SOUTH EASTERN SYDNEY PUBLIC HEALTH UNIT

&

NSW DEPARTMENT OF HEALTH

M5 EAST TUNNELS AIR QUALITY MONITORING PROJECT

REPORT

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1. EXECUTIVE SUMMARY

The effects of human exposure to air pollutants has been the subject of scientific research and government activity for several decades. Accumulating evidence demonstrates that exposure to air pollutants is associated with adverse health effects. Recently research has focussed on exposure in “micro environments” such as inside motor vehicles.

Recent trends of population expansion, increased average vehicle kilometres travelled and increased vehicle ownership rates in cities such as Sydney, has resulted in over-congestion of surface roads. One response has been to build road tunnels. In December 2001, the M5 East freeway was opened to traffic and within six months in excess of 82,000 vehicles were using it daily. This freeway includes twin 4 kilometre tunnels (the longest in Australia), ventilated via a single exhaust stack. As it services major freight interchanges it carries a high proportion of trucks in comparison with other Sydney road tunnels. The combination of high usage (with higher truck numbers) and the ventilation characteristics of the tunnel mean that there is on occasion visible haze in the tunnels.

A key health concern in managing the air quality in tunnels is exposure to carbon monoxide, which is controlled by tunnel ventilation. On a number of occasions since opening, incidents such as breakdowns and accidents have necessitated closure of a tunnel to ensure that motorists are not exposed to excessive levels of carbon monoxide.

In response to community concerns regarding in-tunnel pollution levels we proposed this study to monitor pollutant levels in vehicles to the NSW Roads and Traffic Authority. The purpose of this study is to quantify exposure to several common motor vehicle pollutants during peak periods. We also wished to determine what impact vehicle ventilation has on pollutant levels.

We collected carbon monoxide (CO), carbon dioxide and fine particles over 94 trips and nitrogen dioxide(NO_2), BTEX gases and fine particles over 372 trips, during a six week period. Transit times through the tunnels varied between 3-18 minutes.

All CO levels measured during our study were within World Health Organization guidelines, so that any adverse acute health impacts for tunnel users from CO are unlikely. Carbon monoxide levels were significantly lower when the cabin was closed.

There are no appropriate guidelines for NO_2 exposure in a setting such as this. However, NO_2 levels in open vehicles were similar to those previously shown to be associated with health effects on asthmatics exposed for fifteen to thirty minutes. This study has highlighted the need to better understand and manage NO_2 in road tunnels. We recommend that NSW government agencies with a role in the management of road tunnels collaborate to investigate international advances in this area and develop appropriate NO_2 guidelines for tunnels. Pending these investigations, we would advise motorists in open vehicles and motorcyclists, to avoid using the tunnels when transits are likely to be prolonged, particularly if they suffer from asthma.

Our study found that closing the car windows and switching the vehicle ventilation to recirculate can reduce exposures by approximately 70-75% for CO and NO_2, 80% for fine particles and 50% for BTEX gases. These benefits can be achieved whether or not the air conditioning system is in use.

In summary we have demonstrated that for a range of transits with the cabin open or closed during peak hour through the M5 East tunnels, motorists are unlikely to encounter air pollution that would lead to acute health impacts. We have demonstrated that the simple act of closing the vehicle cabin is an effective precautionary measure to reduce exposure to pollutants when using road tunnels.

