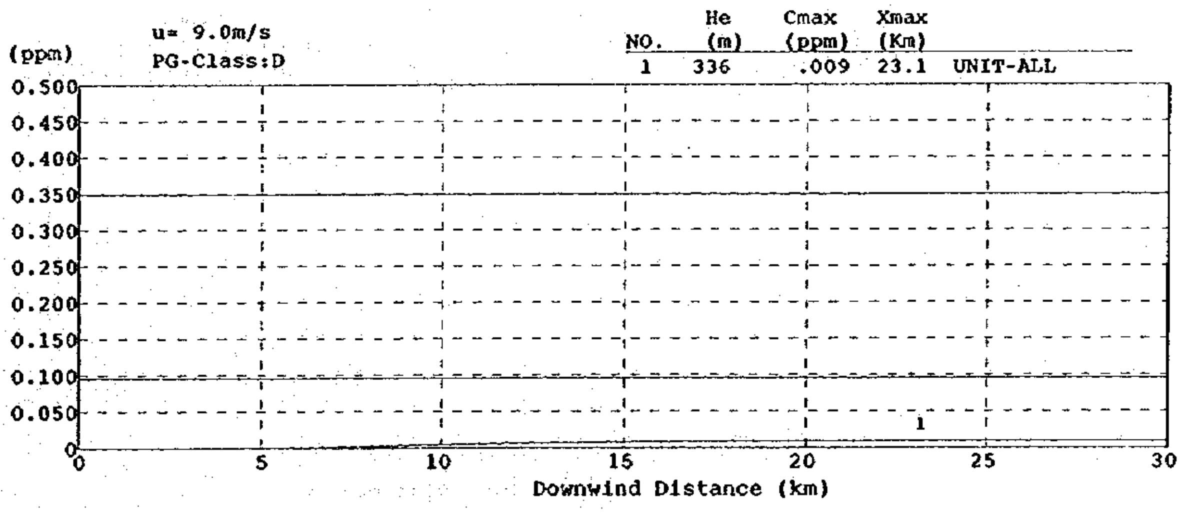


CONCAWE & Plume (SO2)

Candiota Power Station (Future)

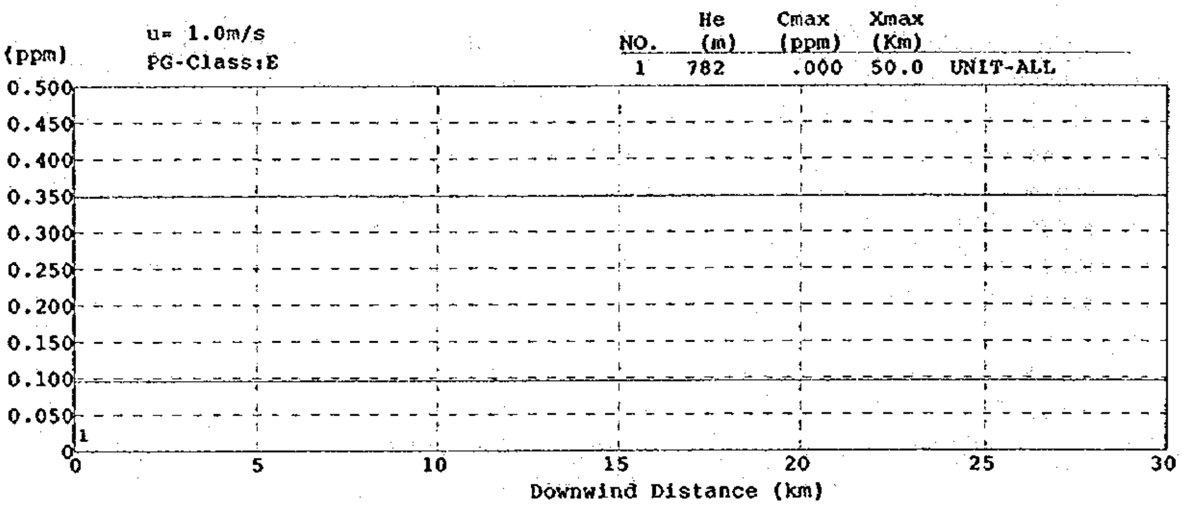


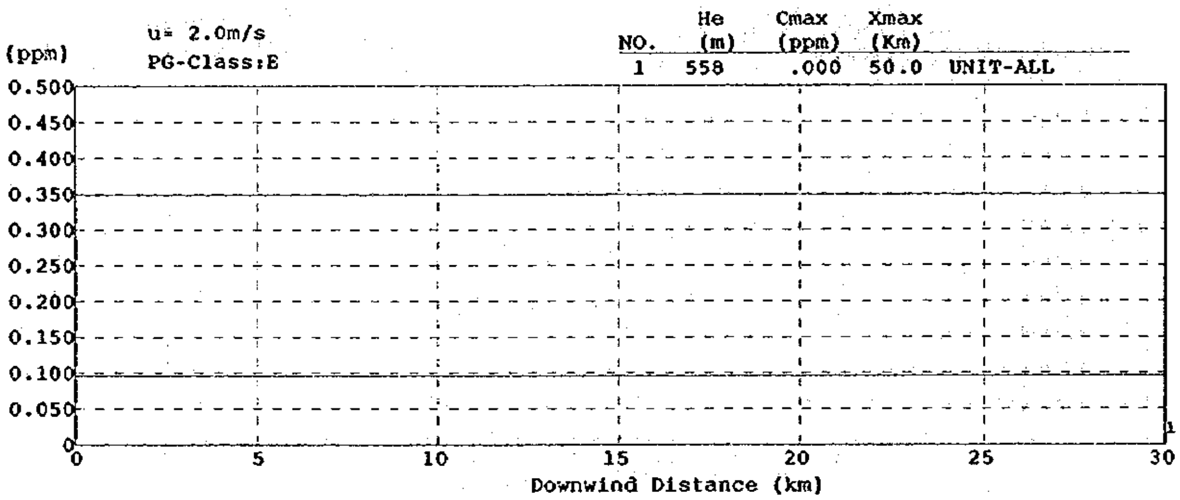


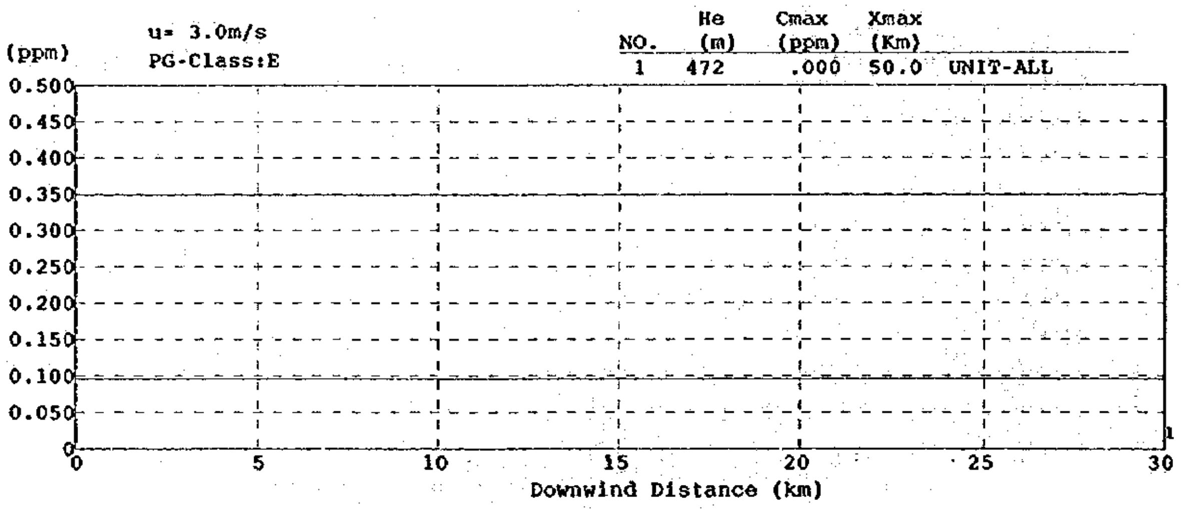


CONCAWE & Plume (SO2)

Candiota Power Station (Future)

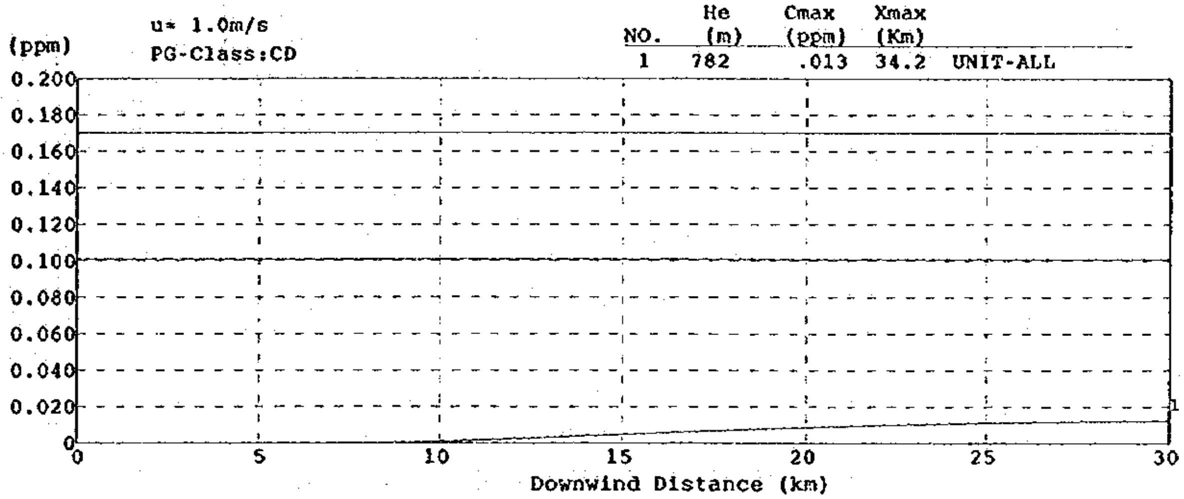


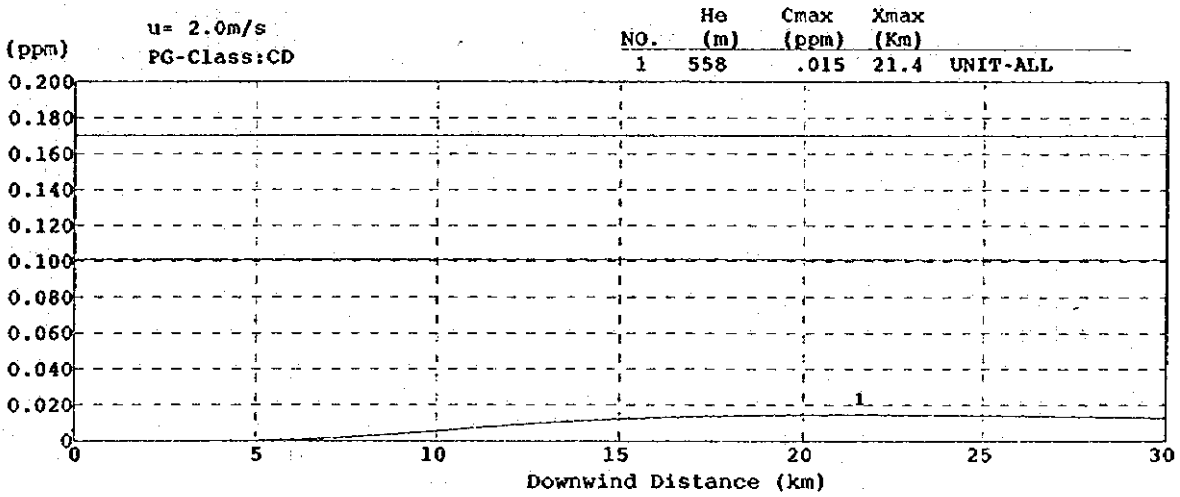


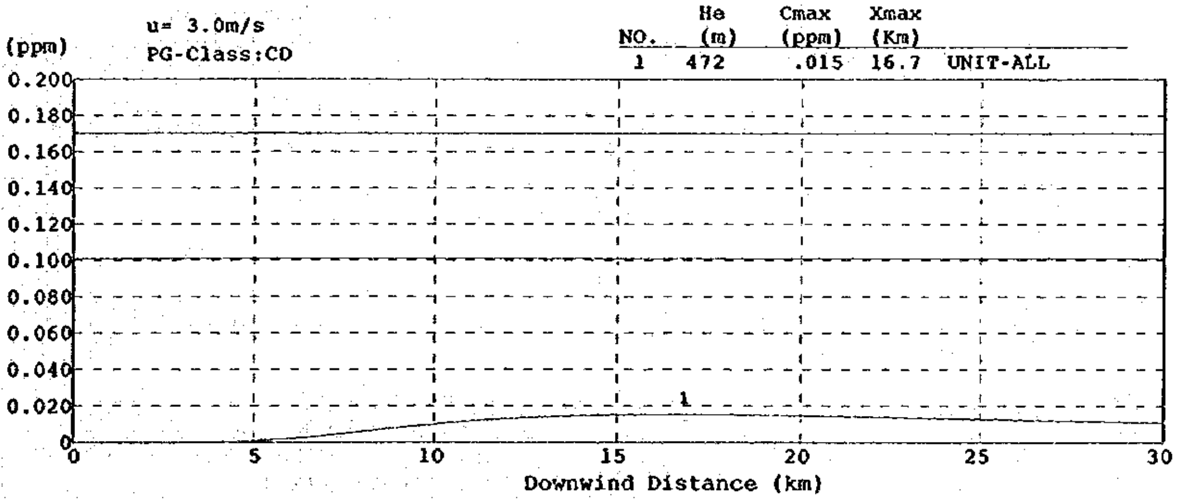


CONCAWE & Plume (SO2)

Candiota Power Station (Future)

