DRAFT (for NO_2 Modeling and Exposure Working Group Review)

Assessment of Possible Worst-case NO_2 Exposure Scenarios Related to Catalyst-based Diesel Trap Aftertreatment

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BACKGROUND

Problem Statement

Measurements of emissions from heavy-duty diesel vehicles (HDDVs) equipped with catalyst-based diesel particle filters (CB-DPFs) show an increase in nitrogen dioxide (NO_2) emissions while total emission of oxides of nitrogen (NO_X) remain approximately constant. In the atmosphere, NO_X emissions emitted primarily as nitric oxide (NO) are oxidized to NO_2 by sunlight-induced reactions of volatile organic compounds (VOC) and then lead to formation of ozone, nitric acid, and ammonium nitrate ("secondary" PM, a major component of PM2.5 in California). For CB-DPF- equipped vehicles, the fraction of NO_X that is emitted as NO_2 is higher and formation of ozone, nitric acid, and secondary PM2.5 will accelerate. However, this photochemical "acceleration" can be offset by 90% VOC reductions measured for CB-DPF-equipped vehicles. Photochemical modeling conducted for southern California (Dabdub et al., 2004; McNerny, 2001; DaMassa, 2002) and central California (McNerny, 2001; DaMassa, 2002) indicates that the VOC reductions balance the NO_2 increases for NO_2 fractions of 20%. These results are independent of CB-DPF penetration. Directionally, NO_2 fractions greater than 20% will increase ozone and secondary PM2.5 in the populated areas of California that already exceed state and national ambient air quality standards. These results led the Air Resources Board to adopt an NO_2 fraction of 20% as an emission limit in 2002. Last year, a three-year delay was given to the retrofit manufacturers in recognition of their difficulties in meeting the goal, some technical issues with the limit, and the 85% reduction offered by the particle filters for diesel particulate matter (DPM), a known toxic air contaminant and a major contributor to California's PM-related health and visibility problems (Lloyd and Cackette, 2001).

While the prior analyses (Dabdub et al., 2004; McNerny, 2001; DaMassa, 2002) concluded that even future, large-scale (90%) penetration of compliant CB-DPFs would not cause violations of state and national ambient air quality standards for NO_2 – primarily due to large NO_X emission reductions expected over the next decade – these investigations only looked at the regional scale and not microenvironments that potentially cause the highest NO_2 exposures. The observation-based investigation of worst-case microenvironments presented here is conducted to complement a

microscale modeling exercise (Servin, 2004) and investigates the impacts of both current technology and assumed compliant HDDVs on NO_2 levels.

NO_2 and PM Health Effects

Epidemiological studies of the health effects of ambient air pollution report statistically significant associations between NO_2 exposure and adverse health effects including respiratory symptoms, cardiorespiratory hospital admissions, reduced lung function, and mortality. A discussion is offered by our group in Dabdub et al. (2004). Evidence from controlled human exposure studies of healthy subjects generally suggests little effect on pulmonary function and respiratory symptoms at NO_2 concentrations up to several times typical ambient levels. However, several recent papers on responses of asthmatics to NO_2 exposure suggest that NO_2 might enhance responsiveness to allergen challenge at concentrations near the current California ambient air quality standard.

Epidemiological studies consistently report statistically significant associations between both short and long-term PM exposure and increased mortality; increased hospital admissions, particularly for heart and/or lung related causes; increased respiratory infections, such as influenza and bronchitis; exacerbation of asthma; reduced lung function; and increased respiratory symptoms. Although PM is quite diverse in terms of particle size, chemical composition, and mix of chemical species among different areas based on the mix of local sources, the associations found are similar across the U.S., Canada, Europe, and Asia (Dabdub et al., 2004).

While it is not possible to conduct a quantitative risk assessment evaluating NO_2 increases against DPM reductions, DPM-related health effects are generally considered more severe, leading to nearly 2000 deaths in California at population-weighted exposure of 1.8 $\mu g/m^3$ estimated for the year 2000, as well as significant morbidity effects (Lloyd and Cackette, 2001).

