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AMBIENT AIR POLLUTION: CARBON MONOXIDE

POSITION PAPER

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NOTE

This document reflects the opinions of the majority of the experts who assisted in its preparation.

It should not be considered as an official statement of the position of the European Commission

Not all experts necessarily share all the views expressed in this document.

AMBIENT AIR POLLUTION: CARBON MONOXIDE

POSITION PAPER

Summary

1. Introduction

This position paper is a background document to support the Commission in the preparation of a proposal for a Directive setting ambient air quality limit values for carbon monoxide (CO). The proposal is required by the Council Directive on the Assessment and Management of Ambient Air Quality (the “Framework Directive”)[1]. The paper reflects the results of discussions in the Air Quality Steering Group, in which representatives from the Member States, Industry and NGO’s assist the European Commission with the development of legislation on ambient air quality. In contrast to similar position papers written earlier, which were written by special working groups, this paper was drafted by a consultant to the European Commission, supported by some members of the Steering Group who contributed to the paper in special CO meetings.

In 1994 the European Union emitted about 44 Mtonnes of CO into the air. By far the largest source is road transport, which accounts for two-third of the emissions. The EU emission trend in the last years was downward, though not in all Member States.

The highest ambient CO concentrations are found near traffic in cities. As a result of current and foreseen emission reduction measures for road traffic, a downward trend in concentrations is observed at many locations, and this trend is expected to continue. The fact that industrial levels are hardly reported suggests that levels near industrial CO sources are not of major concern.

2. Risk assessment

CO readily reacts with haemoglobin in the human blood and as a result the oxygen-carrying capacity of the blood is reduced. In order to protect non-smoking, middle-aged, and elderly population groups with documented or latent coronary artery disease from acute ischemic heart attacks, and to protect fetuses of non-smoking pregnant mothers from untoward hypoxic effects, the World Health Organisation (WHO) recommends that a carboxyhaemoglobin level of 2.5% should not be exceeded. On this basis the WHO adopted in 1996 four guidelines for the maximum CO concentrations.

WHO guidelines:
- *100 mg/m^3 (90 ppm) for 15 minutes*
- *60 mg/m^3 for 30 minutes*
- *30 mg/m^3 for 1 hour*
- *10 mg/m^3 for 8 hours*

[1] 96/62/EC OJ L 296, 21.11.96 p55

Of the annual data series for 1989-1995 in the European APIS data base (mainly from stations near busy streets) 26% exceeded the 8-hour guideline; some Member States reported that exceedences of the guidelines were not observed anymore. Fewer exceedences of the other guidelines occurred.

It is not necessary to use all WHO guidelines separately as bases for air quality thresholds. For the ambient air quality, the 15- and 30-minutes guidelines give no additional protection compared to the 1- and 8-hour guidelines. A few situations have been observed where the 1-hour guideline was exceeded and the 8-hour guideline was not, but the 8-hour guideline is found to be in practice more protective than the 1-hour guideline. It is proposed to set a limit value for CO and base it on the 8-hour guideline. From a practical point of view it is generally preferable to allow a limited number of exceedences per year. However, in the special case of CO the levels are expected to decrease far enough to achieve full protection against exceedence of the WHO guideline.

It is proposed to define the limit value as the 8-hour average concentration of 10 mg/m^3, which should not be exceeded. It is proposed to set the Margin Of Tolerance at 50% of the limit value, decreasing linearly to zero in 2005. It is proposed not to set an alert threshold.

It is proposed to make up-to-date information on ambient CO levels routinely available to the public and appropriate organizations.

3. Assessment of concentrations

The assessment aims at:
- checking whether the limit value is exceeded anywhere;
- supporting air quality management in case of exceedence;
- making information available to the public.

In view of this, the following concentration parameters should be assessed:
- daily maximum 8-hour average in the calendar year;
- average over the calendar year.

Network design (macro-siting) should be based on explicit goals of station representativeness and should facilitate the reporting of territory-covering statistics of CO concentrations. Three types of stations, characterised according to their representativeness, should be considered:
- traffic stations;
- industrial stations;
- urban background stations.

In practice, traffic stations are expected to be the most important types.

Two types of assessments are allowed:
- by measurements alone;
- by measurements and supplementary assessment.

For the first assessment type, a higher minimum station density is needed than for the second type. The assessment requirements also depend on whether the Upper Assessment Level (UAT) and Lower Assessment Threshold (LAT) are exceeded. It is proposed to set UAT and LAT at 70% and 50% of the limit value respectively. Table I proposes minimum densities for stations near diffuse sources in case of assessment by measurements alone.

Table I *Minimum number of stations per zone in case of no supplementary assessment*

Population of agglomeration or zone (millions)	**If maximum concentrations exceed UAT**	**If maximum concentrations are between UAT and LAT**
<0.25	1	1
-0.5	2	1
-0.75	2	1
-1	3	1
-1.5	4	2
-2	5	2
-2.75	6	3
3.75	7	3
-4.75	8	4
-6	9	4
>6	10	5
	If >1, to include at least one urban background station and one traffic oriented station	

For the assessment of pollution in the vicinity of point sources, the number of sampling stations should be calculated taking into account emission densities, the likely distribution patterns of ambient air pollution and potential exposure of the population.

Micro-siting criteria include the requirement for street stations to measure less than 5 metres from the kerbside, but at least 4 metres from the centre of the nearest traffic lane and at least 25 metres from the edge of major street junctions.

For measuring CO the following reference method is proposed: analysis and calibration according to ISO/DIS 4224: non-dispersive infrared spectrometer (NDIR) method.

Assessment by mathematical methods (modelling, interpolation, combinations of models and measurements) are important tools to generate a territory-covering description of the CO concentrations, in particular spatial statistics.

4. Cost implications

A separate study was conducted to identify and estimate costs and benefits of further action beyond existing and planned measures needed to meet the limit values for CO. Two possible limit values were investigated: 10 mg/m^3 as the highest 8-hour mean (proposed) and 10 mg/m^3 as the second highest mean in any year. These levels were investigated in both urban background and hot-spot locations (the latter including kerb side sites). For 2005 no exceedences were expected for the urban background. Exceedences were estimated to occur at hot spots, though in some cities only. The benefit assessment was limited to one type of effect only, congestive heart failure. The benefits to be gained by reducing emissions to meet the limit values were less than estimated costs, though of a similar order of magnitude.

These results are subject to a high level of uncertainty. Important contributions to the uncertainty arise from inconsistencies in inventories between different countries, a lack of good exposure-response relations and the limited scope of the study which did not allow the integration of secondary effects of abatement of CO, for example through emission reductions of other pollutants.

5. Reporting the results

It is proposed that not only data of individual measuring stations should be reported, but, in the case of supplementary assessment, also spatial statistics, in particular the total street-length in exceedence per zone.

Contents

1. INTRODUCTION 9

1.1 Background 9

1.2 CO in the air 9

1.3 Sources of CO 10
1.3.1 World-wide emissions 10
1.3.2 EU emissions 11

1.4 CO in ambient air 14
1.4.1 Data at EU level 14
1.4.2 Data at national level 16
1.4.3 Summary of CO levels 18

2. RISK ASSESSMENT 20

2.1 Effects and risks 20
2.1.1 Health 20
2.1.2 Environment 21

2.2 WHO guidelines for maximum concentrations of CO in ambient air 21

2.3 WHO guidelines versus CO concentrations 21

2.4 Existing standards 23
2.4.1 Existing EU standards 23
2.4.2 Standards in Member States 23
2.4.3 Standards in some other countries 24

2.5 Thresholds to be considered as starting values for EU standards 24
2.5.1 Comparison of the protectiveness of the four WHO guideline values 24
2.5.2 Choosing the limit value 28
2.5.3 Further specifications of the limit value 29
2.5.4 Public information on ambient concentrations 30
2.5.5 Alert threshold 30

3. ASSESSMENT OF CONCENTRATIONS 31

3.1 Introduction 31

3.2 Principles and assessment regimes based on the Directive on Ambient Air Quality Assessment and Management 31
3.2.1 Purpose of the assessment 31
3.2.2 Targets addressed 31
3.2.3 Assessment regimes 31
3.2.4 Assessment in time and space 33
3.2.5 Upper and Lower Assessment Thresholds 34

3.3 Measurement strategy 36
3.3.1 General 36
3.3.2 Network density in the case of no supplementary assessment 37
3.3.3 Network density in the case of supplementary assessment 38
3.3.4 Siting criteria 38

3.4 Measurement methods **41**
3.4.1 Existing sampling methods 41
3.4.2 Existing measuring methods 41
3.4.3 Existing calibration procedures 42
3.4.4 Reference measurement method 43
3.4.5 Screening techniques 43

3.5 Mathematical methods **44**

3.6 Data quality objectives **46**

3.7 Quality Assurance and Quality Control of measurements **47**

4. COST IMPLICATIONS **49**

5. REPORTING THE RESULTS **53**

ANNEX A SPECIAL AREAS OF POTENTIALLY HIGH CO CONCENTRATIONS **55**

CO - POSITION PAPER

1. Introduction

1.1 Background

The Council Directive on the Assessment and Management of Ambient Air Quality[2], the so-called Framework Directive, gives a list of atmospheric pollutants for which the European Commission shall submit to the Council proposals for the setting of limit values and, as appropriate, alert thresholds in relation to the air quality. The pollutants are listed in Annex I to the Directive. In 1995 the Commission and Member States established the Air Quality Steering Group, in which the Commission, the Member States and representatives of Industry and Non-Governmental Organisations participated. It started to work on the first five pollutants sulphur dioxide, nitrogen dioxide, fine particulate matter, suspended particulate matter and lead. Under the responsibility of the Steering Group position papers were drawn up for each pollutant. The two types of particulate pollutants were dealt with in one position paper on particulate matter, and so four position papers were written, which were subsequently used by the Commission to draw up a proposal for a combined new Directive on these pollutants (COM (97) 500).

In the course of the work on the first Daughter Directive, the preparation of position papers for the second group of pollutants ozone, benzene and carbon monoxide, commenced. The position paper for carbon monoxide (CO) was prepared by a consultant to the Commission on the basis of information and comments given by the Steering Group. A group of experts on CO assigned by the Steering Group convened twice for detailed discussions. In addition an economic analysis was conducted.

The current position paper on carbon monoxide only deals with the direct harmful effects of CO in ambient air, in accordance with the Framework Directive. CO is not only a harmful air pollutant in itself, but also a precursor for other pollutants. In particular it is a precursor for continental and global scale ozone and carbon dioxide, which are important greenhouse gases. Ozone also has substantial direct effects on health, vegetation and materials. Pollutants affected by CO will be addressed elsewhere.

1.2 CO in the air

CO is one of the most common air pollutants. It has no colour, odour or taste, it has a low reactivity and a low water solubility. It is mainly emitted into the atmosphere as a product of incomplete combustion. Annually, a large number of individuals die as a result of exposure to very high indoor CO levels, far above ambient outdoor levels. In Flanders, for example, in 1987-1988 about 100 people died, mostly as a result of accidental exposure[3]. For ambient outdoor air, CO is one of the “classical” air pollutants, for which many countries have set air quality limit values. At the EU level no air quality threshold exist currently.

In terms of absolute concentrations CO is the most prevalent of the toxic air pollutants. Its concentrations are expressed in mg/m^3, in contrast to all other pollutants, which are measured in $\mu g/m^3$ or even smaller units.

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[2] Council Directive 96/62/EC O.J L 296 21.11.96 p55

[3] Life in the big city (in Dutch). G. Magnus, 1995, Gemeenschappelijke Gezondheid, Antwerp.

Fortunately the risk thresholds are also in the range of mg/m^3, which is higher than thresholds for other toxic air pollutants of concern.

Conversion (293 K and 101.3 kPa): *1 ppm = 1.165 mg/m^3* *1 mg/m^3 = 0.859 ppm*

CO is not only directly emitted into the air, but can also be formed by chemical reactions from organic air pollutants, such as methane. CO has a residence time in the atmosphere of about three months. At moderate latitudes the time for air to travel around the world is also of the order of months. Since CO formation from organic air pollutants takes place everywhere in the atmosphere, a global background level of CO exists, ranging between 0.05 and 0.15 ppmv (0.06 and 0.17 mg/m^3)[4]. At EU latitudes the global background level is at the high end of this range.

1.3 Sources of CO

1.3.1 World-wide emissions

CO is brought into the atmosphere by two different mechanisms: emission of CO and chemical formation from other pollutants. Table 1 gives an overview of the global anthropogenic emissions of CO[5]. From the table it appears that burning of forest, savannah and agricultural waste accounts for half the global CO emissions. The chemical formation of CO is due to the oxidation of hydrocarbons, and it adds 600 - 1600 Mtonnes to the atmosphere[6]. Two-third of it stems from methane. It is a slow process, and does not give rise to local peak concentrations. However, being a source of the same magnitude of the direct emission, CO formation contributes considerably to the global background level. It is estimated that about one-third of CO results from natural sources, including that derived from hydrocarbon oxidation.

Table 1 *Global anthropogenic emissions of CO by sector in 1990*

Sector	**Emission**	
	Mtonnes/year	**%**
Road transport	206.7	21%
Non-road transport	1.7	0.2%
Residential	218.9	22%

[4] Climate Change 1994, Radiative Forcing of Climate Change and An Evaluation of the IPCC IS92 Emission Scenarios, Intergovernmental Panel on Climate Change, 1995, University Press, Cambridge.

[5] Description of EDGAR Version 2.0, J.G.J. Olivier et al., 1996, RIVM report nr. 771060002, TNO MEP report nr. R96/119, The Netherlands.

[6] Climate change 1994, Radiative Forcing of Climate Change and An Evaluation of the IPCC IS92 Emission Scenarios, Intergovernmental Panel on Climate Change, 1995, University Press, Cambridge.

Industry and power generation	51.2	5%
Deforestation	111.4	11%
Savannah burning	177.0	18%
Agricultural waste burning	207.6	21%
Total	*974.5*	*100%*

1.3.2 EU emissions

Data on CO emissions in the EU are available in the CORINAIR emissions inventory for 1990[7] and 1994[8]. Table 2 and Figure 1 summarise the emissions by source sector for the EU member states. By far the largest source is road transport, which accounts for two-thirds of the emissions of the EU. The contribution from traffic is seen to vary considerably between the Member States (from 30 to 89%). Also for other source sectors the relative contributions deviate from the EU pattern, *e.g.* there is no emission from production processes in the UK. Such deviations may reflect the real emission deviations, but it can not be excluded that differences in emission registration method cause part of the discrepancies.

Not all sectors in Table 1 and Table 2 can be directly compared, but EU emissions by road transport, combustion and production processes are, on a per capita basis, larger than global emissions by road transport, industry and power generation. Conversely, residential emissions, deforestation, savannah burning and agricultural waste burning are more important sources on the global scale. Again, some of the differences may be due to differences in estimation methods.

Figure 2 compares the 1994 emissions with those of 1990. The trend in emissions is downward, though not in all Member States. The emissions in the most important source category, road transport, have gone down as a result of emission reduction measures, such as Inspection and Maintenance and the introduction of the 3-way catalyst, although the effect was partly offset by the growth of the number of vehicle-kilometres.

[7] CORINAIR 90, Comprehensive Summary Report. Final Draft. March 1996. European Topic Centre on Air Emissions / EEA.
[8] CORINAIR 94, Summary Report. Final Draft. 10 April 1997. European Topic Centre on Air Emissions / EEA.

