Bull. Environ. Contam. Toxicol. (2001) 66:433–438
© 2001 Springer-Verlag New York Inc.
DOI: 10.1007/s00128-001-0024-z

Bulletin of Environmental Contamination and Toxicology

Exposure to Nitrogen Dioxide in Buses, Taxis, and Bicycles in Perth, Western Australia

D. Farrar, P. Dingle, R. Tan

Environmental Science, Murdoch University, Murdoch, WA 6150, Australia

Received: 12 June 2000/Accepted: 20 December 2000

Natural sources of nitrogen dioxide are bushfires, lightning and bacterial action. However, in urban areas anthropogenic sources release significantly more nitrogen dioxide into the air. These sources include automobiles, electrical power generation, industrial boilers, incinerators and jet engines. In Perth automobiles are responsible for approximately 51% of the nitrogen oxides released into the air (WPC and DEP, 1996). Nitrogen dioxide levels are recorded throughout Perth using 12 fixed monitoring stations (Grieco *et al.,* 1996).

Due to the fixed nature of monitoring in Perth little is known about individual exposure and how it compares to ambient levels. To increase the knowledge about pollutant exposure associated with transport within Western Australia, buses, taxis and cyclist commuters and couriers were monitored.

The National Health and Medical Research Council (NHMRC) has established a guideline in ambient air at 160 ppb over a period of 1 hour, not to be exceeded more than once a month (Ferrari *et al.,* 1988). The World Health Organisation (WHO) established a nitrogen dioxide 1-hour average standard that should not exceed 110 ppb. The 24- hour average should not exceed 80 ppb (WHO, 1987).

MATERIALS AND METHODS

Monitors. Monitors developed for this study are based on the work by Palmes *et al.,* (1976) and improved by Yanagisawa and Nishimura (1982). Cyclists, bus and taxi drivers used passive monitors in order to monitor personal exposure to nitrogen dioxide. Passive monitors were chosen as they are simple to use, small and don't interfere with the driver or rider. Furthermore, due to their small cost larger numbers of samples can be collected.

Reusable monitors were constructed from an adapted standard 3-section 37 mm aerosol cassette, made by Millipore Corp. The two adaptations made to the cassette were:

Correspondence to: P. Dingle

- A teflon Millipore Corp FA 37 membrane with a 1μm pore size was chemically welded to the top of the middle section. This reduces air jets, yet the high surface porosity and thinness offers little resistance to mass transfer.
- A metal clip was attached to the bottom of each cassette. This allowed the monitor to be worn by the drivers of the taxis, buses and by the cyclists.

Monitor preparation. Glass fibre filters were dried in a thermostatic oven at 105°C for 24 hours to remove possible contamination. Afterwards filters were treated with 0.25 mL 20% triethanolamine (TEA). After waiting 40 minutes for the TEA to spread completely, the filters were dehydrated in a vacuum desiccator without silica gel at 3 to 5 mm Hg for another 40 minutes. Filters were put into the monitors directly and sealed in plastic "clip-lock" bags (Yanagisawa and Nishimura 1982).

Reagents. Absorbing reagent preparation:- the reagent used was Triethanolamine. It was diluted to 20% with UHPW (Ultra High Purity Water).
NEDA solution preparation:- 0.1g of N-(1-naphtyl)-ethylendiamine dihydrochloride (Aldrich) was weighed and dissolved in 100 mL of UHPW.
Azodye forming reagent preparation:- 5.0g sulphanilic acid (BDH Analar) was weighed and dissolved in 700 mL of UHPW, then 50 mL of concentrated phosphoric acid (Ajax Univar) was added and mixed. Finally 50 mL of NEDA solution was added and diluted to 1000 mL.

Nitrate Standard Stock Solution (2.5 mM):- 0.1725g Sodium nitrite (Ajax Analar) was weighed and made up to 100 mL in a volumetric flask with UHPW.

After exposure, the filters were placed in a labelled 10 mL plastic centrifuge tube and treated with azodye forming reagent, using an automatic dispenser. The tubes were capped and mixed and allowed to stand for at least 40 minutes. The tubes were then centrifuged at 3000 rpm for 5 minutes (to remove any suspended solids). The adsorbance was measured with a 10 mm cell using a LKB 4046 spectrophotometer at 545 nm.

