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THE EFFECT OF DIFFERENT AIR QUALITY CRITERIA AND AVERAGING TIMES ON SMELTER SHUTDOWN

by

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SUMMARY

The effects, on shutdown time, of extending the averaging time of the current air quality criterion (1300 μg/m^3) from 3 h to 6 h as well the NHMRC and WHO criteria have been examined for an enhanced copper smelter operation (with no lead smelter emissions) and also the individual base case (ie current) copper and lead smelter emissions

The report is based on accumulating 15 min average ground level concentrations (glc) of SO_2, calculated from a grid based Gaussian dispersion model in conjunction with selection of meteorological data from the MIM weather station to construct the likely loger term average glc.The model has been run to produce running 1, 3 and 6 h averaged for eight days of daytime weather. The procedure has been calibrated for the 3 h averaging time by comparison with procedures already developed from the MIM AQC data base and then extrapolated to different averaging times.

It is concluded that the 6 h averaging time would increase smelter operation during adverse weather by about one third for both the enhanced and base case copper smelter emissions, and that the lead smelter would not have to shut down at all. The shutdown times for the two copper smelter scenarios would be 4.4% and 2.6% respectively for the 6 h period and 6.4% and 3.9% for the 3 h period. Application of the NHMRC and WHO air quality criteria would result in almost complete shutdown when the plume was blowing over the city.

Short term glc from the enhanced copper smelter emissions would be 50% higher than those currently being experienced.

1. INTRODUCTION

This report considers the effect of various SO_2 air quality criteria and averaging times on smelter shutdown time for the copper and lead smelters at Mount Isa. For a given average wind speed, ground level concentrations (glc)of pollutant decrease with increasing averaging time. This is because the wind blows from a greater variety of directions, thereby spreading the "footprint" of the plume over a greater area and resulting in lower glc. In practice a greater range of wind speeds also occurs with longer averaging times. This latter effect mitigates somewhat against the dilution due to plume meander, as the lower wind speeds give rise to disproportionately more glc.

2. METHODOLOGY

In a previous report (Carras and Williams, 1991), we have estimated the ratio of glc over a 3 h period to that for 15 min, by analysing MIM Air Quality Control data on SO_2 glc at the permanent monitoring sites within Mt. Isa. As emission controls are applied when the wind is blowing over the city, the data used for this analysis had to be selected on the basis of certain emission criteria, eg when only the lead smelter was emitting. It is doubtful if this approach can be extended to examine the ratio C_{6h}/C_{15min}. Consequently we have adopted another approach.

Ground level concentrations of SO_2 have been calculated for different averaging times using a Gaussian plume dispersion model incorporating experimentally determined plume rise and dispersion parameters. The model has been described in detail in previous reports (Carras and Williams 1990,1991). Briefly, pollutant glc, C_{xyo} at a distance x from the stack and y from the plume centreline, is given by :

$$C_{xyo} = Q/(\pi\sigma_y\sigma_z u)\exp[-1/2(y^2/\sigma_y^2+H^2/\sigma_z^2)] \quad (1)$$

where Q is the mass emission rate of pollutant, σ_y and σ_z are the characteristic crosswind Gaussian plume widths, u is the horizontal wind speed and H is the effective plume height.

From experimental data, the crosswind dimensions are:

$$\sigma_y = 4.54t^{0.67} \text{ and } \sigma_z = 3.2t^{0.67} \qquad \text{where } t = x/u \quad (2)$$

The effective plume height is the sum of the stack height and the plume rise ΔH due to buoyancy.

Again, based on experimental data, the plume rise is calculated from:

$$\Delta H = 1.3\ F^{0.33}\ t^{0.67} / u^{0.33} \qquad (3)$$

where F is the thermal buoyancy flux:

$$F = (1-T_a / T_g)\ V\ g / \pi \qquad (4)$$

where T_a and T_g are the ambient and stack gas temperatures respectively, V is the stack gas flowrate at stack exit temperature and g is the acceleration due to gravity.

