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# Evaluation of the Levels of Diesel-related Pollutants on School Buses During the Transportation of Children

*Executive Summary  
December 2005*



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This report was prepared in collaboration with:

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The New Brunswick Department of Education

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## ***Introduction***

Diesel emissions are a complex mixture of particles, gases and vapours. Diesel gaseous emissions contain carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), oxides of nitrogen (NO<sub>x</sub>), sulphur dioxide (SO<sub>2</sub>) and volatile organic compounds (VOC), specifically non-methane hydrocarbons, carbonyl compounds such as aldehydes, and polycyclic aromatic hydrocarbons (PAH). Diesel particulate emissions consist of carbonaceous material, usually 75% elemental carbon known as “char” or “soot” and 20% organic carbon. These percentages vary widely depending on engine technology and the type of exhaust technology present. A small fraction of the particulate matter (PM) mass consists of inorganic compounds such as sulphate, water bound to the sulphate and various trace elements (metal oxides) originating from diesel oil and engine material.

Several governmental and scientific agencies have ascertained that diesel exhaust is a probable human carcinogen. Recent studies have also shown a relationship between lung diseases such as asthma and exposure to emissions from diesel engines. There is evidence to suggest that children are especially vulnerable to these effects. School bus rides have been indicated as a potentially important source of exposures to diesel emissions. Levels of diesel-related pollutants on school buses have been investigated in several studies in the United States, which reported a high bus-to-bus variability with the highest concentrations of measured pollutants found in conventional diesel buses. However, most of these studies

have used few buses and have measured pollutant levels without passengers on board. In Canada, little information about the characteristics of these exposures is available for school-day conditions that students typically experience.

The New Brunswick Lung Association, the New Brunswick Department of Education, Health Canada, Environment Canada and Environment and Human Health, Inc. were interested in determining the potential levels of exposure of New Brunswick children to diesel exhaust while commuting to and from school. The geography and population density of New Brunswick communities require a large number of students to travel to school by bus each day. Approximately 95,000, or 77% of all enrolled students, rely on school bus transportation. The objective of this study was to measure actual levels of diesel exhaust pollutants in New Brunswick school buses during children’s daily commutes to and from school, relative to the age of the bus, the length of the bus route, the school region, the bus fuel injection system, weather variables (temperature and humidity) and ambient PM<sub>2.5</sub> levels. The ultimate goal of this study is to help develop policy recommendations aimed at reducing the exposure level of school children to diesel exhaust originating from school buses.

For the purpose of this report, the term “exposure” is defined as the measure of pollutants on buses with children on board. Exposure is not in this context representative of the exposure of one individual child on one individual bus.

## Methods

The study was conducted in the province of New Brunswick, Canada, in two school districts. Children from Kindergarten up to Grade 5 were selected for participation in this study and ranged in age from 5 to 11 years. The air was sampled for children on 63 school days from April 24 to June 19, 2003. Forty-one buses were used, the average age of a bus being 6.6 years (standard deviation [SD] = 4.4 years). Most buses were smoke opacity tested<sup>1</sup> and all passed testing standards. All buses tested in the study were diesel fuelled, with a sulphur content for March of 436 ppm, for April of 427 ppm, and for May of 433 ppm.

Air sampling technicians carried the scientific measuring instrumentation and accompanied the children throughout the school day, including the period of walking or riding to school. Although measurements were taken for the entire day, only exposure values collected during commute time were investigated in the analysis. Buses and sampling days were randomly selected, and a sufficiently large number of bus rides were tested to be representative of the conditions in the community. A different bus route was followed for 63 typical school days of a child; thus 63 days of sampling were completed. Exposure measurements were also collected for 11 days of walking routes. Air sampling technicians kept log sheets to record any factors that could have influenced exposure.