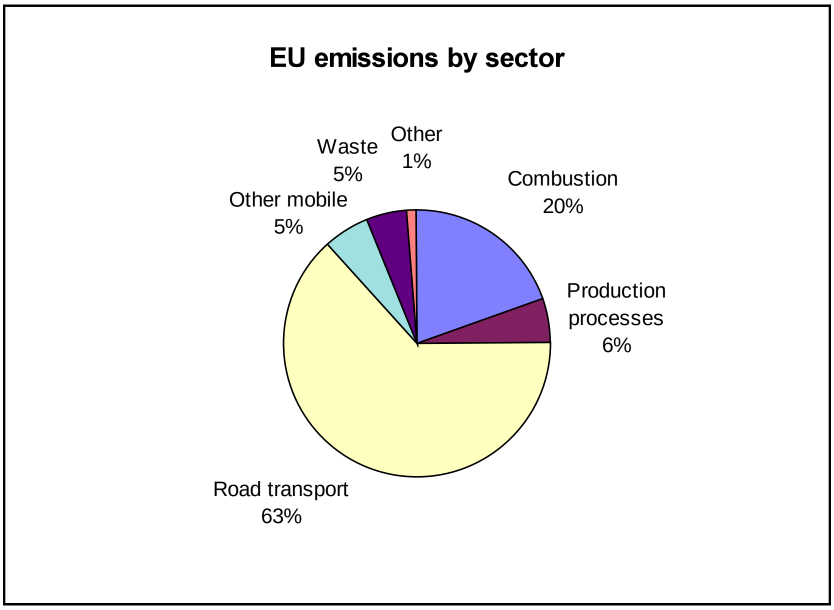

Figure 1 *EU emission of CO by sector in 1994*

Table 2 *Emissions of CO in the EU in 1994 (1000 tonnes)*[9]

Source category	**Combustion**	**Production processes**	**Road transport**	**Other mobile sources and machinery**	**Waste treatment and disposal**	**Other**	**Total**
Austria	506	293	363	12	4	2	1181
Belgium	132	17	995	2	19	0	1166
Denmark	187	0	413	79	0	37	715
Finland	87	0	311	40	0	0	438
France	2455	623	5236	1013	233	107	9668
Germany	1992	606	3953	243	0	13	6807
Greece	19	25	978	38	0	135	1194
Ireland	65	0	261	6	1	0	333
Italy	704	481	5811	678	1527	30	9231
Luxembourg	85	14	44	3	0	0	145
Netherlands	233	112	523	27	3	37	935
Portugal	433	15	733	14	0	0	1195
Spain	1280	233	2739	113	315	133	4813
Sweden	30	5	1164	110	4	2	1315
United Kingdom	427	0	4315	41	48	47	4879
EU	8636	2423	27839	2418	2156	543	44015
EU	*20%*	*6%*	*63%*	*5%*	*5%*	*1%*	*100%*

[9] CORINAIR emission data for 1995 were available at the time of writing, but since emission data were lacking for some countries the set of 1994 was preferred. Official emission data reported under the UN Framework Convention on Climate Change did not contain road transport as a separate sector.

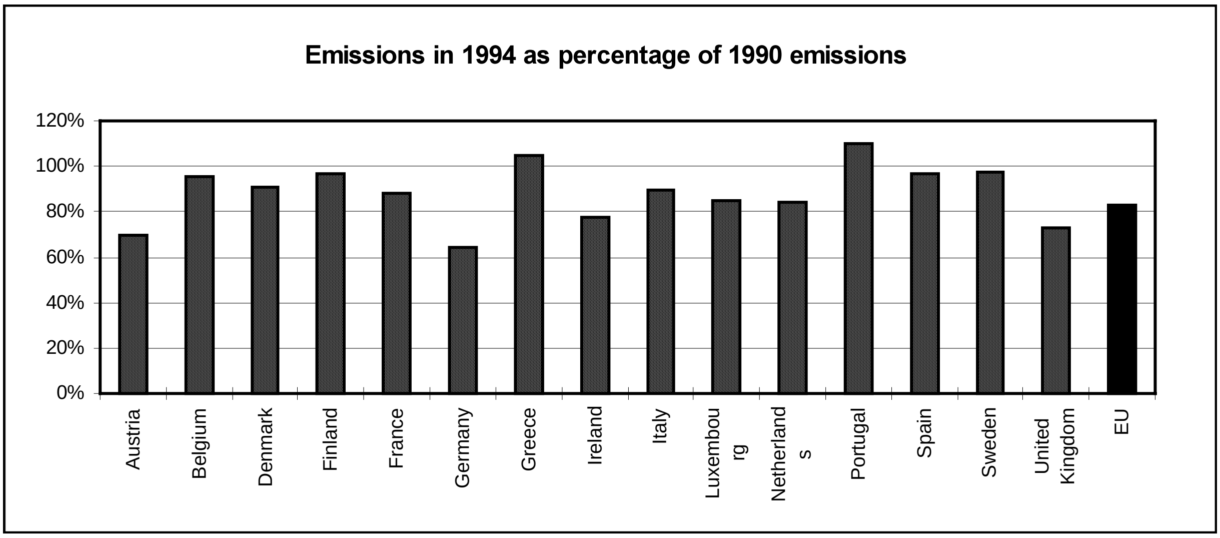

Figure 2 *Emissions in 1994 as percentage of 1990 emissions*

EMEP reports emissions data for a longer time span. The first year for which emissions per country were given is 1980, but emissions were in many cases estimated by setting the emission equal to the value of the first official submission in a later year. Table 3 gives the EMEP emissions[10]; in order to bring out any trends it gives data only for years for which emissions have actually been officially submitted to EMEP. Due to differences in definitions and calculation methods, including revisions of old data of past years that were applied to only one of the data bases, there are differences between the EMEP data and the CORINAIR data, but also here a slightly downward trend in the last years can be noticed. The EMEP data are not complete enough to allow a calculation of the trend in CO emissions of the EU as a whole.

Table 3 *Trend in CO emissions as given by EMEP (1000 tonnes)*[11]

	1980	**1985**	**1990**	**1991**	**1992**	**1993**	**1994**
Austria	1636	1648	1573	1503	1414	1326	1408
Belgium			1124	1131	1177	1147	
Denmark	673	741	770	824	812	732	728
Finland			556				
France	9216	8399	10930	10626	10309	9801	
Germany	15064	12049	10280	9032	8640	8029	7428
Greece							
Ireland			429	428	403	416	
Italy		6919	10347				
Luxembourg		240	171				
Netherlands		1356	1059	959	941	917	897
Portugal			1086	1111	1156	1175	1211
Spain			4778	4866	4801	4813	
Sweden			1347	1312	1275	1236	
United Kingdom	5631	5895	6360	6287	5842	5312	4884

[10] Transboundary Air Pollution in Europe. MSC-W Status Report 1996. Part One; Estimated dispersion of acidifying agents and of near surface ozone. EMP/ MSC-W, Report 1/96, July 1996.
[11] See footnote 9.

Figure 3 illustrates the impact of EU legislation on passenger car emission standards. The last two directives strongly reduce CO emissions. Since many older cars, which do not comply with these standards, are still in operation, a further reduction of traffic emissions is expected in the coming years. The speed of this fleet turnover varies considerably between the Member States. The reductions of emissions per vehicle is expected to be strong enough not to be offset by the growth of traffic.

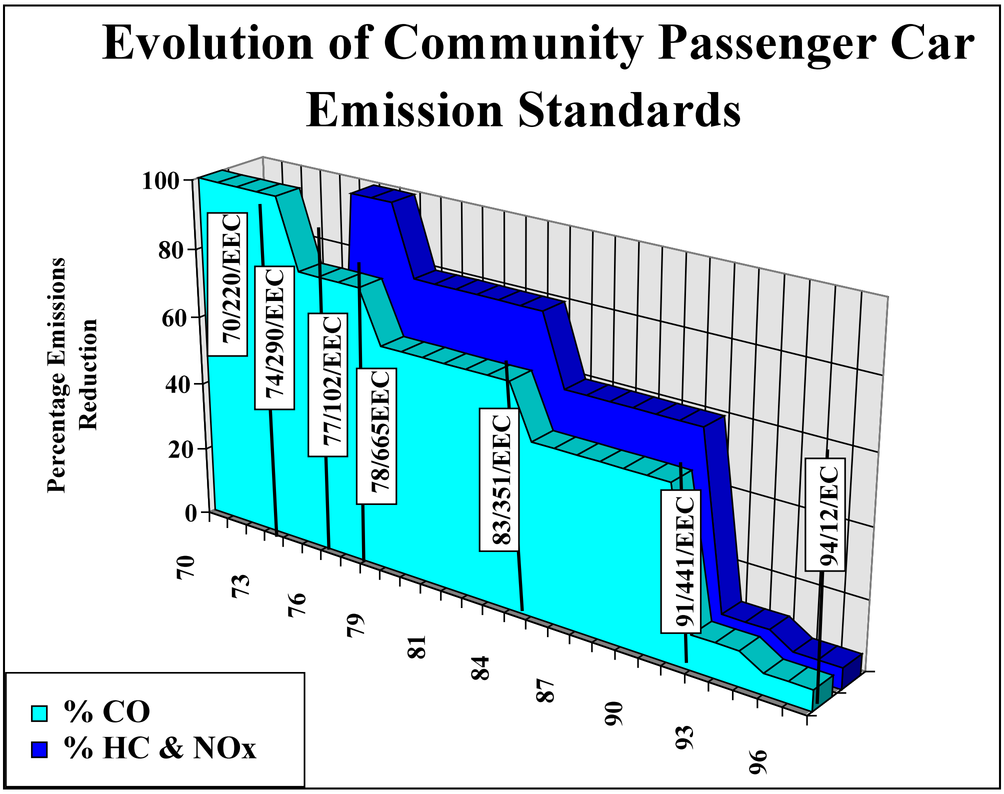

Figure 3 *The impact of EU legislation on passenger car emission standards*

1.4 CO in ambient air

CO has been measured for many years. Monitoring strategies have focused very much on pollution near roads. CO levels in busy city streets are higher than CO near highways, since the amount of CO emitted per kilometre strongly decreases with vehicle speed and also because the ventilation in city streets is less. Ambient CO levels are usually highest in winter, because cold engines emit much more CO than hot engines and also because the atmosphere tends to be more stable than in summer.

1.4.1 Data at EU level

Data from measurements

APIS

In the data base APIS[12] of the European Commission, 491 annual data series of CO from the EU are present, distributed over the period 1981-1995. For most of the stations represented in APIS, only a few years are available.

Table 4 gives an overview of the levels measured at the stations in the period 1989-1995. For some data series a correction factor of 10 has been applied because the original data were not expressed in the correct unit. For the data series with sufficient data capture (at least 75% valid data), which were almost all from traffic stations, statistics of the annual means, the 1-hour maximum and the 8-hour maximum are presented. From the table it is seen that annual mean levels are on the average 1.5 mg/m^3, while the maximum 1-hour and 8-hour means are typically an order of magnitude higher. The highest values of all data series are roughly a factor five higher than the typical values. Since the composition of the stations changed strongly over the years, representative trends could not be derived from these data.

Table 4 *Annual means and maximum 1-h and 8-h mean CO concentrations in data series of 1989-1995 in APIS (mg/m^3)*

CO air quality parameter	Average over all data series	Highest of all data series
Annual mean	1.5	8.4
Maximum 1-hour mean	13.5	64
Maximum 8-hour mean	8.6	44

Dobris

Another source of information on CO levels in Europe is the “Dobris” inventory of urban air quality[13]. In this inventory cities with more than 500 000 inhabitants were asked to provide information on air quality monitoring data. For CO, only information on the station that monitored the highest concentrations was requested in order to get an impression of urban hot spots. Of the 60 stations for which CO levels were reported, 57 were traffic stations. The concentrations reported for the annual mean and the maximum 8-hour mean confirm the general picture found in APIS.

Two out of the 60 CO stations are referred to as city background or city stations, in Bremen and Budapest respectively. In Bremen, the annual average concentration is given as 1.2 mg/m^3 and the 98-percentile (1/2h) given is, surprisingly, almost equal (1.3 mg/m^3).

None of the monitoring data from the EU collected in the Dobris inventory refer to industrial stations. Only one station in Budapest was characterised as such. The concentrations are reported for 1992, with an average of 4.0 mg/m^3 and a 98-percentile of 24-hour mean concentrations of 7.1 mg/m^3.

Data from Auto Oil I

In the European Auto Oil I programme an extensive analysis of the future development of CO emissions and concentrations in the EU was undertaken. In the "business as usual" scenario, which assumed that no additional measures would be developed, the urban background levels were predicted to decrease considerably. For London, where the highest levels were calculated, a decrease from 1.8 mg/m^3 in 1990 to 0.6 mg/m^3 in 2010 (annual average, neglecting the rural background) was found. Taking a representative ratio between the annual

[12] Later incorporated in the AIRBASE data base.

[13] R.J.C.F. Sluyter (ed.), Air Quality in Major European Cities, 1995, RIVM, report nr. 722401004, The Netherlands; NILU, Norway.

average and the 8-hour WHO guideline value, the study concluded that the downward emission trend would bring the urban background levels below the WHO guideline. It was, however, also remarked that if future European air quality standards would be required to be met at roadside locations, the levels there might require more reductions than assumed in the study.

1.4.2 Data at national level

Some Member States and the Union of Industrial and Employers' Confederations of Europe (UNICE) submitted concentration data for this paper. Some expressed the concentrations in terms of the parameters that were in use locally to characterise the CO levels, others expressed it in terms of the WHO guidelines that are taken as the basis for the EU limit values for CO (see Section 2.2).

Austria
In Austria the WHO guideline value of 10 mg/m^3 as 8 hour mean has been exceeded at few sites in 1993 and 1996. The 8-hour mean guideline was found to be much more likely to be exceeded than the 1-hour and half-hour mean guideline values, which were not exceeded in Austria in the period 1990-1997. During the last years, CO concentrations decreased continuously in Austria, except at an industrial site. At this industrial site WHO guidelines were found to be slightly exceeded in 1996.

Belgium
The concentrations provided by Belgium, from three traffic stations in 1996, were below the WHO guidelines.

Finland
Data provided by Finland showed that the WHO guideline of 10 mg/m^3 as 8-hour mean was exceeded at some street stations in the period 1990-1996. Such exceedences occurred during this entire period.

Germany
Germany reported that the CO concentrations in streets with intensive traffic are down to less than 2 mg/m^3 annual average and less than 5 mg/m^3 as 98 percentile of half-hourly means. The German standards of 10 mg/m^3 (annual average) and 30 mg/m^3 (98 percentile of half-hour means) are met everywhere in Germany.
A clear downward trend is visible in Figure 4, which gives the average trend for traffic stations and non-traffic stations in the Rhine-Ruhr area. Since the 98-percentile of half-hour means and the annual means go down, the 98-percentile of 8-hour means can be expected to exhibit a downward trend as well.

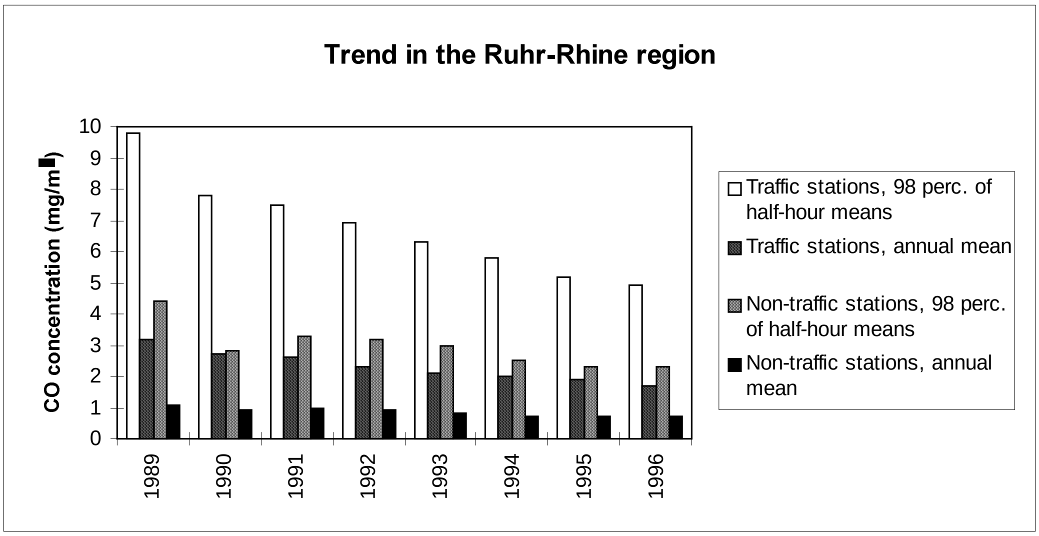

Figure 4 *CO trend observed in the Rhine-Ruhr region.*

The Netherlands

In the Netherlands the limit value of 6 mg/m^3 as 98-percentile of running 8-hour means was not exceeded at regional or urban background sites, while scarce exceedences were found in busy streets. In 1996 the highest 8-hour mean measured was 4.7 mg/m^3, and the highest 98-percentile of 8-hour means 3.3 mg/m^3. A decreasing trend in CO exceedences is reported: the estimated total street length with exceedence of the limit value in the Netherlands was reduced from about 50 km at the end of the eighties to around 5 km in 1995.