Exposure Scenarios Evaluated

In this evaluation of potentially high NO_2 exposures related to the use of CB-DPFs, three scenarios with potential for high exposure were considered, with the worst-case acute NO_2 exposure case assumed to be the simultaneous occurrence of the three. These scenarios were:

(1) Driving on the 710S Freeway (segment from Long Beach to the 5 Freeway, the busiest truck corridor in California) assuming high numbers of trap-equipped HDDVs (based on ARB on-road NO/NO_2 measurements made on the 710 Freeway [Westerdahl et al., 2004]);

(2) Riding in a trap-equipped diesel school bus, with re-entrainment of a fraction of the bus's own exhaust into the cabin ("self pollution") (based on measurements from the ARB School Bus Study [Fitz et al., 2003; Behrentz et al., 2004a,b]); and

(3) Closely following a trap-equipped diesel school bus in stop-and-go traffic (based on the dilution rates calculated for low-speed and low-exhaust pipes [Chan et al., 2001],

high speed dilution rates [Kittelson et al., 1988; Brown et al., 2000], and idling measurements conducted by Allansson et al. [1999]).

Scenarios (2) and (3) can occur at the present time, while (1) will depend on the future fleet penetration of the trap technology. . Figure 1 illustrates the basic principle of the simple exposure model used in this analysis. Current ambient (background) NO_2 concentrations are reflected in the measurements used in the Scenario 1 calculations, but they would have an additive effect on the concentrations calculated in Scenarios 2 and 3.

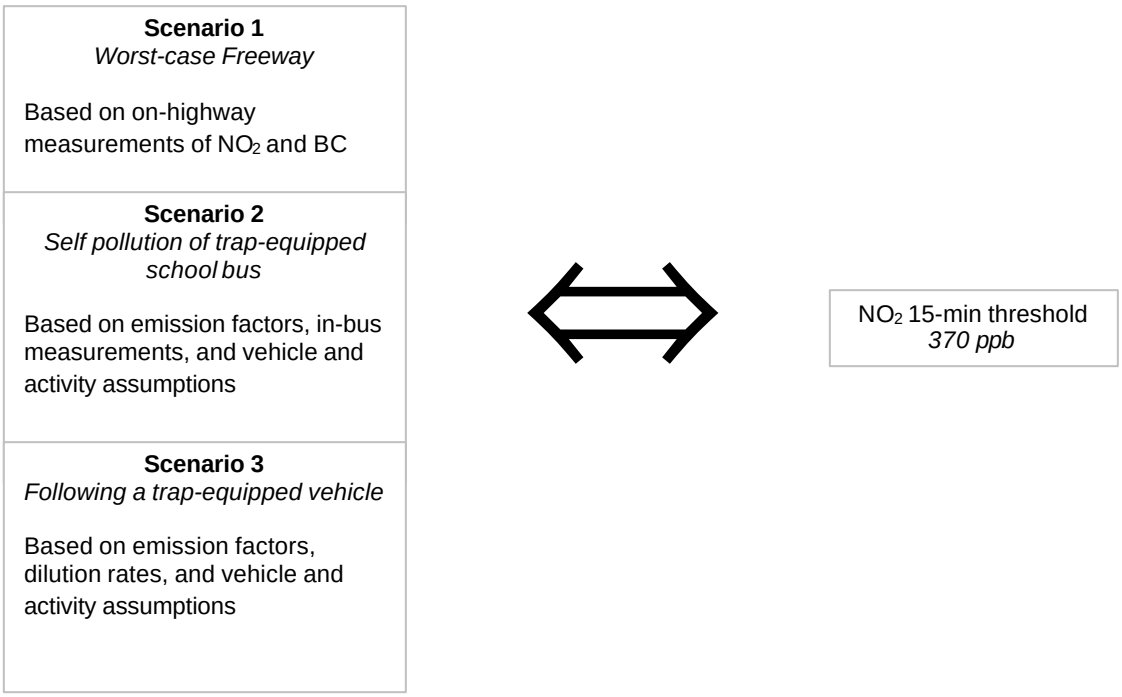

Figure 1. Exposure Model

Because it is the unique concurrence of events that creates the worst-case scenario, these three scenarios were assumed to occur with typical (~50th percentile) concentrations (labeled “high” due to the high exposure scenario conditions). However, for evaluation of these exposure scenarios individually, “extreme” (~90th percentile) concentrations or conditions were also included in this analysis. The post-trap NO_2 fractions are assumed in the extreme case to be 70% of the total NO_X when operated with ultra-low sulfur diesel fuel (10 to 50 ppm) and catalyst inlet temperatures between 275 and 325 degrees Celsius (Warren et al., 1998). The high case is assumed to be 50% of the total NO_X. This case is reflective of in-use levels measured over rigorous driving cycles (Ayala et al., 2002). For comparison to the non-compliant “high” and “extreme” cases, emission rates based on the current 20% NO_2 fraction limit are included using the same scenario conditions as the “high” scenario except for a higher market penetration.