Particulate matter with aerodynamic diameter less than 2.5  $\mu\text{m}$  ( $\text{PM}_{2.5}$ ) was measured using a Dust Trak<sup>®</sup> ( $\text{PM}_{0.1-2.5}$   $\mu\text{m}$ ), and PM with diameter less than 1.0  $\mu\text{m}$  ( $\text{PM}_{1.0}$ ) was measured using a P-Trak<sup>®</sup> ( $\text{PM}_{0.02-1.0}$   $\mu\text{m}$ ). Concentrations of black carbon (BC) and ultra-violet (UV) absorbing aromatic organic materials were measured using a portable, fully automatic Aethalometer<sup>™</sup>. SUMMA canisters were used to collect air samples for volatile organic compounds (VOC), which were analyzed using cryogenic pre-concentration high-resolution gas chromatography and a quadruple mass-selective detection (GC-MSD) method. The sampling was usually carried out at children's breathing zone. Meteorological data, including hourly temperature, relative humidity, wind speed and direction, and cloud cover were collected at Fredericton airport by Environment Canada. Ambient air quality data including  $\text{PM}_{2.5}$ ,  $\text{NO}_x$ , ozone ( $\text{O}_3$ ) and carbon monoxide (CO) were obtained from Environment Canada, monitored at a fixed site in Fredericton, New Brunswick.

The University of New Brunswick Ethics Committee approved the study.

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1. Exhaust opacity testing is a measure of the amount of light that is blocked by particulate matter emitted by diesel engines. The opacity measurement increases as the exhaust fumes become darker.

## Major findings

The average ride was 26 minutes (95% confidence interval [CI] 24–29 minutes). Thus, over a typical school day nearly one hour was spent riding a bus. During the study period, mean temperature was 12°C and the relative humidity was 60%; these were used as cut-off points to separate temperature and humidity into binary variables. The mean level of ambient PM<sub>2.5</sub> during commute times recorded for the entire study period was 5.0 µg/m<sup>3</sup>. In-bus average level of PM<sub>2.5</sub> was 32.1 µg/m<sup>3</sup> (95% CI 28.2–36.5), while the exposure level during walking was 9.7 µg/m<sup>3</sup> (95% CI 7.4–12.7). In-bus concentrations of other air pollutants were 10,786 counts/m<sup>3</sup> (95% CI 8,521–13,656) for PM<sub>1.0</sub>, 0.7 µg/m<sup>3</sup> (95% CI 0.5–0.9) for BC and 775 ng/m<sup>3</sup> (95% CI 593–1,019) for UV absorbing aromatic organic materials. The exposure levels for walking were about one third of those for in-bus concentrations. However, the comparison between the exposure level of pollutants measured in buses and during walking commutes must be done with caution, as the measurements for buses and during walking commutes were not carried out at the same time, for the same length of time and did not follow identical routes.

For PM<sub>2.5</sub>, the values during both walking and bus commutes exceeded the levels found in ambient air. Ambient PM<sub>2.5</sub> values were based on the hourly average, which corresponded to the commute time. It should be noted that ambient pollution data were collected from a single monitoring site in Fredericton, which may not necessarily represent personal exposure levels at the time. The age of the buses (<6 years vs. ≥6 years) did not significantly affect in-bus levels of air

pollutants and neither did temperature (<12°C vs. ≥12°C), although there was a trend that air pollutant levels appeared to be higher during colder days.

Using multivariate linear regression analyses, we further analyzed the impact of factors (weather, bus age, commute duration, ambient particulate concentration) on air pollution levels in buses and when walking. Factors were ranked by importance; those associated with the levels of pollutants measured on the buses and while walking were ambient levels of PM<sub>2.5</sub>, humidity, temperature and duration of the bus ride (not ranked in order of importance). Other factors—which possibly affected commuting exposures—are the number of bus stops, traffic around the bus, configuration of the windows (open windows tend to have higher levels on short rides and lower levels on long rides), and to a lesser degree mechanical characteristics of the bus. The project was not designed to test for the influence of these latter factors. These factors should be analyzed in a subsequent study, because unlike ambient air quality, humidity and temperature, the number of stops, stops near traffic and window configuration can be modified as possible policy measures.

Bus idling, believed to be an important factor, was not a common practice for the buses in this study, and therefore the impact of idling could not be assessed in the results. It is also important to note that these buses were well maintained and met the standard tests for smoke opacity. Although the statistical analyses were conducted using univariate models, data were stratified into various categories of weather conditions and bus age, in an attempt to control for the confounding factors.