The plume rise calculation is terminated after a time, t_c, which is dependent on the buoyancy flux and is given by the empirical relation:

$$t_c = 4.5\ F^{0.6} \qquad (5)$$

For plume centreline concentrations:

$$C_{xoo} = Q/(\pi\sigma_y\sigma_z u)\exp[(-H^2/(2\sigma_z{}^2)] \qquad (6)$$

The output of the model is for an averaging time of about 15 min., a characteristic timescale for convective conditions. There are procedures for estimating glc for averaging times different to that inherent to the model. These have been discussed in a previous report (Carras and Williams, 1989)

Briefly, C_t, the glc at time t is thought to be given by:

$$C_t = C_o\ (t / t_o)^n \qquad \text{where } n= 0.5 \qquad (7)$$

We have examined the likely accuracy of this equation by computing 15 min SO_2 glc from the copper smelter using meteorological data from the MIM weather station. 15 min averages of wind speed and direction were formed from the 5 min average MIM database for eight days, selected at random but which concentrated on days when westerly winds were blowing but included some days with easterly winds. The

15 min averages were compiled for the daytime period only (1000h - 1800h), when mixing is taking place. The dispersion model was run every 15 min , with the source at the centre of a 10 km by 10 km grid with resolution 50 m. Glc were accumulated in each grid square to form longer term running average glc. The longer averaging times were 1h, 3h and 6h. The peak longer term glc was then compared with the average of the 15 min peak centreline glc that occurred in the grid each 15 min. The period for calculating the next longer term averaging time started 15 min after the previous one until the end of the day. (The calculations were, in fact, run until the starting 15 min was the last 15 min period of the day). In principle, the influence of averaging times is independent of the particular emission scenario used in the model

3. RESULTS AND DISCUSSION

The details of the emissions used in the calculations are listed in Table 1.

TABLE 1. Stack Emission Characteristics

Scenario	stack ht. (m)	SO_2 flux (kg/s)	flue gas temp. (^oC)	flue gas flow (Nm^3/s)
Base case Cu	165	18.6	225	265
Base case Pb	270	8.3	95	264
Enhanced Cu	165	27.8	210	267

The results of the computations to determine the value of the exponent, n, in equation 7, are summarised in Figures 1 - 3, which show the ratio of $C_t / C_{15\ min}$ for t = 1h, 3h and 6h respectively as a function of the wind speed (averaged over t). The data show that easterly winds can give rise to quite high values of the ratio $C_t / C_{15\ min}$ presumably because the easterly air flow can be quite coherent, showing little variability. (Another explanation is that the wind vane was defective at this time).