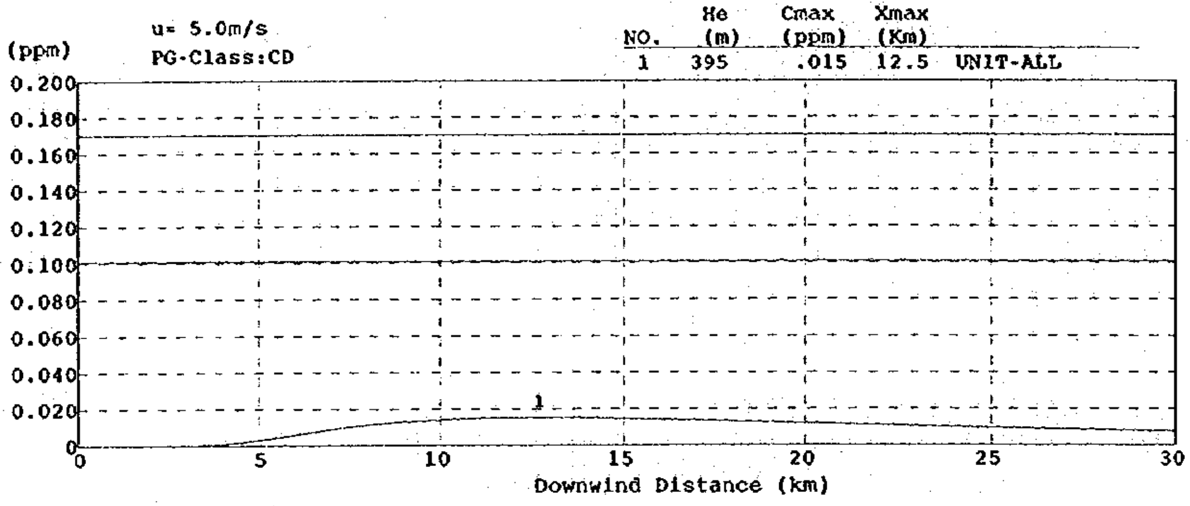


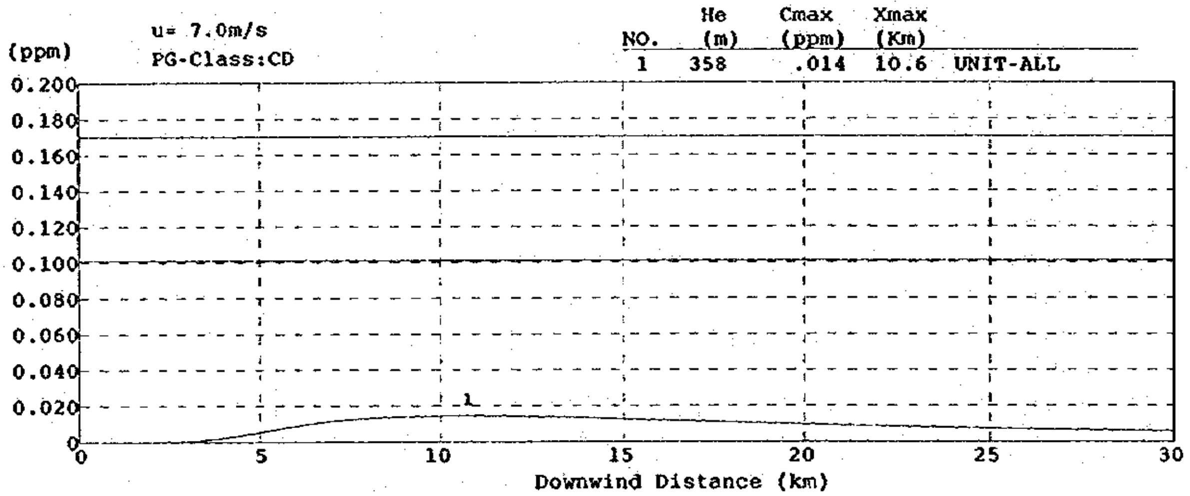


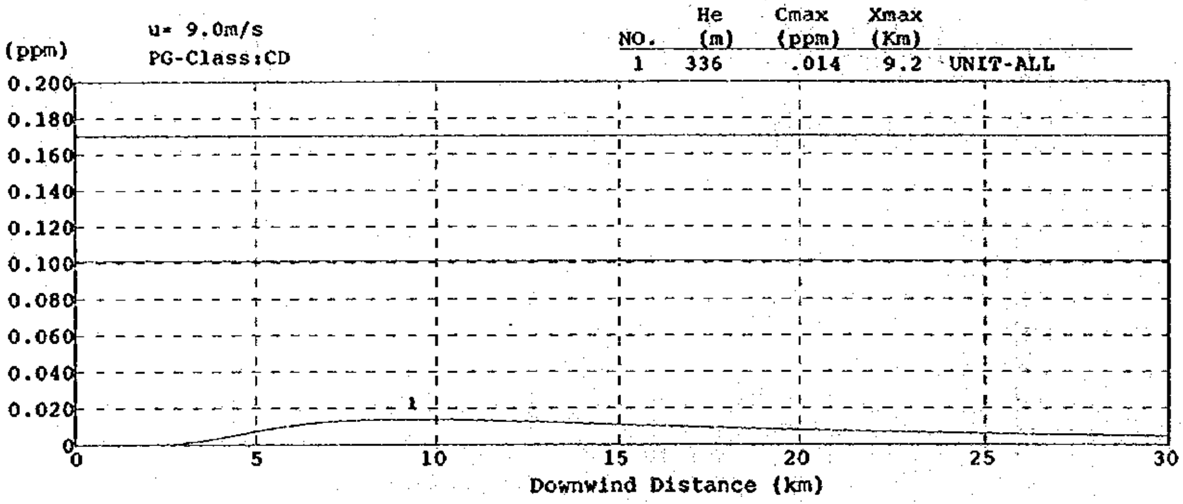


CONCAWE & Plume (NO2)

Candiota Power Station (Future)

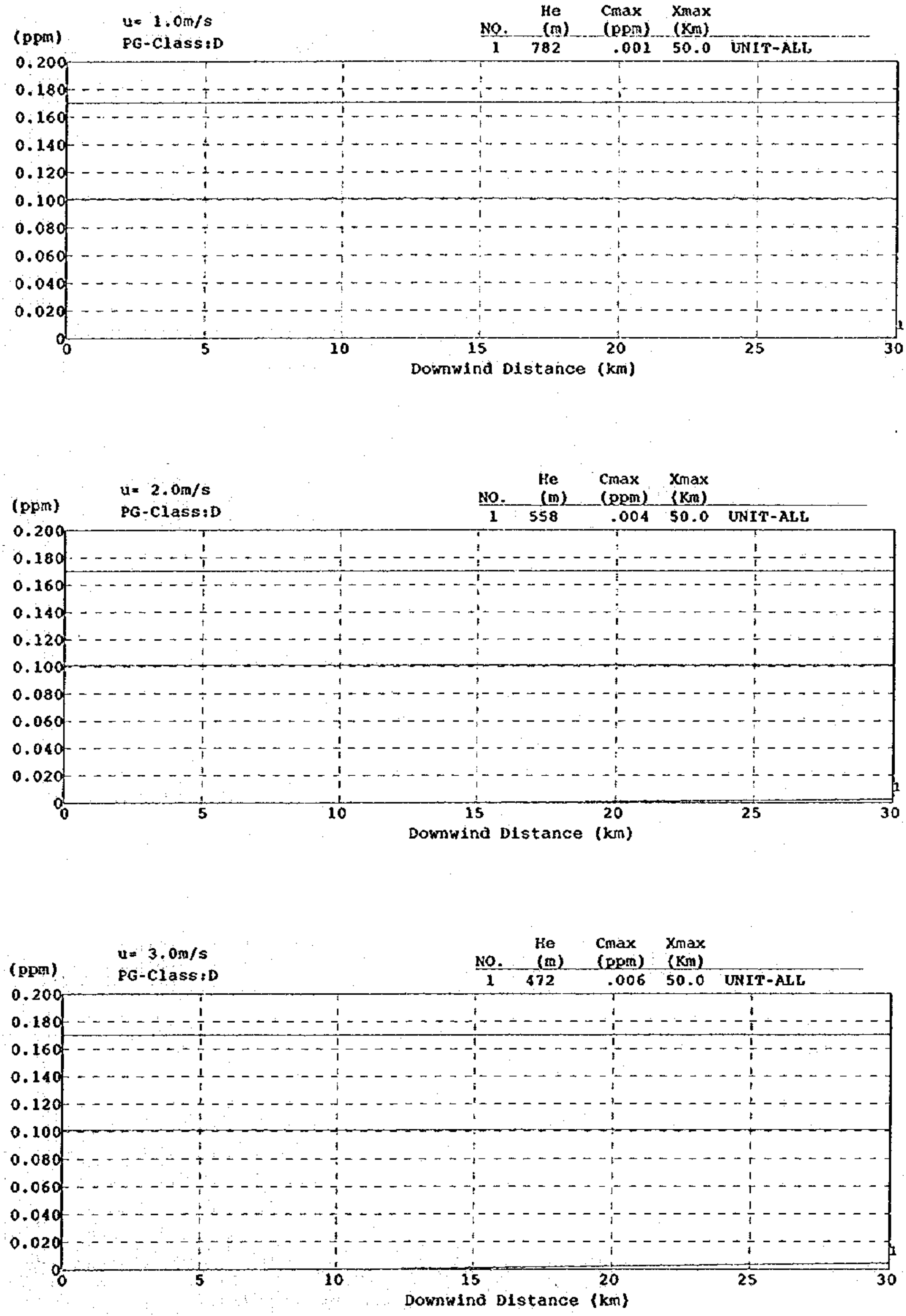






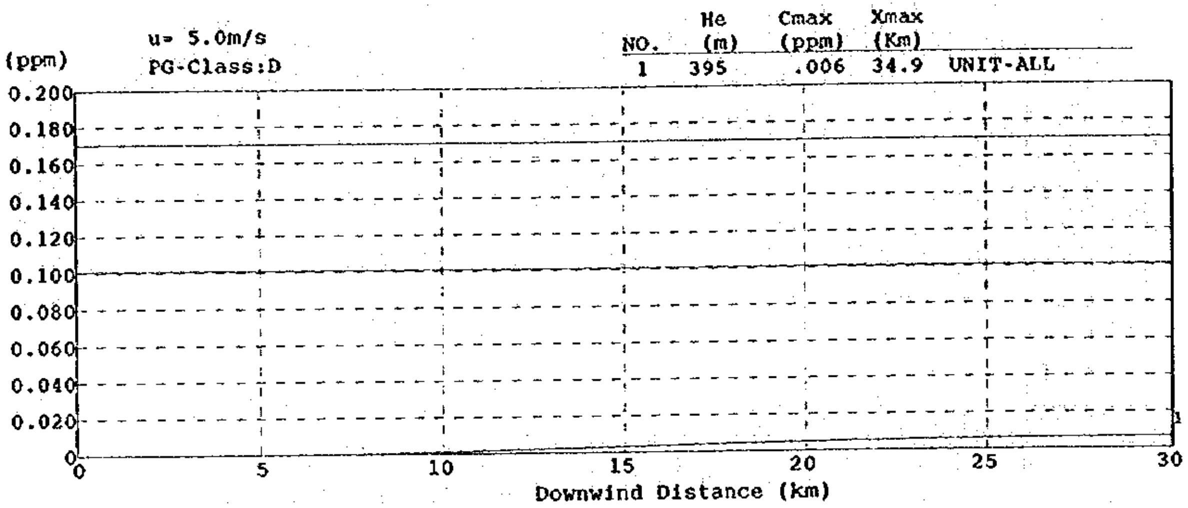
CONCAWE & Plume (NO2)

Candiota Power Station (Future)



CONCAWE & Plume (NO2)

Candiota Power Station (Future)



NO.	He (m)	Cmax (ppm)	Xmax (Km)	
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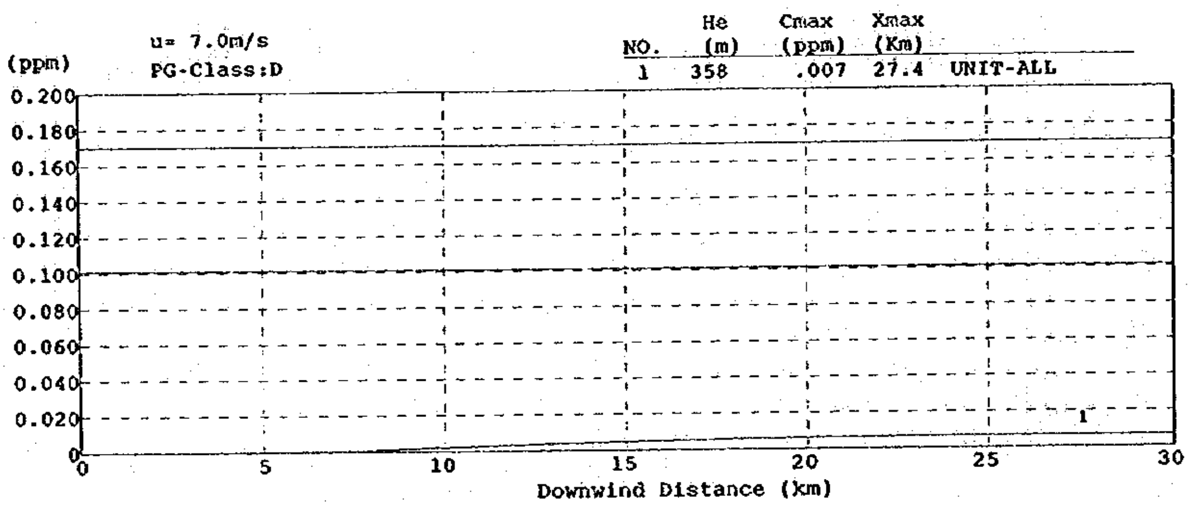

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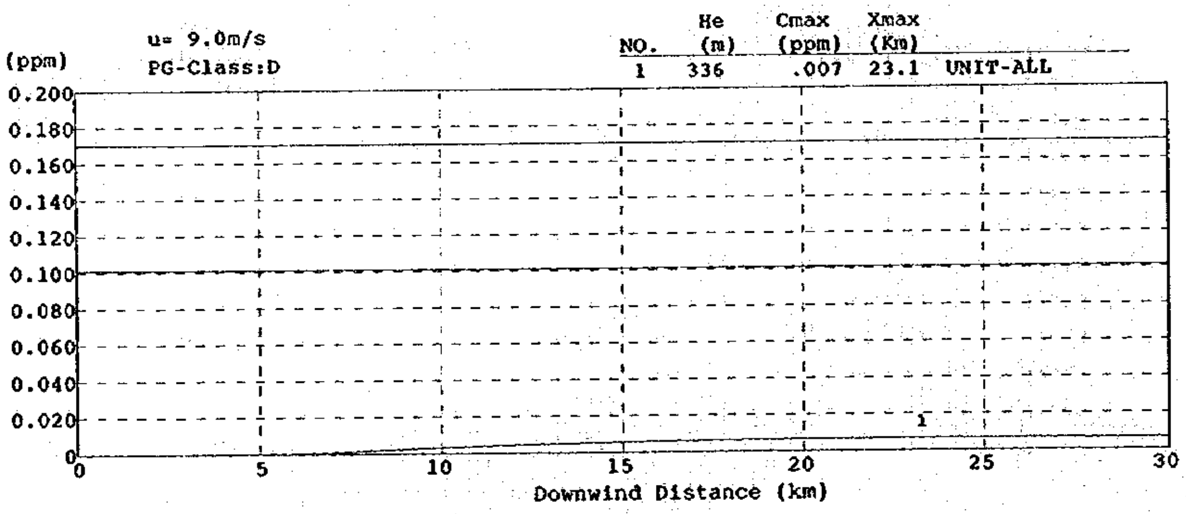