Portugal

Portugal provided data from 16 stations for 1993 and 1994. Information on the sites was not given. Table 5 summarises the data.

Table 5 *Concentrations from 16 stations in Portugal (mg/m^3)*

	Annual mean	Max. hourly mean	Max. 8h mean	Max. daily mean
1993	0.16-2.9	7.1-57	2.5-25	1.9-18
1994	0.87-2.9	6.7-45	2.2-43	1.2-38

Sweden

The number of CO measurement sites has been decreased, because CO is not regarded as a problem anymore. Table 6 gives a summary of the measurement results.

Table 6 *Concentrations in some of the most polluted streets in Stockholm (mg/m³)*

Year:	1973 (4 months)		1995 (whole year)		
	1h max	8h max	1 h max	8h max	98 perc 8h
Polluted streets in Stockholm					
Sveavägen (30 000 veh/day)	10	10	8.9	5.8	4.8
Hornsgatan (40 000 veh/day)	25	15	13	6.8	5.0
Urban background					
Göteborg			8.2	5.0	1.6

Data from tunnels
In the Mont Blanc tunnel CO concentrations, measured when only private vehicles were present, were found to decrease continuously over the period 1970-1996, in spite of traffic growth and the reduction of the tunnel ventilation[14]. Similar patterns were observed in the Gubrist tunnel near Zürich[15].

1.4.3 Summary of CO levels

From the above information the following picture arises.

Rural levels
Although CO is hardly removed from the air during atmospheric transport on the scale of the continent, long range transport does not lead to concentrations of concern. Only in the vicinity of sources, where atmospheric dilution is yet rather low, high levels occur.

City background levels
A clear picture of urban background is not found in the above data. Urban background levels exceeding the WHO guidelines were not observed. It is, however, not certain whether urban background levels, particularly in Southern Member States can reach levels of concern during conditions of low dispersion.

Levels near traffic
Generally, the highest CO concentrations are reported for streets stations. The WHO guidelines are exceeded in some busy streets, but in many countries the levels are going down. This trend is expected to continue in the years to come.

Levels near industry
Some industrial processes (particularly coke production) result in high emissions of CO. When these emissions are released through high chimneys the local ambient concentrations will not increase very much. The fact that only one such location was identified in EU networks, suggests that industrial levels do not pose great problems.

Levels near other sources

[14] Vincenzo Ferro, 1992. Relazione sull'impianto di ventilazione del traforo del Mont Bianco. Studio Professionale Associato Ingg. Ferro e Cerioni, Turin, Italy.
[15] Urs Steinemann, 1995. Verkehrs- und Schadstoffmessungen 1994 im Gubristunnel. Ingenieurbüro für Energie- und Umweltfragen, report nr. US 89-16-06, Wallerau, Switzerland.

Ambient CO levels of concern near other sources, *e.g.* agricultural waste burning, were not reported.

2. Risk assessment

2.1 Effects and risks

2.1.1 Health

The following description of effects and risks is based on the chapter on CO in the Update and Revision of the WHO Air Quality Guidelines for Europe[16].

CO reacts readily with haemoglobin in the human blood to form carboxyhaemoglobin (COHb). The affinity of haemoglobin for CO is 200-250 times that for oxygen, and as a result this binding reduces the oxygen-carrying capacity of the blood and impairs the release of oxygen to extravascular tissues. The most important variables determining the COHb level are CO in inhaled air, duration of exposure and lung ventilation. During an exposure to a fixed concentration of CO, the COHb concentration increases rapidly at the onset of exposure, starts to level off after 3 hours, and reaches a steady-state after 6-8 hours of exposure. Physical exercise accelerates the CO uptake process. The formation of COHb is a reversible process, but because of the tight binding of CO to haemoglobin, the elimination half-life while breathing room air is 2-6.5 hours depending on the initial COHb level. The elimination half-life of COHb is much longer in the fetus than in the pregnant mother.

The toxic effects of CO become evident in organs and tissues with high oxygen consumption such as the brain, the heart, the exercising skeletal muscle, and the developing fetus. The effects of CO exposure at very high concentrations (well above ambient levels) are lethal. High concentrations may cause both reversible, short-lasting neurological deficits and severe, often delayed neurological damage. At COHb levels as low as 5.1-8.2% impaired co-ordination, tracking, driving ability, vigilance and cognitive performance have been observed. In healthy subjects the endogenous production of CO[17] results in COHb levels of 0.4-0.7%. During pregnancy, elevated maternal COHb levels of 0.7-2.5% have been reported, which is mainly due to increased endogenous production. The COHb levels in non-smoking general populations are usually 0.5-1.5% due to endogenous production and environmental exposures. Non-smoking people in certain occupations (car drivers, policemen, traffic wardens, garage and tunnel workers, firemen etc.) can have long-term COHb levels up to 5%, and heavy cigarette smokers have COHb levels up to 10%. Well-trained subjects engaging in heavy exercise in polluted indoor environments can increase their COHb levels quickly up to 10-20%. In indoor ice arenas, there have been recently reported epidemic CO poisonings.

The Commission is required by Article 4.2 of the Air Quality Framework Directive to maintain awareness of the most recent scientific research data on the effects of pollution and if necessary to re-examine the elements on which limit values are based. Such recent information and the references are given in the footnotes [18] [19] [20].

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[16] Air Quality Guidelines for Europe (1999), 2nd edition, Vol. 1, WHO Regional Publications, Regional Office for Europe, Copenhagen, in press.

[17] The carbon monoxide produced by the body's own chemical reactions.

[18] A recent epidemiological study in Athens (Toulomi et al., 1994) found that changes in CO concentrations below these concentrations were associated with daily mortality. However, this association was not

2.1.2 Environment

Adverse direct impacts on vegetation by CO at ambient concentrations have not been reported. As a precursor of carbon dioxide and ozone, CO indirectly contributes to global warming and to direct effects by ozone to vegetation and materials.

2.2 WHO guidelines for maximum concentrations of CO in ambient air

In order to protect non-smoking, middle-aged, and elderly population groups with documented or latent coronary artery disease from acute ischemic heart attacks, and to protect fetuses of non-smoking pregnant mothers from untoward hypoxic effects, the WHO recommends that a COHb level of 2.5% should not be exceeded.
The guideline values (ppm values rounded) and periods of time-weighted average exposures for maximum concentrations of CO in ambient air have been determined in such a way that the COHb level of 2.5% is not exceeded, even when a normal subject engages in light or moderate exercise:

WHO guidelines

100 mg/m^3 (90 ppm) for 15 minutes
60 mg/m^3 for 30 minutes
30 mg/m^3 for 1 hour
10 mg/m^3 for 8 hours

2.3 WHO guidelines versus CO concentrations

The EU APIS data base contains both 1-hour mean and 8-hour mean concentrations. 10- and 30-minutes values are not available, but since these values are less relevant for setting limit values than the other two (see Section 2.6.1), an analysis of these values is not needed.

Figure 5 and Figure 6 present the cumulative distribution of the annual maximum values of the 1-hour means and the 8-hour means respectively. It represents the 327 CO annual data series in the APIS data base over the period 1989-1994. (For some data series an erroneous

significant after adjustment for SO_2 and particulate matter. A more recent paper (Poloniecki et al., 1997) implicates CO in heart attacks in London. In the absence of replications these results must be regarded as preliminary and have not been taken into account in recommendations for limit values.

[19] G. Toulomi, S.J. Pocock, K. Katsouyanni and D. Trichopoulos, 1994. Short-term effects of air pollution on daily mortality in Athens: a time series analysis. Int. J. Epidem., 32:954-967.

[20] J.D. Poloniecki, R.W. Atkinson, A. Ponce de Leon and H.R. Anderson, 1997. Daily time series for cardiovascular hospital admissions and previous day's air pollution in London, UK. Occupational and Environmental Medicine, 54:535-540.

factor of 10 had to be removed first.) It is seen that in 26% of the data series the maximum 8-hour values are above the WHO guideline values, and in 3% above the guideline for 1-hour means.

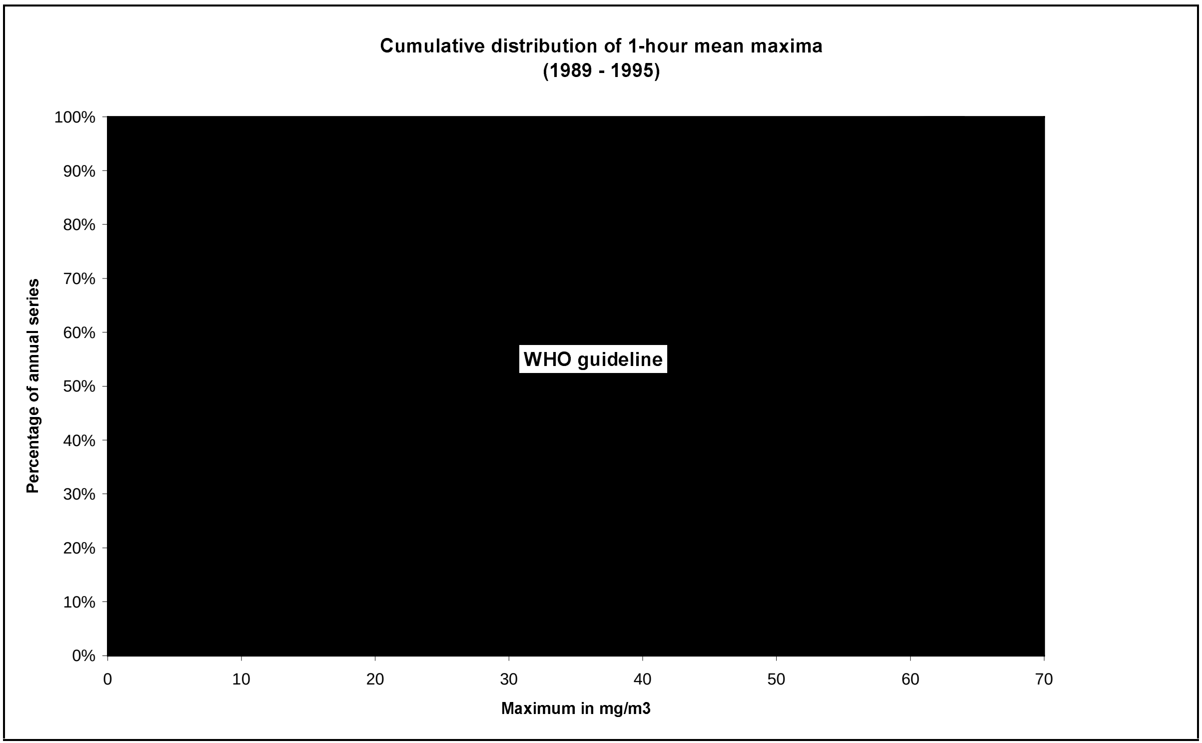

Figure 5 *Cumulative distribution of maximum values in APIS data base: 1-hour means*

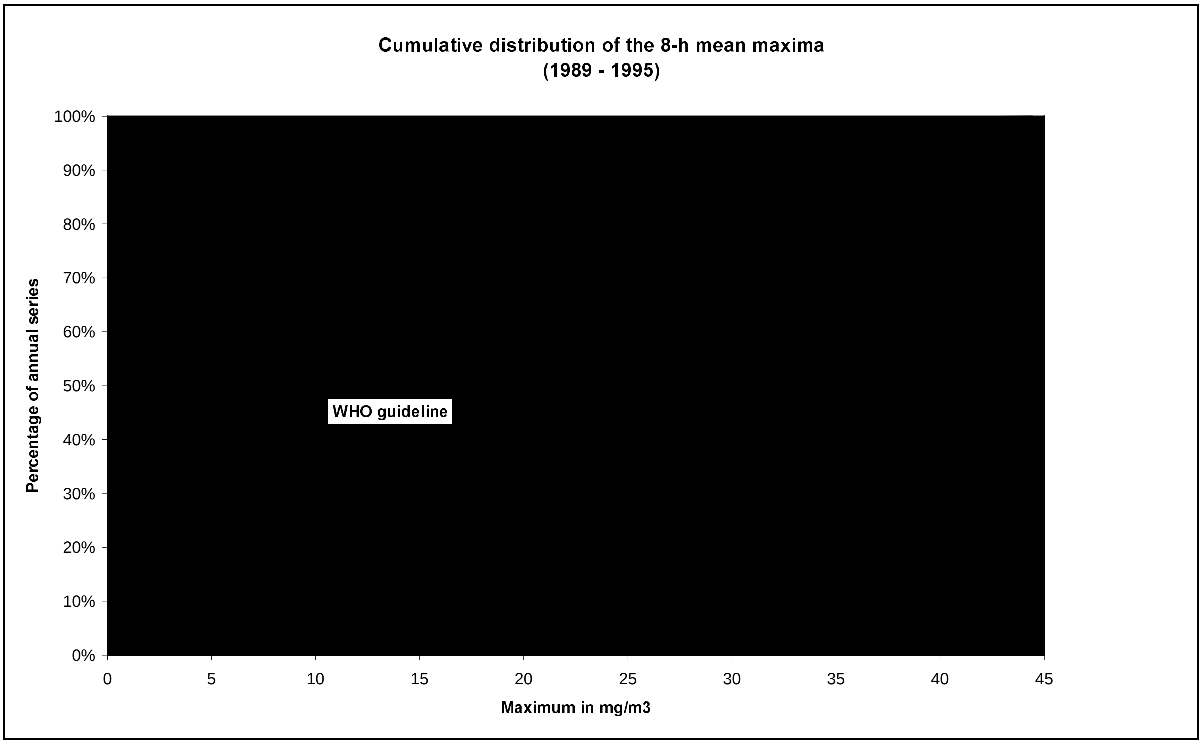

Figure 6 *Cumulative distribution of maximum values in APIS data base: 8-hour means*

In the national data received (Section 1.3.2), exceedences of the guideline for the 1- and 8-hour mean were found in several Member States (Austria, Finland, Portugal). Other Member States reported that no exceedences occurred any more. The German data, being expressed as 98-percentiles of half-hour means, could not be directly compared with the WHO guidelines.

2.4 Existing standards

2.4.1 Existing EU standards

For the European Union there are no existing limit values for CO in ambient air.

2.4.2 Standards in Member States

Member States submitted the following information on their existing air quality standards.