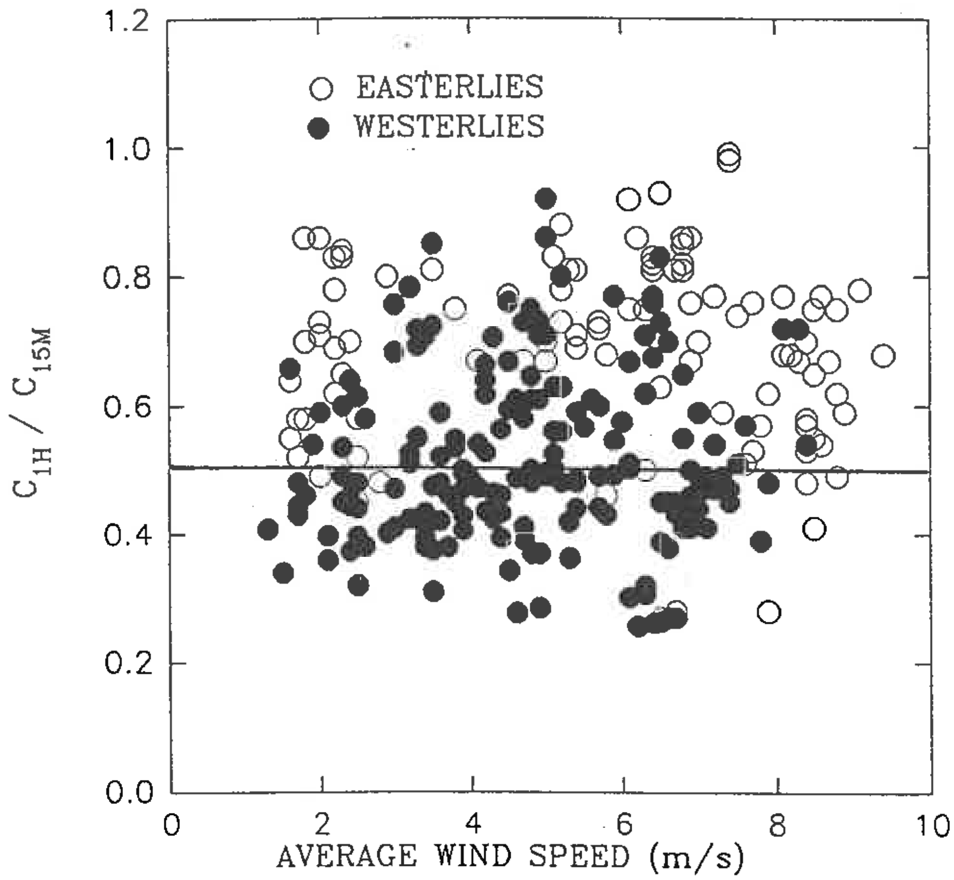

Figure 1 Ratio of 1 hour peak glc to average 15min peak glc as a function of wind speed (line represents n=0.5).

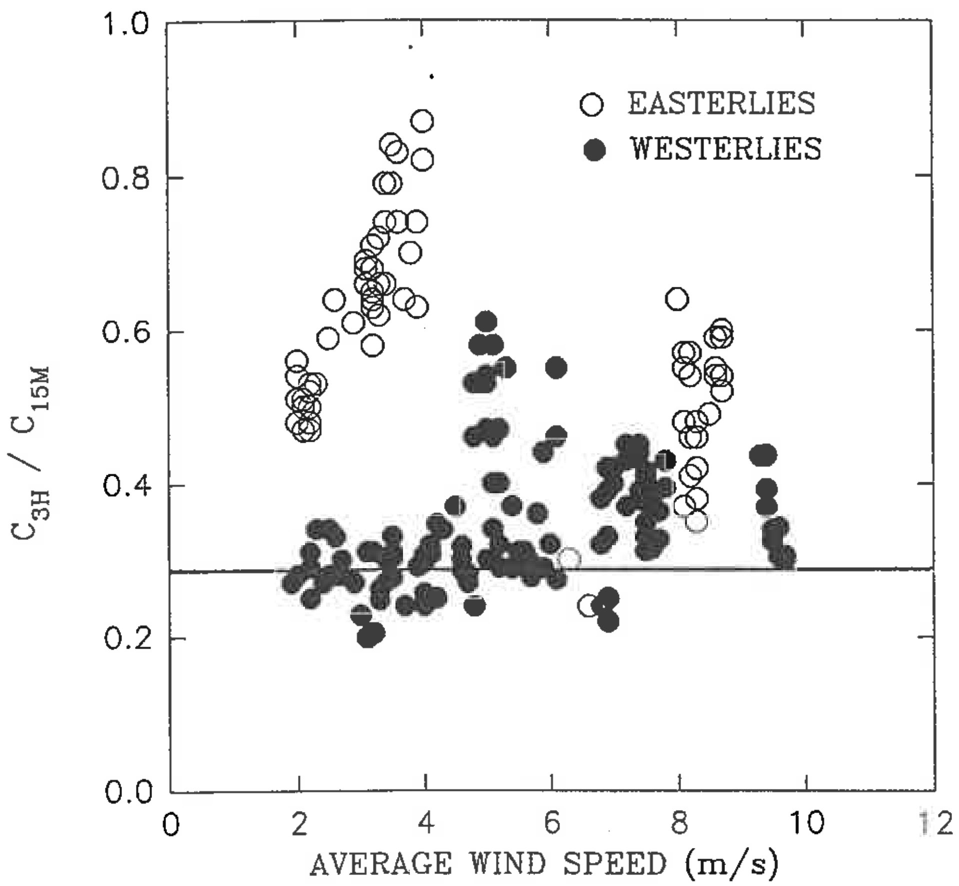

Figure 2 Ratio of 3 hour peak glc to average 15min peak glc as a function of wind speed (line represents n=0.5).

