

EXECUTIVE SUMMARY

The percentage of time that children spend in school and/or day care has continued to increase since the early 1980's. Consequently, children's exposure to diesel exhaust may be highly influenced by their time on-board or within the vicinity of school buses. Previous studies that have specifically focused on the impacts of retrofits on in-cabin concentrations of diesel-associated pollutants have been limited, and sample sizes have been small making it difficult to draw conclusions about the impacts of retrofits on in-cabin concentrations. The objectives of this project were to determine NO_x, CO, CO₂, TVOC, PM_{2.5} mass, and ultrafine (0.02 – 1 µm) PM number concentrations in school bus cabins prior to and following the installation of the following emission control technologies manufactured by the Donaldson Company, Inc.: a.) a Spiracle, and b) a Diesel Oxidation Catalyst (DOC) in combination with a Spiracle. The Spiracle and DOC target emissions from the crankcase and the tailpipe, respectively.

The study was conducted within the Round Rock Independent School District in Central Texas. Five buses with International T444E engines with model years ranging from 1996-2001 were included, along with one bus with a 1985 model year International 6.9L engine. Ultra Low Sulfur Diesel is currently used as the standard fuel in the district. The test program, conducted during July and early August of 2006, consisted of three phases:

1. Before retrofits (six buses; in addition repetitions were conducted on two buses)
2. After installation of a Spiracle (three buses)
3. After installation of a DOC and Spiracle (same three buses as Phase 2)

Two of the six buses had air conditioning systems and were included in all phases of testing. A typical suburban route was driven exactly as usual, simulating pick-up of children near their homes and drop-off and idling in school yards. It was not possible within the framework of this testing program to determine if the air surrounding the bus where outdoor samples were collected was influenced by bus self-pollution or whether the placement of sampling lines on one side of the bus versus the other would have led to different results. Windows remained closed for all tests. Air exchange rates were measured by decay of sulfur hexafluoride (SF₆).

For the selected route, cruising represented the most significant mode of operation for the buses, followed by bus stops, and then idling with either the front door open or closed. The results for all pollutants indicated substantial variability (by as much as or more than a factor of 2) in mean and median in-cabin concentrations both across the bus test population, and, in some cases, between buses with similar characteristics such as age, mileage, and engine type. Median NO_x, PM_{2.5} mass, and ultrafine PM number concentrations prior to retrofits ranged from 67 ppb-143 ppb, 9 µg/m³-15 µg/m³, and 4413 particles/cc-30,450 particles/cc, respectively. Mean NO_x, PM_{2.5} mass, and ultrafine PM number concentrations prior to retrofits ranged from 64 ppb-148 ppb, 9 µg/m³-20 µg/m³, and 6054 particles/cc-32,272 particles/cc, respectively. These results reinforce the need for future testing programs with large sample sizes.

For both PM_{2.5} and ultrafine PM, in-cabin mean concentrations were generally, but not exclusively, slightly lower than outdoor concentrations. However, median in-cabin concentrations were generally higher (ultrafine PM) or showed no pattern (PM_{2.5}).

Median and mean outdoor NO_x and NO concentrations were generally lower than in-cabin concentrations, but intra-test variability was also high. NO_x and NO were the only pollutants that showed pronounced differences between operation modes for some buses with relatively larger mean and median in-cabin concentrations for periods with frequent stops and door openings versus cruising.

CO concentrations were both very low and very close to the resolution of the instrument. The TVOC data exhibited differences of approximately a factor of two in mean/median concentrations between the highest and lowest test values. Future testing with canister samples or other techniques that would allow for VOC speciation would likely provide additional relevant detail.

The Spiracle resulted in statistically significant decreases of mean in-cabin concentrations of NO_x on all three buses, and decreases of NO on two buses. Small additional benefits or slight disbenefits resulted from the addition of the DOC. Results for in-cabin NO₂ concentrations were similar, with disbenefits following the addition of the DOC. In some cases for which data were available, outdoor NO_x, NO, and NO₂ concentrations following the installation of retrofits were lower than outdoor concentrations prior to retrofits. The U.S. EPA has not certified a level of NO_x exhaust emissions reductions for the Donaldson Spiracle/DOC package. The impacts of retrofits on emissions of nitrogen oxides from the crankcase should continue to be investigated.

The TVOC results showed a very similar pattern to that of the NO_x pollutants. The Spiracle and Spiracle/DOC, respectively, resulted in relatively larger reductions of in-cabin PM_{2.5} and ultrafine PM for one bus, but had smaller or essentially no impact on the other two buses. No clear benefit or disbenefit of the DOC was seen for PM as it was for NO_x pollutants. PM_{2.5} concentrations may be affected by differing levels of particle resuspension as well as by variations in the outdoor concentrations. The ultrafine PM concentrations are similarly affected by outdoor levels. A comparison of repetitions (i.e. same bus, same retrofit condition) was conducted for two buses. These data suggested that the results for PM_{2.5} and ultrafine PM were within the range of variation that was seen for the repetitions, suggesting that the results cannot be conclusively linked to the retrofits. Testing on additional buses, as well as testing in a cleaner and more consistent outdoor environment may facilitate assessment of the value of these retrofits for achieving reductions in PM emissions.