The higher NO_2 levels evaluated in this exercise result from the use of CB-DPFs. Thus, simultaneous reductions in total DPM emissions on the order of 85% and concurrent reduction in DPM exposures were also incorporated.

The three scenarios above are considered the worst-case exposures to the public as emissions from workplace HDDVs such as refuse trucks or construction equipment undergo more dilution before exposing the public than emissions from closely-followed HDDVs undergo before reaching vehicle occupants, especially at low speeds and short following distances. HDDV idling scenarios were not considered as California has regulations in place to limit school bus and other idling. Occupational exposures were not considered as these are situations are governed by other agencies, regulatory programs, and health-based standards in California.

The 250 ppb hourly NO_2 California standard was assumed to be the threshold target for health effects. However, a time period of 15 minutes was assumed to be a more reasonable duration of exposure under the simultaneous concurrence of events (1), (2), and (3) described above (i.e., trap-equipped school bus closely following another trap-equipped school bus in stop-and-go traffic on the 710S Freeway). This is because vehicles usually do not follow each other for long periods of time, and the 710S freeway segment is itself only 16 miles long. Outside of this segment, HDDV traffic is much reduced and, consequently, NO_X concentrations are lower. The hourly 250 ppb standard was extrapolated to a higher concentration corresponding to the shorter averaging time as described in a later next section.

SUMMARY OF RESULTS

The analyses discussed in this paper yield the results illustrated in Figures 2 and 3. The deployment of CB-DPFs into the fleet results in increased emissions of NO_2 and a corresponding increase in personal exposure. However, there are simultaneous benefits of significant reductions in emitted DPM and resulting lower exposures.

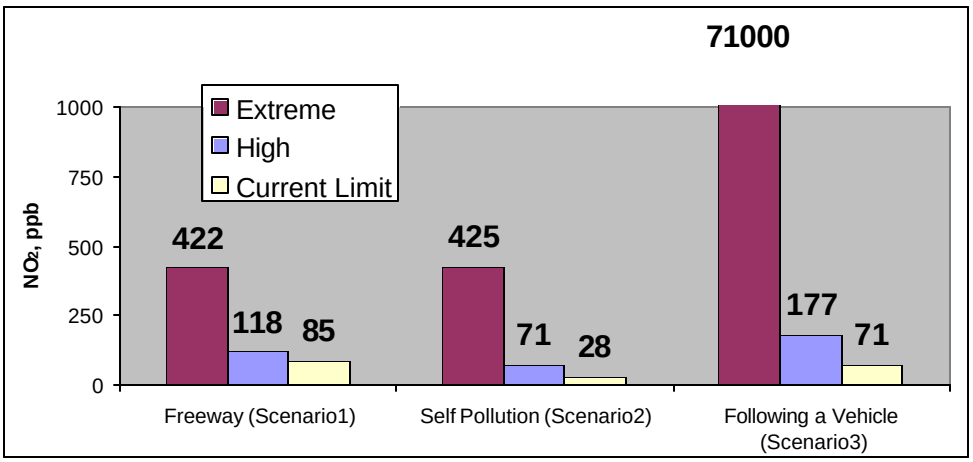

Figure 2. NO_2 concentrations in worst-case scenarios.