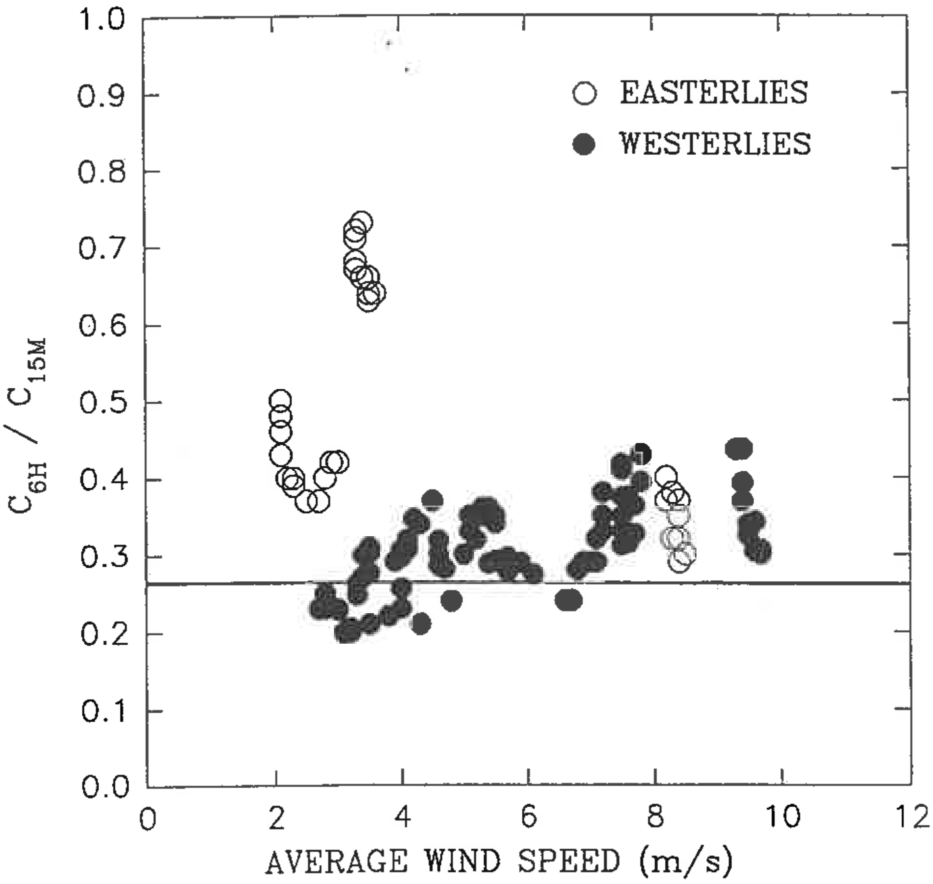

Figure 3 Ratio of 6 hour peak glc to average 15min peak glc as a function of wind speed (line represents n=0.41).

It can be seen that, there is a suggestion that the value of n may decline with increasing t and that n may also be a function of wind speed with higher ratios tending to occur at higher wind speeds. We don't know if these trends are physically meaningful.

In order to calibrate this approach, the line representing the value of C_{3h}/C_{15m} developed using the AQC measurements is shown in Figure 2 and which is equivalent to an exponent, n = 0.5 in equation 7. As our dispersion model is for a worst case 15 min period, ie one with minimum fluctuations of wind speed and direction, an average line through the body of the data points rather than one representing the upper bounds is probably a reasonable choice, at least for the 3h period.

With regard to the 6 h period, there is some argument that the mechanism responsible for spreading the plume out over longer averaging times (namely variations in wind speed and direction) is largely over after 3 h with further spreading being more related to diurnal / synoptic process. This is supported by the model results which indicate only a small decline in the longer term glc. A line representing n = 0.5 would give a value for $C_{6h}/C_{15m} = 0.2$, below the data points in Figure 3. We have chosen a value that gives a similarly placed line (with respect to the data points in Figure 2), which is shown in Figure 3 and equivalent to a value of 0.41 for 6h.

The line for n = 0.5 is depicted in Figure 1 for the 1h data.