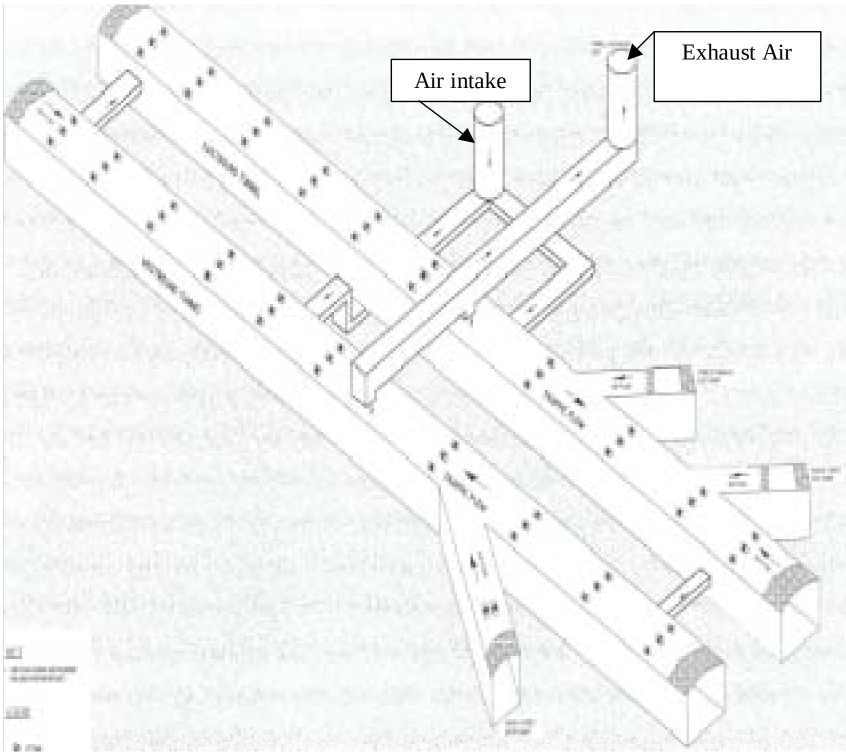
2. BACKGROUND

The M5 East Freeway

The M5 East freeway connects the M5 at King Georges Road, Beverley Hills with General Holmes Drive, Kyeemagh and the Eastern Distributor. The freeway is subject to peak flows eastbound in the morning and westbound in the afternoon. The M5 East tunnel forms part of the freeway route, between Bexley Rd and Marsh St Arncliffe [1]. At 4 kilometres in length, the M5 East tunnel is currently the longest road tunnel in Australia.

The tunnel opened in December 2001 and after six months was used by over 82,000 vehicles daily [2]. The RTA advises that the Operations and Maintenance Reports indicate that in the 12 months from March 2002 to February 2003, 6.9% of traffic was heavy vehicles. The tunnel is ventilated utilising a closed system (ie to avoid exhausting from portals) and fresh air is supplied through an air intake at Duff Street Arncliffe. Jet fans operate against traffic flow at exit portals, and with traffic flow in the Marsh Street entry, to assist the movement of air to an exhaust location. Exhaust air is extracted without filtration through a single stack located approximately 900m north of the tunnel near Turrella railway station [2] (fig 1).

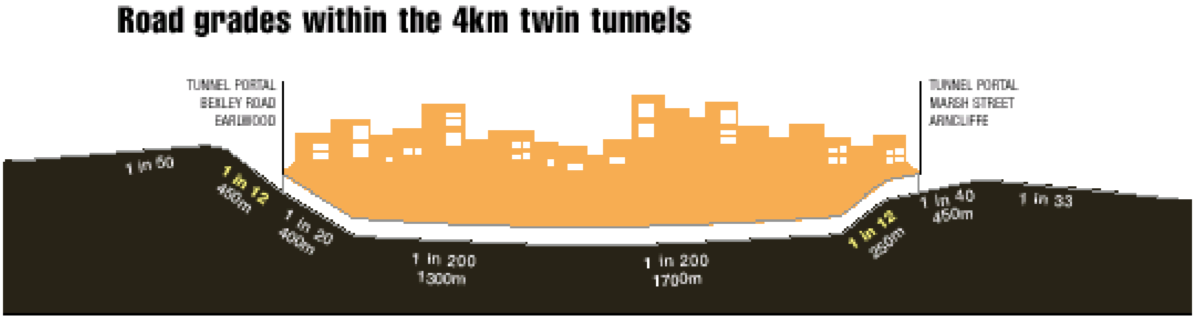
Figure 1: M5 East Freeway Tunnel Ventilation System Schematic



Concerns have been raised in Parliament and the media about perceived poor air quality in the tunnels and it has been alleged that some truck drivers avoid using the tunnels because of air quality.

A condition of consent for the freeway was that the tunnels be operated in compliance with the World Health Organization (WHO) 15-minute guideline for carbon monoxide under all conditions [3]. On a number of occasions the level of carbon monoxide inside the tunnels has exceeded this WHO guideline at a single stationary tunnel monitor. These elevated CO readings were related to times when a breakdown or accident caused traffic congestion in a tunnel. The performance of the tunnel remains under scrutiny from the RTA, the community and the Parliament.

