Road Tunnels and Filtration- The main issues

The rapid development of road tunnels in Sydney has given rise to considerable debate about their health effects, the need for ventilation stacks, their location and the necessity of filtration to remove the concentrated vehicle emissions from both inside the tunnel and from the stack emissions. This debate is separate from and different to wider planning and transport issues, and especially the merits of public transport over motorways, and the effects of motorways on traffic and communities.

The problems with tunnel fumes both inside the M5 East (for drivers) and for those who live and work near its single stack and the tunnel exits (portals) have certainly focused attention on the need for better ways of dealing with the design and regulation of Sydney's tunnels.

This paper deals with some of the main issues, and common questions raised:

- **Impact of Motorways and Tunnels on external air quality**
- **Air quality inside the tunnel**
- **Research evidence of harmful effects**
- **Why is there suddenly a problem with these new tunnels?**
- **Technical possibilities**
- **Economic implications**
- **Are stacks necessary?**

Impact of Motorways and Tunnels on external air quality

Motorways can have a generally beneficial impact on regional air quality if they free up traffic flow and reduce stop-start driving This benefit lasts only as long as traffic flow remains smooth and disappears as traffic growth increases to fill the available road space. For example, for the M5 East, total traffic volume has increased markedly since it opened in December 2001, with over 100,000 vehicles now using the tunnel, compared with original predictions of 50,000 at the time of the EIS and 70,000 in 2001. Moreover, traffic on local streets has also increased as drivers avoid the congested tunnel.

Road tunnels concentrate vehicle exhaust to a much higher level than that experienced along an open road. This concentrated exhaust is then blown from one (or more) stacks and it is the degree to which this exhaust is dispersed which determines the impact on local residents. The hourly average concentration of particulate matter leaving the single M5E stack is between 900 and 1000 $\mu g/m^3$ during all working daytime hours and has exceeded 1400 $\mu g/m^3$ on occasions. (Consent conditions for the Cross City and Lane Cove tunnels permit in-stack PM10 concentrations up to 1600 $\mu g/m^3$)

Affected community groups argue that any possible benefit to the many from reducing overall emissions is bought at the cost of the few who are exposed to the emissions from the stack and that this is intolerable in our society.

It is inevitable that under the weather conditions common in Sydney, stack emissions will sometimes impact on the ground at relatively high concentrations. (An animation of 'ground strike' from a stack exhaust plume is illustrated at http://www.dar.csiro.au/pollution/Meander/index.html)

In addition to the established harmful effects of vehicle pollution, now shown to cause twice as many deaths as those lost through motor vehicle accidents in Australia, it is also possible that vehicle exhaust held over longer periods of time at high concentrations in the confined space of the tunnel becomes even more harmful through chemical interaction.

Residents living close to both the Eastern Distributor and M5East tunnel stacks report that they can clearly smell the tunnel exhaust, and have noticed the increase in grimy dust. They have continued to report significant adverse impacts on their health, for example, eye, nose and throat irritation, headaches and breathing problems. Some have been forced to sell their homes and move because of the impact on their health and the health of their children.

As documented by three Parliamentary Inquiries, the air quality monitoring system set up to measure the pollution impacts is totally inappropriate as it is based on the NEPM (National Environment Protection Measure) which was specifically designed for ambient regional monitoring, not to measure the effects of a point source of pollution. It does not specifically measure the fine particle component which is the major cause of the ill effects from the tunnel and does not adequately represent the impact of 'peak' events.

In 2003, NSW Health after strong community pressure carried out a study where residents around the M5 East stack, were examined by specialists. The study found a strong likelihood that the stack could be the cause of the reported health impacts. However, the second stage of the study released in 2004, which used a random telephone survey and asked residents closed questions about their health over the previous four weeks, found otherwise. This second study was seriously flawed in its design and execution and can be demonstrated to be unreliable and invalid.

For example, it did not correctly determine the actual degree to which individuals interviewed in the telephone survey were exposed to stack pollutants as it used an 'annual average' map of pollutant exposure to determine the exposure of interviewees during the 4 weeks of the survey. This is obviously an invalid study method which is equivalent to assuming that, because Sydney receives a average of 1200mm of rain per year, it will receive 100mm of rain in any one month.

Air quality inside the tunnel.