The 10 min averaging time used by the NHMRC and WHO is not significantly different to that inherent for the model calculations.

The plume centreline 15 min glc for the base case copper and lead smelters are shown in Figures 4 and 5 for wind speeds of 2, 4, 6, 8 and 10 m/s. The corresponding data for the enhanced operation of the copper smelter are presented in Figure 6. These results have been used in conjunction with the appropriate values of n (equation 7) and the data on the frequency characteristics of westerly winds to estimate to the degree of smelter shutdown.

The average annual occurrence of the westerly wind data were described in a previous report (Carras and Williams, 1991) and are summarised in Table 2 along with some statistics for the year 1990-1991 with higher directional resolution. The different air quality criteria considered here are listed in Table 3. The bounds of Mount Isa city, with respect to the smelters, occurs at 2.75 km in the sector 0-70^{o} and at 3.1 km for the 70 - 190° sector. Because the southern bounds of the city extend west of 180°, the adverse winds occur for another 1.7% of the year.

TABLE 2. Air Quality Criteria Used For Evaluating Shutdown Time

	SO_2 CONCENTRATION LIMIT (μg/m^3)		
TIME	NHMRC	WHO	OTHER
10 min	1400	500	-
1 h	700	350	-
3h	-	-	1300
6h	-	-	1300

TABLE 3. Percent Annual Occurrence Of Westerly Winds As A Function Of Wind Speed and Direction

wind speed (m/s)	cumulative % (average of 4 y)
calm	1.0
2	2.8
4	5.1
6	6.7
8	7.5
10+	9.4

Direction (°)	% year 90-91
180-210	3.2
210-240	2.8
240-270	2.6
270-300	
300-330	2.8
330-360	2.6
360-010	1.7