To calibrate the uptake rate of the monitors, a series of chamber experiments were conducted. Known concentrations of nitrogen dioxide were generated dynamically using a Thermo Electron Permeation Calibrator (Model 143) and a Dynacal Permeation Device (size 30T3, 1240 ng/min ±25% at 35°C). The monitors were exposed to different concentrations of nitrogen dioxide for varying exposure periods. A calibration curve was constructed from a nitrate standard stock solution, to provide reference data for the analysed samples. The uptake rate of the monitors was calculated to be 93.2 $mL.min^{-1}$.

The monitors and an information sheet were given to a group of volunteers. The participants opened and closed the monitors and recorded the exposure times on a form supplied.

The monitors were installed in smoke free public transport buses. All buses were powered by diesel fuel, except two that were powered by gas. Two types of buses were monitored; city-clippers, which only operate in the city centre and suburban buses, which operate mainly in the suburbs and only enter the city centre for short periods of time. The monitors were carried with the drivers whenever they changed buses and were only opened during driving. During August and September 127 sets of monitors were supplied to drivers.

All the taxis that were monitored were powered by gas. The monitors were installed inside the taxis and were exposed to the air for a period of the working week. A questionnaire regarding smoking and driving conditions was filled out by each driver.

Both cycling couriers and commuters were monitored. The couriers had a monitor attached to them for one working week. They were opened in the morning and closed when the couriers finished their working day. Monitors supplied to the cycling commuters were opened only during cycling to and from their workplace. To provide an adequate exposure time the cycling commuters used the monitors for 15 days.

RESULTS AND DISCUSSION

Table 1. Nitrogen dioxide concentrations in different types of transport and fixed sites.

Transport type/Site	Mean 24 hour concentration (ppb)	Standard deviation (ppb)	n
Cityclippers	37	10	23
Suburban buses	31	7	64
Taxis	15	6	7
Bicycle Commuters	22	8	8
Couriers	14	10	15
Queens Building	30	9	-
Hope Valley	5	3	-
Cavershum	3	2	-

The 24 hour average ambient nitrogen dioxide level during monitoring, at the Queens Building fixed site, in the city centre was 30 ppb with a S.D. of 9 ppb.

Levels ranged between 12 - 46 ppb. Ambient nitrogen dioxide levels were also measured at Hope Valley and Cavershum, outside of the city centre on the outskirts of Perth. The 24 hour average concentrations measured at these two fixed sites were 5 ppb (S.D. = 3 ppb) and 3 ppb (S.D. = 2 ppb), respectively. The range recorded at Hope Valley was 0 - 14 ppb and at Cavershum it was 0 - 9 ppb. The concentration difference between each stationary site was more than 95% significant.

The nitrogen dioxide levels recorded at the three fixed sites were all below the WHO 24 hour ambient guidelines. Hope Valley and Cavershum both had lower levels than Queens Building. Ambient nitrogen dioxide levels increase when traffic density increased (Mandany and Danish, 1993; Spengler *et al.*, 1983). The elevated levels recorded at the Queen Building site, are likely to be associated with the increased automobile congestion found in the city centre and the 'canyon' effect of the tall buildings and relatively narrow streets (Valerio *et al.*, 1997), which are not found at the other two sites.

Eighty-seven monitors were analysed including 9 duplicate samples. Concentrations ranged between 9 and 54 ppb, with a 24 hour average concentration of 33 ppb (S.D. = 9). The mean 24 hour nitrogen dioxide concentration and standard deviation is given for the city-clippers and the suburban buses in Table 1.

Table 1 displays that the levels associated with the city-clippers are higher than those found on suburban buses. This difference in concentrations is significant ($p<0.05$, $p = 0.0056$), and is most likely caused by the elevated nitrogen dioxide levels in the city centre.

The 24-hour average concentration of the buses is higher than the fixed monitor at Queens building. The increased concentrations associated with the buses may be caused by the fact that they emit nitrogen dioxide themselves and are usually surrounded by other automobiles that produce nitrogen dioxide. Another reason for elevated levels in buses is that they most frequently operate during peak hour traffic, when nitrogen dioxide levels are often higher, where the ambient measurements utilised are an average of the entire day. These factors may explain the significant difference ($p<0.05$, $P = 0.0027$) in concentration between the cityclippers and the Queens Building site.

