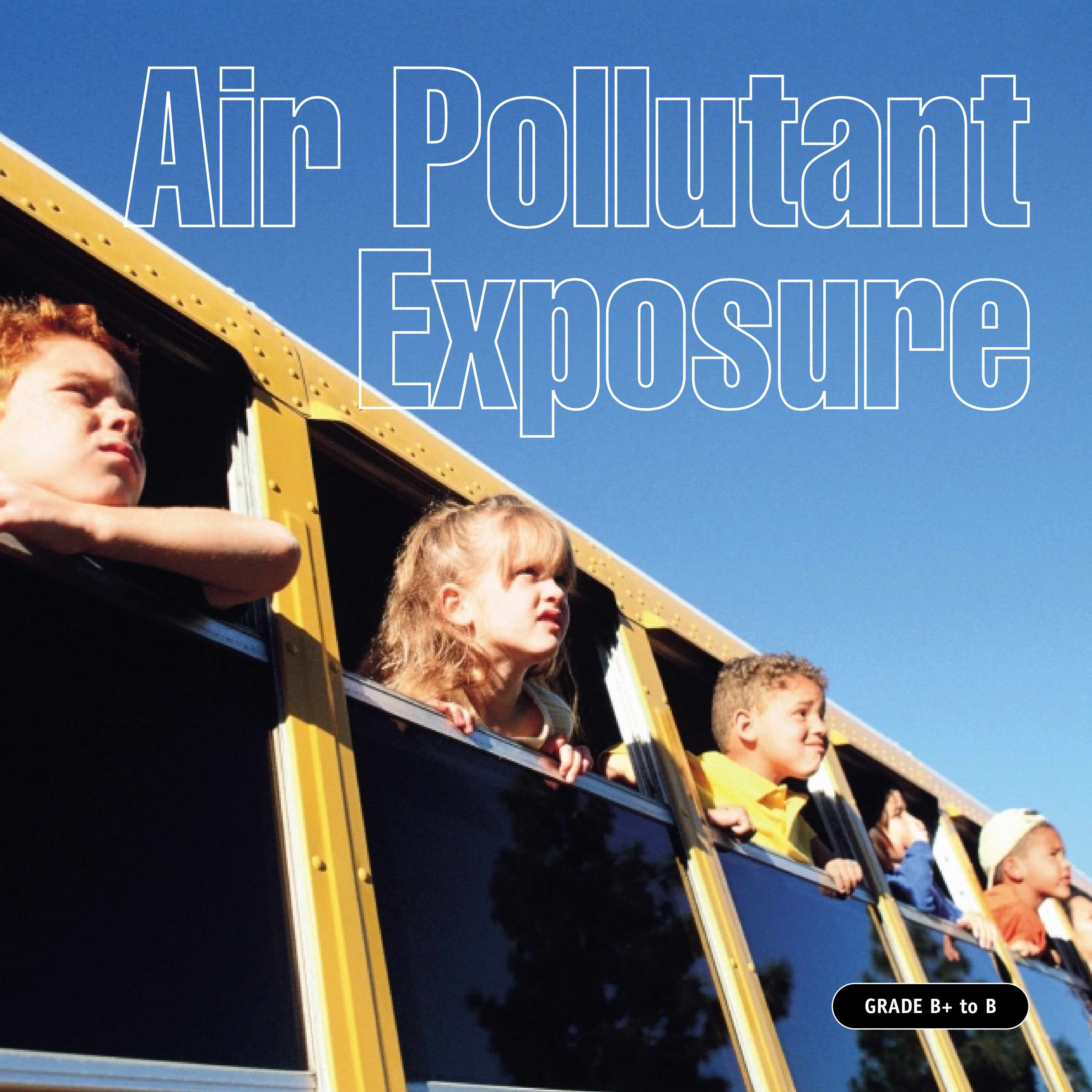
Air Pollutant Exposure



GRADE B+ to B

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INTRODUCTION

Where we live, work, attend school, recreate, or drive—the places we spend our time, and how much time we spend there—determine the concentrations of a given air pollutant to which we are exposed, and the amount of that pollutant we inhale in the course of a day. Yet, traditionally, we have measured our progress in cleaning up the air through long-term monitoring of *outdoor* air pollution levels, rather than what any individual or population actually breathes on a day to day basis. Although long-term measurements of atmospheric concentrations by even a few air monitoring stations can tell us whether emissions of air pollutants are increasing or decreasing, when our focus is on human health effects and what people are actually breathing, data from a handful of widely separated air monitoring stations are less useful. As Kirk Smith, a UC Berkeley Professor of Environmental Health Sciences, is fond of saying, "The place makes the poison," and most of us spend less than 10% of our time outdoors on a typical weekday.