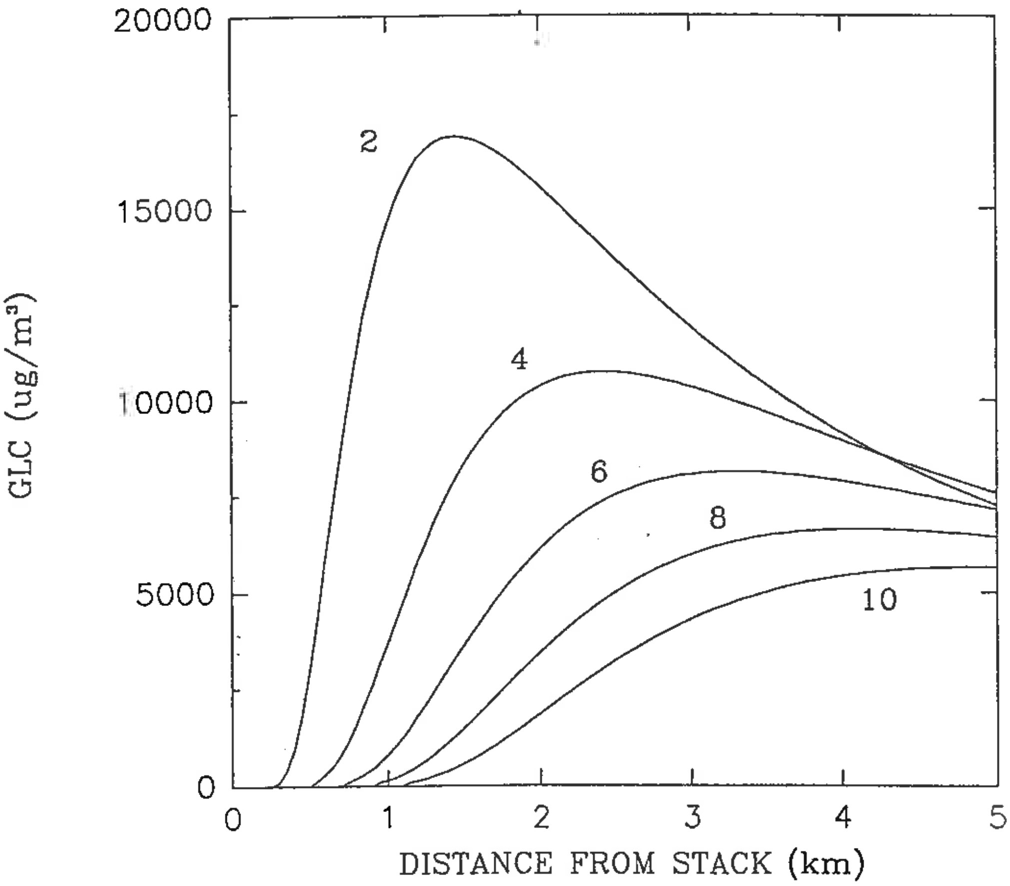

Figure 4 Centreline glc as a function of distance from stack for windspeeds 2,4,6,8, & 10m/s - Enhanced copper smelter emissions.

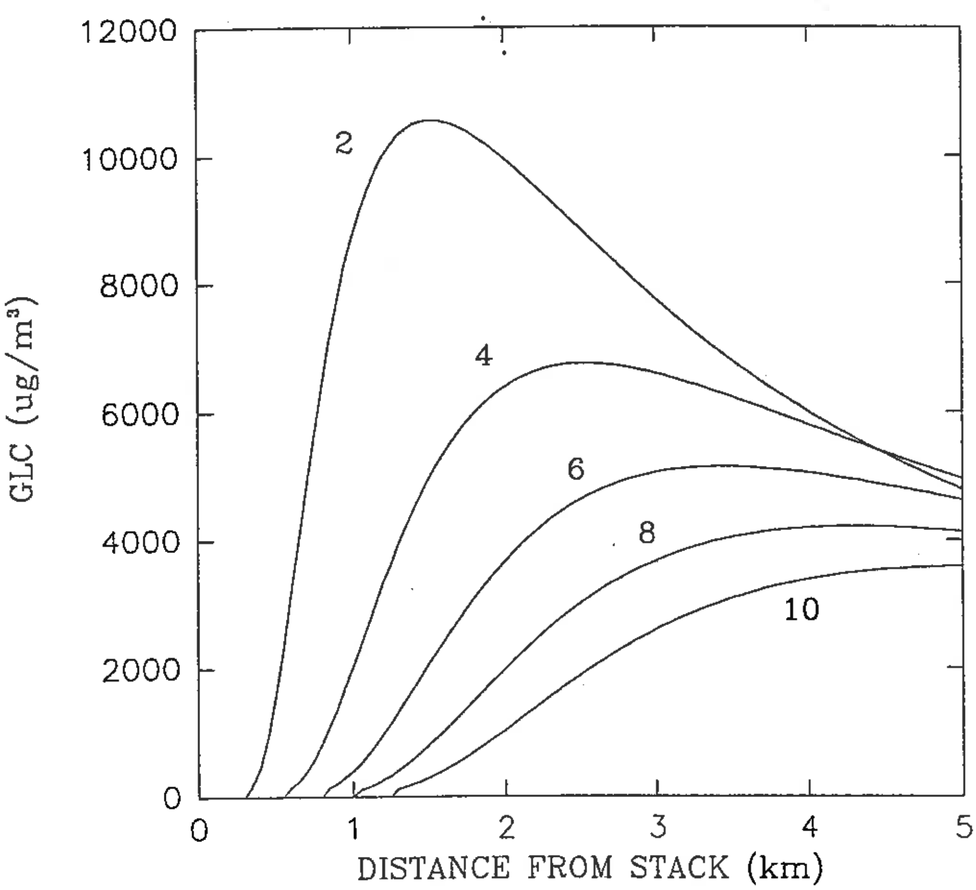

Figure 5 Centreline glc as a function of distance from stack for windspeeds 2,4,6,8, & 10m/s - Base case copper smelter emissions