The nitrogen dioxide concentration in taxis were also significantly ($p<0.05$, $P = 7.71 \times 10^{-7}$) lower than in buses. Fifteen ppb was the average concentration of the 7 taxi cabs monitored. The concentration range was 9 - 25 ppb, with a S.D. of 6 ppb. The lower levels recorded in taxis compared to levels in buses and the levels measured in the city centre is possibly a result of controlled ventilation rates and less time spent in 'peak hour' traffic. Often taxis operate in the evening and when traffic densities are low. However, if they do operate during 'peak hour' times they can control the ventilation inside the taxi by recycling the air, to control the introduction of ambient air. This is done to prevent automobile fumes entering the taxi, rather than limit nitrogen dioxide levels.

Twenty-three monitors were analysed, with a 24 hour average concentration of 17 ppb. The S.D. was 10 ppb and the concentrations ranged between 4 - 37 ppb. Fifteen monitors were carried by the couriers. The 24 hour average concentration of these were 14 ppb, with a S.D. of 10 ppb. The remaining 8 monitors were carried by cycling commuters, with a 24 hour average concentration of 22 ppb. The S.D. was 8 ppb and the range in concentration was 9 - 32 ppb.

The slightly higher concentrations of the commuters compared to the couriers might be explained by the relative time spent on the road near nitrogen dioxide sources. Couriers for example wore the monitor when they enter buildings; therefore monitoring is not limited to road side concentrations. Furthermore, cyclist commuters are often near busy, congested roads. Two commuters who measured their distance and time on the road recorded a mean distance of 41km per day and a mean time of one hour and 50 mins on the road in the city.

None of the 24 hour nitrogen dioxide measurements that were recorded exceeded the WHO 24 hour standard of 80 ppb. The highest 24 hour average nitrogen dioxide concentrations were recorded in the cityclipper buses, with levels significantly higher than the 24 hour average ambient air levels, measured by a fixed monitor (Queens Building).

Nitrogen dioxide levels in taxis were significantly lower than in buses. This difference may be caused by different operation patterns and locations.
The levels recorded by cyclists were also significantly lower than bus levels. This was unexpected as the cyclist couriers in particular were often exposed to the same ambient air as the cityclippers. This difference may have been caused by the time spent inside buildings and avoidance of traffic, by cyclists.

REFERENCES

Ferrari, L, Johnson D, McPhail S, Cattell, F (1988) Air quality in Australian homes- Results of the first Australian study, State Pollution Control Commission, Sydney, NSW.

Grieco A, Mountford P, Kleinfelder R (1996) The Perth photochemical smog study monitoring network, Department of Environmental Protection, Technical Series 82, Perth, Western Australia

Madany IM, Danish S (1993) Spatial and temporal patterns in nitrogen dioxide concentrations in a hot desert region. Atmos Environ 27A :2385 - 2391

Palmes E, Gunnison A, Dimattio J, Tomczyk C (1976) Personal sampler for nitrogen dioxide. American Ind Hyg Assoc J 37: 570-577

Spengler JD, Duffy CP, Letz R, Tibbitts TW, Ferris Jr BG (1983) Nitrogen dioxide inside and outside 137 homes and implications for ambient air quality standards and health effects research. Environ Sci Technol 17:164 - 168

Valerio F, Pala M, Lazzarotto A, Balducci D (1997) Preliminary evaluation, using passive tubes, of carbon monoxide concentrations in outdoor and indoor air at street level shops in Genoa (Italy). Atmos Environ 31:2871 - 2876

Western Power Corporation and Department of Environmental Protection (1996) The Perth photochemical smog study, WPC Report CS20/96 DEP Report 16, Perth, Western Australia

World Health Organization (1987) Formaldehyde. Air Quality Guidelines for Europe, W.H.O. Regional Publications, European Series :23

Yanagisawa Y, Nishimura H (1982) Badge-type personal sampler for measurement of personal exposure to NO_2 and NO in ambient air. Environ Int 8:235 - 242