Advisory Committee on Tunnel Air Quality

TP11:
Criteria for In-Tunnel and Ambient Air Quality

Author: Ian Longley, NIWA Ltd

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Summary

- Ambient air quality guidelines are intended to deal with general population exposure to pollution from various sources, rather than exposure at 'hot spots' or the control of individual point sources.
- In NSW, road tunnel stack and portal emissions are regulated with reference to both the NSW Environment Protection Authority's (EPA) *Approved Methods for the Modelling and Assessment of Air Pollutants in NSW* and the National Environmental Protection (Ambient Air Quality) Measure (AAQ NEPM). However, the latter provides limit values for concentrations in outdoor air arising from the net effect of all emission sources, rather than individual sources.
- In-tunnel air quality criteria are established to protect the safety and health of tunnel users with respect to motor vehicle emissions.
- There is some degree of international consistency amongst in-tunnel and ambient criteria.
- Carbon monoxide (CO) has historically been a good marker for motor vehicle emissions, and the basis of in-tunnel criteria. However, reductions in CO emissions due to improved vehicle technology has advanced more quickly than nitrogen dioxide (NO_2) and particulate emission reductions. Consequently, a guideline based on CO alone can no longer be considered to automatically provide the same protection of health for tunnel-users as in the past.
- At the present time an appropriate level of protection from the effects of all road vehicle pollutants inside tunnels is provided through a combination of the existing in-tunnel CO and visibility limits. However, as the composition of vehicle emissions will continue to change as emissions decrease, the addition of an NO_2 limit would ensure an appropriate level of protection continues in the medium to long-term.
- There are scientific knowledge gaps regarding the effects of very brief (a few minutes) exposures to high levels of air pollutants on health, and regularly repeated exposures, as occur in road tunnels. This requires an appropriately precautionary approach to standard setting that considers the both potential health benefits of a standard and the costs of building infrastructure capable of achieving a standard under all possible conditions (eg energy use and capital investment that is not utilised).

1. Scope

There are significant capital, maintenance and running costs involved in providing forced tunnel ventilation, which also impacts the environment through emissions associated with electricity generation. Ventilation systems should be designed to provide only sufficient ventilation to maintain acceptable air quality in the tunnel to optimise capital and operational costs while also including provision for worst case scenarios. The choice of the criteria for acceptable in-tunnel air quality has been driven by two factors: established evidence of adverse effects on human health associated with short-duration exposure to traffic-related air pollutants (PIARC, 1996, WHO, 2000), and the reduction of visibility in the tunnel (PIARC, 1996).

An additional consideration in ventilation design and operation is the possibility that emissions from the tunnel stacks or portals (generally required to maintain acceptable air quality inside the tunnel) will lead to a breach of ambient air quality limits outside the tunnel. In areas where ambient air quality is close to, or already breaches, local air quality standards, this consideration becomes important and requires maintaining a balance between in-tunnel and ambient conditions.

2. Origin, purpose and limitations of ambient air quality criteria

Ambient air quality criteria are the levels of various air pollutants in the outdoor air (measured over specified durations) which represent a means of judging unacceptable air quality. In the case of road tunnels, ambient air quality criteria are required to judge the net impact of portal and stack emissions and, when combined with non-tunnel sources on, the air quality to which the local community is exposed.

The World Health Organization (WHO) has issued guidelines (WHO, 2000, 2006) regarding the acceptable levels of key air pollutants based on a synthesis of research from around the globe regarding the known effects of these pollutants on human health. The Guidelines cover a range of air pollutants, including those that are the most relevant to motor vehicles: benzene, carbon monoxide (CO), nitrogen dioxide (NO_2) and particulate matter (PM). The WHO guidelines have been widely used as a fundamental reference across the globe, and inform the National Environmental Protection Measure (NEPM) for Ambient Air Quality. The WHO Guidelines are periodically reviewed and updated (as are the NEPM standards) as new evidence on health and exposure trends becomes available.