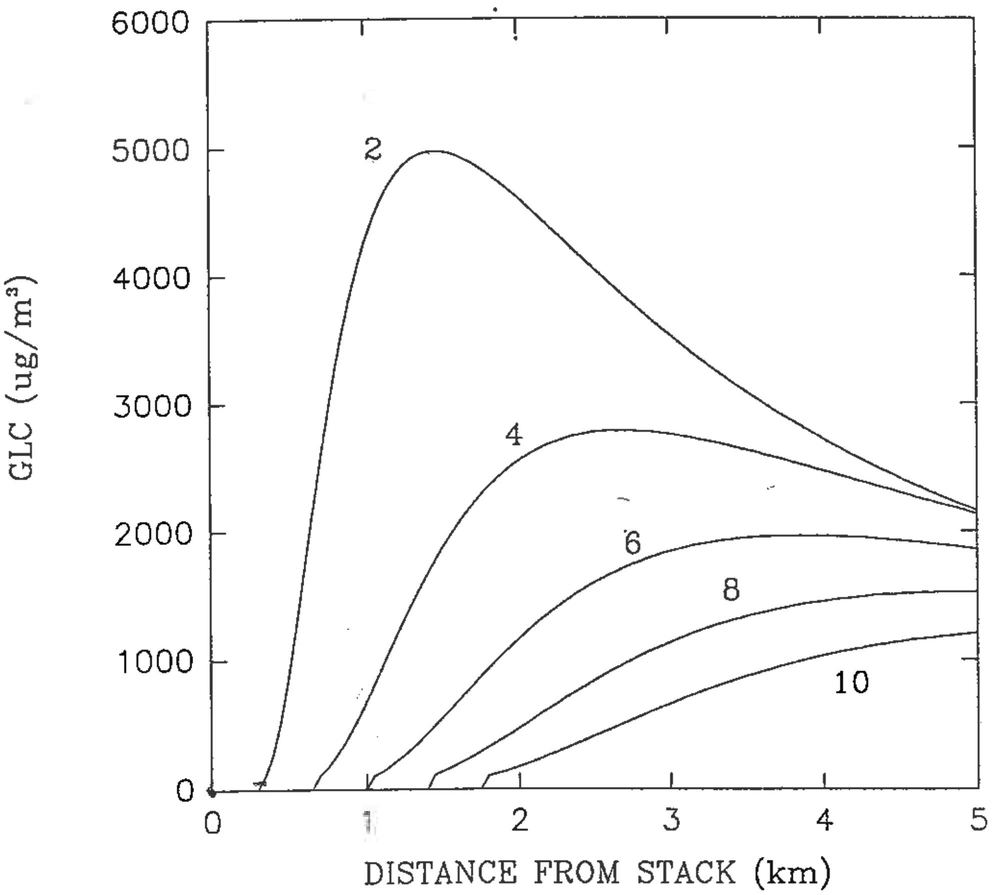

Figure 6 Centreline glc as a function of distance from stack for windspeeds 2,4,6,8, & 10m/s - Base case lead smelter emissions.

Table 4 lists the hours of operation of the smelters, likely to be available during an averaging period of 3 or 6 h for air quality criteria of 1300 $\mu g/m^3$. They are tabulated as a function of wind speed for the enhanced copper emissions and the base case copper and lead smelter emissions and have been rounded down to the half hour. The estimates were derived as follows. If the value of C_{15min} was eg 10,000 $\mu g/m^3$ then the expected value for C_{6h} would be 2,700 $\mu g/m^3$. This value is just over twice the criterion, hence the smelter could operate for 3 h, before shutting down. The different distances in the town limits are only of potential significance when wind speeds are 6 m/s or greater ie when the maximum glc is outside the town limits. Except for the enhanced copper smelter emissions during 10 m/s winds and for the 3 h averaging period, the differences are not significant within the rounding down process.

If the average AQC day is 9 h (ie when the plumes come to ground), then there are only $1^1/_2$ averaging periods for the 6 h criterion, whilst there are 3 for the 3 h case. Consequently, smelter availability can be a greater fraction of the day for the former case. The percentage daily availability, based on a 9 h AQC day is listed in Table 5, for both the 6 h and 3 h criteria, as a function of wind speed for the three emission cases.

The percentage availabilities have been used in conjunction with the wind statistics to estimate likely shutdowns on an annual basis for each of the emission scenarios. Note that these estimates assume that only one stack is emitting for each of the scenarios.