Fig 2: M5 East tunnel height limits and road grades



In order to respond to public concern about possible health risks to people travelling in the tunnel, the South Eastern Sydney Public Health Unit submitted a proposal to the NSW Roads and Traffic Authority to undertake an air-monitoring project. The proposal was to measure carbon monoxide, nitrogen dioxide, fine particles and benzene and related compounds in the cabin while traversing the tunnel in the morning and afternoon peak periods.

Air Pollution

In considering potential adverse health effects of air pollutants it is important to consider both the magnitude and the length of any exposure. These considerations are reflected in standard setting for air pollutants.

In Australia, the National Environment Protection Council (NEPC) sets ambient air quality standards. Standards have been set for each of the criteria air pollutants including: carbon monoxide, nitrogen dioxide, and small airborne particles. These standards form the National Environment Protection Measure for Ambient Air Quality (Air NEPM). The Air NEPM was made on 26 June 1998, developed by Governments, health professionals and the community [4]. The WHO has developed a number of air quality guidelines that are also useful benchmarks against which to judge air pollutant exposures.

In using any standard (or guideline) it is important to consider both the concentration level and the length of exposure nominated in the standard. It can also be important to consider the health evidence on which the standard is based. Appendix A lists Air NEPM and other relevant air quality standards. Standards are not available for most motor vehicle pollutants for the brief exposures typically found in tunnels.

Carbon Monoxide

Carbon monoxide (CO) is a colourless, odourless gas and is the most common pollutant by mass in the atmosphere. The main source of carbon monoxide in the ambient air of a city, such as Sydney, is petrol-fuelled motor vehicles; smaller quantities are produced by diesel-fuelled vehicles and other combustion processes. Carbon monoxide levels, therefore, tend to be greatest in areas of high traffic density [5].

Health effects of exposure to CO are related to the formation of carboxyhaemoglobin (COHb) in the blood, which reduces the capacity of the blood to carry oxygen and impairs the release of oxygen from haemoglobin. Approximately 80-90 % of the absorbed CO binds with haemoglobin to form COHb, the affinity of haemoglobin for CO is 200-250 times that for oxygen. The toxic effects of CO first become evident in organs and tissues with high oxygen consumption, such as the brain, heart and exercising skeletal muscle. The developing foetus is also particularly vulnerable. Severe hypoxia due to acute CO poisoning may cause both reversible, short-lasting, neurological deficits and severe, often delayed, neurological damage, or even death. The effects include impaired coordination, tracking, driving ability, vigilance and cognitive performance at COHb levels as low as 5.1-8.2%. Endogenous production of CO results in COHb levels of 0.4-0.7% in healthy subjects [3].

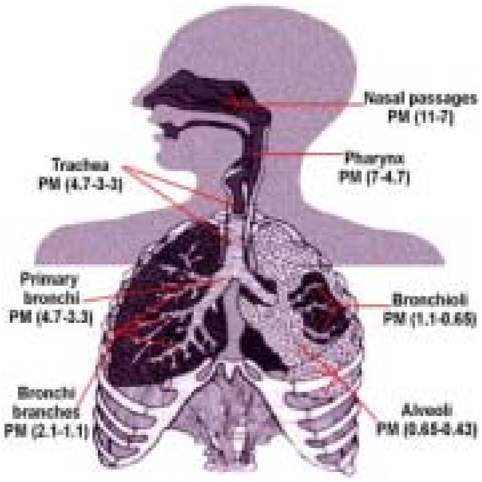
In 1999 the WHO set guidelines for 15-minute average exposure of 87 ppm and 30-minute average exposure of 50 ppm. These guidelines are designed to offer protection in situations where more intense exposure can occur, for example in heavy traffic in urban canyons, enclosed car parks or tunnels [3].

Particulate matter

Particulate matter is used to describe a range of solids suspended in air. Secondary particles are formed in the atmosphere as a result of interaction of gases with other pollutants. Particles are categorized as respirable (0.1-2.5 microns, which is referred to as $PM_{2.5}$), or inhalable (2.5-10 microns). Estimation of PM_{10} includes all particles less than 10microns.