The NEPM standard for PM is expressed in the form of PM_{10} (following the WHO Guidelines) – the mass of particles smaller than 10 microns[1] per unit volume of air. A PM_{10} standard has been adopted in the NEPM because of the relative practical ease of monitoring PM_{10} reliably, combined with a strong epidemiological basis which links episodes of high PM_{10} concentration to a short-term rise in mortality and morbidity across a city's population. NEPM standards also exist for NO_2 and CO (Table 1). 'Advisory' NEPM standards have been established for $PM_{2.5}$.

Of significance in the case of road tunnels is that the ambient air quality standards in the NEPM are intended to deal with general population exposure rather than 'hot spots' or the control of individual point sources. Individual jurisdictions are primarily responsible for the regulation of point sources.

1 1000 microns (μm) = 1 millimetre

The Ambient Air Quality NEPM standards are largely set on the basis of a statistically-expressed risk to a population, rather than the risk to small numbers of individuals close to pollution sources. The PM_{10} standard (and advisory $PM_{2.5}$ standards) also do not represent a threshold for zero or negligible risk, but rather provide a set level of protection for the general population.

It may also be noted that the PM_{10} metric assumes that particles of different compositions from different sources (such as diesel and petrol emissions, road dust, wood or bushfire smoke, desert dust and sea salt) are equally toxic and pose equal risk across the population.

Evidence from toxicological studies suggests that ultrafine particles (UFPs) might pose a specific health risk. Ultra fine particles are particles less than 0.1 micrometres in diameter and in urban air are largely derived from combustion processes including vehicles. Given their extremely small size, even at very high particle numbers, UFPs may yield a very low mass per unit volume. For this reason, the PM_{10} measure, being a mass based metric, is not necessarily the most appropriate measure to also describe concentrations of the UFP size fraction. However, there is currently no routine monitoring specifically of ultrafine particles in Sydney (or other cities), and no strong evidence that they have an impact on population health. Consequently, there is currently no WHO Guideline (or equivalent) for UFPs. However, WHO recognises that there may be a need to develop one in the future. Meanwhile, in many urban areas levels of UFPs are correlated with levels of oxides of nitrogen (NO_X) due to their common dominant source (traffic exhaust). Therefore, it is likely that the NEPM standards for NO_2 currently provide precautionary protection against the suspected risk associated with UFPs.

Table 1: Relevant standards from the National Environment Protection (Ambient Air Quality) Measure. These standards apply to general population exposure rather than 'hot spots' or the control of individual point sources

	Maximum concentrations			
	1 year	24 hours	8 hours	1 hour
Nitrogen dioxide (NO_2)	0.03 ppm			0.12 ppm
Carbon monoxide (CO)			9.0 ppm	
PM_{10}		50 µg/m³		
$PM_{2.5}$ (Advisory reporting standard only)	8 µg/m³	25 µg/m³		

$PM_{2.5}$ = particles of less than 2.5 µm; PM_{10} = particles of less than 10 µm; ppm = parts per million

In NSW, the NSW Environment Protection Authority (EPA) prescribes ambient impact assessment criteria which are outlined in their "Approved Methods for Modelling and Assessment of Air Pollutants in NSW" (the Approved Methods; NSW DEC, 2005).

The impact assessment criteria typically refer to the total pollutant load in the environment and impacts from new sources of these pollutants must be added to existing background levels for compliance assessment. Accordingly, these criteria would typically apply to the net impact of stack and/or portal emissions associated with a tunnel project, added to non-tunnel sources already present in the environment.

Table 2 summarises the ambient air quality goals that would typically be relevant to an assessment of a road tunnel project, sourced from the Approved Methods.