Austria
The air quality standard in Austria is:
- 10 mg/m^3 as moving 8-hour mean

Austria has air quality standards for CO in its Smog Alert Act, defined as moving 3-hour means:
- 20 mg/m^3 for a pre-warning
- 30 mg/m^3 for warning level I
- 40 mg/m^3 for warning level II

Finland
Finland has non-mandatory guidelines for CO:
- 20 mg/m^3 as maximum 1-hour mean
- 8 mg/m^3 as maximum 8-hour mean

Germany
The German air quality standards are:
- 10 mg/m^3 annual mean
- 30 mg/m^3 98 percentile based on half-hour means for one year

The Netherlands
The limit values in the Netherlands are:
- 6 mg/m^3 98 percentile of 8-hour means
- 40 mg/m^3 99.9 percentile of 1-hour means

Temporarily a less strict limit value applies for certain types of busy streets:
- 8.25 mg/m^3 98 percentile of 8-hour means until 1-1-2000

Portugal
The Portuguese air quality thresholds are:
Limit values
- 40 mg/m^3 1-hour mean, one exceedence allowed

- 10 mg/m^3 8-hour mean (running means)

Guide value

- 1 mg/m^3 24-hour mean

Sweden

The Swedish national air quality standard is:

- 6 mg/m^3 98 percentile of 8-hour running means in winter half year as target value

United Kingdom

The UK adopted an air quality target of 10 ppm (11.4 mg/m^3) as the maximum of running 8-hour means, to be achieved by 2005.

2.4.3 Standards in some other countries

USA

The USA National Ambient Air Quality Standard for CO is 9 ppm (10.3 mg/m^3) as 8-hour non-overlapping average not to be exceeded more than once per year.

Japan

The air quality standards of Japan set a limit of 10 ppm (11.4 mg/m^3) to the average daily concentration and a limit of 20 ppm (22.8 mg/m^3) to the 8-hour mean concentration.

2.5 Thresholds to be considered as starting values for EU standards

In this paragraph proposals for the thresholds will be made on the basis of health criteria and practical considerations regarding administrative and monitoring feasibility. Economic aspects will be dealt with in Chapter 4, and may be a reason to reconsider the proposals later. This section first selects the most significant threshold(s) from the set of WHO guidelines, then proceeds to the definition of a corresponding limit value and finally discusses public information, including the possibility of an alert threshold.

2.5.1 Comparison of the protectiveness of the four WHO guideline values

The WHO recommends four concentration levels as guidelines, each with its own averaging time, aimed at preventing the COHb level in blood to exceed 2.5%. An important question is whether all four levels should be taken as starting points for limit values. If one of the guideline levels is in practice never exceeded without any of the others being also violated, there is no reason to use it as a limit value. Including unnecessary limit values would increase the amount of work to be done by Member States without increasing the protection for human health.

60 mg/m^3 for 30 minutes

When comparing the protectiveness of the guideline for the 30-minutes average to that for hourly averages it is easy to see that it is less protective: if the 30-minutes averaged concentration is above the guideline of 60 mg/m^3, the 1-hour concentration must mathematically be above the guideline value of 30 mg/m^3. Consequently the 30-minutes guideline is not useful as a basis for the limit value.

100 mg/m^3 for 15 minutes

To exceed the 15-minutes guideline of 100 mg/m^3 without exceeding the hourly average guideline, would require that during the remaining 45 minutes in the same hour the average concentration would be less than 7 mg/m^3. This seems unlikely in normal situations. In exceptional cases it can be imagined that a short peak, *e.g.* during a few minutes, in an otherwise clean situation would bring the 15-minutes average between 100 and 120 mg/m^3, which would leave the hourly concentration just below 30 mg/m^3. However, if the 15-minutes average would be above 120 mg/m^3, the hourly average guideline would be also be exceeded. So, in practice the hourly guideline is expected to be virtually always more or equally protective compared with the 15-minutes guideline.

In addition to the improbability of situations where the 15-minutes guideline would be more protective than the 1-hour one, the compliance of a 15-minutes limit value would be extremely difficult to assess. From the measuring point of view, many stations would be needed to cover the exceptional cases mentioned above, and the larger amount of data to be handled could pose logistic problems. From the modelling point of view, meteorological or emission data on a 15-minutes basis are not available.

Consequently, it is proposed not to fix a threshold on a 15-minutes basis.

30 mg/m^3 for 1 hour and 10 mg/m^3 for 8 hours
It is not *a priori* clear which of the two remaining guidelines is the most protective one. Mathematically, 30 mg/m^3 during an hour in combination with 7 hours at the background level of 0.2 mg/m^3 would yield an 8-hour average of 4 mg/m^3, which is well below the 8-hour guideline of 10 mg/m^3. Conversely, it is clear that mathematically the 8-hour average of 10 mg/m^3 can be exceeded without violation of the hourly average of 30 mg/m^3. Empirical information is needed to compare the protectiveness of the two guidelines. Table 7 and Table 8 give the results of an analysis of all yearly data series in the APIS data base in 1989-1995, for the maximum, the second highest and for the 98-percentile. Figure 7 and Figure 8 illustrate this for the maximum and the 98-percentile. (It is remarked that the non-random fine-structure in the pattern of data points in Figure 8 is due to rounding off in the concentration values.)

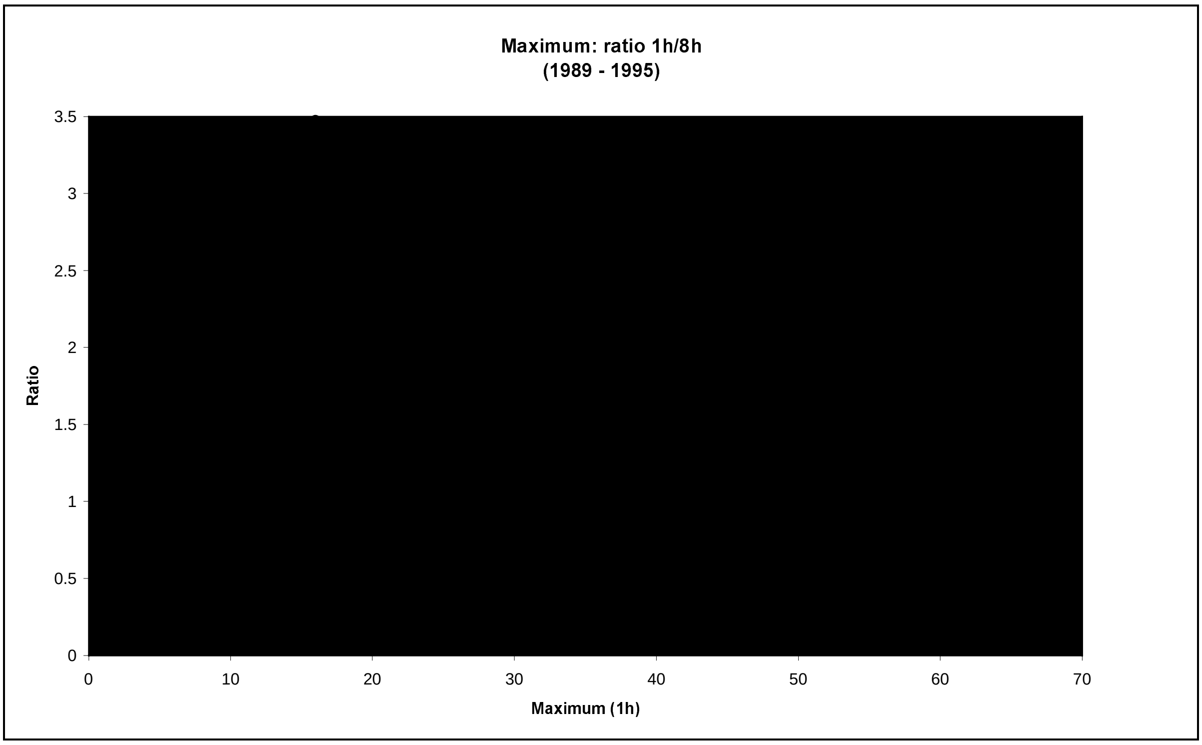

Figure 7 *Ratio between annual maximum of 1-hour means and of 8-hour means, for CO data series in APIS for 1989-1995*

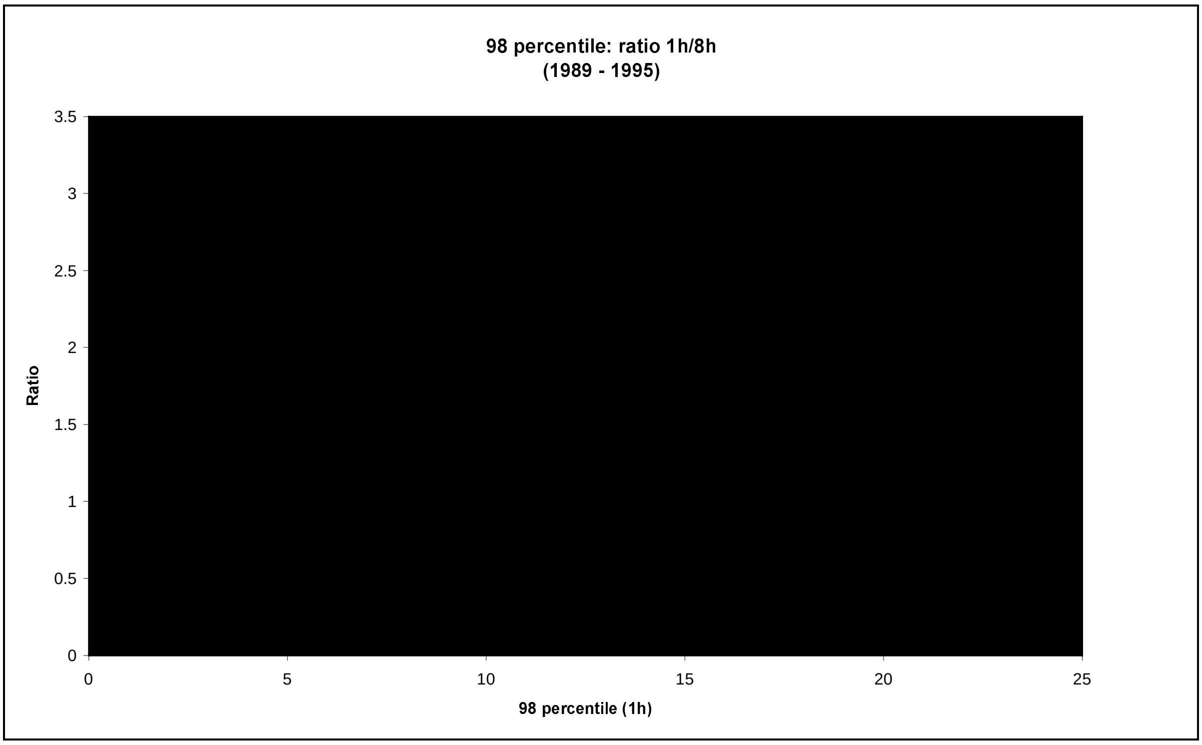

Figure 8 *Ratio between annual 98 percentile of 1-hour means and of 8-hour means, for CO data series in APIS for 1989-1995*

Table 7 *Ratio between 1-hour means and 8-hour means, for data series of 1989-1995 in APIS*

Parameter	**Ratio between 1-hour means and 8-hour means**			
	Average ratio	**Median ratio**	**90-perc. of ratio**	**Maximum ratio**
Maximum	1.61	1.52	2.13	3.5
Second highest	1.58	1.53	1.98	3.3
98-percentile	1.14	1.14	1.25	1.4

Table 8 *Ratio between 1-hour means and 8-hour means, for CO data series of 1989-1995 in APIS where the 8-hour maximum is between 5 and 20 mg/m^3*

Parameter	**Ratio between 1-hour means and 8-hour means**			
	Average ratio	**Median ratio**	**90-perc. of ratio**	**Maximum ratio**
Maximum	1.60	1.51	2.10	3.3
Second highest	1.60	1.55	1.99	3.3
98-percentile	1.15	1.15	1.25	1.4

In most cases the ratio between 1-hour mean values and the corresponding 8-hour values is less than 3, which is the ratio between the corresponding guidelines. So, the guideline for the 8-hour mean is usually more protective than the guideline for the 1-hour mean, and is consequently the most suitable point of departure for the setting of a limit value. Since, however, the 8-hour mean is not in all cases more protective than the 1-hour mean, one can not exclude the 1-hour mean guideline as a possible second limit value.

The question of whether the 1-hour average should be proposed as a limit value in addition to the 8-hour average can not be separated from the question of which parameter of the frequency distribution (maximum or another percentile) is to be chosen. Of the 307 annual data series in APIS for 1989-1995, five series had a maximum of the 1-hour average that was more than 3 times higher than the maximum 8-hour mean. In order to check whether the stations where concentrations are around the WHO guideline values exhibit a similar behaviour, a selection was made of the data series with the maximum 8-hour mean between 5 and 20 mg/m^3. This reduced the number of APIS data series to 228, and here three cases were found to have a ratio higher than 3. So, if the WHO guidelines would be expressed as a limit value in terms of the maximum, the 8-hour guideline would not completely protect against exceedence of the 1-hour mean guideline.

For percentiles other than the maximum, it is less probable that the [1-hour : 8-hour] ratio would be above 3. The second highest of the 1-hour mean found in the APIS data base was only in one data series more than 3 times the second highest 8-hour mean, and all 98-percentile of 1-hour values were much less than 3 times the 98-percentile of 8-hour values. So, if the WHO guidelines would be in expressed as percentiles that are sufficiently far below the maximum, the 8-hour mean would in practice be the most protective one.

For the communication to the public and also for administrative reasons, one should not set more limit values than necessary. In practice, the 8-hour guideline is seen to be much more protective than the 1-hour guideline, and exceedence of the 1-hour guideline will be improbable when the 8-hour guideline is maintained. Also, occurrences of cases where the 1-

hour exceeds the WHO guideline while the 8-hour averages does not, are difficult to cover with a fixed monitoring network or to calculate by modelling.

Logistically, there is no clear preference for a 1-hour or 8-hour average: CO measuring data are always available as hourly averages, and it is easy to calculate 8-hour averages from hourly averages.

Since the 8-hour average guideline is normally the most protective, it is proposed to take this value as the starting value for the limit value.

It should be noted that short-term exposure to high concentrations of CO can occur in situations which would not normally be regarded as ambient air as defined in the Air Quality Framework Directive. This is discussed in Annex I to this paper.

2.5.2 Choosing the limit value

Number of exceedences to be allowed
When defining a limit value, one should consider whether exceedences should be allowed or not. For the general public a limit value expressed as a level that is allowed to be exceeded several times is more difficult to understand than a maximum allowed value. Also, a maximum allowed value can be chosen as a direct equivalent of the WHO guideline.

On the other hand, there are strong arguments against expressing the limit value as the maximum. Of all statistical parameters, the maximum concentration is the most variable one. This would mean that a zone may, from year to year, fluctuate in and out compliance with the limit value. Since this variation is often mainly due to meteorological conditions, the compliance state would have a large variation that can not be influenced by air quality management. From the administrative point of view one should attempt to minimise such fluctuations. A second reason often given for not choosing the maximum, is that the maximum concentration can not be assessed very reliably. Models can not calculate the maximum concentration accurately. Measuring the maximum reliably may be difficult due to instrumental malfunction or to interruptions for maintenance and calibration. Anomalous maximum values may also occur as a result of unrepresentative sampling during a small period, *e.g.* because of a very incidental source such as the exhaust of an incorrectly placed truck during a short time. It was however agreed by the Steering Group during discussions on sulphur dioxide, nitrogen dioxide, particulate matter and lead that problems of this second type should be dealt with by good quality control regimes rather than by increasing numbers of allowed exceedences.

If a certain number of exceedences would be allowed, exceedence of the WHO guideline would also be allowed to occur, unless the limit value is set so far below the WHO guideline that exceedence of it would be highly improbable. The frequency distribution of the highest concentrations varies not only between stations, but also from year to year. Consequently, selecting a very low limit value for this reason, would result in a limit value that is overly stringent in most situations.