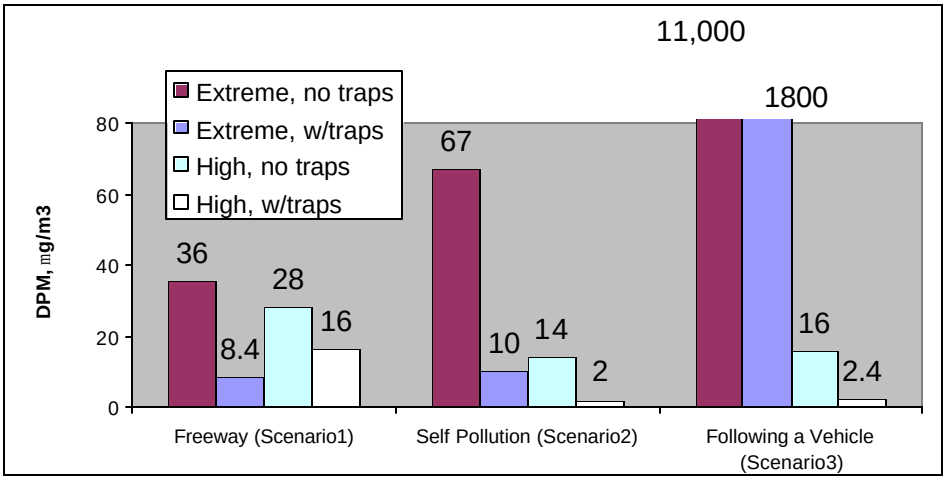

Figure 3. DPM concentrations in worst-case scenarios, with and without CB-DPFs.

(Note: Compliant CB-DPF ("current limit") DPM reductions same as "high" scenario except for Scenario 1 (due to higher assumed penetration) where concentrations are 28 µg/m³ with no traps and 6 µg/m³ with traps.)

CALCULATIONS

NO_2 Concentration Threshold

To estimate equivalent concentrations to the 250 ppb hourly standard for different averaging times, a power law relationship was used. This relationship was based on a modification of Haber's Law (where the product of constant concentration and time is assumed to elicit the same health effect). This assumption was used by the California Office of Environmental Health Hazard Assessment (OEHHA) to calculate toxic air pollutant standards as described in their document "The Determination of Acute Reference Exposure Levels for Airborne Toxicants" (OEHHA, 1999). OEHHA used the equation:

$$(\text{Conc})^n \text{ X Averaging Time} = \text{Constant} \qquad \text{(ten Berge et al., 1986)}$$

where the exponent *n* ranged from 0.8 to 3.5, depending on the compound and the averaging time (ten Berge et al., 1986). Based on the animal NO_2 exposure studies of Hine et al. (1970), ten Berge et al. assigned a value of 3.5 to the exponent *n* for NO_2. Based on the above equation, the 15-minute threshold NO_2 concentration corresponding to 250 ppb for one hour is **370** ppb. (This value is more conservative [lower] than if the default OEHHA value for *n* of 2 is used, which would give 500 ppb.)

Scenario 1 - Worst-Case Freeway NO_2 Scenarios

The highest possible roadway NO_2 concentrations in California were assumed to occur on the 710S Freeway, the freeway with the highest diesel truck traffic volumes in Los Angeles. NO_2 concentrations were assumed to increase if significant fractions of the

diesel trucks were equipped with CB-DPFs, while overall NO_X emissions from these trucks were assumed to remain unchanged.

Baseline NO and NO_X concentrations were determined from recent on-road measurements. In Spring, 2003, NO_X, NO, and NO_2 concentrations were measured on four different days (Westerdahl et al., 2004). NO concentrations were 410 ± 130 ppb, NO_X concentrations were 470 ± 150, and NO_2 averaged 15% of total NO_X. The highest segment-average NO concentration was 570 ppb, and NO_X concentrations for this day were 670 ppb. The scenarios are illustrated in Table 1.

Table 1. Elements of Scenario (1) - Worst-Case Freeway NO_2 Levels

	NO_X Concentrations	**Trap Penetration Rates**	**Trap-Equipped Fleet Average NO_2 Fraction**	**Freeway Concentrations**
Extreme scenario	670 ppb (highest daily 710S average)	90%	70%	670 ppb NO_X x 70% NO_2 fraction x 90% penetration=**422** ppb NO_2
High scenario	470 ppb (average of 710S for four days)	50%	50%	470 ppb NO_X x 50% NO_2 fraction x 50% penetration = **118** ppb NO_2
Current limit scenario	470 ppb (average of 710S for four days)	90%	20%	470 ppb NO_X x 20% NO_2 fraction x 90% penetration = **85** ppb NO_2