The results are listed in Table 6. The enhanced copper smelter would be shutdown for 4.4% of the year using an AQC criterion of 1300 $\mu g/m^3$ over 6 h, whilst the current base case operation would be shut for 2.6% of the year. Using a 3 h averaging period increases the shutdown times by about 50%. These calculations show that the base case lead smelter could run continuously for the 6 h period but would have to stop during light wind westerlies, which occur for 1.5% of the year.

TABLE 4. SMELTER AVAILABILITY

OPERATING HOURS

Averaging Time

Enhanced copper smelter emissions

Wind speed	6 hours		3 hours	
(m/s)	2.75 km	3.1 km	2.75 km	3.1 km
2	1.5	1.5	0.5	0.5
4	3	3	1	1
6	3.5	3.5	1.5	1.5
8	5	5	2	2
10	6	6	3	2.5

Base case copper smelter emissions

Wind speed	6 hours		3 hours	
(m/s)	2.75 km	3.1 km	2.75 km	3.1 km
2	2.5	2.5	1.0	1.0
4	4.5	4.5	2.0	2.0
6	6	6	2.5	2.5
8	6	6	3	3
10	6	6	3	3

Base Case Lead Smelter Emissions

Wind speed	6 hours		3 hours	
(m/s)	2.75 km	3.1 km	2.75 km	3.1 km
2	6	6	2.5	2.5
4	6	6	3	3
6	6	6	3	3
8	6	6	3	3
10	6	6	3	3

TABLE 5. Smelter daytime availability

Enhanced copper smelter emissions

	percent daytime availability	
W'speed (m/s)	6 hours	3 hours
2	30	15
4	65	30
6	70	50
8	90	65
10	100	100 (85)

Base case copper smelter emissions

W'speed (m/s)	6 hours	3 hours
2	55	30
4	80	65
6	100	80
8	100	100
10	100	100

Base Case Lead Smelter Emissions

W'speed (m/s)	6 hours	3 hours
2	100	80
4	100	100
6	100	100
8	100	100
10	100	100

TABLE 6. ANNUAL SMELTER SHUTDOWN TIMES

	Averaging Time	
Smelter scenario	6 hours	3 hours
Enhanced copper	4.4%	6.4
Base copper	2.6%	3.9%
Base lead	0%	1.5%

Turning to the NHMRC and WHO criteria, we find that the smelters would be shut during all adverse weather (ie 11.1% of the year) for all the scenarios considered here except for the base case lead smelter operating under the NHMRC 1 h criterion at wind speeds of 8+ m/s. For this AQC criterion, the lead smelter would be shut for 8.8 % of the year.

Because we are of the opinion that the lower values of C_{6h} with respect to C_{3h}, may be due more to synoptic influences, it would be difficult to quantify whether there was any relief as the plume passes over the western edges of the city. At most, there would be a 10% improvement in shutdown times.

Whilst this report has concentrated on the effect of a 6 h AQC criterion of 1300 $\mu g/m^3$, it should be noted that the short term (3 min) glc produced by a convective downdraught from the enhanced copper smelter emissions are very high (roughly 4 - 5 times the 15 min values)and similar to those Case Z outline in a previous report (Carras and Williams, 1991). As the emissions are from a single stack, the short term peaks would be about 50% higher than those currently experienced. It should also be noted that, on occasions, a downdraught may persist for 10 min or more.

4. CONCLUSIONS

The calculations bcarried out in the present report indicate:

(1) The decrease of glc with increasing averaging time becomes less significant at averaging times longer than 3 h.

(2) The use of an AQC criterion of 1300 $\mu g/m^3$ over 6 h increases operating time during westerly winds for both the enhanced and base copper smelter operation by

about 50% compared to using 1300 $\mu g/m^3$ for 3 h. The base case lead would not have to shutdown at all.

(3) The application of NHMRC or WHO 1 h standards would not permit the smelters to operate in westerly winds apart from the base case lead smelter under the NHMRC standard and then only when wind speeds were 8 m/s or more.

(4) The short-term SO_2 glc arising from the enhanced copper smelter would be 50% higher than occur now.

5. REFERENCES

Carras J.N. and Williams D.J. 1989. Calculation of ground level concentrations of SO_2 for various copper smelter processes. Investigation Report 1829R.

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