In view of these considerations, the Steering Group proposed to allow exceedences for the various limit values of the pollutants mentioned above. In the special case of CO, however, the Steering Group felt that the situation is different. Road traffic is almost the sole cause of exceedence of the WHO guideline. Since the EU-wide measures will cause large reduction of

CO traffic emissions in all Member States, the Steering Group expected that in the next few years the exceedence of the WHO guideline will disappear altogether. The disadvantages of a limit value defined in terms of a maximum not to be exceeded were considered less important than the merit of directly implementing the WHO guideline.

It is proposed to set the limit value as the 8-hour average concentration of 10 mg/m^3 which is not to be exceeded.

2.5.3 Further specifications of the limit value

Spatial specification of the limit value
The Framework Directive not only designates measurements, but also mathematical methods such as computer models as assessment tools. Since models have more potential than measurements to assess the concentration distribution in space, it is better to describe the spatial aspects of the limit values not in terms of measurement strategy, as is usually done, but also at the level of the definition of the limit value.

The limit value should apply to concentrations at heights between 1.5 and 4 metres at all locations in the EU territory that are accessible to the public.

In the assessment of small-scale peaks by measurement or modelling, peaks of very small size should not be taken into account in the comparison with the limit value. The exposure time needed for the health effect to build up is an important criterion for choosing this minimum size. The limit value is proposed to be an 8-hour average concentration, but one should realise that this value has been chosen with the intention to protect against exceedence of all WHO guidelines for CO in ambient outdoor air, including the one for 15 minutes. Since for CO peaks roads are of main importance, the micro-scale specification will be explicitly related to traffic situations, in particular busy streets. As a guideline, a sampling point should be sited to be representative of air quality in a surrounding area of no less than 200 m^2 at traffic orientated sites. Near road traffic, concentrations to be compared with the limit value should be at places at least 25 metres from the edge of major street junctions and at least 4 metres from the centre of the nearest traffic lane. The concentrations to be assessed should also be no further than 5 metres from the kerbside.

In publicly accessible pedestrian areas in confined spaces, such as tunnels and traffic parking garages, good air quality should be maintained. As a result of high traffic emissions in combination with limited ventilation, CO concentrations can be very high, and it is very important that measures are taken to protect the public against high exposure. Annex A discusses this matter in more detail. It is not proposed to achieve health protection in such areas by applying the limit value for ambient air quality there directly. It can be regulated more appropriately by ventilation regulations. It is remarked that a similar situation exist for other traffic related pollutants such as NO_2 and particulate matter.

Margin of tolerance
The Framework Directive allows to set a margin of tolerance, in order to avoid that Member States need to report actions plans for zones where limit value exceedences are likely to disappear within a few years. This is particularly relevant in the case of CO, since levels near roads are generally expected to decrease as a result of the gradual replacement of the current car fleet by cleaner vehicles (see also Chapter 1).

It is proposed to set the Margin of Tolerance at 50% of the limit value and to decrease it linearly to zero in 2005.

2.5.4 Public information on ambient concentrations

In its proposal for a Council Directive relating to limit values for sulphur dioxide, oxides of nitrogen, particulate matter and lead (COM (97) 500) the Commission has included a provision which would require Member States to make up-to-date information on these pollutants routinely available to the public as well as appropriate organizations such as environmental and consumer organisations, organizations representing the interests of sensitive populations and other pertinent health care bodies. This information could be provided by means, for example, of broadcast media, press, information screens or computer network services. It is proposed to apply this important provision also to CO. The information on ambient concentrations of CO should be updated on at least a daily basis, and wherever practicable, on an hourly basis. The information should include any exceedences of the limit value. It should provide a short assessment in relation to the limit value and information regarding effects on health.

2.5.5 Alert threshold

The Framework Directive opens the possibility to establish also an alert value, to immediately inform the population in case of short-term high concentrations. In the case of SO_2 and NO_2 it was decided to set such an alert value. Since CO has also short-term effects, this approach could be followed here as well. If the reasoning used for SO_2 and NO_2 would be followed, an alert value of 100 mg/m^3 would be found for CO. This level is so high that even in the recent past it was unlikely to be exceeded anywhere in outdoor ambient air. After implementation of the CO Directive, when the downward trend of CO levels will have proceeded further, this value would have no practical meaning. A second consideration to take into account is that an alert would be issued via the media and consequently a considerable size of people should be affected to justify alerts. Although high CO levels could under adverse meteorological conditions occur simultaneously in several highly trafficked streets in a large area, the high CO levels would still often be of a local character. In the case of CO, it does not seem feasible to inform the public with the purpose to take protective action, because it would be very difficult to address the information to the public exposed in the particular streets, without using a prediction system. So, adding CO to the list of Alert Values is felt to have more important drawbacks than merits. ***It is therefore proposed not to set an alert value***.

3. Assessment of concentrations

3.1 Introduction

The Framework Directive gives general criteria and prescriptions on the air quality assessment, which have to be detailed for each pollutant in the Daughter Directive concerned. The concentrations must be assessed over the whole area of the Member States. Prior to the entry into force of the Directive, a preliminary analysis has to be made to determine the concentration distributions over the territories in order to enable the Member States to define, before the Directive enters into force, appropriate monitoring networks and other assessment techniques.

The use of several assessment techniques will be possible, subject to minimum requirements regarding the number of measuring points, the type of measuring techniques and mathematical techniques; these requirements depend on the ratio between the concentration and the limit value.

3.2 Principles and assessment regimes based on the Directive on Ambient Air Quality Assessment and Management

3.2.1 Purpose of the assessment

In the Framework Directive the following aims of air quality assessment are addressed:
1. checking whether the limit value is exceeded anywhere over the territory of Member States;
2. supporting the management of air quality where the limit value is exceeded;
3. making adequate information available to the public.

3.2.2 Targets addressed

In principle, human health, ecosystems and also materials are targets to be protected under the Framework Directive. In the case of CO, however, the air quality assessment needs only to refer to the human health. Assessment of CO in relation to the effect on ozone formation or other indirect effects of CO is outside the scope of the CO Daughter Directive.

3.2.3 Assessment regimes

Article 6 of the Framework Directive gives prescriptions regarding the assessment methods to be applied. It stipulates that in "agglomerations" (zones which have a special status in the Framework Directive) measurements are always mandatory if an alert value has been set, and further it links assessment regimes to two threshold levels below the limit value which serve as criteria to distinguish between these regimes. These two assessment thresholds will be described hereafter as Upper Assessment Threshold (UAT) and Lower Assessment Threshold (LAT), at x% and y% of the limit value respectively (see Figure 9).

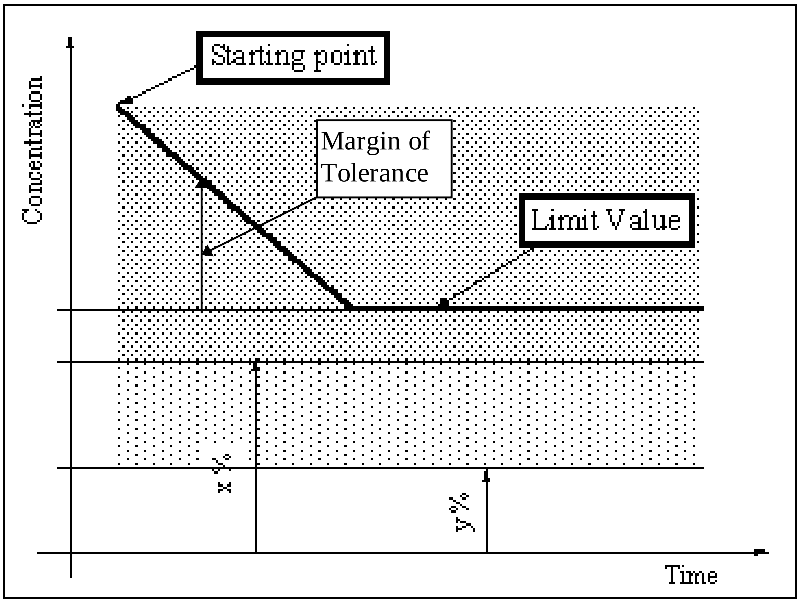

Figure 9 *Principle of the limit value: UAT (x%) and LAT (y%); margin of tolerance*

Both the compliance state and the assessment regime are linked to entire zones. It is important to note that exceedence of the limit value determines whether the air quality within a zone is in compliance or not, and does not differentiate between the assessment regimes prescribed for that zone. Conversely, exceedence of the UAT or LAT determines which assessment regime is prescribed in the zone, while it has no implications for air quality management. Figure 10 illustrates this.

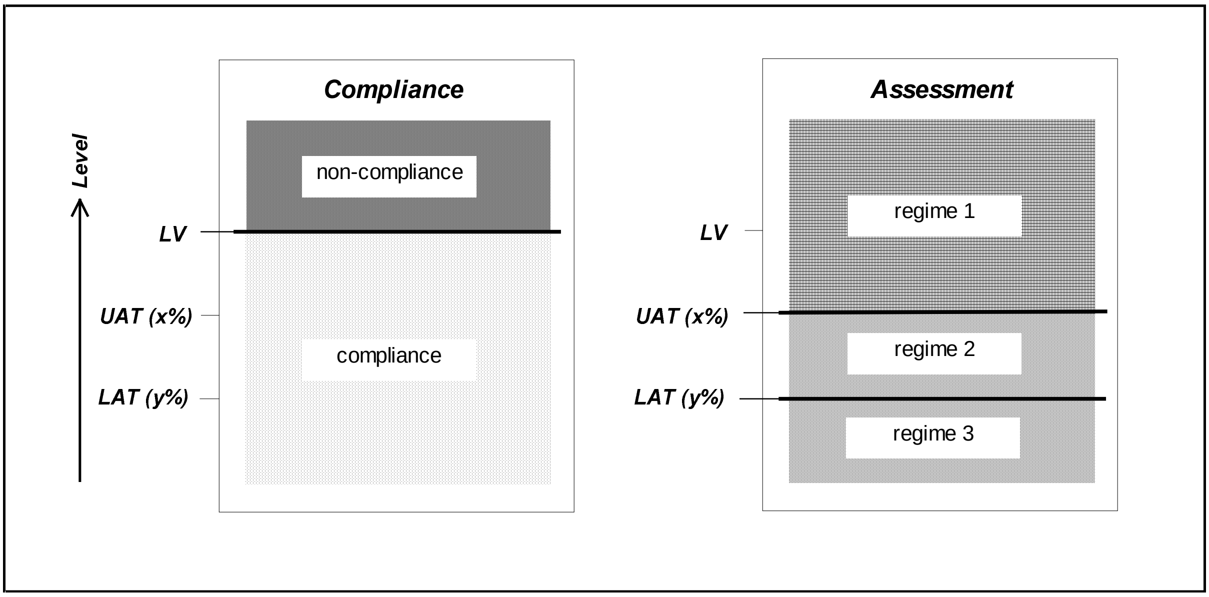

Figure 10 *Implication of exceedence of the limit value, UAT and LAT for compliance judgement and assessment requirements in a zone*

Following the Framework Directive, one arrives at three types of zones[21], each with its own assessment regime:

1. Zones in which the highest levels exceed UAT (regime 1 in Figure 10);
2. Zones in which the highest levels exceed LAT, but not UAT (regime 2);
3. Zones where the highest levels are below LAT (regime 3).

The Framework Directive gives several prescriptions regarding these three types of zones. Table 9 indicates the assessment regimes associated with these types.

Table 9 *Summary of assessment regimes*

Zone	**Assessment regime, from the strictest (top) to the mildest (bottom) requirements**
1. Where highest levels > UAT	Based on fixed measurements (at least one site per zone), may be supplemented by modelling
2. Where highest levels > LAT	Combination of fixed measurement (at least one site per zone) and modelling allowed
3. Where highest levels < LAT	Modelling, objective estimation, indicative measurements allowed

3.2.4 Assessment in time and space

3.2.4.1 Assessment in time

The limit value for CO applies during the entire year, and compliance is judged on the basis of each calendar year. Table 10 lists the concentration parameters to be assessed. The assessment should provide not only the CO concentration parameters defined by the limit value, but also concentration data that are needed for air quality management (AQM), including trend analysis. For the latter purpose the annual average concentration is an important parameter.

Table 10 *Averaging times and statistical parameters to be assessed*

Averaging time	**Statistics**	**Purposes**
8 hour	Maximum in the calendar year	Limit value, AQM, public information
Year	-	AQM, public information

Preliminary assessment

Before the assessment system to be used in an area can be definitively established, a preliminary assessment of the air quality situation in the Member States is required. This assessment should identify the zones where the highest concentrations are above the UAT and LAT and should also give information for air quality management purposes. If historic data are available, this assessment should be based on the situation in the last five years. A description of the initial assessment has been given in the guidance document[22] by the

[21] For pollutants for which an alert threshold has been set, the Framework Directive requires measurement in each agglomeration, irrespective of the levels. Since for CO no alert threshold is proposed, this requirement does not apply here.

[22] R. van Aalst, L. Edwards, T. Pulles, E. De Saeger, M. Tombrou and D. Tønnesen (1998). Guidance Report on Preliminary Assessment under EC Air Quality Directives.

EEA/TCAP and the European Commission (JRC and DGXI) with the assistance of Member States.

Revisions of the assessment regime

When the assessment regime needed in a certain area has been determined on the basis of the preliminary assessment, the assessment system will be set up. However, the assessment regime, which depends on whether the limit values are in danger of being exceeded, may change due to long-term trends in the concentrations. A period of one year would be too short to judge this, since exceedence rates fluctuate due to annual meteorological variations. Consequently, in zones where the highest levels are normally somewhat below the limit value, these levels may fluctuate to values above it in an unfavourable year. The introduction of the Upper Assessment Threshold attempts to avoid that in situations where the limit values are in danger to be exceeded, less stringent assessment requirements would enter into force after a year when no exceedences happened to occur. If the assessment regime would yearly be fixed by exceedences of UAT in the previous year, it would also fluctuate from year to year. To avoid the assessment requirements to change yearly, a period of five years for revision of the assessment regime is proposed. The assessment regime could be based on the median value of the five annual exceedence rates of the UAT: if three or more years were in exceedence the assessment regime will be based on exceedence, if only less than three years were in exceedence the assessment regime will be based on no exceedence.

The same applies to assessment regimes based on exceedence of LAT. The numerical values for the UAT and LAT will be proposed in Section 3.2.5.

In case the levels undergo a rapid and structural change, *e.g.* due to the introduction of important sources, an additional half-term assessment is needed to determine whether the assessment system should be adapted to the new assessment needs.

Temporary Margin of Tolerance

For CO a Margin of Tolerance was introduced in Chapter 2. It is important to note that the assessment regimes are not linked to the Margin of Tolerance (see also Figure 9), so the Margin of Tolerance will not affect the assessment procedures.

Trends

For trend analysis purposes it is important that stations remain in operation for a long period.

3.2.4.2 Assessment in space

Each Member State must divide its territory into zones and specify the borders of each zone. In the directive on CO this is not to be limited, but possibilities for a common approach may be explored while developing general guidance on the implementation of the Daughter Directives in the near future. A question to be discussed could be whether a single zone may contain several non-contiguous built-up areas that are smaller than agglomerations within it.

The assessment should be carried out in accordance with the definition of the limit value as described in Section 2.5. Since the limit value applies everywhere in ambient air, the CO concentrations have to be assessed everywhere. The assessment should take into account that very small-scale peaks are not to be tested against the limit value.

3.2.5 Upper and Lower Assessment Thresholds

3.2.5.1 Upper Assessment Threshold

The UAT will be chosen on the basis of the interannual variation of the concentrations. If in three out of five years (see Section 3.2.4) the concentrations are above the UAT, the most stringent assessment regime applies. If these concentrations are below the UAT, the Framework Directive relaxes the obligations regarding the assessment system somewhat. The accuracy of this less stringent assessment methodology should be sufficient to make it reasonably certain that the concentrations found near the UAT will in reality not be above the limit value.