Table 2. Estimated DPM Reductions

	BC Concentrations	**DPM Concentrations**	**Trap Penetration Rates**	**Trap Efficiency**	**Freeway DPM Reductions**
Extreme scenario	17.5 µg/m³ BC (highest daily average for 710S)	**35.7** µg/m³ DPM (highest daily average for 710S)	90%	85%	35.7 µg/m³ x 90% penetration x 85% removal = **27** µg/m³ DPM
High scenario	13.8 µg/m³ BC (average of four days for 710S)	**28.2** µg/m³ DPM (average of four days for 710S)	50%	85%	28.2 µg/m³ times 50% penetration x 85% removal = **12** µg/m³ DPM
Current limit scenario	13.8 µg/m³ BC (average of four days for 710S)	**28.2** µg/m³ DPM (average of four days for 710S)	90%	85%	28.2 µg/m³ times 90% penetration x 85% removal = **22** µg/m³ DPM

Scenario 1 - DPM Exposure Reduction due to Traps on Worst-Case Freeway

The deployment of CB-DPFs, which result in increased tailpipe NO_2 emissions, concurrently result in reduced emission of and exposures to DPM. The magnitude of

reductions, illustrated in Table 2, were based on Aethalometer measurements of black carbon (BC) made during the study by Westerdahl et al. (2004). To convert these black carbon concentrations, a factor of 2.04 is used, the same value as used in the ARB Toxic Air Contaminant Identification Document (ARB, 1998). This is a reasonable value, based on evaluating elemental carbon (EC) fractions in diesel engines as a function of load, and the Aethalometer response to EC (Fruin et al., 2004). However, it is acknowledged that EC emissions from HD engines display a strong dependence on duty cycle (ARB, 2004), but such consideration is beyond the scope of the present exercise.

Scenario 2 - Worst-Case School Bus NO_2 Self Pollution Scenarios

Self pollution has been shown to be an important contributor to pollutant concentrations on board school buses in a study conducted for ARB (Fitz et al., 1998; Behrentz et al., 2004a,b). Self pollution appears to be worse when windows are closed and generally increases with the age of the bus, although buses older than 1993 are not good candidates for the CB-DPFs because of their relatively higher PM emissions.

Intrusion Rates

ARB's school bus study found the following fractions of exhaust making it back into the bus cabin based on measurements of an inert tracer gas added to the bus exhaust (Behrentz et al., 2004; Fitz et al., 2003) during closed window conditions:

Table 3. Intrusion Rates from ARB's School Bus Study

Model Year	Rate of Intrusion
1975	0.29%
1985	0.13%
1993	0.02%
1998	0.04% (trap-equipped bus)
2002	0.04% (CNG bus)

Based on these figures, we assumed "high" and "extreme" intrusion rates of 0.04% and 0.10%, respectively.

NO_2 Emission Rates and Concentrations in Exhaust and Cabin

NO_X emission rates are taken from the available literature and are assumed, for the extreme case, to be levels as measured over a rigorous driving cycles such as the New York Bus Cycle (NYBC). In the case of "high" emission rates, those are assumed to be levels representative of heavy-duty engine emissions over the certification cycle (UDDS) (Ayala et al., 2002).

Assuming a nominal 9000 liters per minute of exhaust produced by a heavy-duty engine (8.3 L, 4-stroke, turbocharged operating at 1500 rpm) as done in the school bus study (Fitz et al., 2003) over a duty cycle like the Central Business District (which is 2 miles long and lasts 10 minutes):

Table 4. Scenario 2 – Self Pollution

	NO_2 Emission Rates	NO_2 Concentrations in Exhaust	In-cabin Concentration
Extreme scenario	50 g NO_X/mile x 70% = 35 g NO_2/mile	(35 g NO_2/mile x 2 miles) / (10 minutes x 9000 lpm) = 0.0008 g NO_2/liter = 800,000 µg/m^3 = 425,000 ppb NO_2	0.10% x 425,000 = **425** ppb
High scenario	30 g NO_X/mile x 50% = 15 g NO_2/mile	(15 x 2)/(10 x 9000) = 333,000 µg/m3 = 177,000 ppb NO_2	0.04% x 142,000 = **71** ppb
Current limit scenario	30 g NO_X/mile x 20% = 6 g NO_2/mile	(6 x 2)/(10 x 9000) = 133,000 µg/m3 = 70,600 ppb NO_2	0.04% x 70,600 = **28** ppb

Scenario 2 - DPM Exposure Reductions due to Traps on School Buses

The use of CB-DPFs in the scenario described above would result in reductions of PM emissions and a corresponding reduction in the DPM exposures due to self pollution.