There are constant complaints about the air quality inside the M5E tunnel and it certainly fails the 'smell' test, probably the most reliable indication of the potentially harmful nature of the atmosphere in the tunnel. Currently, the only enforceable regulation relating to pollutant levels inside a tunnel is for carbon monoxide. For the M5 the condition reads: *70. The tunnel ventilation system(s) must be designed and operated so that the World Health Organisation (WHO) 15-minute carbon monoxide (CO) goal of 87 ppm is not exceeded under any conditions.*

Following a number of exceedences of this goal in the M5E tunnel, the RTA has attempted to redefine this goal. This means that if a person thought that they had been exposed to higher levels of carbon monoxide they would have to establish the exposure lasted for longer than 15 minutes rather than being able to rely on the instrumentation installed in the tunnel. Despite objections by community groups, similar goals incorporating the concept of personal exposure, have been set in the conditions of approval for other later tunnels. The ability to enforce them is yet to be demonstrated.

There are no other enforceable standards set for Sydney tunnels, however the tunnel operators claim to observe the visibility standards suggested by PIARC, the world road tunnelling association, to ensure drivers can see far enough to avoid obstacles. According to PIARC, this standard leads to a 'very uncomfortable atmosphere'.

Pollutant levels outside the M5E tunnel mostly remain between 20-40μg/m^3 PM10 and 20 –90 μg/m^3 NO_2 (over a 24hour average). Inside the tunnel, they can be over 1400μg/m^3 PM10 and 900μg/m^3 nitrogen dioxide (NO_2). Mean exposure levels, as estimated by the NSW Health study into in-tunnel air quality, were NO_2 : 370±60μg/m^3 and PM2.5 388±106 μg/m^3. These levels were reduced by about 75% by closing car windows and recirculating air inside the car.

As these levels are above the range of exposures and concentrations known to trigger delayed asthmatic attacks in sensitive individuals, the NSW Health report suggested that these people, and drivers in open vehicles and motorcyclists should avoid using the tunnel and that motorists should close car windows before entering the tunnel. In addition NSW Health as early as February 2002 suggested that the RTA should warn motorists by means of signs but as yet the RTA refuses to do so.

The NSW Health in-tunnel air quality study failed to examine the impact of repeated trips through the tunnel and of the interaction of different pollutants, especially that of NO_2 and PM2.5. This is a major deficiency.

Other potentially harmful components of in-tunnel air include volatile organic compounds (VOC), of which benzene is probably the major contributor of risk, and poly-aromatic hydrocarbons (PAH). In the tunnel atmosphere many of these volatile components are captured on the surface of carbon particles (PM2.5), increasing the toxicity.

Research evidence of harmful effects

Exposure to fine particles, especially the ultra fine particles below PM2.5, results in adverse short term effects such as cough, phlegm, mild to severe irritation of eyes and upper airways and exacerbation of asthma, and long term effects such as cancer, heart disease and premature deaths. Increased levels of particulate pollution are directly related to increases in hospital admissions, city wide. There is no safe threshold for exposure to particles, especially those associated with diesel engine exhaust.

Another major component of vehicle exhaust and tunnel air is nitrogen dioxide. It is a strong irritant causing eye and lung irritation and the onset of asthma.

Research carried out in Sweden since 1996 for PIARC has identified a significant impact on sensitive (healthy allergic asthmatic) individuals exposed to tunnel air. Experimental subjects were exposed to common tunnel pollutants as follows:

- NO_2 levels of 500µg/m^3 for half an hour
- NO_2 levels of 500µg/m^3 for three 15 minute periods over 2 days
- in a road tunnel to NO_2 levels of 300 µg/m^3 together with PM2.5 levels of 100µg/m^3.

(It is not technically feasible to expose people to PM2.5 in the absence of other pollutants, but nitrogen dioxide is available as a pure gas, able to be used in an exposure chamber).

In each case there was a similar increase in sensitivity to allergen which occurred some time after the actual exposure. The response to NO_2 is not surprising, considering the known irritant effect of the gas however there are two other conclusions of significance to tunnel ventilation design:

- short exposure times act cumulatively over periods likely to be experienced by commuters.
- nitrogen dioxide and fine particles (PM2.5) act additively.

The NO_2 and PM2.5 levels experienced in the M5 tunnel are significantly higher than those in the Swedish study but the exposure time in the M5E is shorter. The result of the three 15 minute exposures in two days is representative of reactions to the exposures likely in Sydney tunnels.