The numerical value of the UAT is derived from empirical data on the interannual variability of the concentrations. Although many data series exist to investigate this, a problem is that no information on industrial sites exists. In general, it can be expected that the maximum concentrations around point sources fluctuate from year to year more widely than maximum values near roads. Since no data on industrial sites are available, and also because it is unclear whether exceedences should be expected at such locations, the value of the UAT will be based on the traffic data.

An analysis of the interannual fluctuations for the APIS data series covering the entire period of 1989-1995 was carried out. It was found to comprise 12 stations with at least five years of data, which were located in Greece, the Netherlands and the UK. Table 11 presents the normalised standard deviation for the highest 8-hour mean per year. The interannual variation itself also fluctuates between the stations, which is illustrated by the two last columns.

Table 11 *Normalised standard deviation of daily maximum 8-hour averaged CO concentration for the 12 complete data series in APIS for 1989-1995*

	Average	**Lowest**	**Highest**
Maximum 8-h mean	30%	16%	60%

The analysis indicates that the standard deviation is typically 30%. In a separate analysis of 40 Austrian sites a value of 25% was found. If the 95% confidence range for not exceeding the limit value is chosen as the criterion for the UAT, the limit value should be above the UAT by twice the standard deviation:

$$Limit\ Value = UAT * (100\ \% + 2 \times 30\%).$$

From this the value for UAT is calculated at 63% of the limit value. The percentage found from the Austrian set is somewhat higher, on the other hand some individual stations will have a larger interannual variability than the average value, including stations near CO point sources. A further pragmatic consideration is that the assessment regimes mentioned in the Framework Directive are to be set at the time of the implementation of the Daughter Directive, so already before the year 2005, the first year in which the limit value is to be met. Since CO levels are generally going down, this would mean for some zones that although the levels will be expected to be below the UAT by 2005, they are not yet at the time of implementation of the directive. So stations will have to be put up, even though they will not be needed anymore in 2005. Because of this the Steering Group preferred to round the percentage upwards in setting UAT to 70% of the limit value.

It is proposed to set the Upper Assessment Threshold at 70% of the limit value.

3.2.5.2 Lower Assessment Threshold

The Framework Directive allows to use the mildest assessment regime when the concentrations are sufficiently far below the limit values, *i.e.* below the Lower Assessment Threshold (LAT). Taking the approach to base LAT on three times the standard deviation, as used earlier in the position paper for particulate matter, LAT can be calculated according to:

$$Limit\ Value = LAT * (100\ \% + 3 \times 30\%),$$

which results in a value of LAT of 57% of the limit value. Rounding this value upwards would result in a LAT only 10% below UAT. It was however considered prudent to be somewhat more conservative in delineating the mildest assessment regime, so the calculated value is rounded down in the case of LAT.

It is proposed to set the Lower Assessment Threshold at 50% the limit value.

3.3 Measurement strategy

3.3.1 General

Theory versus practice
Before specifying the measuring strategy for CO, it is remarked that the design of monitoring network is in practice always a compromise of theoretical considerations and practical restrictions. The assessment criteria given here should be approached as much as is reasonably possible. This holds especially true for multi-pollutant stations in urban areas. The prescriptions should, where possible, be harmonised with those of other Daughter Directive pollutants and possibilities to measure several pollutants at one station should be promoted.

Measurements alone are insufficient for assessment and air quality management
The Framework Directive gives certain prescriptions concerning the measurement strategy (see Section 3.2). Even a dense measuring network can not give a complete picture of the concentrations in a zone, since it does not measure everywhere. At least there should be, in addition to the measurements, an interpretation of the measurement results. So, a meaningful measurement strategy can not be defined without considering how the measurement results will be complemented with some sort of additional assessment (see also Section 3.5).

Relation with “other assessment methods"
The Framework Directive stipulates that the air quality in Member States should be assessed on the basis of common methods and criteria. For the EU as a whole it would be desirable to implement a sophisticated combination of measuring and other assessment methods in all Member States. However, the methodology of combining measurements and other assessment methods is still in development and far from completion. The practice and the experience in the various Member States are very different. Because of this, two assessment methods of different sophistication are proposed to be allowed:

1. an assessment essentially based on measurements alone,
2. an assessment based on measurements and supplementary assessment.

The first method is the purely measurement-based approach that has been employed in many networks, but which provides no basis to estimate concentrations at locations where no station

is present. Consequently, a relatively large number of stations is required to give a satisfactory picture of the concentration distribution in a zone.
The second method uses existing scientific knowledge in addition to monitoring results and requires less stations to give a satisfactory description of the concentration distribution in a zone. Especially for CO, for which air pollution near roads is the most important type of pollution situation, this type of generalisation can be very efficient. Although dispersion conditions can vary strongly from street to street, traffic related pollution situations tend to be more homogeneous than industry related pollution situations.

Continuity
For trend analysis purposes it is important that stations remain in operation for a long period. This should be an major consideration in revising and optimizing a network.

3.3.2 Network density in the case of no supplementary assessment

Minimum station densities
For the determination of the network density the station density will be expressed as the number of stations per inhabitant. For rural stations a specification per zone is not useful, because only few stations in a large area are needed. Since rural levels can be assumed to be below the LAT, a specification is not given here.
It is recommended to define the station density requirements consistent with those for other pollutants with similar characteristics. The requirements for NO_2 in the Common Position for the first Daughter Directive is used as guidance for CO. Table 12 gives the proposed number of stations for diffuse sources.

Table 12 *Minimum number of stations per zone in case of no supplementary assessment*

Population of agglomeration or zone (millions)	**If maximum concentrations exceed UAT**	**If maximum concentrations are between UAT and LAT**
<0.25	1	1
-0.5	2	1
-0.75	2	1
-1	3	1
-1.5	4	2
-2	5	2
-2.75	6	3
3.75	7	3
-4.75	8	4
-6	9	4
>6	10	5
	If >1, to include at least one urban background station and one traffic oriented station	

It is not useful to specify numbers of stations around point sources, since the stations needed to assess the air quality sufficiently depend strongly on the source characteristics. For the assessment of pollution in the vicinity of point sources, the number of sampling stations should be calculated taking into account emission densities, the likely distribution patterns of ambient air pollution and potential exposure of the population.

3.3.3 Network density in the case of supplementary assessment

Network density depends on the supplementary assessment method
The added value of the supplementary assessment should at least compensate the reduction in the number of stations compared to the case of no supplementary assessment. As long as this assessment method has not been described, it is difficult to express its added value in terms of the numbers of stations that can be omitted. It is recommended that the supplementary assessment will result in an annual report on the spatial distribution of the concentrations in each zone, including territory-covering information on the exceedences, and that this report will be forwarded to the Commission together with the measurement data from the measuring stations. For the rural and probably also the urban scales the CO levels are so low that maps, as proposed for some other pollutants, are not needed. Instead, spatial statistics covering these scales is sufficient. For the local scale, streets and industrial locations should be distinguished. For streets, spatial statistics should be given, *e.g.* in the form of accumulated street length with levels above the limit value. For industrial locations the total area where exceedence occurred (in km^2) should be quantified. See also Chapter 5 on reporting.
The spatial statistics should be of sufficient accuracy, but it is very difficult to quantify this accuracy. It would be meaningless to require that the quality of the information in the statistics should be equivalent to that of a network that would exist in the case of no supplementary assessment, since the concentration in such a network is specified only where a station is present.
The minimum number of stations would at least be the minimum that the Framework Directive prescribes: fixed measurements should be done in each agglomeration and in each zone where the levels are above the LAT. So, in those zones the minimum number of station should at least be one. It is expected that the supplementary assessment will allow to generalise measured concentrations from one location to other similar situations. In the case of industrial stations, however, very different situations are imaginable, between which the concentration patterns can not be related. Only for situations that can be generalised to other similar situations a reduction of the measuring effort is possible.

3.3.4 Siting criteria

The strategy for the siting of monitoring stations can be separated into two main elements: criteria for the *macro-siting* (or network design), which describe how the stations of a network should be distributed within the entire concentration field that is to be assessed, and criteria for the *micro-siting*, which describe how the station should be exactly positioned within the area that was chosen on the basis of macro-siting, in particular with respect to very small-scale concentration gradients.

Macro-siting

Macro-siting should optimise the information on the concentration distribution within the territory to be assessed. A second aim of macro-siting is to optimise the generation of air quality management information, *i.e.* data for the analysis of source contributions to the levels and of trends, but this will not be discussed here.

Before elaborating macro-siting criteria, the concept of representativeness will be discussed in more detail. Also the concentration data that the assessment should produce should first be addressed.

The concept of *representativeness* is particularly important for the assessment of numerous similar small-scale situations, like streets or small industries, which can not be individually assessed by monitoring or modelling. One often assumes that the results of an assessment of one location can be used (are representative) for other, similar locations. Some examples may clarify this. It is often assumed that concentrations monitored in one or a few streets are representative for the other relevant streets. The background levels in a city are often assumed to be characterised by one or two stations. A set of model calculations of the concentration distribution around a few small industrial sources can be assumed to be representative for similar sources elsewhere. The essence of using the concept of representativeness is that data for a small set of locations can be translated/extrapolated to data for a much larger area (though with limited accuracy). This is also the essence of macro-siting strategy.

Section 3.4 below discusses "other" assessment methods, including methods to extrapolate measurement data to other locations. It is advantageous to take the potential of these methods into account in the macro-siting strategy. However, since a generally accepted methodology does not yet exist, it is not possible to have a particular method in mind when describing a macro-siting strategy here. The strategy described here will therefore be general and flexible enough to link up to the existing way of working, and on the other hand it will incorporate the potential of combining measurements with mathematical methods.

In Chapter 5 it is discussed how the concentration distribution should be reported. It is proposed that the reports should not be restricted to merely the air quality at the stations, but also give information on locations without a station. A practical way to do this and to link this to the measuring network is to divide the entire territory in areas of types that correspond to station type (traffic, industrial, urban background, rural). The spatial concentration distribution over each type of area can be derived from the concentration data of the station(s) of the corresponding type. (Further subdivisions in area types could be made if the available data allow this, *e.g.* various street types.)

Departing from the goals of the assessment, the macro-siting strategy can now be described. It will be expressed only in general terms here and its further elaboration will be left to the committee attached to the Directive. The basic principle was stated already above: *macro-siting of stations should optimise the information on the spatial concentration distribution within the zones.*

The network designer should answer the question how the spatial distribution of exceedences can best be described. (Since the measurements are continuous in time, the temporal distribution needs no special consideration.) The designer should first estimate *where* exceedences may be expected (in the first stage of implementation of the Directive this will be the preliminary assessment, later it will be the revision of the assessment). Then the designer should distinguish *at which types of locations* the exceedences are expected. For CO this is typically near busy streets and possibly near particular industrial sites. It can not be excluded that situations occur where the urban background is not negligible. Information on rural levels is of importance to understand the levels, but is hardly important for managing exceedences of the limit value. Consequently three types of stations are expected to be relevant:

- Traffic stations

- Industrial stations
- Urban background stations

The designer should then investigate how a limited number of stations should be distributed to give the best description of the exceedences in the territory.
Each relevant location type should be covered by one or more stations of the corresponding type. Out of the very large number of locations of a certain type that are to be assessed, the designer should select one or several locations that are, as well as possible, representative of all other locations of this type. The designer should consider the possibilities to generalise the measured concentrations, *i.e.* translate the results to the other locations of the type considered (see Section 3.4). Depending on the type of locations, this could *e.g.* be done by mathematical inter/extrapolation (not very useful for CO), by modelling or (as is currently often done) by demonstrating without using formalised methods that the stations are representative for certain areas. Based on the possibilities to generalise the results of measurements at individual locations, the designer should then determine the measurement locations. The designer should report the estimated or calculated representativeness of each station for the entire set of location types that it represents (*e.g.* by reporting whether a street station represents the worst case (maximum) in the area or a typical (median) busy street - this should be elaborated in more detail). In the case of no supplementary assessment (Section 3.3.2), the set of stations by itself should be as much as possible representative of the exceedence situations that occur in the zone. In the case of supplementary assessment (Section 3.3.3), this would also be important, but then, in addition, the station locations should be chosen so as to optimise the possibilities for generalisation.

The above procedure hypothetically assumes that the existing network can be completely redesigned. In practice, the possibilities for restructuring the network are more limited. Also, for reasons of continuity (*e.g.* for trend analysis) one should change the locations of existing stations only as a last resort. The existing network should, however, be analysed according to the above procedure, and for existing stations that are not changed, the information on the representativeness should be reported.

For reasons of efficiency, the possibilities of co-locating monitoring sites for pollutants with similar spatial concentration distributions should also be taken into account.

Micro-siting

The purpose of micro-siting is to position the inlet of the station so that the measured concentration approaches as closely as possible the local level that should be assessed. Apart from practical criteria such as accessibility, safety, availability of electrical power, which will not be elaborated here, the major decision is to choose the exact position within the area that was chosen on the basis of the macro-siting strategy.

Vertically, the height of the inlet should be between 1.5 metre (the breathing zone) and 4 metres above the ground.

The horizontal position should be chosen so that the measurement should capture the small-scale peaks that are just large enough to be relevant for testing against the limit value. This implies that too small-scale peaks (or dips) in the concentration should be avoided. For traffic stations, this means that the inlet should not be closer than 25 metres from the edge of major street junctions, and that the inlet should be less than 5 metres from the kerb side.

Measurement at industrial sites should typically be representative of areas of 100 metres in diameter or more. At urban background stations such small scale peaks are not expected to occur. Concentration gradients due to sinks of CO (due to deposition or chemical removal from the atmosphere) are generally negligible on the micro-scale.

3.4 Measurement methods

The measurement of CO can be divided in three separate steps:

- the sampling method;
- the measurement or analysis method;
- the calibration method (when the analysis method is not absolute).

The following tables gives the most current used methods and their main advantages and disadvantages.

3.4.1 Existing sampling methods

Table 13 gives an overview of existing sampling methods.

Table 13 *Existing sampling methods*

Method [1]	**Description**	**Reference**	**Advantages/Disadvantages**
1. Laminar flow method	Flow 150 l/min, tube diameter 15 cm Inert material: glass, stainless steel, Teflon	EPA	+ isokinetic sampling, sample unaffected
2. Turbulent flow manifold	Modular sugar cane design Inert material: glass, stainless steel, Teflon		+ low cost, modular construction
3. Sampling without manifold	Direct connection of analyser inlet to station sampling head		+ low cost, efficient sampling

[1] Instruction manual for Air Pollution Monitoring" Vol. I: Sulfur Dioxide Monitoring, EUR 14550/IEN

3.4.2 Existing measuring methods

Table 14 gives an overview of existing measuring methods.

Table 14 *Existing measuring methods*

Method	**Description**	**Reference**	**Advantages/Disadvantages**
1. Manual methods			+ cost effective - discontinuous and time consuming measurements
1.1 Gas chromatographic method	CO is separated on a GC column from the components of the air sample, catalytic reduction of CO, measurement of CH4 by FID	ISO 8186	+ free from interferences
1.2 Diffusive sampling	Diffusive sampling onto absorbent + photometry or electrochemical detection		+ cost effective - possible interferences - integrated measurement over several days
2. Automated methods			+ continuous, real time measurement - requires regular calibration and maintenance
2.1 NDIR	Measurement of IR absorption	ISO/DIS 4224	+ sensitive, stable, accurate
2.2 Hot HgO-method [1]	Reaction of CO and HgO followed by photometric determination of Hg vapour.		- use of mercury - possible interferences

[1] W. Seiler, H. Giehl and P. Roggendorf. Detection of Carbon Monoxide and Hydrogen by Conversion of Mercury Oxide to Mercury Vapor. Atmospheric Technology, 1980 (12).

3.4.3 Existing calibration procedures

Table 15 gives an overview of existing calibration methods.