PM emission rates were taken from the latest heavy-duty truck emissions research (CRC Project E-55). Admittedly, bus engines are designed to meet more stringent emission standards than truck engines and the available research literature supports this assertion for in-use bus emissions. However, because the California school bus fleet still includes a significant number of older mid-1980 engines and because the E-55 dataset is the most comprehensive to date, it is reasonable to consider those emission factors in the context of this "bounding" exercise. PM show strong reductions as model year advances (Clark et al., 2003). Over transient operation, the extreme case corresponding to the 90th %le results in emissions of 3 g of PM/mile. In the case of high emissions, the E-55 study suggests emissions of 1.8 g of PM/mile. Assuming the same engine parameters and operating conditions as those used above to calculate in-cabin concentrations for NO_X yields the following results:

Table 5. Estimated Self-Pollution DPM Reductions in Scenario 2

	Intrusion Rates	DPM Emission Rates	DPM Concentration in Exhaust	In-Cabin Concentration due to Self-Pollution	Reductions in On-Board Concentrations due to Traps
Extreme scenario	0.10 %	3 g PM/mile	(3 g PM/mile x 2 miles) / (10 minutes x 9000 lpm) = 0.0000667g PM/liter = 66,700 µg/m³ DPM	0.10% x 66,700 µg/m3 = **67** µg/m³ DPM	67 x 85% = **57** µg/m³ DPM= 28 µg/m³ BC
High scenario	0.035%	1.8 g PM/mile	(1.8 x 2) / (10 x 9000) = 40,000 µg/m³ DPM	0.04% x 40,000 µg/m3 = **14** µg/m³ DPM	14 x 85% = **12** µg/m³ DPM= 6 µg/m³ BC
Current limit scenario	0.035%	1.8 g PM/mile	(1.8 x 2) / (10 x 9000) = 40,000 µg/m³ DPM	0.04% x 40,000 µg/m3 = **14** µg/m³ DPM	14 x 85% = **12** µg/m³ DPM= 6 µg/m³ BC

For comparison, the ARB School Bus Study average in-cabin concentration for the uncontrolled diesel buses with windows closed was 12.5 µg/m³ BC, which reflects both self-pollution and roadway concentrations.

Scenario 3 - Worst-Case Followed Vehicle NO_2 Exposure Scenarios

Driving at low speeds with accelerations (stop-and-go traffic) during times of little or no wind is a worst-case scenario for high exposures to emissions from surrounding vehicles and, particularly, from the vehicle being followed. Reduced dilution occurs due to reduced air speeds around the vehicle and reduced turbulent mixing; higher emissions occur due to accelerations.

The worst type of diesel vehicle to follow is a low-exhaust diesel vehicle, i.e., either a delivery truck or school bus (Fruin et al., 2004). Significantly greater BC concentrations were measured inside vehicles following diesel vehicles with low exhaust pipe locations, which are typically located at the rear or the center of the vehicle, compared to vehicles with high exhaust locations like tractor-trailer combinations, which have exhaust pipes near the front of the vehicle (Fruin et al., 2004).

Dilution at low speeds is much reduced, but very few dilution rates are reported in the literature. Chan et al. (2001) modeled and measured dilution of vehicle exhaust at idle during periods of calm winds (< 0.1 m/s). Good agreement was observed between measurements and modeling, and a center-line dilution rate of only ~6 was observed at 2 m and ~10 at 5 m (high rpm condition). However, it is unlikely that a following vehicle would have its air intake exactly align with a plume centerline, so these dilution rates are considered a lower possible bound.

At the other end of the spectrum is following a high exhaust configuration such as a tractor trailer at high speeds. Kittelson et al. (1988) as cited in Brown et al. (2000) measured dilution rates of 1000 about 30 meters from the stack of a tractor-trailing at 50 to 55 mph, up to a dilution factor of about 2500 at 100 meters from the truck stack. Dilution rate was found to increase linearly with distance until the turbulent wake of the vehicle, where an extra three-fold dilution occurred.