Particles from the burning of petrol and diesel are a complex mixture of sulphate, nitrate, ammonium, hydrogen ions, elemental organic compounds, metals, poly nuclear aromatics, lead, cadmium, vanadium, copper, zinc, nickel, amongst others. Larger particles (PM_{10}) tend to be produced by mechanical processes (eg. wind erosion) as well as combustion, whereas $PM_{2.5}$ is generally produced by combustion processes such as motor vehicle exhaust and solid fuel heater emissions [6].

Fig. 3: Penetration of particulate matter to the respiratory system.



[7] Original source [8]

Acute health effects of particulates include increased daily mortality, increased rates of hospital admissions for exacerbation of respiratory and heart diseases, fluctuations in the prevalence of bronchodilator use and cough and peak flow reductions [3]. Particulate air pollution is especially harmful to people with lung disease such as asthma and chronic obstructive pulmonary disease (COPD), which includes chronic bronchitis and emphysema, as well as people with heart disease. Exposure to particulate air pollution can trigger asthma attacks and cause wheezing, coughing, and respiratory irritation in individuals with sensitive airways. Recent research has also linked exposure to relatively low concentrations of particulate matter with premature death. Those at greatest risk are the elderly and those with pre-existing respiratory or heart disease [7].

Fine particles ($PM_{2.5}$) are of particular health concern because they can be inhaled deep into the lungs where they can be absorbed into the bloodstream or remain embedded for long periods (refer fig.3).

Australian studies have also shown adverse health effects associated with exposure to particulate matter [9], [10], [11], [12], [13]. Current studies have been unable to define a threshold below which no health effects occur. Recent studies suggest that even low levels of fine particle exposure are associated with health effects.

There are no standards available against which to judge the potential effects of short-term (less than 24-hour) exposure to high levels of fine particles.

Nitrogen dioxide

Nitrogen oxides (NO_x) refer to a collection of highly reactive gases containing nitrogen and oxygen, most of which are colourless and odourless. NO_x gases form when fuel is burned; automobiles, along with industrial, commercial and residential sources, are primary producers of nitrogen oxides. In Sydney, motor vehicles account for about 70% of emissions of nitrogen oxides, industrial facilities account for 24% and other mobile sources account for about 6% [5].

In terms of health effects, nitrogen dioxide (NO_2) is the only oxide of nitrogen of concern. NO_2 can cause inflammation of the respiratory system and increase susceptibility to respiratory infection. Exposure to elevated levels of NO_2 has also been associated with increased mortality, particularly related to respiratory disease, and increased hospital admissions for asthma and heart disease patients [10].

Chamber studies, where people were exposed to varying concentrations of NO_2 for 30 minutes to several hours, have demonstrated adverse impacts on asthmatics at levels over 200ppbv. The National Environment Protection Council (NEPC) adopted a NO_2 standard of 120ppbv or 245 $\mu g/m^3$ for a one-hour average by applying a safety factor to the 200ppbv level found in the chamber studies [4]. In recent years, peak levels in metropolitan Sydney have ranged from 90 - 130ppbv, and it has been uncommon for the daily Air NEPM standard to be exceeded [5].

BTEX gases

BTEX is a term referring collectively to the volatile organic compounds benzene, toluene, ethylbenzene, and xylene. They are commonly found together in crude petroleum and petroleum products such as petrol. BTEX are also produced on the scale of megatons per year as bulk chemicals for industrial use as solvents and for the manufacture of pesticides, plastics, and synthetic fibres.

The only standards available for short-term exposure to air toxics are occupational standards. Levels in some occupational settings are many times higher than are found in road tunnels or other areas open to the public.

Benzene

Acute (short-term) inhalational exposure of humans to benzene may cause drowsiness, dizziness, headaches, as well as eye, skin, and respiratory tract irritation, and, at high levels, unconsciousness [14]. Benzene is a genotoxic human carcinogen, and can also cause anaemia through bone marrow depression.

Acute effects have not been observed below 500ppbv. As there is concern that exposure at lower levels over a life-time could be associated with developing cancer, some countries have set a benzene standard for ambient air. As these standards relate to long-term exposure they typically use a one-year averaging period.