Following the publication of these results the Vagverket (Swedish National Roads Administration 2003) examined the implications of regulation of nitrogen dioxide at 4 different levels,

Exposure level	Assessment of suitability
1000µg/m^3	inappropriate as it gives no protective margin for sensitive individuals
500µg/m^3	inappropriate as it gives no protective margin for sensitive individuals
300µg/m^3 / 30 min exposure	at best, marginal because higher levels of particles could be experienced in the tunnel which would add to the impact, especially with asthmatic individuals who may be in a state of heightened sensitivity
150-180µg/m^3 / for 15 to 30 min	judged to contain a margin of safety for all but the most sensitive individuals in the presence of particles but noted that it lacked experimental verification.

The limit of 180µg/m^3 NO_2 for half an hour correlates with to the proposed Swedish EPA level for ambient NO_2 of 90µg/m^3/1hr. (The Australian NEPM goal is 250µg/m^3/1hr and the WHO ambient goal is 200µg/m^3/1hr)

Nitrogen dioxide exposure levels in the M5 tunnel rarely exceed 500µg/m^3 however the level 300µg/m^3 is exceeded during the majority of day time hours. This level also occurs in the presence of PM2.5 levels of up to 3 times those experienced in the Swedish experimental exposure.

Based on these observations, it is clear that the levels currently existing in the M5 are higher than is desirable or safe.

Although it is obviously desirable to reduce exposure to both of these pollutants, the removal of either would lead to a significant reduction of the risk to drivers in the tunnel.

Why is there suddenly a problem with these new tunnels?

It is frequently suggested that these problems were not experienced in older road tunnels. The reason for this is both simple and very complex and relates both to changes in vehicle emissions and tunnel ventilation technology.

Until recently, the volumes of air required for tunnel were determined entirely by the need to dilute carbon monoxide to safe levels. The other pollutant of major concern was lead from compounds used to increase the octane rating of petrol. Until recently, experience had generally shown that if carbon monoxide was successfully controlled, other pollutants would be kept to safe or at least acceptable levels.

The only exceptions were in Japan which had an exceptionally high level of diesel vehicles and in Norway where road dust generated by studded tyres was a problem. Experiments in these countries led to the development of electrostatic precipitator filtration for dust and particulate matter, first installed in the Taruga tunnel in Japan in 1979. Currently there are about 60 installations world wide.

Over the last 20 years there has been a significant change in vehicle emissions due to the introduction of unleaded petrol and catalytic converters:

- Lead levels have been reduced to negligible levels
- Carbon monoxide levels have been reduced by about 85% in light petrol engines.
- Sulphur dioxide levels have dropped due to the use of low sulphur fuels
- Nitrogen dioxide levels have tended to increase due to the introduction of more efficient engines.

The 'Euro' requirements for the reduction of PM10 emissions from diesel engines have led to a progressive reduction in particulate matter however this has had an unforseen adverse impact on the harm caused by particulate emissions. Although PM10 levels have been reduced by up to 60% (by weight), the number of fine and ultrafine particles has significantly increased, thus making diesel exhaust more harmful than it previously was because it can now penetrate more deeply into the lungs. A very large proportion of particles in tunnel air are less than 1 micron in diameter. Diesel exhaust is now known to be a cause of lung and other cancer.

The 2000 guidelines put out by PIARC, the international road tunnelling association clearly state that as a result of these changes carbon monoxide is no longer a suitable 'marker' for tunnel air quality. As a proportion of tunnel air related to carbon monoxide, the harmful components nitrogen dioxide and PM2.5 have increased by a factor of at least 3.

Technical possibilities

Technology to remove fine particles is now highly developed with manufacturers in both Japan and Norway having achieved efficiencies of removal of fine particles of between 80 and 95% with air flow velocities in excess of 10m/s. Other manufacturers are also prepared to offer equipment but this has not been proven in actual installations. A number of manufacturers also offer nitrogen dioxide removal systems but only one, that developed by Alstom Power Norway, has been actually installed in a tunnel. Recently the Nikkei News (25th Jan.2004) reported that nitrogen dioxide removal equipment will be installed in all (10) ventilating towers of the Tokyo Central Belt Highway tunnels, starting in 2005.