2. Origin, purpose and limitations of ambient air quality criteria

Table 2: Air quality criteria contained within the Approved Methods for pollutants relevant to road tunnel assessments

Pollutant	Standard	Averaging Period
NO_2	246 µg/m³	1 hour
	62 µg/m³	Annual
PM_{10}	50 µg/m³	24 hour
	30 µg/m³	Annual
SO_2	712 µg/m³	10-minutes
	570 µg/m³	1 hour
	228 µg/m³	Annual
CO	100 mg/m³	15-minute
	30 mg/m³	1 hour
Benzene	0.029 mg/m³	1 hour
Xylene	0.19 mg/m³	1 hour
Toluene	0.36 mg/m³	1 hour
Ethyl benzene	8 mg/m³	1 hour

Note: gas volumes are expressed at 25°C and at an absolute pressure of 1 atmosphere (101.325kPa)[2]

2 Concentrations of gases in air may be expressed in two ways: mass of gas per volume of air, or volume of gas per volume of air. The conversion between them depends on temperature and pressure.

3. Origin, purpose and limitations of in-tunnel air quality criteria

In-tunnel air quality criteria are established to protect the safety and health of tunnel users. Separate criteria are used for occupational exposure of workers in the tunnel. In-tunnel air quality criteria are a major factor in determining the size and performance requirements of the tunnel ventilation system. In many tunnels air quality in the tunnel tubes is continuously monitored, and the ventilation is actively adjusted to maintain pollutant concentrations below the criteria. In-tunnel air quality criteria typically allow exposures to higher pollutant concentrations than ambient air criteria due to the much shorter exposure times (usually no more than a few minutes).

3.1. Established criteria for carbon monoxide and visibility

Globally, the most widely adopted in-tunnel exposure limits are for CO. This choice is supported by CO being the only traffic-dominated air pollutant for which WHO Guidelines exist for exposure durations relevant to passage through a road tunnel (typically a few minutes). Specifically, the WHO Guideline states that concentrations of CO averaged over a 15 minute period should not exceed 100 µg/m^3 (equivalent[3] to 87 ppm at 25°C); the exposure at this level should not persist beyond 15 minutes, and should not be repeated within 8 hours. This exposure level is based on maintaining a level of carboxyhaemoglobin (COHb) in the blood below 2.5 %. CO is also relatively resistant to physical or chemical change within a road tunnel (unlike NO_2, see below), making it relatively simple to monitor.

The WHO Guideline has been adopted by the Permanent International Association of Road Congresses (PIARC) for road tunnels, and national agencies around the world have either adopted or adapted the PIARC recommendations. The criterion is usually expressed as the maximum concentration of CO permitted within the tunnel, averaged over 15 minutes. For example, 15 minute limits of 87 ppm are applied in Sydney tunnels, the limit is 100 ppm at the mid-point in Norway, and 120 ppm in the United States. This approach has a long history, has been proven to be relatively simple to implement, and has been used as the basis of most tunnel ventilation designs. For CO, health evidence has confirmed that the concentration limit and averaging time can be traded-off without altering the protection provided. A higher level of CO may be allowed in a tunnel if a transit time below 15 minutes can be assured.

Table 3: PIARC recommended in-tunnel carbon monoxide (CO) limits

Traffic situation	CO-concentration	
	Design year	
	1995	2010
	ppm	ppm
Fluid peak traffic 50–100 km/h	100	70
Daily congested traffic, standstill on all lanes	100	70
Exceptional congested traffic, standstill on all lanes	150	100
Planned maintenance work in a tunnel under traffic	30	20
Closing of the tunnel	250	200

A visibility limit (generally following advice from PIARC) is also applied in most tunnels for the purposes of safety, but this also provides some protection against the impacts of PM on the health of tunnel users. Loss of visibility is not related directly to effects on health, but has indirect effects, such as driver stress, as well as presenting a hazard to safe driving. However, the visibility in a tunnel is directly related to the presence of particles that scatter visible light and light absorption by larger dark particles, such as soot. These particles are believed to have a direct effect on human health, but the impacts over such short durations are not known with sufficient confidence to support a health-based guideline. The WHO Guidelines for PM cover exposure durations of 24 hours and one year only, and are only strictly applicable to these exposure periods.

3 Concentrations of gases in air may be expressed in two ways: mass of gas per volume of air, or volume of gas per volume of air. The conversion between them depends on temperature and pressure.