Toluene

Toluene is added to petrol, used to produce benzene, and used as a solvent. Acute exposure to toluene can cause respiratory or neurological irritation, which may manifest as headache. Acute effects have not been observed under 100ppm.

Ethylbenzene

The primary sources of ethylbenzene in the environment are the petroleum industry and the use of petroleum products. Ethylbenzene exposure causes eye and respiratory irritation, and neurological effects such as dizziness. High levels are required to produce these effects (1000ppm).

Xylene

Xylene is an aromatic hydrocarbon which exists in three isomeric forms: ortho, meta and para. Acute exposure to high concentrations of xylene can result in neurological effects such as headache, nausea and dizziness in humans. These seem to occur above 100ppm.

3. THE STUDY

Aim/Objective

The overall aim of the project was to measure carbon monoxide, carbon dioxide, nitrogen dioxide, fine particles and BTEX gases (benzene, toluene, ethylbenzene, xylenes) inside a vehicle, and carbon monoxide and nitrogen dioxide levels outside a vehicle travelling in the M5East tunnel during peak traffic periods and to compare these results to published air quality standards where appropriate. The study also aimed to determine if recommendations could be made regarding cabin ventilation settings in order to decrease exposure to air pollutants.

Methodology

Pilot Study

A pilot study was undertaken to assess the minimum exposure time required for analysis of nitrogen dioxide and BTEX passive samplers prior to beginning the project. These passive samplers have not been used routinely for monitoring short exposure periods in previous investigations. The pilot study was undertaken in a well-maintained, government vehicle with windows down, whilst traversing the westbound tunnel in the afternoon peak period between 4–6 pm with one nitrogen dioxide sampler and one BTEX metal tube exposed in-cabin. Both samples were sent the following day to CSIRO Division of Atmospheric Research for analysis.

This pilot demonstrated that 90 minutes in the tunnel was adequate exposure for the passive samplers. It also demonstrated that the number of trips required to accumulate a 90-minute minimum exposure by only measuring one tunnel morning and afternoon was impractical. We further noted that traffic conditions in both tunnels in the afternoon peak were heavy. Therefore, it was determined that the 90-minute passive sampler exposure time would include eastbound and westbound tunnels in the morning period between 7–9 am and westbound and eastbound tunnels in the afternoon between 4-6 pm.

Sample Size Calculation

We needed to determine the minimum number of samples required to detect a difference in air quality between ventilation scenarios. Sample size calculations were based on a recent study monitoring in cabins of commuters to Central Sydney Area Health Service. Preliminary mean cabin nitrogen dioxide levels were 30ppbv, with a standard deviation of 14. It was estimated that a sample size of 10 was enough to confidently detect a 50% difference in levels.

Study Execution

Air monitoring was undertaken over 32 consecutive weekdays between 30 October and 12 December 2002. The monitoring equipment was installed in a well-maintained, government 2000 model Toyota Camry Station Wagon and operated by the same person throughout the study. The vehicle was driven by a second officer in the left-hand lane on all tunnel trips.

A daily record sheet was designed (see Appendix B) and was completed during each trip. The details recorded were the total time taken to travel through the tunnels each day, the number of trips in each tunnel in the morning peak and afternoon peak periods, and general comments relating to incidents in tunnels, subjective traffic volume and subjective consideration of visibility in the tunnels. Six officers rotated the driver's role.

Cabin Monitoring

1. Measurements were taken of the CO, CO_2, $PM_{2.5}$, NO_2 and BTEX gases inside the vehicle whilst traversing the tunnel.

2. Vehicle Ventilation
Three different ventilation types were used in cabin during the monitoring which attempted to replicate real case scenarios. The ventilation scenario was randomly selected each day. In all cases the external air vent was closed. The three types were:
Ventilation Type 1 *–Air conditioner off, windows closed, recirculating air*
Ventilation Type 2*- Air conditioner on, windows closed, recirculating air,*
Ventilation Type 3 *–Three windows open, air conditioner off.*

3. Carbon Monoxide and Carbon Dioxide were measured using a TSI Q – Trak Indoor Air Monitor (Model 8551) (manufactured in Minneapolis, Minnesota, US and supplied by Kenelec Scientific Victoria, Australia). Separate measurements were taken in the eastbound tunnel during the morning peak period between 7-9 am; in the westbound tunnel in the afternoon peak period between 4-6 pm; and in the eastbound tunnel in the afternoon between 4-6 pm. The device was programmed to log every second and to calculate trip averages.