NO.	He (m)	Cmax (ppm)	Xmax (Km)	
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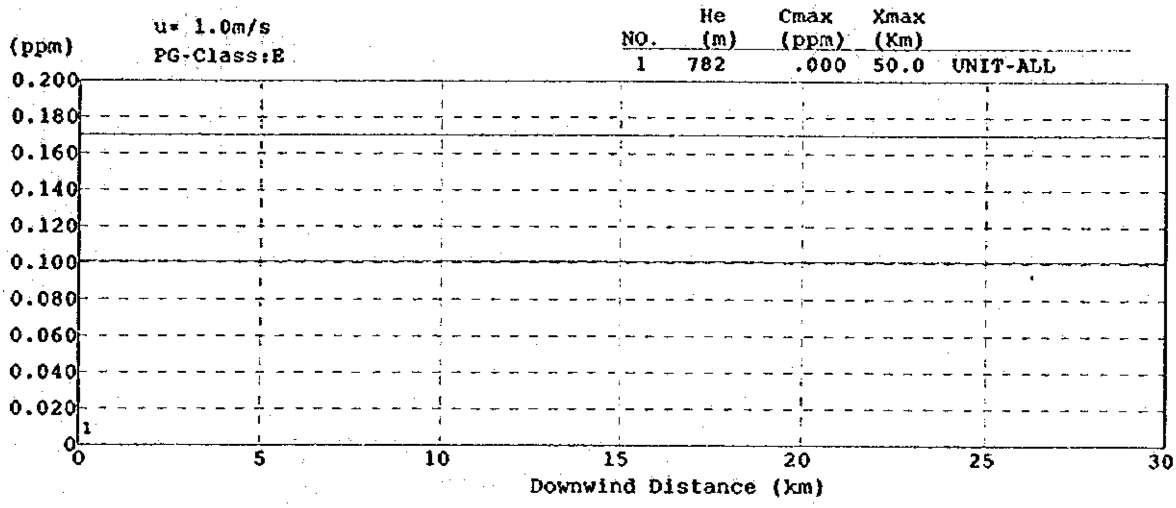
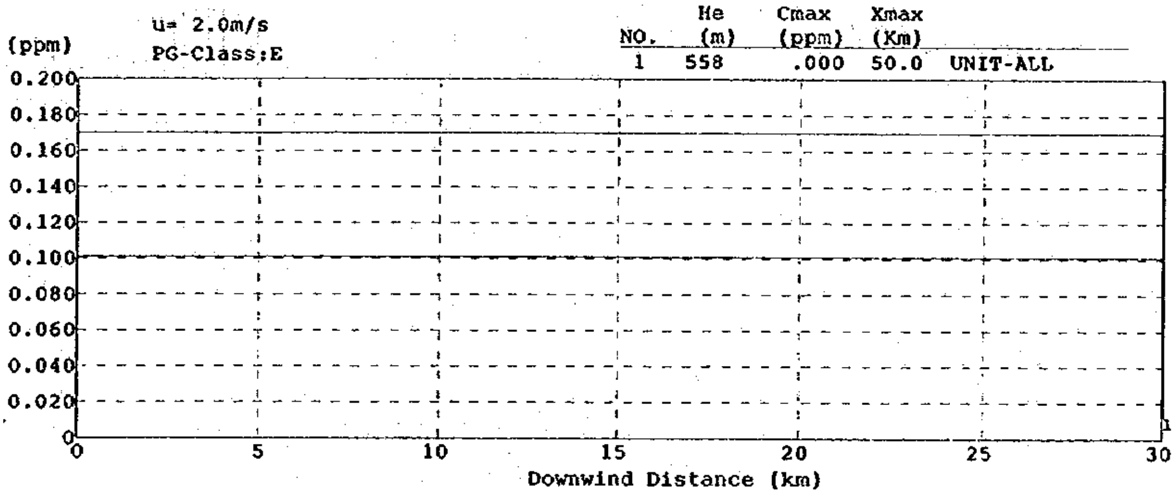
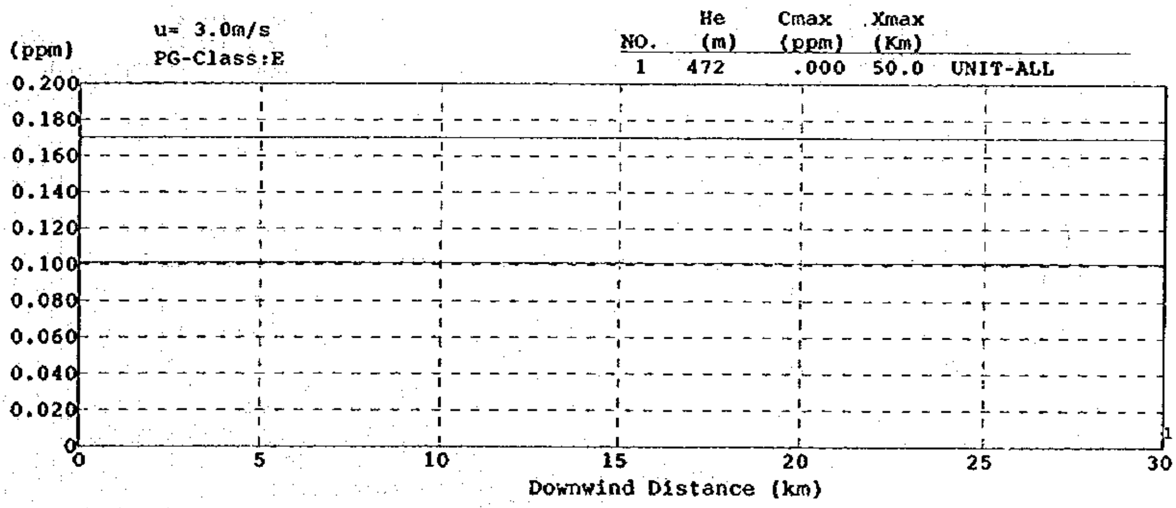
CONCAWE & Plume (NO2)

Candiota Power Station (Future)

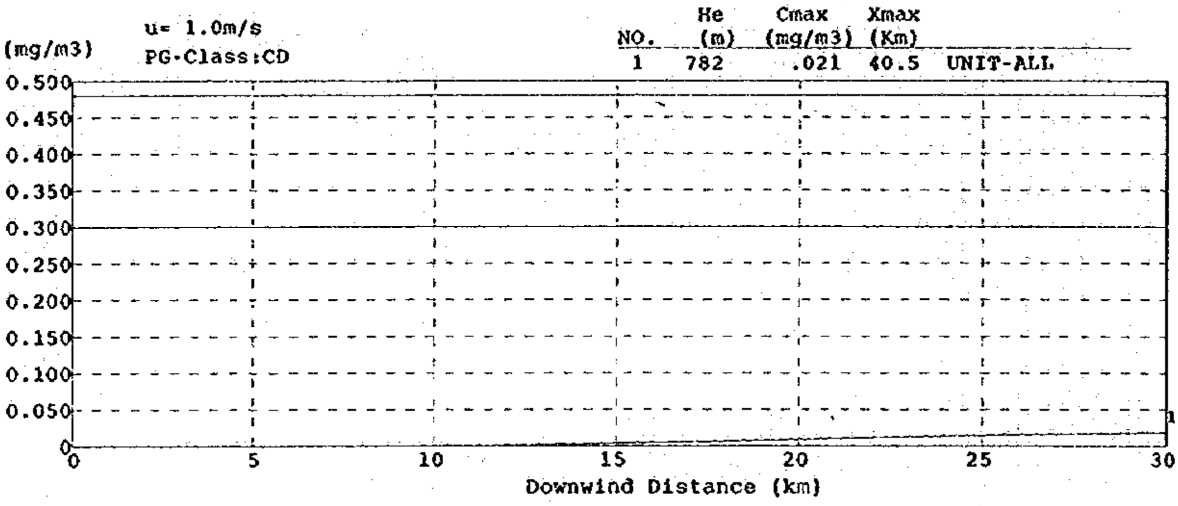


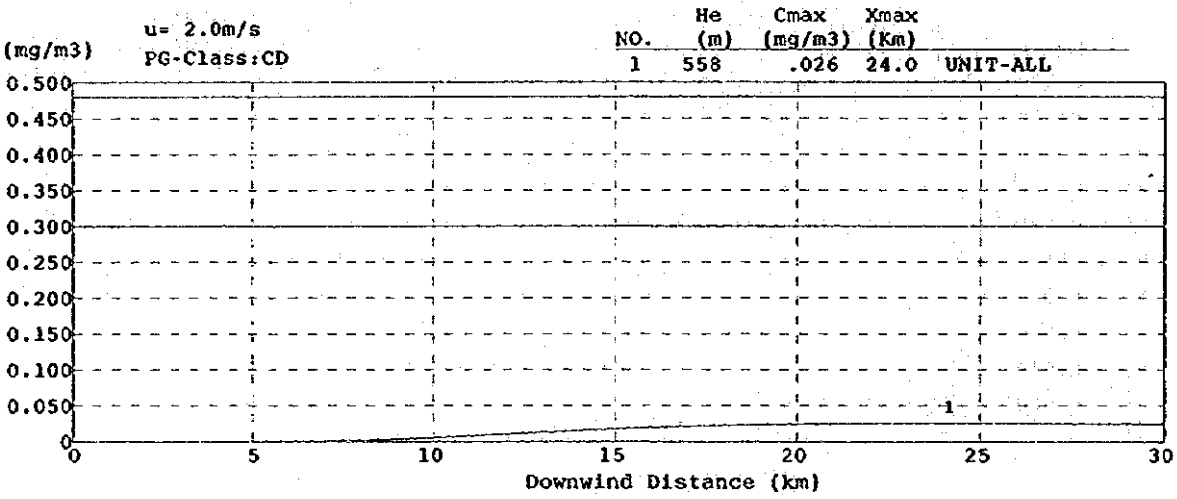


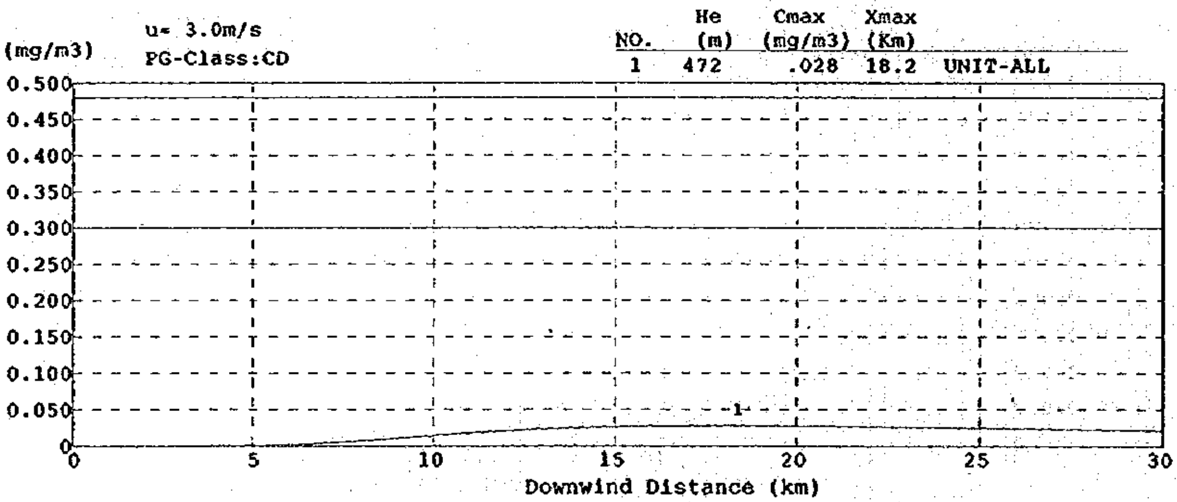


CONCAWE & Plume (NO2)

Candiota Power Station (Future)

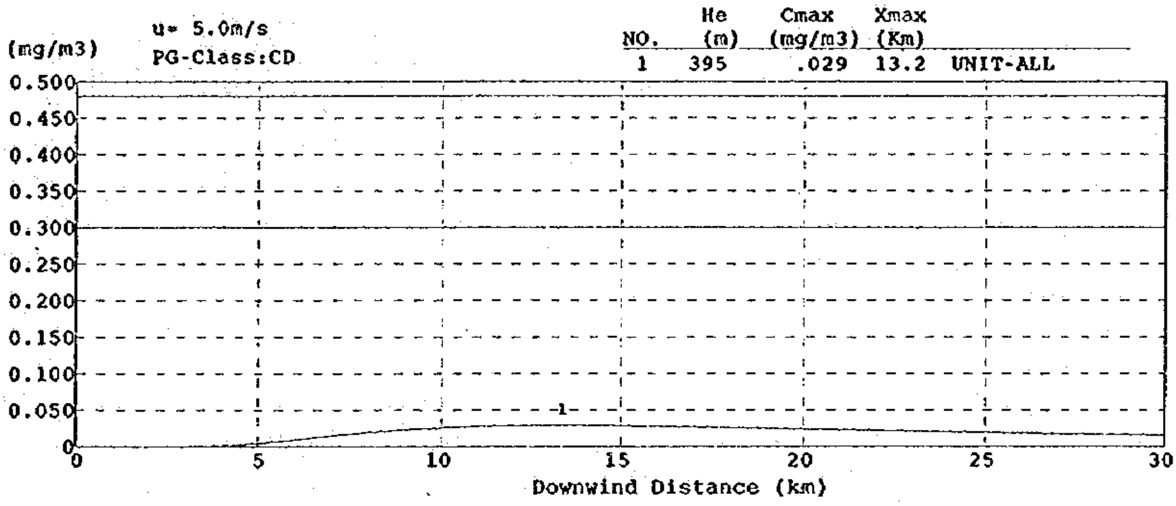


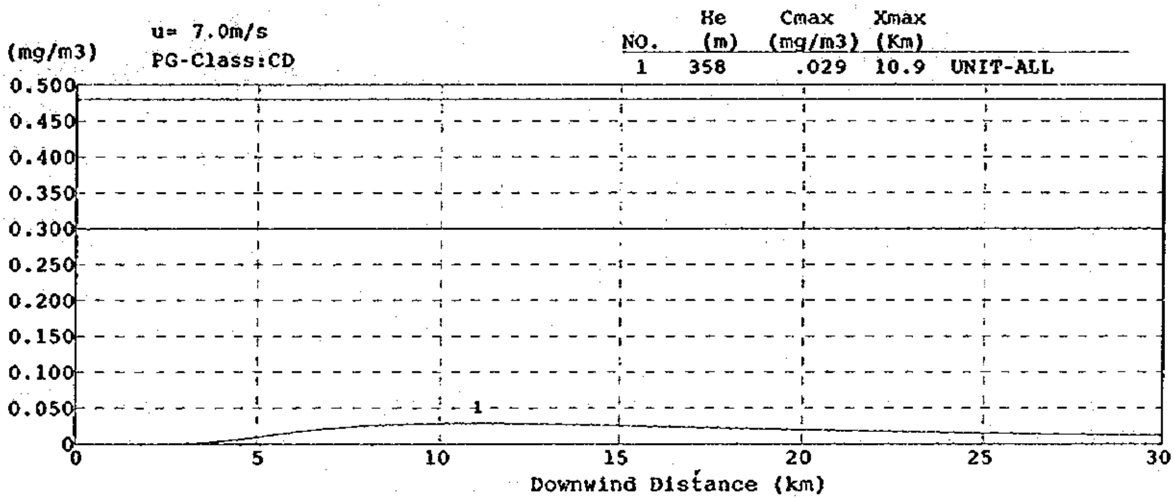


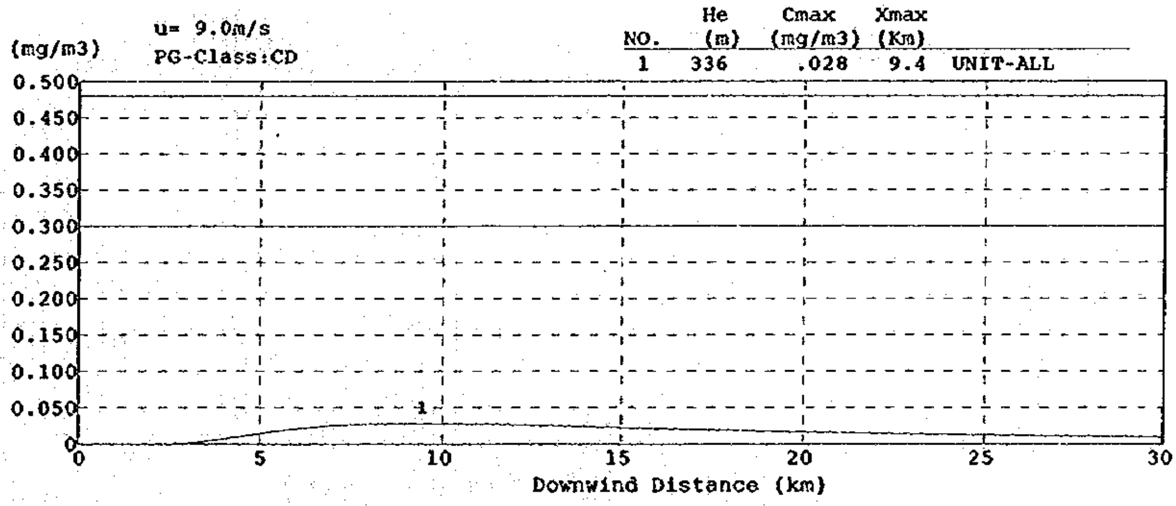


CONCAWE & Plume (Dust)

Candiota Power Station (Future)