Overall, traffic exhaust dilution rates on-highway appear to range over nearly four orders of magnitude as indicated in Table 6, with exposure estimates showing a strong dependence on these dilution rates. For example, using the extreme (425,000 ppb) and high (177,000 ppb) NO_2 exhaust concentrations for school buses calculated above under Scenario 2, and dilution ratios of 6 and 1000 for extreme and high exposure conditions, respectively, concentrations entering the bus air intake might range from 71,000 ppb to 177 ppb. This example shows nearly three orders of magnitude difference. Some mixing of in-cabin air with lower concentrations will also occur, but this is also difficult to quantify.

It is noted that under the assumptions for the extreme case of Scenario 3, the NO_2 standards would likely be exceeded for diesel vehicles with or without a filter.

Table 6. Scenario 3 – Following Trap-Equipped Vehicle

	NO_2 Concentrations in Exhaust (Same as Scenario 2)	In-cabin Concentration
Extreme scenario	425,000 ppb NO_2	425,000 ppb/ 6 = **71,000** ppb NO_2 (low exhaust pipe at 2 m distance, no wind, plume centerline, no dilution in following vehicle cabin)
High scenario	177,000 ppb NO_2	177,000 / 1000 = **177** ppb NO_2 (high exhaust pipe, >50m following distance, 55 mph, tractor-trailer turbulence)
Current limit scenario	70,600 ppb NO_2	70,600 / 1000 = **71** ppb NO_2 (high exhaust pipe, >50m following distance, 55 mph, tractor-trailer turbulence)

Therefore, to accurately estimate where, within this large range of NO_2 concentrations, a particular scenario might fall, actual measurements would be necessary. The only direct measurements of NO_2 concentrations of a CB-DPF-equipped vehicle at close range available were the measurements of Allansson et al. (1999). In this work, Allansson et al. measured NO_2 near an idling truck with a low exhaust pipe. Fourteen 1-, 10-, and 30-second NO_2 measurements 1 meter downwind of the exhaust were made. The maximum 30-second concentration was 1250 ppb. Maximum concentrations decreased with increasing averaging time.

To estimate a maximum 15-minute concentration, the maximum concentrations for 1, 10, and 30 seconds were plotted and extrapolated to 15 minutes, as shown in the following graph:

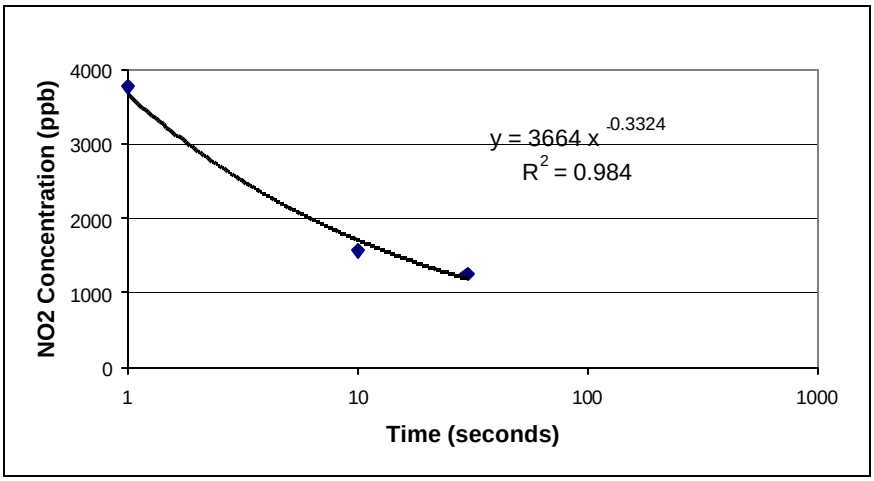

Figure 3. Maximum NO_2 Concentration versus Time for Near-Field Idling Tests

The 15-minute concentration extrapolated from the equation above is 380 ppb, near the 370 ppb standard derived for 15 minutes. However, this 380 ppb figure is quite uncertain, not only from the extrapolation made above, but also because this study did not include accelerations or calm wind conditions. Finally, the NO_2 emission rates for

this vehicle were not given, so it is also unknown how the vehicle studied compares to typical school bus emissions.