3. Origin, purpose and limitations of in-tunnel air quality criteria

Table 4: PIARC recommended in-tunnel visibility limits

Traffic situation	Visibility	
	Extinction coefficient K	Transmission (beam length: 100 m)
	m^{-1}	%
Fluid peak traffic 50 – 100 km/h	0.005	60
Daily congested traffic, standstill on all lanes	0.007	50
Exceptional congested traffic, standstill on all lanes	0.009	40
Planned maintenance work in a tunnel under traffic	0.003	75
Closing of the tunnel	0.012	30

3.2. Management of other in-tunnel pollutants

Most of the health evidence regarding exposure to traffic pollutants other than CO is based on ambient exposure lasting hours, days or longer, and the significance of exposure of a few minutes or less remains a major gap in the scientific knowledge. The uptake and effect of CO on the body is rapid and understood, but the way in which other key pollutants, particularly NO_2 or particles, interact with the body is less well established. It is clear that many thousands of people use road tunnels every day without any apparent ill-effects, indicating that, although based on incomplete knowledge, tunnel ventilation based on existing air quality criteria is providing a significant level of health protection. Nevertheless, limited scientific evidence indicates the potential for subtle adverse effects amongst susceptible individuals. Researchers have observed respiratory effects in asthmatics in a study of exposures to road tunnel air, albeit with exposures of 30 minutes (Svartengren et al., 2000) and two hours (Larsson et al., 2010). This evidence and other studies of traffic pollution exposure suggest that the possible effects of high exposures to air pollution in road tunnels include aggravation of existing asthma, immediately or over subsequent hours, and slightly increased risks of a cardiovascular event in susceptible individuals within a few days. Accrued effects from repeated tunnel use might include small increases in lifetime risk of cancer and potential for increased bronchitic events or respiratory infection, although the same risk arises from spending long periods in general road traffic.

In the past a CO guideline has been used on the assumption it provides adequate protection for the full range of constituents of road traffic air emissions. However, improvements in vehicle technology over the last two decades have led to major reductions in emissions per vehicle of CO and other exhaust pollutants (Longley et al., 2010). Reductions in PM and nitric oxide (from which most NO_2 is indirectly formed) emissions from vehicles have also occurred, but to a lesser degree, and improvements lag behind CO reductions by perhaps a decade. Furthermore, in Europe (where there generally is a higher proportion of light duty diesel vehicles within the fleet) there has been an observable increase in primary emissions and formation of NO_2 in response to the fraction of diesel-powered vehicles on the road (Carslaw 2005, NPRA, 2013). Consequently there is relatively more NO_2 (and PM) per amount of CO in tunnel air than was previously the case.

Consequently, a guideline based on CO alone can no longer be considered to automatically provide the same protection of tunnel user health as in the past. This is recognised around the world, and has led many bodies to consider or implement NO_2 exposure limits in addition to the current CO limits. However, different authorities have applied different levels and different exposure times, reflecting scientific uncertainties and different precautionary stances (Table 4).

The World Road Congress has recommended an NO_2 limit of 1 ppm, not to be exceeded more than 2 % of the time (PIARC, 2000). More demanding NO_2 limits have been adopted in France and Hong Kong, with the most demanding limits proposed in Sweden. These are based on a precautionary approach in view of evidence that asthmatics are more susceptible to NO_2. However, this is based on evidence from exposures of 30 minutes or more and, unlike for CO, the significance for much shorter duration exposures to NO_2 is currently unknown. The Norwegian Public Roads Administration has a limit of 1.5 ppm at the tunnel end and 0.75 ppm at its mid-point (NPRA, 2004). The New Zealand Transport Agency has adopted a design standard of 1 ppm (15 minute averaging time), but has not implemented a monitoring compliance standard, in part due to difficulties in monitoring in-tunnel NO_2.