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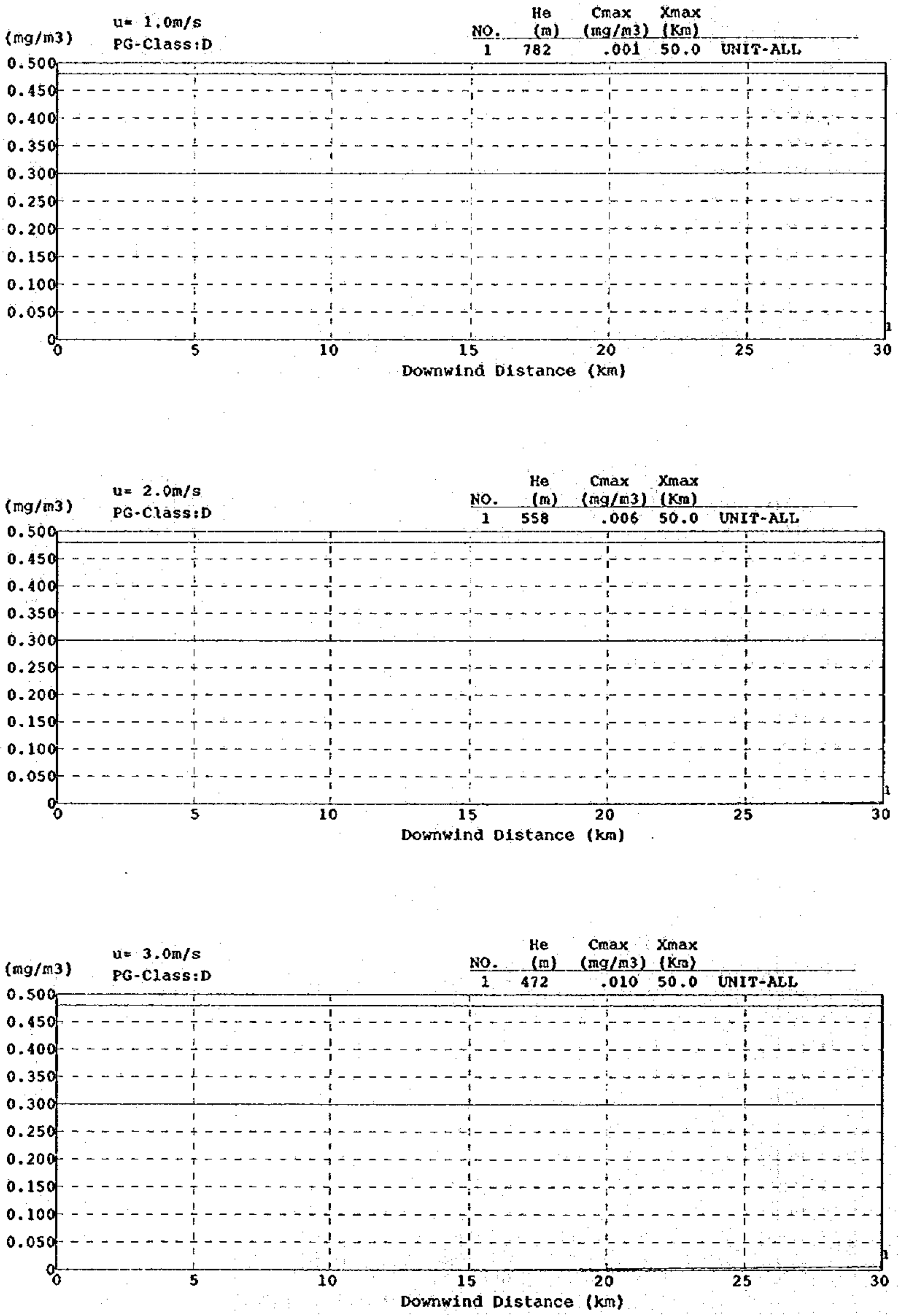

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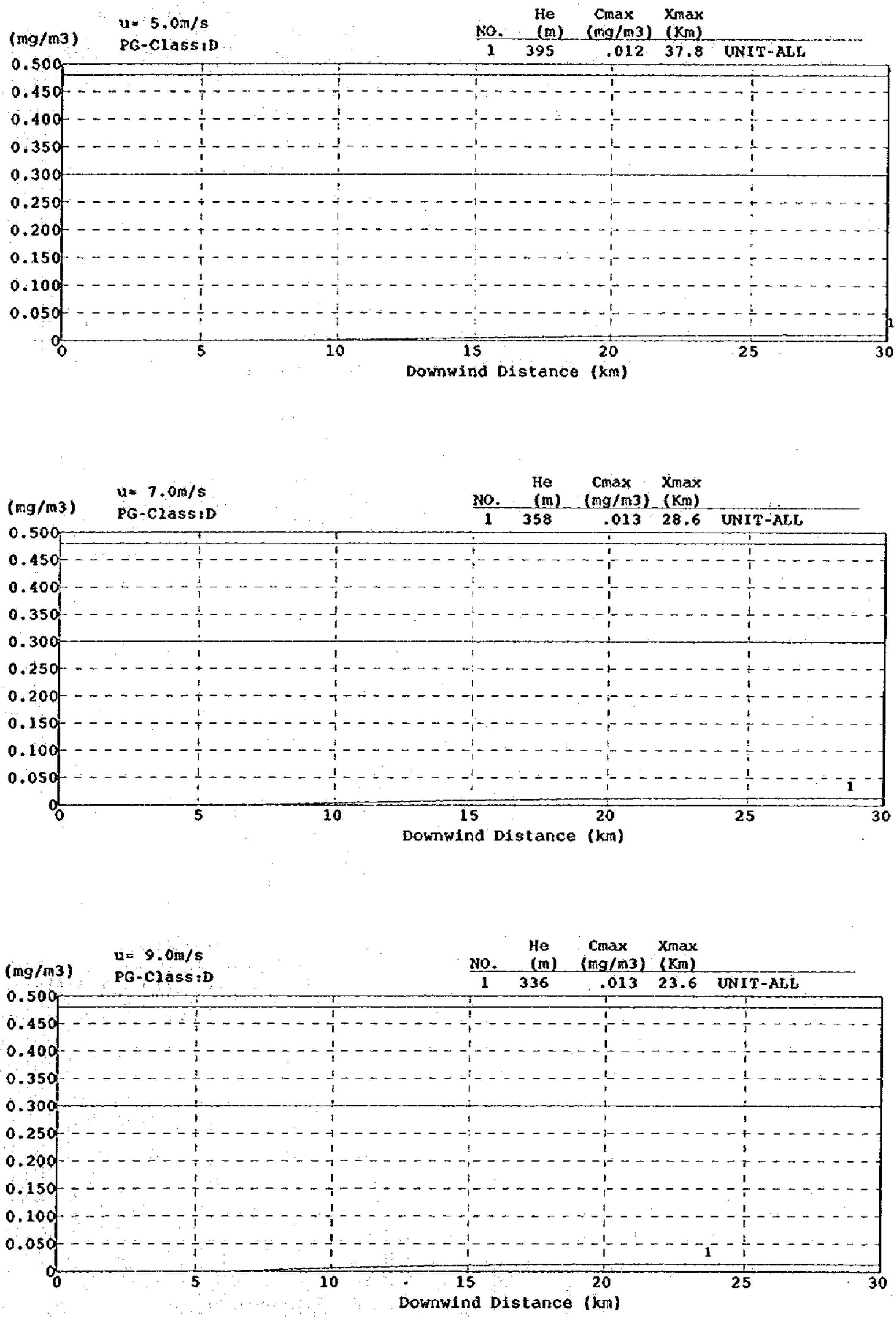

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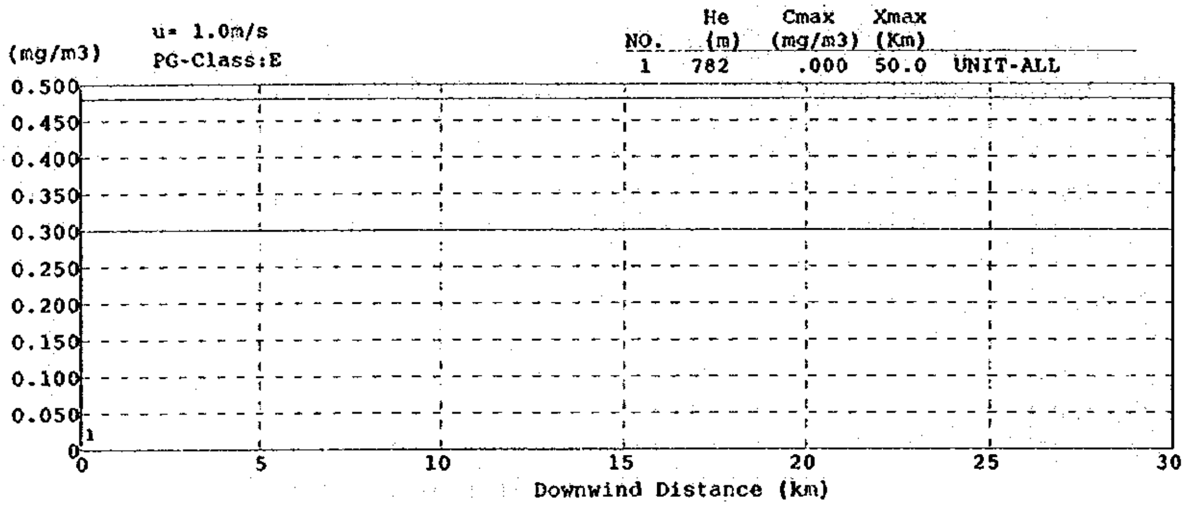

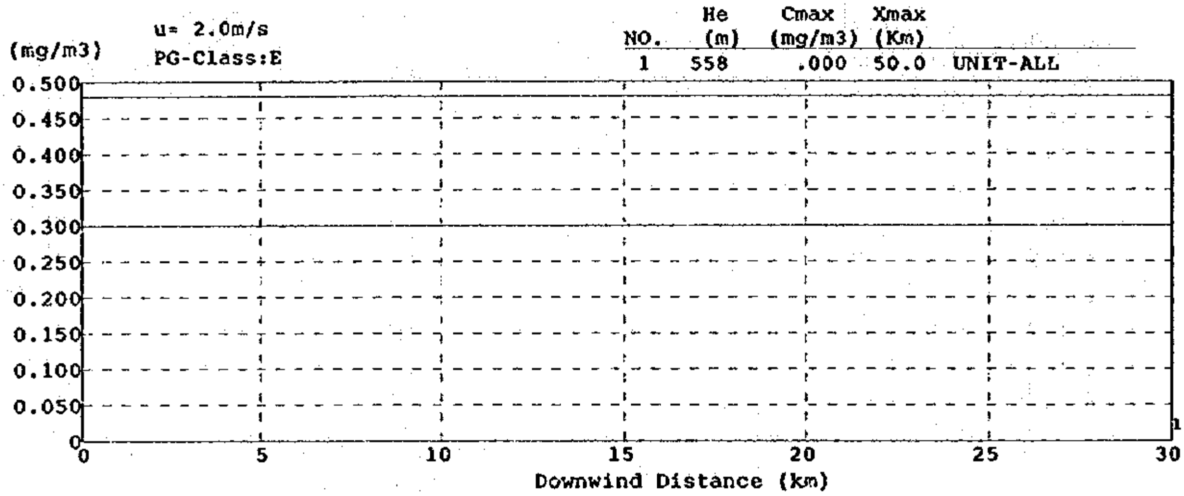

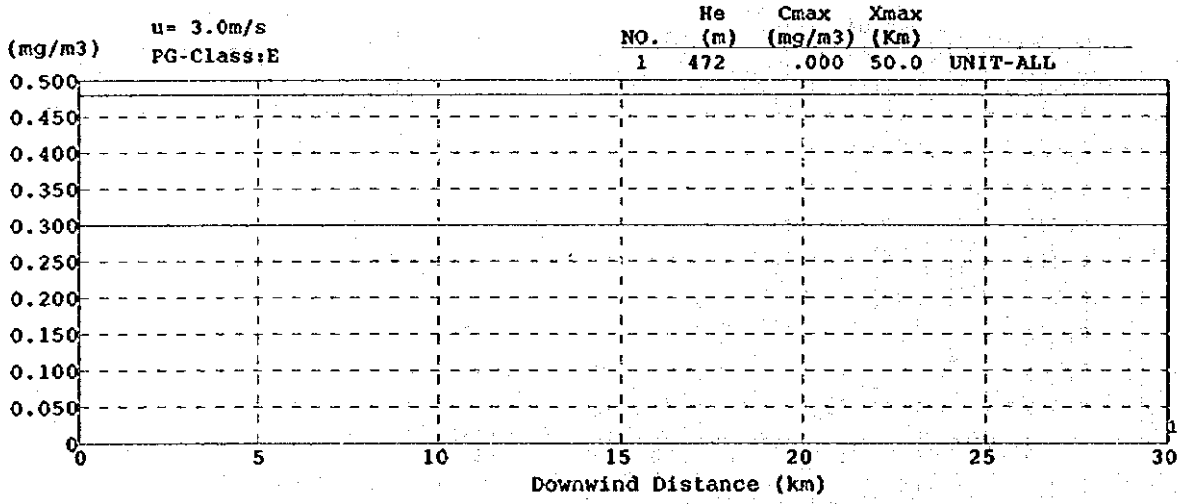

CONCAWE & Plume (Dust)

Candiota Power Station (Future)

Appendix 8-1

Various Air Pollutant Control Measures at Thermal Power Plants (#069, 070)

8.1.1 Measures against Sulfur Oxides

(1) Implementation of Fuel Measures

This is a measure that the volume of sulfur oxides discharged from thermal power plants is reduced by lowering the sulfurization of coal, heavy oil, and crude oil, by using light gas oils such as naphtha, NGL (natural gas liquid), etc., with a small volume of sulfur as a fuel, or by using gas fuels such natural gas (including LNG : liquefied natural gas), etc.

(2) Implementation of Facility Measures

This is a measure that sulfur oxides are removed directly from flue gas by means of flue gas desulfurization facilities. **Table 8.1.** shows various kinds of desulfuring methods.

Table 8.1 Kind of Flue Gas Desulfurization Processes

	Kind of Processes	Absorbent	Regime of absorbing solution	Raw material		By-product
Wet type	Lime-Gypsum process	Calcium sulfite $CaSO_3$	Slurry	Calcium carbonate Slaked lime Quick lime	$CaCO_3$ $Ca(OH)_2$ CaO	Gypsum
	Mg-Gypsum process	Magnesium sulfite $MgSO_3$ Calcium sulfite $CaSO_3$	Slurry	Slaked lime Calcium carbonate	$Ca(OH)_2$ $CaCO_3$	Gypsum
	Sulfite Tank-Mirabilite process	Sodium sulfite Na_2SO_3	Solution	Caustic soda	$NaOH$	Mirabilite Discharging
	Sulfuric tank recovery method			Caustic soda	$NaOH$	Soda sulfite
	Sulfite tank-Gypsum process			Calcium carbonate Slaked lime Quick lime	$CaCO_3$ $Ca(OH)_2$ CaO	Gypsum
	Sulfite tank-Sulfuric acid process			—		Sulfuric acid
	Diluted sulfuric acid - Gypsum process	Diluted sulfuric acid	Solution	Calcium carbonate	$CaCO_3$	Gypsum
	NH_3-Ammonium sulfate process	Ammonium sulfite $(NH_4)_2SO_3$	Solution	Ammonia	NH_4OH	Ammonium sulfate
	NH_3-Gypsum			Slaked lime	$Ca(OH)_2$	Gypsum
	Al-Gypsum process	Basic aluminum sulfate $Al_2(SO_4)_3 \cdot Al_2O_3$	Slurry	Calcium carbonate	$CaCO_3$	Gypsum
	Mg process	Magnesium sulfite $MgSO_3$	Solution	Magnesium hydroxide	$Mg(OH)_2$	Magnesium sulfate Discharging
Dry type	Activated carbon absorption process	Activated carbon		Activated carbon		Sulfur
	Spray dryer process	$Ca(OH)_2$ Na_2CO_3	Slurry	Slaked lime Sodium carbonate	$Ca(OH)_2$ Na_2CO_3	Gypsum Others

1) Wet Type Lime - Gypsum Method and Facilities

The wet type lime-gypsum flue gas desulfurization basic process is a method based on the following procedures : 1) sulfur dioxide (SO_2) in flue gas is gas-liquid-contacted with absorbing solution slurry containing limestone in the absorbing tower in order to get calcium sulfite, 2) the calcium sulfite in this absorbing solution is completely oxidized with air in order to get gypsum, 3) after free water is separated from the gypsum, the gypsum will be taken out as a by-product. **Figure 8.1** shows a schematic flow diagram of a lime-gypsum process desulfurization facilities.