Scenario 3 - DPM Exposure Reductions due to Traps on Followed Vehicle
Like the followed-vehicle NO_2 exposure scenario, the DPM concentrations and exposure reductions due to traps depend strongly on assumptions about dilution rates, so have a large range. These are presented in Table 7.

Table 7. Estimated Followed-Vehicle DPM Reductions for Scenario 3

	DPM Emission Rates (same as scenario 2)	DPM Concentration in Exhaust	Following Vehicle In-cabin Concentration	Reductions in On-Board Concentrations due to Traps
Extreme scenario	3 g PM/mile	(3 g PM/mile x 2 miles)/(10 minutes x 9000 lpm) = 0.0000667g PM/liter = 66,700 µg/m³ DPM	66,700 / 6 = **11,100** µg/m³ DPM (low exhaust pipe at 2 m distance, no wind, plume centerline, no dilution in following vehicle cabin)	11,100 x 85% = **9,400** µg/m³ DPM= 4600 µg/m³ BC
High scenario	1.8 g PM/mile	(1.8 x 2)/(10 x 9000) = 40,000 µg/m³ DPM	40,000 / 2500 = **16** µg/m³ DPM (high exhaust pipe, >50m following distance, 55 mph, tractor-trailer turbulence)	16 x 85% = **13.6** µg/m³ DPM= 6.7 µg/m³ BC
Current limit scenario	1.8 g PM/mile	(1.8 x 2)/(10 x 9000) = 40,000 µg/m³ DPM	40,000 / 2500 = **16** µg/m³ DPM (high exhaust pipe, >50m following distance, 55 mph, tractor-trailer turbulence)	16 x 85% = **13.6** µg/m³ DPM= 6.7 µg/m³ BC

CONCLUSIONS

The one-hour NO_2 California standard of 250 ppb was converted to a 15-minute threshold of 370 ppb to facilitate the evaluation of shorter and more likely high exposure traffic conditions that could occur on a California freeway.

To the extent that the assumptions made are deemed sufficiently reasonable and realistic, the bounding exercise described in this paper suggests that if non-compliant CB-DPF technology with significant NO_2 slip gains market penetration, situations on some California roads can be expected to lead to acute exposures to NO_2 concentrations significantly above the ambient one-hour standard of 250 ppb or the converted 15-minute limit of 370 ppb.

For the case of traps meeting the current limit of a 20% NO_2 fraction, the 370 ppb limit does not appear to be exceeded, even during the simultaneous occurrence of the three “high” exposure scenario conditions. In the cases of individual “high” exposure scenarios for non-compliant CB-DPFs, where the NO_2 to NO_X fractions were assumed to be a more realistic 50% and the fleet penetration of the CB-DPF technology was a less ambitious 50%, the 370 ppb standard does not appear to be exceeded by any of the scenarios alone. However, results from this analysis suggest that the NO_2 threshold may be violated from the cumulative effect of the simultaneous occurrence of the three

“high” exposure scenarios, or individually in any one of the three “extreme” scenarios in isolation.

The weakest evaluation in the preceding analysis was estimating NO_2 concentrations while closely following another vehicle equipped with a CB-DPF (Scenario 3). In this case, results depend strongly on dilution rates that are difficult to estimate and can range over several orders of magnitude. Evaluating these scenarios may require direct measurements such as those reported by Allansson et al. (1999).

The same situations that result in increased NO_2 exposures concurrently yielded significant reductions in exposures to DPM. Neither of these issues should be considered in isolation. DPM is a toxic air contaminant in California and the importance of reductions in DPM exposures are clearly a high agency priority, as delineated in California’s Diesel Risk Reduction Plan. While a quantitative assessment of the relative importance of increased NO_2 exposure in the context of simultaneous reduced DPM exposure is not possible, it is understood that most of the air pollution-related health effects in California are due to high levels of PM2.5 and PM10, including DPM.

This analysis concludes that compliance with the current NO_2 fraction emission limit of 20%, based on preventing increases in ozone and secondary PM2.5, would also prevent exceedances of the current California 1-hour NO_2 ambient air quality standard, even under worst-case exposure scenarios. When compliant HDDVs become available, we suggest on-road studies to measure NO_2 exposures for one vehicle closely following another.

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