Table 15 *Existing calibration methods*

Method	**Description**	**Reference**	**Advantages/Disadvantages**
1. Static volumetric method	A known volume of CO is added to a known volume of complementary gas, under controlled temperature and pressure conditions	ISO 6144	+ good precision and accuracy + cost effective (also suited for other pollutants) - difficult handling - Control of CO purity required
2. Gravimetric method (high or low concentration mixtures	A chamber is weighed before and after introduction of a certain quantity of CO, then filled up with air or N2 and pressurised.	ISO 6142	+ easy handling + good precision for high concentration mixtures + gas cylinders commercially available
3. Dynamic volumetric method	Introduction of a given flow rate of a gas into a constant flow rate of a complementary gas. The gas is usually a high concentration gas mixture obtained by the gravimetric method.	ISO 6145	+ easy handling + good precision - unknown accuracy

3.4.4 Reference measurement method

The following reference method is proposed:

- analysis and calibration according to ISO/DIS 4224: non-dispersive infrared spectrometer (NDIR) method.

3.4.5 Screening techniques

The on-line monitoring of atmospheric pollutants in the air quality monitoring networks generally requires expensive and sophisticated measurement techniques. Simpler measurement techniques, called indicative or screening techniques, may offer a cost-effective alternative to the conventional techniques. Among them, the diffusive sampling technique or the use of a mobile laboratory for grid monitoring is an interesting screening element.

A diffusive sampler consists of a tube, one end containing a chemical substance that fixes the pollutant. The pollutant is sampled onto the absorbent at a rate controlled by the molecular diffusion of the pollutant in the air. The amount of pollutant collected by the sampler is a function of the ambient air concentration integrated over the sampling period. After exposure of the samplers over a few days' periods, the tubes are closed and returned to the laboratory for analysis by colorimetric techniques. This sampling technique applied for CO is not very popular and further investigation has to be made. A guide for the selection and the application of the diffusive sampling technique is currently being prepared by CEN/TC 264 - WG 11. Diffusive samplers for a direct reading measurement of CO are commercially available ("Dräger-Röhrchen") but not yet validated.

The main advantage of the diffusive sampler is that it does not require any pump or electrical power and that it runs unattended during the sampling period. It yields a time-integrated measurement over a certain period (*e.g.* 8 hours), but concentration peaks such as those occurring during short episodes are hardly detected.

A screening based on the use of a mobile laboratory for grid monitoring is also of interest as the pollutant spatial distribution over a larger area can be assessed. Grid monitoring is performed by dividing the particular area of interest into a grid of squares, and by measuring the pollution levels in each grid cell. The measurements are made during short periods of time at each intersection of the grid lines, and repeated over the course of a year. The dates and hours for the measurements are chosen randomly but in such a way that they are evenly distributed over the months, the days of the weeks and the hours of a day. The measuring schedule is laid out so that no neighbouring intersections are measured at the same day. The single values measured at the four corners of each grid are used to calculate the mean concentration value for each grid cell.

3.5 Mathematical methods

General

The Framework Directive explicitly mentions the possibility to use models (or, more generally, mathematical methods) in cases that the concentrations are higher than the UAT or LAT, and allows the sole use of modelling where the LAT is not exceeded. In general, any methods that are able to expand the measuring results where the limit values are approached or exceeded can be of great value, both for analysing the extent of exceedences and for air quality management.

Modelling source contributions and concentration distributions
Two important applications of modelling should be distinguished: (a) the analysis of the causes of air pollution, *i.e.* the contributions from the various sources of air pollution, and (b) the description of the concentration distribution in time and space. The first type, although very important for the management of air pollution, will not be discussed here. Modelling for the description of the concentration distribution in time and space will be discussed in more detail in the following paragraphs.

Combinations of models and measurements

In the following the term model will be used for any formalised (algorithmical) method to calculate concentrations. In this section some important examples of the application of mathematical models and the relation with measurements are discussed.

a. Using models without local measurements
In situations where no local measurement data are available and where direct inter/extrapolation of the results of the nearest stations can not be applied (*e.g.* near a small

point source) models can be used to estimate the local concentrations. The credibility of the results depends on the quality of the emissions and meteorological input parameters, and on the results of (earlier) model validation studies.

b. Integrating modelling and measuring results
In general, the quality and credibility of modelling results will improve when calculated concentrations are directly compared with concentrations that are measured within the time period and the area that the calculations pertain to. A very important question is how differences between calculated and measured concentrations should be dealt with. Often, inaccuracies of the model input (emissions, meteorology) are large enough to explain the differences. In such cases, it is justified to improve the modelled concentration field by adjusting the input (within the uncertainty range) to improve the agreement. This procedure can be regarded as intelligent extrapolation of measurements, rather than modelling. It has the advantage that it adds information on emissions and dispersion to the information given by the monitoring stations, without degrading the monitoring results. Objective mathematical methods can be used to do this, but one should note that this approach usually relies on subjective evaluations of the uncertainty ranges of the various adjustable parameters. Especially when the model has been specially designed for this procedure, it can be a powerful assessment tool. It should be noted that this procedure is not (yet) generally applied. An example of an operational procedure is the CAR model as used in the Netherlands. This model contains a few adjustable parameters, which are annually fitted to the results of ten street stations and is subsequently used to calculate concentrations in complete networks of streets.

c. Interpolation of measuring results
More common than the intelligent interpolation described above is the direct interpolation which does not take information on emissions or dispersion into account. This is useful for uniform areas, but one should be aware that small-scale variations can not be identified. This method is often used for larger scale patterns, but for describing CO levels near the limit value it is of little use.

Mathematical models for CO

Many computer models for the dispersion of gaseous substances such as CO have been developed and applied. These models need input regarding emissions, meteorology and sometimes topography. In most areas many sources contribute to the concentrations, and so a comprehensive calculation of the concentrations would require a very extensive emission data base. Because rural and urban background concentrations of CO are generally below levels of concern, model applications for CO are usually directed at the local scale, and calculate only the contribution of sources in their direct vicinity, while the contributions of other, more remote sources are taken into account by adding measured background concentrations.

Since the highest CO levels occur near traffic, in particular low speed traffic in the urban environment, street models are the most important model types for CO. These models form a special class, that is different from the type of models that is commonly used for the point sources such as chimneys. In the street models, the individuals cars are not distinguished, but aggregated to a line source or a 3-dimensional volume representation of the traffic. Because both the emission pattern and the dispersion between buildings are very difficult to model accurately, decades of research have still not resulted in models that are both comprehensive and accurate. Most street models have a limited range of applicability. In particular, many models describe the dispersion within idealised street canyons, but can not be used at street junctions or where building lines are interrupted. Most models are have difficulty to calculate the air quality parameter corresponding to the limit value (maximum 8-hour average). Wind tunnel models, in which the atmospheric dispersion in specific street configurations are physically modelled, are not very suitable, because of the high costs per configuration and because they can not quantify the emissions. Some models aim at broad applicability instead of the highest accuracy. For individual streets the performance is poorer than specialised models, but for generating a comprehensive overview of the air quality around streets in a zone they are probably the only truly operational model type. The accuracy of such a model can be improved if it is adjusted to measurements; the model can then be used as a generalisation method for measurements.

For the dispersion around chimneys of *e.g.* industrial sources numerous variations of the Gaussian plume model are in use. Probably many models need to be adapted to calculate the maximum 8-hour average concentration. Models for the dispersion at regional and larger scales exist, but are not relevant here.

Criteria for models

Since there are no standard methods available that can be prescribed as the only methods allowed or as reference methods, the requirements of the models (and other mathematical method) will need to be described in other ways, preferentially in terms of the accuracy of the results. It should be noted that it would be unrealistic to require that the model results are more accurate than the results of a (dense) monitoring network, which also have several inherent shortcomings. A distinction should be made between the requirements for the various assessment regimes. The accuracy requirements for models are given in Section 3.6.

3.6 Data quality objectives

Data quality objectives must be established in order to comply with the assessment objectives. They will be defined in terms of required precision and accuracy, minimum time coverage and minimum data capture. Below, these requirements are preliminary expressed as the expected capabilities of the assessment methods. For the time being, the possibilities to relate the requirements directly to the assessment regime is not considered.

Required accuracy:

- Fixed measurements (continuous): 15 % (individual measurements);
- Indicative measurements: 25 % (individual measurements);
- Modelling: 50 % for 8h means;
- Objective estimation: 75 %.

The accuracy of the measurements is defined as laid down in the “Guide to the Expression of Uncertainty of Measurements” (ISO 1993), or in ISO 5725-1 “Accuracy (trueness and precision) of measurement methods and results” (ISO 1994). The percentages are given for individual measurements, averaged over the period considered by the limit value, for a 95% confidence interval (bias + two times the standard deviation). The accuracy for fixed measurements should be interpreted as being applicable in the region of the appropriate limit value. The accuracy for modelling and objective estimation is defined as the maximum deviation of the measured and calculated concentration levels, over the period considered by the limit value, without taking into account the timing of the events.

The values proposed are based on the performances that can be achieved by implementing techniques corresponding to the current state of the art for the various methods, and on the basis of approval of measuring devices. The accuracies given for modelling and indicative estimation should however be regarded as indicative, since current knowledge does not allow to give generally applicable accuracy numbers.

Minimum time coverage of the measurements:

- Fixed measurements: 100 % (continuous or quasi-continuous);
- Indicative measurements: 14 % (one measurement per week at random, evenly distributed over the year, or 8 weeks evenly distributed over the year).

Minimum data capture:

- Fixed (continuous) measurements: 90 %. A 90 % data availability requires a well-planned maintenance, which should not be carried out when concentrations can be expected to be high.

The requirements for minimum data capture and time coverage do not include losses of data due to the regular calibration or the normal maintenance of the instrumentation.

3.7 Quality Assurance and Quality Control of measurements

Quality assurance is a system of procedures that ensures that:

- measurements are precise and accurate;
- results are comparable and traceable;
- data are representative of ambient conditions;
- optimum use is made of resources.

The major constituents of a quality assurance program concern:

- network design (Section 3.3): number of stations, siting criteria;
- measurement technique (Section 3.4): sampling, analytical and calibration procedure;
- equipment evaluation and selection: validation of methods, test of instrument performances;
- routine site operation: calibration in field conditions, maintenance, management and training.

QA/QC procedures are described in the WHO UNEP GEMS/AIR Methodology Review Handbook Series, Volume 1, "Quality Assurance in Urban Air Quality Monitoring".

Currently QA/QC programs only exist in a few monitoring networks of the EU Member States and with a variable degree of efficiency.

With the change of the monitoring networks foreseen with the implementation of the Framework Directive, it is expected that a lot of new laboratories, with among them a great number of private companies, will be in charge of the monitoring task. This will require particular measures to assure the quality of the measurements and the capability of the laboratories:

- Accreditation of laboratories: different standardised QA/QC systems have been developed in recent years such as the Good Laboratory Practice (OECD), the ISO 9000 and the EN 45000 laboratory accreditation procedures. The EN 45001 procedure was developed by CEN in collaboration with the European Commission and is best adapted for testing laboratories in the field of air pollution measurements. Laboratories applying for accreditation are audited by a national or international accreditation organisation. This audit mainly concerns aspects such as laboratory installation and equipment, qualification and training of personnel, proper quality control, technical audit and traceability of the measurements. The request for laboratory accreditation is the only enforceable way to ensure an effective QA/QC procedure.
- Validation of the measurement methods and standardisation at CEN or ISO level.
- Certification of equipment, test of instrument performances (the development of a standardised CEN test procedure is therefore urgently needed).
- Organisation of intercomparison at EU level: organisation by the European Commission of EU-wide intercomparison exercises (round-robin tests, inter-laboratory exercises, spot checks in the monitoring networks) to ensure comparability of the measurements at international level.
- Publication by the European Commission of guidance documents, organisation of training’s and workshops.

4. Cost implications

In Chapter 2 recommendations for a limit value for CO have been given on the basis of an assessment of the risks of CO. A limit value defined in the Daughter Directive on CO will be binding from the date by which it must be met. Because of this, practical considerations should be taken into account; in particular costs and benefits of meeting the limit value and the consequences of not doing so should be identified. This evaluation of costs and benefits is one of several inputs to the decision making process.

Economic analysis is a specialist task. DGXI therefore engaged a team of consultants, led by AEA Technology, and asked them: to assess likely concentration concentrations of CO across the Union in the year 2005, taking into account the effects of existing and planned legislation; to determine whether further action would be needed to reach by 2005 a possible limit value of 10 mg/m^3 either as maximum 8-hour mean concentration or as second highest 8-hour mean concentration; and if further action would be needed, to identify the least cost means; to assess the benefits of meeting these limit values. The study also included benzene. At several stages of the work interim results were discussed by the Steering Group.

The remainder of this chapter has been taken from the Executive Summary of the draft final report on this study[23].

The methodology for the air quality assessment within this study was largely based on extrapolation of the results of the Auto-Oil programme. Auto-Oil provided detailed modelled assessments of urban background air quality across 7 cities, these cities being broadly representative with respect to air quality of all cities in the European Union. Auto-Oil also provided a set of data and assumptions that had been widely reviewed, discussed and agreed by European decision makers and other interested parties already. Accordingly it formed a good position from which to start. The analysis considered 3 cities in detail, Athens, Cologne and London, and then extrapolated results for these three cities to the level of the EU as a whole.

Given the earlier results of the Auto-Oil programme there was little point in investigating CO purely from the perspective of urban background concentrations. This indicated that proposed limits would not be exceeded anywhere in the EU in 2005. Hence this study focused on the hot-spots where high concentrations are most likely to be found (for example close to busy roads). This was not an easy task, given the scale over which concentrations vary in such locations. Rather than model hot spot concentration from emissions and data on topography and local meteorology, it was decided to extrapolate [urban background:hot spot] ratios from comparable monitoring sites in the same city. This gave the advantage of using data from real monitoring locations, and thus it was hoped would be reasonably indicative of measurements to be made in the future.

Three ‘baseline’ scenarios were defined. First conditions were considered without account being taken of the existing draft directives on fuel quality and passenger car emissions that had been produced as a result of the findings of the first Auto-Oil programme. This allowed the approach taken for extrapolation of Auto-Oil data to be checked against the results of

[23] M.R. Holland (1998). Economic evaluation of air quality targets for CO and benzene. AEA Technology, draft final report.

Auto-Oil. The next scenario introduced the draft Auto-Oil directives on fuel quality and vehicle emissions, which were currently in the form of Common Position. Next (for Athens alone) measures were introduced which had been identified in the earlier economic evaluation study of possible air quality limits for SO_2, NO_x, PM_{10} and lead. According to that study Athens was the only city of the three considered here likely to experience exceedences of limit values. To meet the limits in Athens it was suggested that road pricing and the use of buses running on compressed natural gas (CNG) or liquid petroleum gas (LPG) would be introduced.

The occurrence of exceedence in the three cities is summarised in Table 16, considering the most restrictive scenario for each.

Table 16 *Occurrence of exceedence in three cities, considering the most restrictive scenario for each*

Limit	**Athens**	**Cologne**	**London**
Urban background			
10 mg/m^3 highest 8 hour mean	no exceedence	no exceedence	no exceedence
10 mg/m^3 2nd highest 8 hour mean	no exceedence	no exceedence	no exceedence
Hot-spots			
10 mg/m^3 highest 8 hour mean	exceedence	no exceedence	exceedence
10 mg/m^3 2nd highest 8 hour mean	exceedence	no exceedence	exceedence

The extent to which emissions are reduced across each of the cities in response to legislation on air quality would be dependent on the type of measures introduced to combat excess levels. Small localised exceedences would be most likely to be addressed by local traffic management measures, with limited effect on emissions elsewhere (assuming that they do not displace traffic to other areas). Larger exceedences affecting broad areas of a city may need to be addressed through further action on fuel quality or vehicle design. Such measures could affect emissions everywhere.