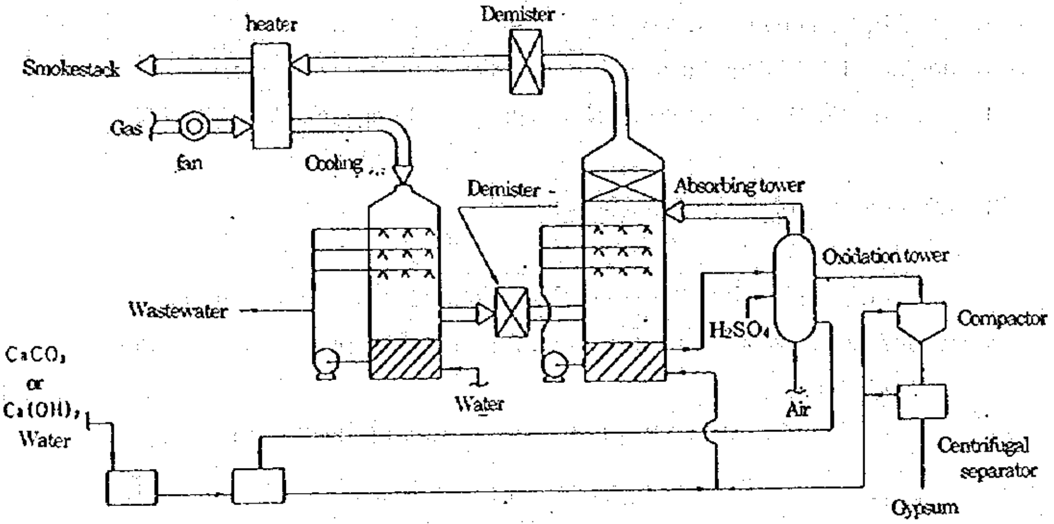

Figure 8.1 : Schematic flow diagram of a lime-gypsum process desulfurization facilities

2) JBR Method and Facilities

The JBR (jet bubbling reactor) method is a kind of lime-gypsum method that SO_x in flue gas is absorbed, oxidized, and neutralized with limestone as a neutralizer.
This method is simple and revolutionary, because the number of facilities is small, the area where such facilities are installed is also small, and the construction and operation costs are lower than those in the case of other methods as well as it is possible to solve scaling problems.
Figure 8.2 shows a schematic flow diagram of a JBR method desulfurizer.

(2) Basis for Adoption of Wet Type Lime - Gypsum Method Flue Gas Desulfurization Process

Lime - gypsum method flue gas desulfurization facilities have the following characteristics, and are widely employed in Japanese power plants because it is the most reliable and the economical one from the general point of view.

1) Its process is relatively simple and high SO_2 removal efficiency can be obtained.
2) Operation is stable and the facilities can withstand severe load changes.
3) Long continuous operation is possible.
4) Lime, the absorber, is found in abundance and costs low.
5) Gypsum which is a collected by-product can be sold as raw material of cement, gypsum boards etc, and can be stored relatively easily without environment pollution.
6) Secondary environmental pollutants are not generated.
7) Safe chemicals and chemical matter are used.

Because of the above-mentioned advantages, the lime - gypsum method is widely employed abroad. It is considered that this process is the most advantageous selection in circumstances where lime can be obtained easily.

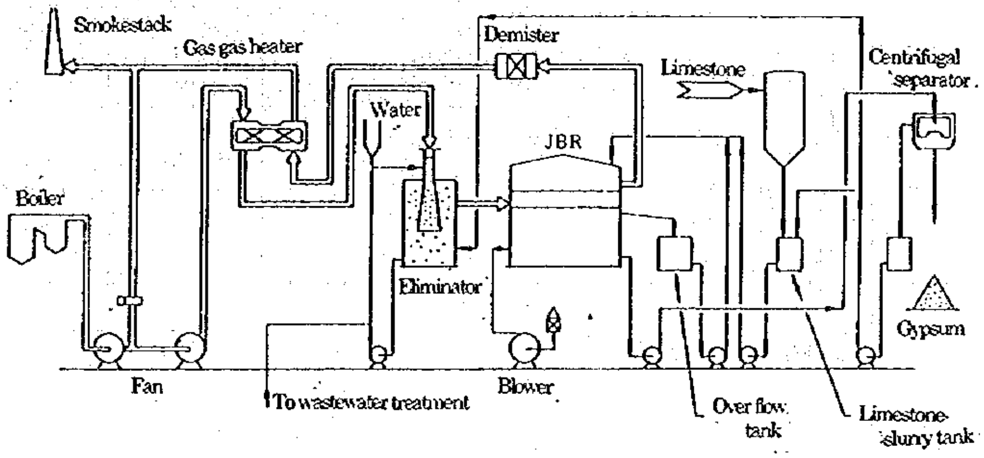

Figure 8.2 : Schematic flow diagram of a JBR method desulfurization facility

(3) Simple Flue Gas Desulfurization

Though wet type lime - gypsum method flue gas desulfurization facilities have the advantageous characteristics mentioned above, its construction cost is expensive. Therefore, research and development of flue gas desulfurization facilities are being carried out now aiming at wide use of flue gas desulfurization facilities in the world by cutting down expenses sharply by simplifying facilities and processes as much as possible. Generally, reduction of construction cost of facilities is achieved with the items shown in **Table 8.2**. In addition, consideration of the user side is important.

In order that the simple desulfurization process will be introduced in facilities in various countries, it is expected that cost will be cut down to around 1/5 - 1/3 of that of the present lime - gypsum method. Although it can not be forecasted at the present time whether or not it will be possible, development is being promoted now to satisfy such needs.

Table 8.2 Measures to Cut Down Construction Cost of Flue Gas Desulfurization Facilities

Item	Description	User Side's Consideration
Decrease of engineering time	New planning and designing will not be conducted each time.	Using flue gas desulfurization facilities with standard arrangement, standard capacity and standard specifications
Miniaturization of devices/ machines comprising facilities	Deletion of design surplus, Development of new design	Lowering the demanded level of desulfurization rate within the range where no matters won't occur in view of environmental preservation.
Examination of materials of devices/machines	Conversion from high-grade materials to low-priced materials	Supporting with a regular maintenance plan.
Simplification of processes	Development of process where some of constituent devices/machines/facilities are omitted/integrated	Lowering demanded levels of peripheral matters such as quality standards of gypsum.
Omission of some of constituent devices / machines / facilities by simplifying the control method		Adopting a minimum automatic control process required

(4) Operation and Maintenance Technologies

1) Operation

In many cases, operation of flue gas desulfurization facilities adopted in Japanese thermal electric power plants is operated automatically with instrumentation control systems. However, since full automation from starting to stopping is difficult from the viewpoint of safety and economy, facilities are left to operators' judgement and operation. Therefore, it is the most important point to educate operators so that they can cope with exactly whatever kinds of events occur. Some of makers of flue gas desulfurization facilities have developed teaching materials for education, and computer software for operation supporting systems which help judgement. It is one way to use them. As the alarm may sound during normal operation, operators need to judge the situation and take necessary actions.

Though Japanese flue gas desulfurization facilities had many troubles in the early stage, the number of troubles is small now as a result of pH control and regular maintenance and inspection.

2) Maintenance

For flue gas desulfurization facilities adopted in thermal electric power plants in Japan, as the minimum condition is capability of continuous operation for 1 - 2 years, reliability of long continuous operation is emphasized upon designing. However, the point to see is importance of inspection at the time of regular inspection and overhaul of facilities by repair work. It is important to establish a maintenance system with a special organization formed, including supply of spares, understanding of problems and structures of each kind of facilities, establishment of a cooperation system with makers concerned, preparation of regular inspection manual and solution of troubles during normal operation. It is also necessary to install an isolation dumper capable of shutting gas out completely in the gas system, considering that people go inside the facilities for inspection/maintenance in case operation stops for an accident or one system is separated.

(5) Construction Cost and Maintenance Cost

In the case of installation of wet type lime - gypsum method flue gas desulfurization facilities, construction cost is as high as ¥15,000 - ¥7,000/kW in Japan. For example, for facilities to be built in a power plant of 500MW, required construction cost ranges from 3.5 billion yen to 7.5 billion yen. If simple desulfurization process where SO_2 removal efficiency is lowered a little is employed, construction and operation costs will be able to be reduced. Maintenance cost depends on the concept of designs. If due consideration of technical subjects is given to design and reliable parts are used, maintenance cost will be low. Though there is no typical figure, annual direct maintenance cost excluding of labor cost of a maintenance team is around 2% of construction cost.

(6) Tendency of Future Technologies

Lime - gypsum method flue gas desulfurization process has a history of about 25 years, and is a completed process which can be used practically in full. However, controlling situation surrounding power plants is severe, and there is possibility of further improvement of disulfuring capacity and introduction of technology to eliminate drainage (non-draining).
On the other hand, in order to spread flue gas desulfurization processes in the world and to protect global environment, simple flue gas desulfurization processes where construction cost is cut off sharply have been already established. **Table 8.3** shows noteworthy flue gas desulfurization technique other than lime - gypsum method flue gas desulfurization.
For the electronic beam method among them, Japanese electric power company has developed facilities of 225MW jointly with an engineering and construction contractor and tests are now being carried out. Although the seawater desulfurization method is not used in Japan because of low desulfurization efficiency, there are examples in Norway, India etc.

Table 8.3 Tendency toward the Future of Flue Gas Desulfurization Technique

Name etc.	Description	Problems etc.
Electric beam method	Method to convert NO_x and SO_2 to mixture of ammonium nitrate and sulfate by irradiating flue gas with electric beam under the existence of ammonia and then activating NO_x and SO_2. Because temperature of gas doesn't fall much, there are advantages such as no cost of re-heating and no drainage. It is said that construction and operation costs of this method can comprehensively compete with those of the lime - gypsum method.	Though by-products can be used as manure, they are subject to sales routes and market size.
Seawater desulfurization method	Method to disulfurize by Ca/Mg contained in seawater. Used seawater is treated and discharged. As a large quantity of seawater is required, it is necessary that a power plant is adjacent to the seashore.	Assessment regarding sea pollution.

8.1.2 Measures against Nitrogen oxides

As measures for reduction of nitrogen oxides, there are three methods; fuel measures, combustion improvement and installation of flue gas denitrification facilities.

(1) Implementation of Fuel Measures

This is a measure to restrain the amount of nitrogen oxides emitted from thermal power plants by using light gas oils (naphtha and NGL), LNG etc. with a small amount of nitrogen as a fuel.

(2) Combustion Improvement

As to thermal NO_x, the higher combustion temperature inside a furnace is, also the higher O_2 concentration is , and the longer retention time in high temperature is, the more No_x is generated. So the quantity of NO_x generation can be restrained by reducing O_2 concentration in combustion gas by restraining excess air.

Measures for restraint of NO_x emission by means of combustion improvement include the low excess-air combustion method, the two stage combustion method, the exhausted-gas mixture method and the process employing a low NO_x burner.

1) Two-Stage Combustion Method

Two-stage combustion process is a method based on the following procedures: 1) the supply of air to the lower part of a furnace is restrained for combustion in reduction atmosphere, 2) subsequently the insufficient amount of air is added from the upper part of the furnace, and as a result volume of NO_x generated by combustion is restrained. Though this method is effective particularly for coal combustion, observation and care are required because the combustion is likely to be unstable, and there are tendencies that the unburned combustibles in ash increase and more dust is generated.

There is another measure which takes one more step forward. In this method fuel is blown into the upper part of flames combusting in furnace, in order to be burned in reduction atmosphere and reduce NO_x generation., and then further air is blown into furnace to make complete combustion. With this process, NO_x can be reduced by around 50%. (It is called Furnace Denitrification, Three-Stage Combustion or Re-burning process.)

However, as a little higher height of a furnace is required, it is difficult to apply this method for existing furnaces.

2) Flue Gas Recirculation

The flue gas recirculation process is a method to reduce NO_x by returning a part of flue gas at around 350 to 400°C to the vicinity of a burner and mixing it with combustion air so as to lower combustion temperature and O_2 concentration during burning.

Too much volume of recirculated flue gas is effective for reduction of NO_x. However, as the more volume of recirculated flue gas exists, the poorer combustion occurs, it is considered that the limit of the volume of recirculatied flue gas is 20 - 30 % of that of combustion air.

3) Low-NO_x Burner

Low-NO_x burner has the structure to promote burning under the optimum conditions by forming the combusting area with concentrated fuel and that with lean fuel in the burner part so as to make premixed combustion and diffuse combustion in each burner. With this structure, generation of NO_x is reduced by lowering combustion temperature and oxygen concentration in the burner part and shortening the retention time of combustion gas.

4) Measures for Reduction of NO_x by Means of Combination of Combustion Improvement measures

It is possible to further reduce emission of NO_x with synergetic effect of combination of combustion improvement measures. In many cases in small-sized facilities, NO_x is decreased by 20 - 40 % by changing fuel from heavy oil to kerosene or by using low NO_x burners. In the large-sized facilities, NO_x is decreased by up to around 60 - 70% by combining low NO_x burners, two stage combustion, flue gas recirculation etc. NO_x at an exit of a burner is decreased to 150 - 300ppm in the case of a coal burner, and to 80 - 200ppm, 60 - 100ppm and 40 - 80ppm in the cases of heavy oil, kerosene and gas respectively. NO_x emission standards can be generally cleared with these combustion improvements. However, in Japan, as emission is regulated severely with the local regulations and agreements, various kinds of more desulfurization measures to dispose of flue gas is necessary.

Measures for reduce NO_x by means of combustion improvement are as shown in **Figure 8.3** and **Table 8.4**.

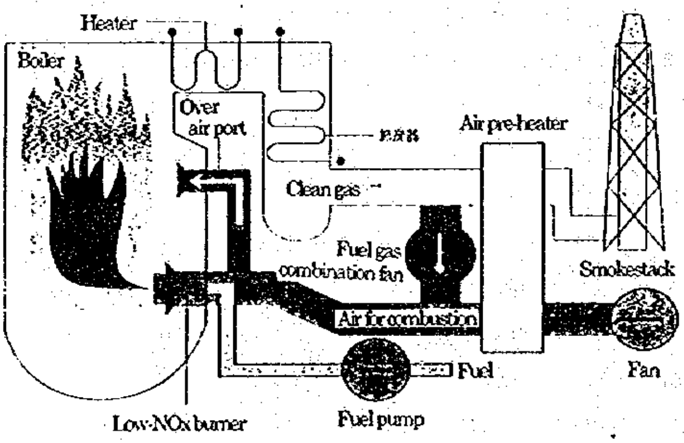

Figure 8.3 Measures for reduce NO_x by Combustion Improvement

Table 8.4 Reduction of NO_x by Combustion Improvement (#070)

(Unit: NO_x ppm)

Fuel		Coal	Heavy oil	Kerosene	Gas
N(%)		0.7~3	0.1~0.5	0~0.3	0
Converted value		6	4	4	5
①	Standard combustion	550~800	400~500	350~450	300~400
②	Excess air	600~900	500~600	400~500	350~450
③	Low oxygen combustion	450~650	300~400	250~350	200~300
	③+ Two stage combustion	300~500	200~300	150~250	150~200
④	③+ Flue gas recirculation	350~550	200~300	150~250	150~200
⑤	④+ Flue gas recirculation	200~400	200~300	100~150	80~120
⑥	⑥+ Low NO_x burner	150~300	80~200	60~100	40~80

(3) Implementation of Facility Measures

As a measure to remove NO_x by disposing of flue gas, there is a flue gas denitrification process. As the reactivity with absorbing solution is low because the large portion of nitrogen in flue gas exists as NO, the dry process is exclusively used.