The NO_2 removal systems are also claimed to remove a significant proportion of volatile organic compounds. All NO_2 removal systems require the installation of electrostatic precipitator filtration equipment to remove particles form the air before it enters the gas removal system

The main problem in the M5East tunnel comes from the fact that it is undersized for the volume of traffic now using it, and it uses a single stack as the outlet. It is not feasible to further increase air flows within the tunnel to increase dilution of the pollutants as this would lead to dangerously high air flow speeds at the centre of the tunnel. Emission of pollutants from the portals is prohibited by the conditions of approval, except during emergencies.

There are at least two possibilities to significantly improve the conditions inside the M5E tunnel. The technologies involved would also assist in reducing similar problems in future tunnels. It is obvious that removing pollutants inside a tunnel improves the situation for those living or working outside the tunnel.

The first possibility is to use established electrostatic precipitator technology to progressively clean the air in ceiling mounted units as it moves along the tunnel. This technique is being increasingly used overseas, most recently in the Stromsas tunnel in Norway and the Aqua Line tunnel under Tokyo Bay in Japan. It has become possible as electrostatic filtration systems have now been designed to deal with high air velocities, thus reducing the size of the installation.

In addition there is the possibility of installing both filtration and NO_2 removal equipment at the portals of the tunnel to clean the air to a degree sufficient to allow safe dispersal of the remaining air. The only remaining toxic component should be a low level of carbon monoxide which could be safely dispersed vertically into the air. This would require extensive study and consultation to ensure that no further risks or impacts occur for the local community.

Economic implications

It has been regularly, and wrongly, claimed that the installation and use of electrostatic precipitator equipment is prohibitively expensive, both to install and run.

Both major users of the technology, the Japanese and the Norwegians claim an overall economic benefit from the use of the filtration technology, above and beyond that which accrues from the improvement of external air quality. Specifically, the Japanese claim a whole of life reduction in ventilation cost, as compared to 'traditional' methods of ventilation, in excess of 30%.

The saving occurs when ventilation systems are designed to take advantage of the technology (rather than it being fitted to an existing design) and comes from the reduction in the size and number of ventilation fans required and the reduction in maintenance and running costs.

In the case of the Laerdal tunnel in Norway, the use of combined filtration and nitrogen dioxide removal removed the necessity to drive an exhaust stack through 1100 metres of rock. The system is capable of cleaning 180 cubic meters of air a second and the total cost was $US6 million, of which less than half was from the electrostatic precipitator. This cost was regarded as high because the whole system was installed 6km into the tunnel and 1100 metres under ground in a very remote area.

As a cost comparison, the decision to move from the original 3 stack proposal for the M5 to the single stack at Turrella cost an additional $30 million and added an additional $l million per year to the running cost of the tunnel. The additional ventilation tunnel for the Cross City tunnel, which would be unnecessary if filtration was used, is costed at $40 million, similarly for the longer Lane Cove tunnel with its two stacks, the cost is $60mill. The M5E tunnel uses about 32 - 35 Gigawatt hours (million Kwhrs) of electricity per year costing over $3 million per year. This is equivalent to 32000 tonnes of greenhouse gases per year. Electrostatic precipitators to clean 900 cubic meters of air a second in the tunnel would only consume 30Kw. Annual energy consumption would be about 1 Gigawatt hour per year, but fan usage may be reduced.

Are stacks necessary?

Road tunnels can be designed which do not need stacks, especially those located in rural and remote areas, where traffic volumes are generally low. Rural tunnels up to 4 km in length are often ventilated through their portals at ground level. Except in unusual circumstances, large tunnels constructed in existing urban areas will require some sort of structure to disperse exhaust gases since there is no technology currently available to remove carbon monoxide.

Although the volume of air needed inside the tunnel is to a large degree determined by carbon monoxide levels, the size and nature of these dispersal structures is determined almost entirely by particulate matter. An impact of 5 - 10μg/m^3 of PM10 for 1 hour from a tunnel would be unacceptable, however this represents a 200 fold dilution of the stack emissions. Such impacts are predicted to occur around the M5E stack. A similar dilution of carbon monoxide, even if present in the stack exhaust at the maximum allowable concentration of 87ppm would represent a ground level concentration of 0.4ppm, negligible in impact when compared to the recommended 1 hour WHO exposure level of 25ppm.

The structures required for the dispersal of the carbon monoxide alone contained in the tunnel exhaust can be much simpler and smaller than those required for particulate matter and nitrogen dioxide. They would be closer in size to those used to ventilate city car parks and their actual size is more likely to be determined by the need to safely disperse fumes in the case of fire than by any other consideration.