4. $PM_{2.5}$ was measured using a TSI DUSTRAK Aerosol Monitor (Model 8520) (manufactured in Minneapolis, Minnesota, US and supplied by Kenelec Scientific Victoria, Australia). Separate measurements were taken in the eastbound tunnel during the morning peak period between 7-9 am; in the westbound tunnel in the afternoon peak period between 4-6 pm; and in the eastbound tunnel in the afternoon between 4-6 pm. The device was programmed to log every second and to calculate a trip average for $PM_{2.5}$.

5. $PM_{2.5}$ was also measured gravimetrically using an MicroVol 1100 Low Flow-rate Sampler (Ecotech, Melbourne, Australia) fitted with a size selective inlet of 2.5microns. Particulate was collected on a stretched Teflon filter that was changed every 5 days. Particles were collected over a 90-minute period per day during travels in both tunnels in the morning and afternoon peaks. Each single measurement was thus a weekly total covering all ventilation types.

6. Nitrogen Dioxide was measured using a passive sampler (supplied by the CSIRO Atmospheric Research Branch, Aspendale, Vic., see Appendix C) which was located centrally within the vehicle. Passive gas samplers operate on the principle of molecular diffusion of a gas onto a filter coated with a sorbent species, integrated over the time of exposure. In order to accumulate the required minimum 90-minute exposure period the sampler was exposed each day during consecutive trips through the eastbound and westbound tunnels in the morning peak period between 7-9 am; and in the afternoon peak period between 4-6pm. The number of trips per day ranged between 8-16. Between tunnel transits the samplers were capped. Each single measurement was thus a daily total for a specified ventilation type.
These samplers have been validated by CSIRO against standard methods for estimating nitrogen dioxide [15].

7. BTEX gases were measured using a passive BTEX sampler (supplied by the CSIRO Atmospheric Research Branch, Aspendale, Vic., see Appendix C). In order to accumulate the required minimum 90-minute exposure period the sampler was

exposed each day during consecutive trips through the eastbound and westbound tunnels in the morning peak period between 7-9 am and in the afternoon peak period between 4-6pm. The number of trips per day varied from 8-16. Between tunnel transits the samplers were capped. Each single measurement was thus a daily total for a specified ventilation type.
This method complies with the International Standards Organization method for passive sampling of BTEX gases.

External Monitoring

1. External measurements were taken of carbon monoxide, carbon dioxide and nitrogen dioxide simultaneously with the cabin monitoring.
2. Carbon monoxide and carbon dioxide were measured using a TSI Q–Trak monitor with the probe fixed to the roof of the car. The protocol outlined above for cabin monitoring was replicated for external monitoring.
3. Nitrogen dioxide was measured using a passive sampler that was attached to the outside of the vehicle whilst traversing the tunnel. The protocol outlined above for cabin monitoring was replicated for external monitoring.

Other Data Sources

Data on traffic counts and fixed tunnel air monitoring for carbon monoxide was obtained from the RTA. The RTA records averages of carbon monoxide at 15–minute intervals, the reading used for comparison in this study was the one taken closest to the time of the researchers traversing the tunnel.

NSW Environment Protection Authority provided ambient air quality data from the permanent stations at Earlwood and Rozelle.

Analysis

All information collected from the TSI Dustrak and the two TSI Q-Traks were downloaded each day into the Trak Pro software program. These devices were programmed to monitor every second, and provided readings for CO, CO2, PM2.5, temperature and humidity.

The CSIRO, RTA and NSW EPA provided data in spreadsheet format. Values for individual xylene isomers were added to obtain a total xylene level.

All data were entered or merged and analysed using SPSS version 11.5.1.

Differences between ventilation scenarios were tested using the independent samples t-test; comparisons of study monitoring and fixed tunnel monitors were tested using Pearson’s correlation.