In the dry process, a method to reduce NO_x to N_2 is employed. Ammonia is generally used as a reducing agent which reacts selectively with NO_x.

Various kinds of main dry method flue gas denitrification process are shown in **Table 8.5**.

Table 8.5 Kind of flue gas denitrification process

Dry method	Wet method
• Selective catalytic reduction process • Non-selective catalytic reduction process • Non-catalytic reduction process • Catalytic cracking process • Absorption process • Adsorption process • Electron beam irradiation process	• Gas-phase oxidation absorption process • Liquid-phase oxidation absorption process • Complex-salt-generating absorption process

1) Denitrification Process

Denitrification processes can be classified into two methods, according to installation places of denitrification reactor, as follows :

① High-Dust Denitrification Process

This is a process where flue gas from boiler is introduced directly to denitrification facilities and then dust is removed by an Electrostatic Precipitator in the rear stream.

It is general to adopt this process for boilers using such fuel as LNG, heavy or crude oil.

② Low-Dust Denitrification Process

This is a process to denitrify after dust removal. The Electrostatic Precipitator is installed in the upper stream of denitrification facilities. It is sometimes used for denitrification of gas containing a large amount of So_x and dust.

As for both processes, denitrification facilities do not put any restriction. Either system should be determined upon a practical plant plan, with comprehensive examination.

2) Denitrification Catalyzer

① Required conditions for denitrification catalyzer :

1. High denitrifying capacity in the temperature range where it is used
2. Few side reaction such as conversion from SO_2 to SO_3
3. Sufficient durability
4. Sufficient mechanical strength and heat resistance
5. Abrasion resistance, in the case of flue gas containing dust likely to cause abrasion

As catalyzers which satisfy these conditions, several kinds of catalyzers are put to practical use now. For main ones, porous ceramic such as titan and aluminum is used as a carrier, to which several kinds of metal oxide compounds etc. are given as an active component.

② Selection of Denitrifying Catalyzers

Catalyzers are required to have capabilities according to properties of flue gas.
In case of clean gas exhausted, using LNG as a fuel, catalyzers only with heat resistance should be selected because flue gas doesn't contain dust and SO_x which causes deterioration.
For dirty gas exhausted using heavy/crude oil or coal as a fuel, as flue gas contains dust and SO_x, it is necessary to consider how to dispose of them.
Table 8.6 shows variety of boiler fuel and points to be duly considered for selection of catalyzers.
Figure 8.4 shows the entire arrangement plan including denitrification facilities by catalytic reduction of nitric oxide with ammonia.

Table 8.6 Variety of Boiler Fuel and Points to be duly Considered for Selection of Catalyzers

Kind of Fuel		Considerations
Gas		High activity, heat-resistance
Heavy/Crude Oil		High activity, heat-resistance, resistance to suffering from dust poison, SO_x resistance, Low SO_3 conversion rate
Coal	Low-Dust Denitrification	Ditto
	High-Dust Denitrification	Ditto, abrasion resistance

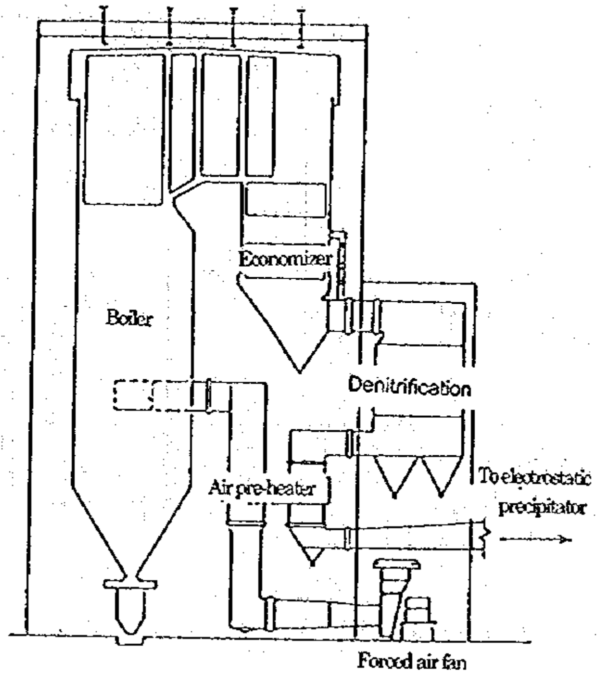

Figure 8.4 The Entire Arrangement Plan including Denitrification Facilities by Catalytic Reduction of NO_x with ammonia

3) Construction Cost of Denitrification Facilities

Construction cost of denitirification facilities largely differs according to types of fuel and demanded performances.

For example, cost of denitrification facilities with the 0.8 - 1.0 of ammonia injection mol ratio and the 80 % of denitrification rate is roughly estimated as follows:

Boiler burning heavy/crude oil :	¥4,000 - 5,000/kW
Boiler burning coal :	¥6,000 - 7,000/kW

The cost of a storage tank amounts to the large part of facilities cost of an ammonia injector necessary for denitrification facilities. Facilities cost of the facilities is ¥4,000 - 5000/tank capacity (m^3).

All of above-mentioned facilities costs exclude foundation work cost.

For reference, an example of cost of denitrification facilities for electric power generation (on 1981) is shown in **Table 8.7**.

Table 8.7 Example of Cost of Denitrification Facilities

Method	Facilities cost	Operation cost	Efficiency	Difficulty of operation	Range of application	Use	Difficulty of maintenance
Condition	thousand yen / m^3/H	thousand yen / m^3/H ① NO_x concentration ② Operation ratio ③ Cost of chemicals		%	gas volume Nm^3/H	facilities required	Difficult/ Average/ Easy
Ammonia catalytic reduction process	0.6-7.0	0.3-2.8 ① 60-400ppm ② 70% utilization factor ③ ¥60,000/t	Under 90	Average	70,000 ~3 million	·Boiler ·Gas turbine ·Diesel ·Garbage furnace ·Heating furnace in chemical plants	Average
Ammonia non-catalytic reduction process	≧0.7	≧0.8 ① 100-150ppm ② 70% utilization factor ③ ¥60,000/t	Under 40	Easy	570,000 ~1 million	·Garbage furnace ·Heating furnace in chemical plants ·Boiler	Easy

8.1.3 Measures for Control of Soot and Dust Emissions

(1) Implementation of Fuel Measures and Operational Measures

Unburned carbon is generated in case of mono fuel combustion of heavy/crude oil and fly ash in case of coal combustion. As for measures against soot and dust emissions, there are two approaches; 1) Fuel measures that decrease generation of dust by using high quality fuel and 2) Operational measures that restrain dust by improving combustion control.

(2) Implementation of Facility Measures

There are also soot and dust emissions removing processes using gravitational force, inertia force, electric force, etc. Various kinds of these facilities which adopt such force for dust collection are shown in **Table 8.8**.

1) Kinds and features of dust collectors/precipitators

Kinds and features of each collector/precipitator are shown in **Table 8.9**.

Table 8.8 Classification of dust collecting facilities by dust collecting action force

Name	Gravitational force	Inertial force	Centrifugal force	Thermodynamic force	Diffusion force	Electric force	Sonic force
Gravitational dust collector	◎						
Inertial dust separator	○	◎	○				
Centrifugal dust collector	○	○	◎	△			
Scrubbing dust collector	○	◎		△	◎	△	
Filter dust separator	○	◎			◎	△	
Electrostatic precipitator	○	○			○	◎	
Sonic precipitator	○		○			◎	

Note: Marks ◎ and ○ show collecting action force mainly acts, and mark △ shows action force required for aggregation effect.

2) Summary and features of main collectors/precipitators

① Centrifugal dust collector

The facilities turn gas, and separate and collect particles in gas by centrifugal force acted on particles. Cyclone (cyclone separator) is the typical centrifugal dust collector.

a. There is another method to use several same cyclones in series arrangement. However, pressure loss is increased with this method, while further improvement of collection efficiency is not expected.

b. Small cyclones in parallel arrangement is called multicyclone. Gas flow rate is 10 to 25m/s. Figure 8.5 illustrates one example of the multicyclone.

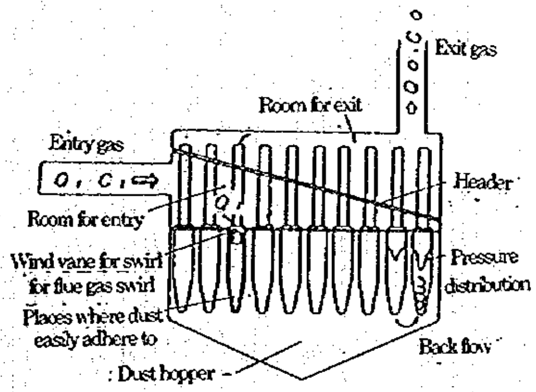

Figure 8.5 Axial-flow reaction type multicyclone

Table 8.9 Kinds and features of dust collectors/precipitators

Kinds	Feature	Type	Diameter of Perticle μ m	Apparent electric resistance rate of dust	Operating Temperature °C	Removal level	Pressure loss mmH_2O	Basic flow rate m/s	Facility cost	Operating cost
Gravitational dust collector	Equipment which separates particles in dirty gas by free sedimentation with gravitational force.	settling chamber	50≦	No limit	Dew point or higher ~400	Collection efficiency 40~60%	10~15	1~3	Low	Low
Inertial dust separator	Equipment which separates particles using inertia by colliding dirty gas against baffle to change direction of air flow suddenly.	Louver type	10≦	No limit	Dew point or higher ~400	Collection efficiency 50~70%	30~70	15~	Low	Low
Centrifugal dust collector	Equipment which separates particles using centrifugal force by turning dirty gas	Cyclone	3≦	No limit	Dew point or higher ~400	Several $10mg/m^3$	50~150	Around 10	Middle	Middle
Scrubbing dust collector	Equipment which collects particles by scrubbing dirty gas with droplet or liquid film to make particles adhere and flocculate to very large size.	Venturi scrubber	~0.1	No limit	No limit	Around $20mg/m^3$	300~800	60~90	Middle	High
Filter dust separator	Equipment which separates particles by passing through filter body such as cotton, wool, synthetic and glass fiber, etc.	bag filter	~0.1	No limit	Dew point or higher ~200	Less than $5mg/m^3$	100~200	0.01~ 0.03	Middle ~High	Middle~ High
Electrostatic precipitator	Equipment which electrifies particles in dirty gas using corona discharge and separates the charged particles by electric force.	EP	~0.03	10^4~10^{11}	Dew point or higher ~400	Less than $5mg/m^3$	10~20	0.5~ 1.5	High	Low~ Middle

Note 1) There is sonic precipitator also, however, it has not yet been for practical use.
2) Values represent an outlines and differ in accordance with types.
3) In case of wet type process, the upper limit of temperature is approximately 80℃.

② Filter dust separator

There are two types of filter dust separator. One is the bag filter type which employs surface filtration method that separates and collects dust on the surface of relatively thin filter cloth, and the other is the packed bed filter type which employs internal filtration method that separates and collects dust inside of the filter bed with filter medium. The bag filter type is more popular as filter dust separator.

Advantages and disadvantages of filter dust separator are shown in **Table 8.10**.

Table 8.10 Advantages and disadvantages of filter dust separator

Advantages	*Enables to collect submicron particles in high efficiency. *Not influenced by electric resistance of dust. *Fluctuation of temperature at outlet is less affected by that at inlet.
Disadvantages	*Pressure loss is high. *Improper for gas processing at dew point or less. *Improper for hygroscopic dust and high adhesive dust. *Not suitable for high temperature gas processing because of its material. *Regular replacement of filter cloth is required.(every 2 to 3 years) *Even one part of breakage at filter cloth causes large decrease in collection efficiency.

③ Electrostatic precipitator (EP)

EP charges dust particles in gas by corona discharge to collect them. EP is adopted mostly to the boiler for electric power generation, because 1)EP is less affected by properties of gas and dust, 2)the pressure loss is low, 3)collects fine particles easily, and 4)enables to collect dust in high efficiency.

a. Principle of collection

For electrostatic precipitation, several forces such as electric force, diffusion force, inertia force, gravitational force, etc. are utilized as collecting action force, but the main one is electric force. As shown in **Figure 8.6**, in general the discharge electrode of core wire is negative electrode and the collecting electrode of flat plate is positive electrode. High tension direct current power supply is applied to charging. As electric field strength is risen, gas around the discharge electrode is locally broken and corona discharge is occurred, which generate negative corona and forms large quantity of negative ion

Negative ion and free electron move to the collecting electrode. If gas including dust is blown into here at this moment , particles in gas are charged in a flash. The charged particles are moved by Coulomb force (electric force) to the collecting electrode, and separated and collected. The collected particles on the collecting electrode are peeled off/removed by hammering impact, etc.

b. Structure of EP

As shown in **Figure 8.7**, EP is composed of the apparatus below.

- Discharge electrode which discharges corona.
- Collecting electrode which collects charged particles.
- Direct current high voltage generator.
- Hammering apparatus for peeling off dust adhered to the collecting electrode.
- Ash handling system which delivers collected dust.

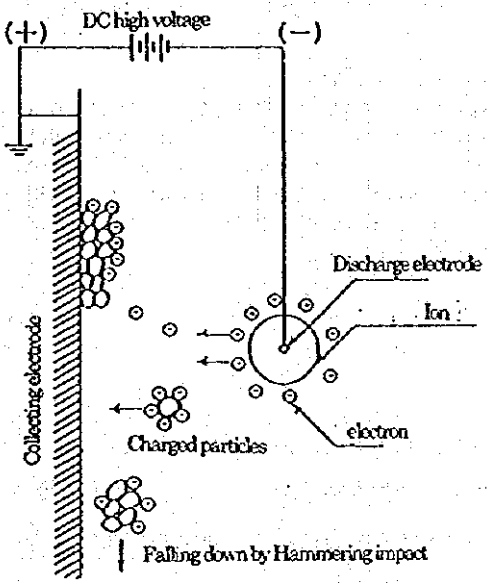

Figure 8.6 Principle of electrostatic precipitation

3) The latest electrostatic precipitator

The largest problem of dust removal in coal boiler is to overcome back ionization phenomenon, that is, to maintain and improve collecting performance against high-resistant dust. As mentioned in the previous item EP for high-resistant dust already had been developed and used practically.

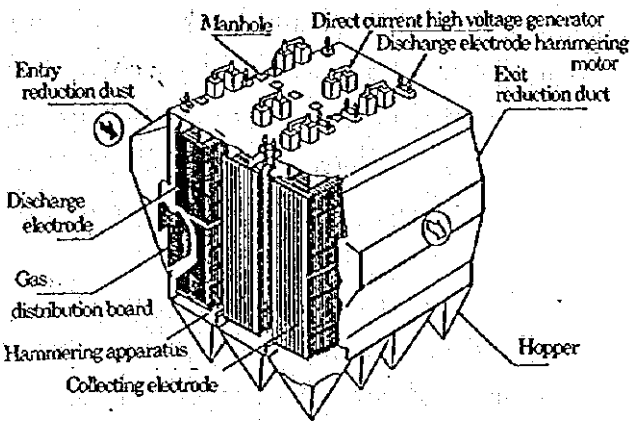

Figure 8.7 Structure of EP

① New charging type EP

It is necessary to turn down current to restrain back ionization in the normal direct current charging method, so applied voltage must be dropped for operation. As voltage is dropped, electric field strength in the precipitation space is also dropped. It causes depression of dust charging activity by non-uniformity of corona current from the discharge electrode, as well as lowering of dust collecting efficiency, and further deterioration of EP performance. However, short-time application of high voltage to the discharge electrode in pulse state makes uniform distribution of corona current from the discharge electrode. In addition, changing crest value (voltage), amplitude, and frequency of applied pulse permits to obtain higher peak voltage than that at direct current charging. Therefore, improvement of dust collecting performance is permitted.