Analysis of CO effects based on available epidemiological data is subject to much uncertainty, given the limited amount of data that exist. Three exposure response functions had been reported in the literature, for acute (short term) effects on mortality, ischaemic heart disease (disease associated with a lack of blood supply to the heart) and congestive heart failure (CHF). Of these only the last appears reasonably robust, once account has been taken of other pollutants. However, the logic of including one type of heart disease but not another for which there appears reasonable grounds for believing that there should be an association with CO may be questionable. Equally, including heart disease, but not premature mortality may also be questionable. At the same time it has to be said that the effect of CO exposure from ambient air may just be to bring the date of hospitalisation or death forward by a limited time: the primary cause of heart disease or the timing of death may lie elsewhere (e.g. smoking, diet, lack of exercise, etc.). The epidemiology unfortunately does not provide answers to these questions. Available ‘response profiles’ showing the effects linked to different concentrations of carboxyhaemoglobin (COHb) in blood are reasonably well accepted but are not amenable to application in this type of analysis. Estimated impacts and associated costs given for CO here should thus be regarded as very uncertain, with this uncertainty reflecting the limited attention that has so far been given to CO in epidemiological studies.

Results are given only for Athens and London as no exceedences were calculated for Cologne. In Athens, for the scenario in which both the Auto Oil Directives are in force, and the proposed air quality standards for NO_x and PM_{10} are adopted, the number of cases reduced by setting the limit values investigated ranged from 78 (against the 10 mg/m^3 as second highest 8 hour mean concentration annually) to 121 (against the 10 mg/m^3 as highest 8 hour mean concentration). Estimated annual benefits associated with this were 0.6 million ECU and 0.9 million ECU respectively. In London, results were similar with reduced incidence of cases of 68 and 216 per year against the two limit values, and with benefits of 0.5 and 1.7 million ECU per year.

The following secondary benefits have been identified in the study for measures that could be used to reduce CO levels though most were not quantified:

Abatement measure	Burden affected	Impacts affected
Traffic calming, public transport subsidies, etc.	Emission of all transport pollutants (SO_2, NO_x, PM_{10}, VOCs, CO_2 etc.)	Effects on health, materials, ecology
	Risk of accidents	Death and injury, material damage
	Congestion	Travel time
	Noise	Amenity
Emission constraints	Emission of all transport pollutants (SO_2, NO_x, PM_{10}, VOCs, CO_2 etc.)	Effects on health, materials, ecology

Some of these effects could be easily quantified using the models available to the study team. However, consideration of the additional benefits of reducing emissions of other pollutants appeared to the team to go against the spirit of the Framework Directive on Ambient Air Quality. Essentially the study could end up justifying CO controls through reductions in other pollutants (particularly SO_2, PM, NO_x) below limit values already agreed by the EU. The team felt strongly that it would be preferable to conduct a much broader analysis when the Directives come forward for revision, including for example all transport related emissions in a single study.

Table 17 presents results at the European Union level (following extrapolation from the 3 cities). For both limits costs at the EU level were found to be greater than the benefits of reducing emissions in hot-spots (though not of course in the urban background where no exceedences were seen).

Table 17 *Summary of benefits and costs at the EU level*

	Limit	No. of cases	Benefits MECU	Costs MECU
Urban background	10 mg/m^3 max		no exceedence	
	10 mg/m^3 2nd highest		no exceedence	

Hot-spot	10 mg/m^3 max	5000	39.3	105 - 122
	10 mg/m^3 2nd highest	2600	20.8	45 - 53

The most important sensitivities from this analysis are:

- Assessment of ratios between urban background and hot-spot concentrations;
- Assessment of the effects on CO and benzene levels of the limit values proposed for NO_x, SO_2 and PM_{10};
- The extent to which traffic calming and other measures will be introduced to reduce congestion, noise and accidents;
- The real nature of the health effects of CO.

The largest constraint arises from this last point. A robust cost-benefit assessment of CO could not be carried out until better data are available on the extent and severity of associated health effects. In the context of the overall assessment made, i.e. including also benzene, costs would largely be shared between the two pollutants, given that many of the measures identified for control are the same.

5. Reporting the results

Article 11 and Annex 4 of the Framework Directive lay down the information that Member States will have to report to the European Commission. Depending on the levels, the required information may include data on the concentration levels in the zones, the causes of the pollution and other air quality management information. This chapter focuses on how data on the levels in the zones could be reported to the Commission.

Counting exceedences
When exceedences of the limit value occur and have to reported to the Commission, the question of how the 8-hour periods of the limit value are to be counted becomes relevant. If all running averages would be counted, exceedences could overlap, e.g. one could have 24 exceedences in one day. To avoid overlapping time windows, fixed time windows could be chosen, e.g. 0-8, 8-16 and 16-24h. This would, however, overlook in many cases the highest 8-hour mean of the day; in particular the morning traffic peak period would be divided over two periods. If the time window would not be fixed, the procedure of finding the maximum number of exceedences of non-overlapping periods would not be very transparent. It is proposed to choose the method of daily 8-hour maximum: select the highest daily 8-hour average from the 24 moving averages and test this value against the threshold. This procedure counts the “exceedence days”. For a complete specification the assignment of the 8-hour period to a calendar day should also be defined: it is proposed to assign each 8-hour period to the day of its last hour (so the period 17-1h is the first 8-hour period of a day).

Spatial concentration distribution
In Chapter 3 it was remarked that the assessment strategy and the requirements for reporting the results of the assessment can not be developed independently. Even more so, the assessment strategy should be directly aimed at generating the results that should be reported. Since the form of the results of the new assessment tools introduced by the Framework Directive, in particular mathematical models, differs very much from the form of measurement results, the currently existing reporting procedure should be reconsidered.

Until now, the reports of results of air quality assessment in the framework of EU air quality directives have been limited to statistics of measurement results. This is basically a report of the temporal pattern of concentrations at a limited number of points in space (station sites). For reasons of harmonisation the European Commission has spent much effort in defining standardised reporting formats.

In addition to the concentration statistics, also an extensive description of the stations is reported to the Commission, including information on the surroundings of the stations, such as the type (urban, suburban or rural), character (residential, commercial, industrial, agricultural, natural) and nearby sources. Although this typification gives satisfactory information on the station itself, it does not include any information on how representative the station is for other locations of the same type. Since it is known that Member States currently apply different measuring strategies, particularly regarding the location of stations with respect to the highest values, it is not possible to extrapolate the reported data to territory-covering information. In Section 3.3 on measuring strategy it was proposed to add to the information on stations at least additional information on how representative a station is for the type of locations that it belongs to (is it an "average" site, or the worst case in the zone).

The Framework Directive allows the use of modelling in zones where the levels are below the LAT and requires reports on these zones every three years. It would be very useful to develop a common form for reporting such modelling results for the future Daughter Directives. This also applies to the results of supplementary assessment according to Section 3.3.3 in areas where the concentrations are above the UAT/LAT. When a combination of modelling and measuring is applied, it would be unsatisfactory when the reports to the Commission would be limited to the data of the monitoring stations. The Commission would receive less (though better defined) data in the case of supplementary assessment than in cases without it.

A reporting format for the concentrations should be developed that includes, besides statistics of the temporal distribution of concentrations, information on the spatial concentration distribution in the zones. It is proposed to develop statistical parameters on the spatial concentration, analogous to the temporal statistics that are now being reported by monitoring stations. It is questionable whether maps of CO would give information that is useful at the EU level. The most relevant example for CO would be the total street length above the limit value.

Annex A Special Areas of Potentially High CO concentrations

The Need to Consider Special Areas

Certain publicly accessible pedestrian areas in confined spaces, such as tunnels and parking garages, can experience a build up of high concentrations of pollutants emitted from vehicles. It has therefore been suggested that the limit value for CO should apply in these special areas. However, the Council Directive on Ambient Air Quality Assessment and Management (96/62/EC) is intended to improve *ambient* air quality, defined as “outdoor air in the troposphere, excluding work places”. It is not clear whether these special areas fall within the Directive’s definition of ambient air quality. Furthermore, the mechanisms of the Framework Directive, dividing territories into zones, developing action plans etc., may not provide a suitable means of dealing with them.

Obviously, the limit value does apply to CO levels in ambient air near outlets of tunnel air.

Health Effects of Short-Term Exposure to High Concentrations of CO

As mentioned in Chapter 2, the COHb level increases rapidly at the onset of exposure to high CO concentrations. Thus concerning the effects of CO exposure not only average but also peak concentrations should be considered.

Exposure during several hours to an approximately constant CO concentration (for example only small variations from an 8h average value) results in a comparatively slow increase of the COHb level until it reaches a steady state. In contrast, peak concentrations may lead to a very rapid increase of the COHb level. Taking for example a 1h average concentration of about 30 mg/m^3 as a basis, a 60 minutes exposure to a constant CO concentration results in a linear increase of COHb from 1 to about 2% at the end of the 1h period. The same COHb level may be reached after only 10 minutes exposure to 140 mg/m^3, remaining at 1.9% at the end of the 1h period even though the CO concentration in the remaining part of the hour would be as low as 5 mg/m^3 (healthy non-smoker, light activity). A rapid COHb increase may affect especially organs like the heart or the brain, and in sensitive groups levels of concern may be reached.

Types of Special Areas

- Indoor Car Parks: are considered to be outside the provisions of the Framework Directive, so are not covered in this Annex.
- Road Tunnels: the case is less clear. Road tunnels are public highways and this is clearly a public health issue. For these reasons, concentrations of CO in tunnels are considered further in this Annex and suggestions are made for managing risk within them.

Concentrations of CO in Road Tunnels

In road tunnels CO levels can be much higher than near roads due to the limited ventilation in tunnels. In measuring campaigns in Belgium the levels in some tunnels in Brussels were found to be about ten times higher than those in a street canyon[24]. In Germany CO levels of 115 mg/m^3 and more were measured[25].

The Permanent International Association of Road Congresses has recommended criteria for pollutant concentrations inside tunnels. The recommended criteria for CO are presented in table A1.

Table A1 *PIARC-recommended maximum permissible CO concentrations inside tunnels*[26]

		CO limit at peak traffic (ppm) [1]	
Type of Tunnel		**Smooth traffic**	**Congested traffic or standstill**
Urban tunnels (used to capacity)	Daily congested	100	100
	Seldom congested	100	250
Inter-urban tunnels	Highway or mountain	150	250

1 ppm = 1.165 mg/m^3

Tunnel Ventilation and Factors Affecting Ventilation

Road tunnels can be ventilated both passively and actively. Passive ventilation relies on natural air movements (i.e. in very short tunnels) or a through-draught created by traffic moving inside the tunnel 'pushing' air along in their own direction of travel. Slotted or perforated ceiling also allow passive dispersion of pollutants. Active systems include ceiling fans fitted in the tunnel headspace or ventilation through side vents along the tunnel's walls.

In modern tunnels of any significant length, a combination of active and passive ventilation is normal. Shorter or older tunnels may rely solely on passive ventilation.

A number circumstances can lead to the build up of undesirable CO concentrations:
- inadequate tunnel ventilation;
- traffic accidents/congestion - emissions increase and through-draught is reduced;
- traffic-counterflows within a single tunnel bore - can decrease the through-draft compared with traffic flowing in the same direction within the single tunnel bore;
- failure of active ventilation systems;
- vehicle fires within the tunnel.

Tunnel mouth and vents serve as point sources of CO, which can affect local air quality in adjacent areas.

Risk Management Methods

[24] P. vanderstraeten and A. Derouane. Road tunnels and air pollution. Proceedings of the Congress on Air Quality in European Cities, Brussels, October 1995.

[25] E. Lahmann. Luftverunreiniging - Luftreinhaltung. Eine Einführung in ein interdisziplinäres Wissensgebiet. Paul Parey Verlag. 1990.

[26] Permanent international Association of Road Congresses, XVIIIth World Road Congress Road Tunnels, Brussels 13-19 September 1987, Technical Committee Report No. 5.

In taking measures to reduce exposure to undesirable concentrations of CO in road tunnels, it is worth noting the following factors:

- CO concentrations in the tunnel;
- CO concentrations in vehicles versus in the tunnel;
- time spent by different tunnel users within the tunnel (or series of tunnels) - e.g. pedestrians, cyclists, motorcyclists, motorists, children, adults;
- degree of CO uptake of different tunnel users - e.g. pedestrians, cyclists, motorcyclists, motorists, children, adults;
- the numbers of each type of tunnel user.

The above factors will vary with time of day, traffic conditions etc. and it is important to quantify the degree, number and duration of any undesirable exposures that may occur. The following texts outlines a number of risk management steps that may be cost-effective depending upon the specific circumstances of concern.

1. General measures to reduce CO concentrations in tunnels

Traffic management measures to ease congestion will also help to reduce CO concentrations and exposure to CO in tunnels. Examples include the scheduling of maintenance work at night to avoid congestion or traffic-counterflows during busy periods.

In cases of severe congestion, accident, or fire it may be necessary to prevent vehicles from entering the tunnel altogether. Where traffic is stationary within a tunnel and this situation is likely to persist for some significant period, electronic signs can be used to advise drivers to switch off engines.

In certain cases it may be possible to reduce CO concentrations in the tunnel more permanently by retrofitting existing tunnels with improved active ventilation systems or air purification systems (see the section below). It is important to note that many tunnels may not lend themselves to such retrofits, e.g. where headspace is so limited that there is insufficient room for installing ventilation fans. In such circumstances the cost of increasing the tunnel diameter/height may be prohibitive.

2. Specific measures to reduce CO-exposure of motorists in tunnels

Measures to limit concentrations in the tunnel will also limit the exposure of motorists if the in-vehicle CO concentrations are influenced by the tunnel CO concentrations. However, simple short-term risk management methods may be much more cost-effective. Such measures include closing windows/sunroofs, recirculating air within the vehicle, or switching off vehicle ventilation system altogether, before entering the tunnel and for the duration of the tunnel journey. Road signs can help to prompt motorists to take these actions for themselves. If motorists are delayed inside the tunnel, electronic information systems may help to reduce an individual's CO uptake by reducing stress.

3. Specific measures to reduce CO-exposure of non-motorists in tunnels

Measures to limit concentrations in the tunnel will also limit the exposure of non-motorists using the tunnel. In certain circumstances it may be appropriate to deny access to non-motorists, e.g. pedestrians and cyclists. Such limitations on access might be denied at all times or only during those periods of the day that are of concern.

Tunnel air purification systems

Purification of tunnel air is difficult because of the need to treat large volumes of air containing particulate and multiple gaseous pollutants in low concentrations. Unfortunately, these various demands place different requirements on the air purification system and these tend to be mutually exclusive and therefore expensive to achieve.

A study carried out for the US Federal Highway Administration in the years 1974 to 1977 concluded that an air purification system would need to have three basic units:

- electrostatic precipitators to remove particulate;
- catalytic oxidation with Hopcalite to oxidize CO to CO_2 (and another catalyst to oxidize NO);
- activated carbon to remove NO_2 and hydrocarbons.

Very few tunnels in the world employ any form of air purification system. Norway appears to be the most advanced in investigating the possibilities of these techniques and started a research programme to determine the possibility of cleaning polluted tunnel air in 1987. Practical experience exists regarding particulates and NO_x[27].

Other pollutants

It is remarked that the tunnel levels of other traffic related pollutants, e.g. NO_2, particulate matter and hydrocarbons, are often higher than in streets. CO inside the tunnel used to be the trigger for forced ventilation, but since CO levels have declined in the past years, it tends to be replaced by NO_x as the ventilation criterion. Obviously, ventilation triggered by a single pollutant will have a beneficial effect on the levels of the other pollutants as well.

[27] H.J. Eirik and B.K Ottar. Ventilation and air cleaning technologiy for road tunnels - Particle cleaning and NOx cleaning. Publication of Public Roads Administration, Directorate of Public roads, Norway, undated.