Even greater uncertainty exists surrounding the effects on health of brief exposure to PM, and especially UFPs, and the best way to quantify that risk. At the present time an appropriate level of protection from the effect of UFPs is likely to be provided through a combination of the existing CO and visibility limits. However, as the composition of vehicle emissions will continue to change as emissions decrease, the addition of an NO_2 limit would ensure an appropriate level of protection continues in the medium to long-term.

3.3. In-tunnel air quality criteria for occupational exposure

For most substances two types of occupational exposure limit generally exist – one as an 8-hour average, intended to represent a typical workday exposure, and the other as a 15-minute average, intended to protect against peak short-term exposures.

For CO the short-term exposure limit provided by the National Institute for Occupational Safety and Health (NIOSH) of 200 ppm seems to have been adopted universally. Occupational exposure limits have higher concentration values than the ambient air quality guidelines both because of their shorter averaging periods, and because they are assumed to apply only to healthy adults (children and pregnant women in particular require extra protection from CO exposure). NIOSH also has a recommended 8-hour exposure limit of 35 ppm. PIARC recommends a limit of 30 ppm for road tunnels, reducing to 20 ppm from 2010. However, this recommendation appears to not have any supporting documentation to provide a rationale.

Similarly to in-tunnel criteria for tunnel users, there is no internationally agreed short-term (15-minute average) occupational exposure limit for NO_2. Occupational NO_2 limits vary between countries and determining bodies, and have tended to change with time. In the US, the American Conference of Governmental Industrial Hygienists (ACGIH) and NIOSH have recommended a short-term exposure limit (STEL) of 5 ppm (15-minute average). This value has subsequently been adopted in many other countries, including Japan, Australia and New Zealand. However, NIOSH also state a recommended exposure limit (REL) of 1 ppm (15-minute average). In the UK a limit of 8 ppm was introduced in 2000 and reduced to 5 ppm in 2002. The limit was withdrawn in 2003 as it was felt that it did not provide adequate protection.

3. Origin, purpose and limitations of in-tunnel air quality criteria

Table 5: In-tunnel air quality guidelines adopted around the world

Contaminant	Threshold concentration	Averaging time	Notes
CO	200 ppm	3 minutes	Cross City and Lane Cove tunnels, Sydney
	120 ppm	15 minutes	United States
	100 ppm	15 minutes	PIARC
	87 ppm	15 minutes	M5 East, Cross City and Lane Cove tunnels, Sydney
	70 ppm	15 minutes	PIARC from 2010; Clem7 and Airport Link tunnels, Brisbane
	100 ppm	5 minutes	Hong Kong
	50 ppm	30 minutes	Cross City and Lane Cove tunnels, Sydney
	50 ppm	15 minutes	CityLink tunnels, Melbourne
NO_2	1 ppm	15 minutes	New Zealand (design standard only)
	1 ppm	5 minutes	Hong Kong
	0.75 ppm	15 minutes	Norway (tunnel midpoint)
	1.5 ppm (tunnel end)	15 minutes	Norway (tunnel end)
	0.5 ppm	20 minutes	Belgium
	0.4 ppm	15 minutes	France from 2010

Table 6: Road tunnel Occupational Safety air quality guidelines adopted

Contaminant	Threshold concentration	Averaging time	Notes
CO	20 ppm	8 hours	PIARC recommendation from 2010
	30 ppm	8 hours	PIARC recommendation
	35 ppm	8 hours	US (NIOSH) Recommended Exposure Limit
	200 ppm	15 minutes	US (NIOSH) Short-Term Exposure Limit; widely adopted internationally
NO_2	1 ppm	15 minutes	NIOSH Short Term Exposure Limit
	5 ppm	8-hours	OSHA Recommended Exposure Limit

4. Further information

For further information related to this topic please see:

Technical Paper 2	*Air quality trends in Sydney*
Technical Paper 3	*Health impacts of motor vehicle pollution*
Technical Paper 4	*Road tunnel ventilation systems*
Technical Paper 5	*Road tunnel stack emissions*
Technical Paper 6	*Road tunnel portal emissions*
Technical Paper 10	*Regulations impacting road tunnel emissions*

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