② Wet type EP

Wet type EP has been used as the industrial dust separator for a long time. Among various flue gas treatment systems for electric power plant, which are required higher performance, wet type EP is the most suitable to collect dust and mist at outlet of wet type desulfurizer.
The basic structure of wet type EP is the same as that of dry type except that spraying water through spray nozzle from upper part of the collecting electrode and flowing down the collected dust constantly with liquid film. Wet type EP permits high flow rate of gas in EP and compact system in size, because it is never affected by electric resistance of dust and free from re-litter. However, it requires not only large quantity of water and slurry treatment process for collected dust but also lowering of gas temperature up to saturation temperature.

③ High temperature EP and low temperature EP

Adoption of high temperature EP started in the United States in 1970's for coal thermal power plant. Since high temperature EP collects dust at the high temperature range (320 to 380°C) where electrical resistivity of dust drops, it can collect even dust which could not be collected by conventional EP. However, the following points must be considered for adoption; 1)quantity of processing gas increases because of the high temperature range, 2)the structure should resist high temperature, and 3)heat loss should be prevented.

Low temperature EP collects dust at lower temperature range (90 to 100°C) than that of conventional EP, opposite to high temperature EP. Volume of processing gas is small because of the low temperature range, and the system is compact in size.

Structures of both EP's are the same as that of conventional EP.

4) Advantages and disadvantages of electrostatic precipitator

Advantages and disadvantages of electrostatic precipitator are shown in **Table 8.11**.

Table 8.11 Advantages and disadvantages of electrostatic precipitator

Advantages	•Suitable for gas processing in large capacity. •Enables to collect submicron particles in high efficiency. •Has excellent durability, and maintenance is simple and also its cost is low. •Permits processing of high temperature gas. •Has also wet type and it enables to collect mist. •Relatively resists fluctuation of operating condition.
Disdvantages	•Costs for charging facility, control system, etc. are high. •Collection efficiency is affected by ρ_d of dust, and it is lowered at $10^4\ \Omega \cdot$ cm or less and $10^{11}\ \Omega \cdot$ cm or higher. •System is large in size. •High manufacturing accuracy is required.

5) Cost of dust collector

Cost of dust collector largely differs in accordance with the types. In addition, it also depends on kind of dust generating source, required collection efficiency, and system size.

① Construction cost

As for construction cost per gas flow rate Nm ^{3}/h, approximately ¥300 to ¥2200 for centrifugal dust collector, ¥300 to ¥2100 for filter dust separator, and ¥400 to ¥4400 for eletrostatic precipitator. The construction cost largely differs depending on specification of additional facility and range of estimation.

② Annual operation cost

As for difficulties of operation and maintenance, centrifugal dust collector and electrostatic precipitator are ranked easy, and filter dust separator is ranked normal. In the case that annual operation time is 6100 hours and cost of electric power is ¥14/kwh, annual operation cost per $1m^3N/h$ of gas flow rate is ¥100 to ¥1000 for centrifugal dust collector, ¥300 to ¥1100 for filter dust separator, and ¥100 to ¥1000 for electrostatic precipitator.
The higher required collection efficiency is, the higher annual operation cost is, in any type.

Table 8.12 Costs of dust collectors

Facilities	Type	Construction cost	Annual cost	Efficiency	Difficulty of Operation	Application Range	Difficulty of Maintenance	Remarks	
		¥1,000 /Nm^3/h	¥1,000/year/ Nm^3/h Conditions ①Operation rate 70% (apx6100h) ②Cost of electric power ¥14/KWh	%	Difficult Average Easy	Gas Volume Nm^3/h	Difficult Average Easy	Size of subjected particle μ m	Pressure loss mmH_2O
Dust Collector	Centrifugal force	0.3~ 2.2	0.1~1.0	50~ 99	Easy	580,000~ 3,000	Easy	100~3	50~150
	Filtration	0.3~ 2.1	0.3~1.1	93~ 99.9	Average	2,400,000~ 3,000	Average	20~0.1	100~200
	Electrostatic	0.4~ 4.4	0.1~1.0	50~ 99.9	Easy	2,160,000~ 18,000	Easy	20~0.05	10~20

8.1.4 Implementation of Litter Control Measures for particulate

In case that coal is used as a fuel, litter control measures for particulate are required, at acceptance and disposal of coal and in coal yard, and also litter of coal ash at transportation.

(1) Litter control measures for particulate at acceptance and disposal of coal

There are methods to prevent litter of particulate by installing water spray system, closing coal conveyor, etc.

(2) Litter control measures for particulate in coal yard

There are methods to prevent litter of particulate to the surrounding area by installing water spray system, net and fence to cut-off wind, windbreak, etc.

8.1.5 Implementation of Measures for high-efficiency electric power plant in whole

Measures such as improvement of heat efficiency in the electric power plant and reduction of electric power inside of the plant effectively promote to reduce volume of air pollutants emission.

Appendix 8-2 Stack Gas Monitoring Equipment in Brazilian Market

1. Manufacturer and Distributor of Exhaust Gas Measuring Device

Company	Address and Phone Number	Products	Dealing Form	Maintenance Service	Remarks
Sindus	Av. Rocco Aloise, 15-Porto Alegre / RS-Brasil - 91110-390 (051) 340 5197	Exhaust gas Total Reduced Sulfur analyzer ;O_2, CO, CO_2, NOx, and Total Hydrocarbon analyzers ; All of them are automatic continuous analyzer, possible to choose measured items, and possible to set variable range : [TRS analyzer : US$ 22,000]	Main parts (such as optical system sensor) are imported from U.S. and assembled in Brasil as original devices.	Visiting check and inspection fee : (Porto Alegre) [R$ 50/h]	Performance tests by PMT & CEEE. Products have been installed at pulp and cement plants.
Digimed	Rua Arnaldo Magniccaro, 1254 Campo Grande-Santo Amaro / SP (011) 522 9844	Exhaust gas dust monitoring device (automatic continuous optical dust monitoring device) ; O_2, CO, CO_2, SO_2,, H_2, and S analyzers are planned to be developed and manufactured. [Dust monitoring device : US$ 16,000]	Ditto	Visiting check and inspection fee : (Sao Paulo) [R$ 15 - 20/h]	Products have been installed at iron works and pulp plants.
Borges & Katayama Consultoria e Representacoes Ltda.	Rua Romao Gomes, 135-Butanta 05502-030-Sao Paulo / SP-Brasil (011) 212 4858	Exhaust gas dust monitoring device (automatic continuous optical dust monitoring device) ; Exhaust gas velocity meter(ultrasonic flow meter) [Dust monitoring device: US$ 19,000 / Velocity meter: US$ 16,000]	Distributor of U.S. maker. [Installation fee: 10-20% of the device price]	Visiting check and inspection fee : (Sao Paulo) [R$ 100/h]	Imported from U.S. Import tax rate : 70%
ENERGETICA	Rua Gravatai 99 209 751-030 Rio de Janeiro / RJ 55-21-241-1998	Various exhaust gas automatic continuous analyzer (for O_2, CO, CO_2, SO_2,,and NOx) ; Devices for batch measurement [Alternative to the JICA Equipment]	Distributor of the Thermoelectron Co. Ltd.	Treated by distributor in Brasil	Ditto
SHIMADZU do Brasil Rep. Ltda	Av. Paulista, 726 corj 904. CEP 01310-100 Sao Paulo / SP (011) 284 3055	Various exhaust gas automatic continuous analyzer (for O_2, CO, CO_2, SO_2,,and NOx) ; Devices for batch measurement [the same as the JICA Equipment]	Devices are not manufactured in Brasil	Sales control only	Brazilian local office functions as support for distributors and transit
MICRONAL S.A.	Rua Joao Rodrigues Machado 25 CEP 04707-904 Sao Paulo / SP (011) 536 3100	Ditto [the same as the JICA Equipment]	Distributor of SHIMADZU in Brasil	Maintenance and inspection by payment base	Imported from Japan Import tax rate : 70%
Quimitron Industria e Comercio Ltda.	Avenida Seta de Setembro,1353 09912-010 Diadema / SP Brasil (011) 456 5722	Widely used exhaust gas analyzers; Possible to supply peripheral equipment for the total system [Alternative to the JICA Equipment]	Distributor of HORIBA Ltd.	Ditto	Imported from Japan Import tax rate : 70%

2. For Reference

Yokogawa America do Sul S.A.	Avenida jurua, 149-Alphavill e 06455-010-Barueri / SP. (011) 725 1433	Various exhaust gas automatic continuous analyzers (for O_2, CO, CO_2, SO_2,,and NOx) ; Wind vanes and anemometers	Devices are not manufactured in Brasil. There are no distributor in Brasil	—	Imported from Japan, as needs. Demands for environmental measurement are poor. There is no plan of promotion.
Prameq Industria e Comercio Ltda.	Rua Gandavo, 363, Vila Clementino CEP 04023. Sao Paulo-SP (11) 36-452RPJL＊BR	Exhaust gas measuring company. It also manufacture exhaust gas measuring analyzers, but not for sale. Own use only.	Depending on demands of measurement of stack gases.	Measuring fee : [R$ 1,000/time (for 2 samples)]	There are more than 3,000 experiences at pulp and cement plants, etc.

Appendix 8-3

NOTES ON MANAGEMENT OF AMBIENT AIR MONITORING STATIONS

This is prepared to recommend items notable for maintenance and inspection of ambient air monitoring stations, in order to obtain reliable accurate data for a longer period.

1. Inspection and Maintenance (I & M)

There are two scheduled I & M works. The **Frequent Work** is to check, confirm, clean, etc. to keep normal continuous operation. The **Seasonal Work** is to avoid mal-functioning by changing deteriorated parts. Tables 1A and 1B are composed to indicate the inspection and maintenance items with frequencies. Individual items must be referred to the respective manuals supplied by the manufacturers.

The **Overhaul Maintenance** is recommendable when encountering excess period of missing data, or when it is judged difficult to keep accuracy by ordinary maintenance, even if appropriate maintenance is performed. An analyzer will deteriorate by aging of its parts. As a rule of thumb, once in three to five years of an overhaul may be needed. The **Emergency Work** is to give quick and temporary repairs to abnormal or broken parts of the instrument. Usual maintenance people in the power plant can not carry out the overhaul or heavy repair work of SO_2, NOx, and span gas generators. It shall be asked for services from the agents in Brazil.

All the action taken and numerals checked and confirmed should be recorded in the ledger.

2. Performance Test

Automated analyzers shall be tested for their performance to know capability, individual character, and reliability. Timing and test items are as follows:

(a) Timing of Performance Test
- After repairing a damage which may affect accuracy
- After overhaul maintenance

(b) Items of Performance Test
- Zero and span drifts
- Repeatability

Table 1A Frequent I & M Work

Instrument	Frequency	Description
SO_2 Analyzer NOx Analyzer	Once a week	1. Review the previous inspection report. 2. Check conformity of the indicated data with the one of the pen recorder, and check if the data is stored. 3. Confirm the sufficiency of remaining recording paper. 4. Confirm the correctness of the indicated time. 5. Check any abnormality in pump sounds. 6. Check any abnormality of sampling lines. 7. Confirm whether an alarm is signaled.
Data Logger Recorder	Once a fortnight	1. Change a sampling filter. 2. Check pressure of the standard gas cylinders. 3. Check whether silica gel is still usable. 4. Replace charcoal when silica gel is replaced. 5. Calibrate zero and span ranges 6. Check the correction factors of the 0 and span ranges. 7. Confirm various analogue data: SO_2 Analyzer a sample flow rate, a lamp voltage, a cell pressure, a cell temperature NOx Analyzer a sample flow rate, a detective cell pressure
Net Pyrradiometer	Once a fortnight	1. Check whether there is no broken poly-dome 2. Clean a poly-dome
Rain sampler	Once a fortnight	1. Confirm mobility of a lid 2. Clean a rain sensor

Table 1B Seasonal Work

Instrument	Frequency	Parts to be Replaced
SO_2 Analyzer	Once a year	1. Catalyst 2. A diaphragm valve of a pump 3. An air filter for purge 4. A Bolston Filter 5. A Xenon lamp 6. A HC cutter 7. Silica gel
	Once in 2 years	1. Pump
NOx Analyzer	Once a year	1. Catalyst 2. A diaphragm valve of a pump 3. Catalyst of An ozone decomposer 4. An air filter 5. An UV filter 6. A PPD capillary
	Once in 2 years	1. A pump unit
	Once in 3 years	1. An electro-magnetic valve
Sampling System	Once a year	1. Teflon pipes and a funnel

3. Costs of Spare and Consumable Parts

For your budgetary purpose, costs of spare and consumable parts for one year operation in one station are as follows in Japan (1997, US \$ 1= ¥ 120):

SO_2 Analyzer	US \$ 3,000
SO_2 and NOx Analyzers	US \$ 6,000

For exact estimation, you should ask quotation from the agents. The specifications and requirements of the parts are given in the JICA Equipment Lists.

4. Calibration of Scale

Calibrate the scale in order to keep normal and accurate performance of an analyzer. The known concentration sample passes through the sensor for the calibration. The scale is calibrated at zero, and span (around 90% point of the maximum range), assuming the calibration curve is straight. In order to check the straightness of the curve, four or five points will be used for calibration in full range.

5. Life of Automated Analyzer

A period of seven to ten years is the best anticipated life of an analyzer, even if appropriate maintenance is performed. An analyzer will deteriorate by aging of its parts.

6. Stock of Monitored Data

Monitored data should be kept at least for five years. The data may need to be reviewed or confirmed later.

7. Spare Unit

To avoid long period of data missing by overhaul, break down, or else, or to double check the data when abnormality is resulted, a spare unit is recommendable to be kept in store. Especially imported units may need to repair for longer if it cannot be fixed domestically.

8. Safety Precaution at Monitoring Stations

The standard gases are stored in high pressured cylinders which have to be handled carefully. It is better to establish a safety precaution plan as the standard procedure observing related laws, regulations, or decrees. As some of the gases are poisonous, ventilation of the station with fresh air is recommendable during calibration, not so as to inhale the gases.

While replacing parts, turn off the main switch of the analyzer in order to avoid an electric shock.

9. Organization for I & M

In order to generate reliable, accurate and steady data for a longer period and to use the data effectively and timely, an organization in charge of a) field work of I & M, b) data management, and c) overall management of the monitoring stations shall be established in each power plant. The roles b) and c) may be performed by the same person such as a laboratory manager or an engineering manager of the plant.

The role a) is usually played by laboratory technicians. The frequent I & M (once a week or a fortnight) can be carried out within one day for three stations. The seasonal work may need one day for one station.

10. Training of Technicians

It is recommendable to prepare a complete and concrete set of operation, inspection, maintenance, and data management manuals in the own language. The set is mandatory to educate or train newly recruited personnel for the purpose. OJT by the already trained engineer will be enough for the time being. However, if the chain of such technology transfer becomes longer, the technologies or know-how will be distorted.