The majority of VOC tested for were above the detection limit. Benzene is of particular concern because it is carcinogenic. The results show that the average benzene levels measured on buses were within the range of average levels found at typical urban locations between 1989 and 1998 (1.8–3.6  $\mu\text{g}/\text{m}^3$ ). This implies that exposure levels are similar to those experienced by pedestrians in urban sites.

Some bus routes and buses tended to be either consistently low or high in exposure. The reason for these observations is not yet clear. The sample size was too small to make any conclusions. It is possible that engine temperature, degree of load, temperature and local traffic density may have added to this variability. This observation may suggest that it is possible to reduce exposures on commutes by implementing changes to the conditions under which the bus ride and routes occur. Further work will be directed toward determining which management changes are most effective.

Although the technologies used in these engines did not make a significant difference on exposure levels, engines with electronically controlled fuel injection systems seemed to be on average cleaner with respect to  $\text{PM}_{2.5}$ , BC and UV absorbing organic material than those with mechanically controlled fuel injection systems. Cumulative exposure results show a significantly higher level of  $\text{PM}_{2.5}$  with mechanical injection than electronic injection, when humidity conditions were restricted to less than 70%.

The present study is one of the largest and most extensive studies of diesel exposure during actual school bus commutes performed to date. This rich dataset allows for the analysis of the relationships between bus emissions and children's exposure to a variety of compounds. Overall, the study found that children's levels of exposure to air pollutants on school buses were lower than those found in other studies, such as the ones conducted in Los Angeles and in 15 towns in Connecticut. Buses remain a good transportation option because they are safe and cut down on the number of vehicles on the road, resulting in decreased overall air pollution levels.

## ***Limitations and uncertainties***

Several limitations and uncertainties in this study need to be acknowledged to accurately interpret the results.

As noted above, the exposure monitoring for buses and during walking were not carried out at the same time, for the same length of time, or for an identical route. Therefore, when comparing the exposure levels of air pollutants in buses and during walking, bias may be introduced, and the results may be misinterpreted. No definitive conclusion should be drawn from this comparison.

Ambient pollution data were collected from a single monitoring site in Fredericton, which may not necessarily represent personal exposure levels in a neighbourhood during commuting time. Exposure misclassification may be introduced if one compares ambient air pollutant levels with exposure levels in a bus and during walking. An interpretation of the results must be made with caution.

Many factors may influence the exposure levels in a bus, such as weather conditions, bus conditions, idling, windows open or closed, number of times opening the doors, surrounding traffic density and the type of vehicles. Some of the factors may confound the results. Our statistical analyses are largely univariate analyses, which did not take into account all confounding factors. However, data were stratified into various categories according to weather conditions, bus age and the length of bus rides, in an attempt to control for these confounding factors. Additionally, a multivariate regression analysis was conducted on pollutants to test the contributions of factors to in-bus pollutant levels.

Although in this study the exposure levels in a school bus were postulated to be largely attributable to the diesel bus emissions, with the exception of BC, none of the exposure measures is considered to be an accurate surrogate measure of diesel exhaust due to the presence of numerous other common sources. Even BC can have sources other than diesel exhaust. Several variables that could affect exposure levels in a school bus (e.g., seasons, self-pollution, surrounding traffic counts and types, roadside pollutant concentrations) were not analyzed in this study, as the information necessary was either not available or not collected. This study is more of a commuter exposure study than a bus diesel exhaust exposure study.

It is important to note that “afternoon” commutes did not always occur at the same times. Pick-up times ranged from 12:00 to 15:00 p.m., and on some days the same buses picked up the students at noon, 14:00 p.m. and/or 15:00 p.m. on the same day. It is therefore possible that contaminants from previous rides were present during the later ride. The impact of surrounding traffic pollution would also be smaller during noon hour than in the afternoon after rush hour has started.

This study sampled a large number of buses and measured the exposure level of many children on different days. Under realistic conditions, day-to-day pollutant levels in buses varied markedly.

During the various categories of comparison, each category had a different sample size (i.e., a different number of buses in each group), which may have introduced some uncertainties in the analysis when the sample size was too small (e.g., PM<sub>2.5</sub> concentrations were sampled four (4) times during walking commutes in cold weather).

Although parallel measurements were taken on several days, the variability between duplicate samplers was not assessed, which could limit our ability to determine how much of the differences in the exposure measurements were due to variability between monitors.