Appendix 8-4 Maintenance of Continuous Stack Gas Monitoring Analyzers (except dust analyzers)

Type of Inspection	Description of Execution	Frequency of Inspection etc.
Regular	Replacement of the following parts etc.	once a year
	1. Recording part	
	a. Head of a pen for pen writing	
	b. Reeled	
	c. Ink pad	
	d. Ink tube	
	2. Sample flow part	
	a. Flow meter (calibration)	
	b. Pump inner valve, diaphragm	
	c. Sample piping	
	3. Programmer part	
	a. Back-up battery	
	b. Surge absorber	
	4. Peripheral part	
	a. Sample lead-in pipe	
Emergency	1. Finding and removing trouble	Upon occurrence of abnormality
	2. Starting after removal of power stop	

① Performance Test of Automatic Analyzer

A performance test should be carried out to grasp performance, instrumental errors and reliability of measured values of an automatic analyzer. Time of conducting a performance test ant test items are as follows:

a. Time of Conducting Performance Test

- (a) When new automatic analyzer is purchased
- (b) After repairing any faults to be affect on measuring accuracy.
- (c) After regular inspection or overhaul is carried out

b. Items of a Performance Test

- (a) Zero drift
- (b) Span drift
- (c) Repeatability
- (d) Linearity
- (e) Stability of sampling flow rate

② Scale Calibration

The scale calibration should be regularly carried out to confirm that an analyzer works properly and accurately, as well as to maintain such performance. Dynamic calibration using the standard gas should be adopted for scale calibration, . Usually, with a calibration curve considered as a linear equation, calibration should be carried out at three points; the zero point, the span (a point around 90% of the maximum value of a scale of the analyzer) and a middle point of them. In order to confirm linearity of the calibration curve, calibration should be done at four or five points between the zero point and the span, at need.

③ Overhaul

Even if the sufficient maintenance and inspection is carried out for an automatic analyzer, as components are wasted or abraded as operation time elapses, deterioration of performance resulted from such waste/abrasion is not avoidable. Therefore, if it is found that missing time increases remarkably or that it is difficult to maintain measuring accuracy by means of regular inspection only, overhaul should be carried out.

④ Life of Automatic Analyzers

Since an automatic analyzer is operated at all times, deterioration of components, accompanying use of it, is not avoidable. Though performance of an automatic analyzer is maintained by maintenance and inspection, according to comprehensive judgement from frequency of trouble occurrence due to deterioration, its life is generally around 10 years.

Appendix 8-5 CMB(Chemical Mass Balance) Method

A8.5.1 Outline of CMB Method

CMB (Chemical Mass Balance) method is a type of receptor model or statistical model to estimate the contributions from sources to ambient SPM concentration. The sources of SPM are divided into artificial sources and natural ones. The former includes the different kinds of factories, various types of motor vehicles, etc. The latter includes soil particles, sea salts particles, and others. One special feature of SPM component is the high contribution by natural sources and it is therefore very difficult to establish a completely physical model for estimating SPM due to natural processes. Hence, the CMB method provides an alternative way to effectively estimate the contributions by artificial and natural processes.

The particles are categorized into primary particles and secondary particles. The primary particles are those emitted in particulate form, but the secondary particles are those emitted in gaseous form and then converted to particulate form. For example, some parts of SO_2 are converted to SO_4 and finally to sulfuric acid or some forms of sulfate. CMB method targets the primary particles and the contributions by the secondary particles are estimated from their chemical components. CMB method targets the primary particles, and the secondary particles are directly evaluated from the measurement of ambient SPM.

The mathematical formulation of CMB method is explained as the followings. The receptor model for estimating the contributions by pollution sources is based on the law of conservation of mass. For example, assuming that (p) numbers of emission sources exist and suppose no interaction follows where mass change occurs, SPM concentration (C) measured at the receptor is obtained by taking the sum of contributions (S_j) of each emission source as in equation (1).

$$C = \sum_{j=1}^{p} S_j \qquad (1)$$

Similarly, concentration (C_i) of component (i) in the SPM is expressed by equation (2). Here (a_{ij}) is the mass fraction of source contribution (j) possessing component (i) at receptor.

$$C_i = \sum_{j=1}^{p} a_{ij} S_j \qquad (2)$$

Assuming that (n) numbers of components are analyzed at the sources and receptors, then an equation is set up for each component. If the number (n) is greater than or equal to a number (p), we could obtain the answer by solving the set of (p) set of linear equations.
When the number (n) is greater than (p), a set of accurate values is obtained by minimizing the value (χ^2) expressed in equation (3).

$$\chi^2 = \sum_{i=1}^{n} \frac{\left(C_i - \sum_{j=1}^{p} a_{ij} S_j\right)^2}{w_i^{-2}} \qquad (3)$$

Here (w_i) are the weights according to the extent of errors in measurement.
Equation (4) is the matrix from expression of equation (2).

$$C=AS \qquad (4)$$

Here (C) is n-dimensional vector of component concentration, and (A) is n by p matrix of mass fraction of sources, and (S) is n-dimensional vector of contributions by sources.

Generally, the solution by the least squres method is as the followings.

$$S=({}^{t}AWA)^{-1}\,{}^{t}AWC \qquad (5)$$

Here, (W) is a diagonal matrix with diagonal components of w_i^2. ${}^{t}A$ is transpose of matrix A and X^{-1} is inverse matrix of matrix X. Errors of estimations for the source contributions depend on the way the weights (w_i) are chosen.

A8.5.2 An Example of CMB Method

(1) Analysis of Elemental Composition

Here, an example of CMB method to evaluate source contributions with chemical element compositions of ambient SPM and various sources **(Ref.71)**. The chemical element compositions of ambient SPM and sources used are compiled in **Table A8.5.1.**

Ambient SPM samples are collected during 2 weeks by low volume air samplers for each season at 8 representative stations in Osaka prefecture. Osaka prefecture is the second populated prefecture in Japan. The samples are analyzed for 39 chemical elements by Neutron Activation Method, and for elemental carbon (EC) and organic carbon (OC) by Thermal Manganese Oxidation Method.

Target sources were assumed as soil, sea salt, steel factory, oil burning facility,

Table A8.5.1 Elemental Composition of Ambient SPM and PM Sources

	Ambient		Soil		Sea Salt		Steel		Oil Burning		Incineration		Diesel Vehicle	
	Concentration	Content	Content	E.F.	Content	E.F.	Content	E.F.	Content	E.F.	Content	E.F.	Content	E.F.
	ng/m³	%	%		%		%		%		%		%	
Na	583	1.5	1.38	0.94	30.4	**21**	1.36	0.92	1.00	0.68	12.0	**8.2**	0.0150	0.010
Al	498	1.3	6.43	**5.1**	<0.0001	<0.0001	0.999	0.79	0.210	0.17	0.420	0.33	0.0610	0.048
Si	1220	3.1	-	-	0.00870	0.0028	-	-	-	-	-	-	-	-
S	2100	5.3	-	-	2.60	0.49	4.79	0.90	9.60	1.8	13.0	**2.4**	3.70	0.70
Cl	707	1.8	0.0584	0.033	55.1	**31**	3.41	1.9	0.0920	0.051	27.0	**15**	0.0660	0.037
K	520	1.3	1.91	1.5	1.10	0.84	1.32	1.0	0.0850	0.065	20.0	**15**	0.0370	0.028
Ca	415	1.0	1.88	1.8	1.17	1.1	4.51	**4.3**	0.0850	0.081	1.10	1.0	0.0610	0.058
Sc	0.0881	<0.0001	<0.0001	**4.1**	<0.0001	<0.0001	<0.0001	0.59	<0.0001	0.040	<0.0001	0.21	<0.0001	0.010
Ti	54.8	0.14	0.468	**3.4**	<0.0001	<0.0001	0.100	0.72	0.0740	0.53	0.0900	0.65	0.0110	0.079
V	10.8	0.027	0.00477	0.18	<0.0001	<0.0001	0.0125	0.46	0.920	**34**	0.00270	0.099	<0.0001	0.028
Cr	9.27	0.023	0.00726	0.31	<0.0001	<0.0001	0.316	**13**	0.0210	0.89	0.0850	**3.6**	<0.0001	0.029
Mn	40.1	0.10	0.0709	0.70	<0.0001	<0.0001	2.20	**22**	0.0120	0.12	0.0330	0.33	0.00120	0.012
Fe	657	1.7	3.21	1.9	<0.0001	<0.0001	15.7	**9.5**	0.460	0.28	0.610	0.37	0.0360	0.022
Co	0.584	0.0015	<0.0001	0.58	<0.0001	<0.0001	0.00440	**3.0**	0.00310	**2.1**	0.00210	1.4	<0.0001	0.088
Ni	6.46	0.016	0.00300	0.18	<0.0001	<0.0001	0.290	**18**	0.490	**30**	-	-	0.00180	0.11
Cu	36.0	0.091	0.0400	0.44	<0.0001	<0.0001	0.370	**4.1**	-	-	0.360	**4.0**	-	-
Zn	192	0.48	0.0611	0.13	<0.0001	<0.0001	5.15	**11**	0.0400	0.082	2.60	**5.4**	0.0560	0.12
As	6.49	0.016	<0.0001	0.034	<0.0001	<0.0001	0.0103	0.63	0.00230	0.14	0.0150	0.91	<0.0001	0.016
Se	1.46	0.0037	-	-	<0.0001	<0.0001	0.00511	1.4	0.00480	1.3	-	-	<0.0001	0.027
Br	5.82	0.015	<0.0001	0.027	0.190	**13**	0.0144	0.98	<0.0001	0.058	0.0830	**5.6**	0.0199	1.3
Rb	1.53	0.0039	0.00825	**2.1**	<0.0001	0.091	0.00768	**2.0**	-	-	0.0260	**6.7**	-	-
Ag	0.363	<0.0001	0.00310	**3.4**	<0.0001	0.0095	0.00542	**5.9**	-	-	0.0150	**16.**	-	-
Cd	6.69	0.017	-	-	<0.0001	<0.0001	0.0252	1.5	0.0240	1.4	0.0500	**3.0**	-	-
Sn	20.1	0.051	-	-	<0.0001	<0.0001	0.281	**5.5**	-	0.043	0.300	**5.9**	-	-
Sb	6.30	0.016	<0.0001	0.017	<0.0001	<0.0001	0.00900	0.57	<0.0001	-	0.0610	**3.8**	<0.0001	0.014
I	5.37	0.014	-	-	0.170	**13**	-	-	-	-	-	-	<0.0001	0.065
Cs	0.177	<0.0001	<0.0001	0.82	<0.0001	0.0065	-	-	-	-	0.00120	**2.7**	-	-
Ba	14.3	0.036	0.0535	1.5	<0.0001	0.0024	-	-	-	-	0.0390	1.1	-	-
La	0.587	0.0015	0.00267	1.8	<0.0001	<0.0001	<0.0001	0.19	-	-	<0.0001	0.52	<0.0001	0.013
Ce	0.778	0.0020	0.00611	**3.1**	<0.0001	<0.0001	0.00687	**3.5**	-	-	0.0170	**8.6**	<0.0001	0.056
Sm	0.0446	<0.0001	<0.0001	**3.7**	<0.0001	<0.0001	<0.0001	0.19	<0.0001	**6.7**	<0.0001	0.41	<0.0001	0.022
Eu	0.0143	<0.0001	<0.0001	**2.4**	-	-	-	-	-	-	-	-	-	-
Yb	0.0414	<0.0001	<0.0001	**2.4**	-	-	-	-	-	-	-	-	-	-
Lu	0.00324	<0.0001	<0.0001	**3.1**	-	-	-	-	-	-	-	-	-	-
Hf	0.0473	<0.0001	0.00105	**8.8**	-	-	-	-	-	-	-	-	-	-
Ta	0.0437	<0.0001	<0.0001	1.5	-	-	-	-	-	-	<0.0001	0.73	-	-
W	1.22	0.0031	<0.0001	0.13	<0.0001	<0.0001	0.00474	1.5	-	-	-	-	-	-
Pr	85.9	0.22	-	-	<0.0001	<0.0001	1.44	**6.6**	0.0330	0.15	1.70	**7.8**	0.0490	0.23
Th	0.0991	<0.0001	<0.0001	**3.6**	<0.0001	<0.0001	-	-	-	-	-	-	<0.0001	0.048
EC	7070	18.	1.00	0.056	<0.0001	<0.0001	0.500	0.028	30.0	1.7	0.500	0.028	68.0	**3.8**
OC	3610	9.1	-	-	-	-	-	-	-	-	-	-	-	-

Note) E.F.: Effective Factor=Contents in Source/Contents in Ambient
Source Contents not less than 1.0 %: Underlined, E.F. not less than 2.0: in Bold Letter
Shaded Row: Tracer Elements Selected

incineration facility, and diesel vehicle. The chemical compositions of the sources are determined from the actual measurement and the literature values.

(2) Selection of Tracer Elements

Tracer elements which are characteristic for each emission source, must be chosen for CMB method. One indicator for selection is contents in the sources, and content values not less than 1 % are underlined in **Table A8.5.1**. Another indicator is 'Effective Factor', and the effective factor (E.F.) is defined as the following.

$$E.F. = X_{i,source} / X_{i,ambient}$$

$X_{i,source}$: Content of Element (i) in Sources

$X_{i,ambient}$: Content of Element (i) in Ambient

The elements with large E.F. for each source are as the followings.

Soil:	Hf, Al, Sc, Sm, Th, Ti, Ce
Sea Salt:	Cl, Na, Br, I
Steel:	Mn, Ni, Cr, Zn, Fe, Pb
Oil Burning:	V, Ni
Incineration:	Ag, K, Cl, Ce, Na, Pb, Rb, Br, Zn
Diesel Vehicle:	EC

Cl and Br were eliminated because of possible fractionation in the atmosphere. Hf, Th, Ce, Ni, Pb, Ag, Rb were eliminated because of inaccurate contents values in some sources.

Finally, Na, Al, K, Sc, Ti, V, Cr, Mn, Fe, Zn, Sm, and EC are selected as the tracer elements for CMB method.

(3) Source Contributions to Ambient SPM

The concentrations of the twelve (12) elements in ambient SPM are input to Ci of equation (2). The contents of the twelve elements (12) of eight (8) sources are input to aij. By solving the equation, the contributions from the sources were obtained as in **Table A8.5.2**.

Table A8.5.2 Source Contributions to Ambient SPM

Sources	Contributions $\mu g/m^3$
Soil	8.7±0.8
Sea Salt	0.7±0.3
Steel	2.1±0.3
Oil Burning	1.1±0.2
Incineration	1.8±0.4
Diesel Vehicle	9.9±1.8
Unknown	15.2
Total	39.5

Around 60 % of the contributions were explained by CMB method, and the contributions of diesel vehicle and soil particles exceeded 20 %, respectively.

Appendix 8-6 Specifications of SPM Meter

Following are example specifications of the ambient air SPM monitoring instrument. Model A is the product of Horiba which is available through Quimitron Industria, Sao Paulo. Model B is cited from a catalogue of another Japanese manufacturer named DKK Corporation in Tokyo.

Examples of Specifications of SPM Meters

Items	Model A	Model B
Principle	Beta ray absorption	Beta ray absorption
Beta source	^{14}C, sealed	^{147}PM, sealed
Application	SPM, less than 10 μ m	SPM, less than 10 μ m
Range	0-0.25/0.5/1.0/5.0 mg/m^3	0-1.0/5.0 mg/m^3
Measurement cycle	30 min/1/3/12/24 h	1 h
Accuracy	±10 μ g/m^3 or ±10% of reading	±10 μ g/m^3 or ±10% of reading
Sample tape	Rolled glass fiber	Rolled glass fiber
Sample flow	16.7 liter/min	18 liter/min
Sample pump	in a separated unit	included
Ambient temperature	0～40℃	-10～40℃
Data display	On screen	Print recorder
Data output	Voltage or mA signal	Voltage or mA signal
Power	100/115/230 AVC, 50/60Hz	100 AVC, 50/60Hz
Dimensions	430 w × 310 h × 400 d mm	460 w × 1000 h × 500 d mm
Weight	Approximately 19kg	Approximately 70kg