Although the study participants were chosen randomly, the study was also based on which children followed the most convenient routes to get a representative sample. The schools referred the children to the researchers, and selection bias could have occurred when selecting children.

## ***Recommendations***

1. Eliminate bus idling. Although bus idling is not a major issue in this study, an anti-idling policy for schools is strongly recommended by several organizations, including the United States Environmental Protection Agency (Clean School Bus USA: [http://www.epa.gov/otaq/schoolbus/anti idling.htm](http://www.epa.gov/otaq/schoolbus/anti%20idling.htm)). It recommends this policy not only to reduce the levels of exposure to diesel exhaust, but also to reduce fuel wastage and engine wear and tear. Bus drivers should also undergo periodical training to understand the issues pertaining to idling. There should also be a no-idling policy in effect for all other vehicles on the school grounds.
2. For short bus routes, consider reducing the number of stops or relocating stops to areas with lower traffic density. Frequent stopping and opening/closing of doors allow for greater contribution from outside sources (i.e., surrounding traffic) to the levels of air pollutants in the bus.
3. To avoid self-pollution, consider re-engineering bus exhaust pipes to extend to the left rear-end of the bus, so that exhaust will not be emitted on the same side of the bus as the doors. An even better location to release exhaust is from a stack above the back of the bus, as the vacuum created at the back of the bus when in motion draws exhaust from lower pipes back toward the bus. Crankcase exhaust should be released from the same location.

4. Investigation of alternative methods of the ventilation of the bus cabin is needed and air-filtering systems should be considered. In the literature, there is a discrepancy in the pollutant levels between public transit buses, which usually have air conditioning, and school buses, which usually do not.
5. It is strongly recommended that retrofitting of buses be given high priority to reduce emissions. Retrofit measures include pollution control devices such as diesel oxidation catalysts and diesel PM filters. Low sulphur diesel to be introduced in 2006 is necessary to introduce this retrofit technology. This study shows that the engines with electronically controlled fuel injection systems appear to be on average cleaner with regard to PM<sub>2.5</sub>, BC and UV absorbing organic material than those with mechanically controlled fuel injection systems. Further investigation is warranted to confirm these findings.
6. In the future, whenever a new bus is purchased or contracted, only low-emission vehicles should be chosen.
7. Avoid caravanning. Buses leaving school in the afternoon should leave at staggered departure times to avoid tailgating. Bus drivers should be instructed to avoid other diesel school buses whenever possible.

## ***Future work***

Results from this school bus exposure study have suggested several issues that deserve more attention in future work.

1. Data on traffic density, the type of vehicles on the road with school buses, and road-side and ambient pollutant data within the community need to be collected to differentiate the sources of pollutants in a school bus and better represent the driving conditions of the school buses.
2. The exposure levels experienced by children in this study need to be placed in context with the levels they might experience during the rest of their school day. Future work to be completed using this dataset includes investigating all day exposure concentrations compared with on-bus exposure levels. Preliminary results show that in-class exposure levels of PM<sub>2.5</sub> can reach levels comparable to on-bus exposures, which suggests that important indoor sources exist.
3. In future exposure studies, additional modes of transportation may be included for comparison to bus and walking routes. Commutes by car and use of public buses could be introduced as comparison groups, as well as buses that run on different types of fuel (e.g., natural gas, bio-diesel). To compare cars with school buses, it must be kept in mind that if school buses were to be replaced more private cars would be required, which may result in higher levels of pollutants emitted to ambient air, although in-car pollutant levels may be low because the driver does not need to open the doors often.

4. To provide a more controlled environment, scripted exposure studies may be carried out to assess the levels of exposure to school bus exhaust that children experience. The use of specific commuting routes under set conditions would increase comparability of the routes and eliminate much of the bias present from confounding factors.
5. The relative contribution of self-pollution originating from both crankcase emissions and tail pipe exhaust to pollutant levels in a bus needs to be assessed.
6. This school bus study should be repeated in different seasons (winter, fall, summer) to determine if there are changes in exposure levels with changes in ambient conditions.
7. Panel epidemiological studies may be designed to investigate the health impact of exposure to air pollutants in a school bus.