This article focuses on the relatively young science of air pollution exposure assessment, which attempts to accurately characterize which pollutants (and their concentrations) adults or children are breathing in the specific places, or "microenvironments," where they spend most of their time. Over the past two decades a paradigm shift has occurred in exposure studies, moving us away from a reliance on a scattered network of outdoor air monitors measuring only a few pollutants, and toward the measurement of a much wider range of species in homes, schools, motor vehicles and work environments—the places where people typically spend 90% of their time. As a result, we now understand that high concentrations of certain air pollutants in these microenvironments, plus the large amount of time people spend there, can lead to *much higher* exposures than indicated by outdoor concentrations measured at distant sites. The most dramatic evidence shows, for example, that the time someone spends in the microenvironment of their vehicle each day is typically the most important factor in their overall exposure to diesel particulate matter. Thus, reducing traffic congestion, as suggested in the previous article, could have significant public health benefits, in addition to economic and quality of life benefits.

The paradigm shift in how we measure air pollution exposure, together with new measurement tools and sophisticated models, has dramatically improved our ability to quantify the exposure of adults and children to a wide range of air pollutants. With improved understanding of exposure, the results of epidemiological studies of air pollutant health effects are also improving.

While in a few cases these powerful new studies have provided some reassurance about human exposures, other cases unfortunately have served to heighten our concerns, particularly about the exposures of children and other vulnerable populations to a wide range of hazardous air pollutants, both gaseous and particulate.

This article, using recent and ongoing studies in Southern California, summarizes the current state of the art in air pollutant exposure assessment. The article differs from four previous Report

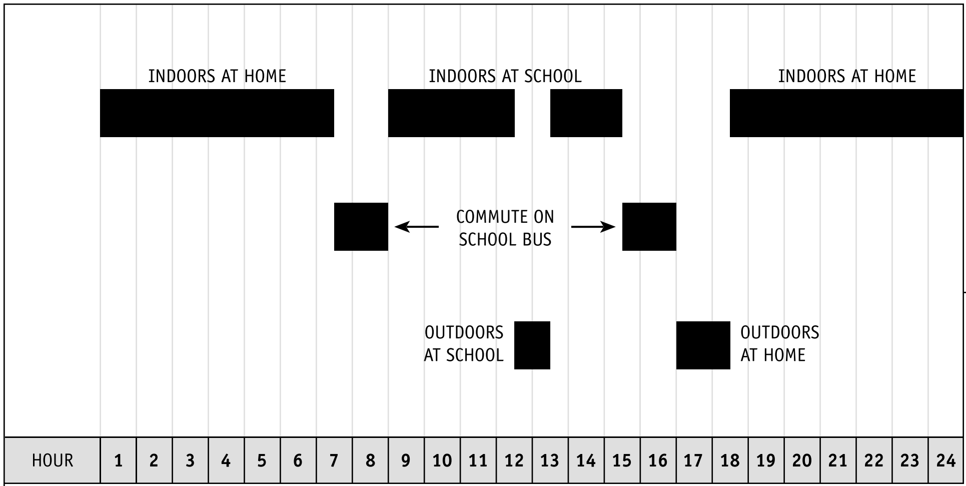

Figure 1. Time-activity pattern for a child on a school day

Almost all adults and children spend more than 90% of their time each weekday indoors or in a vehicle.

Card articles on air pollution that focused primarily on levels of pollution in outdoor air (RC 1998, 2000, 2001, 2003), and illustrates the new paradigm of microenvironmental measurement and modeling that the air pollution community is practicing here in Southern California and throughout the world. The article attempts to answer the question: How well do we understand the amounts and kinds of air pollutants adults and children are breathing in Southern California? It also provides recommendations for reducing the exposure of vulnerable populations, especially children, to hazardous air pollutants, based on new information provided by recent exposure assessment studies.

HUMAN TIME-ACTIVITY PATTERNS

One important impetus for new approaches to air pollutant exposure assessment has been the development of quantitative information about how people spend their time during a typical day. Through the use of carefully designed "time-activity" diaries distributed to relatively large numbers of participants, researchers have collected detailed data on how much time adults and children spend in their homes, vehicles, schools and workplaces, at recreational facilities, and outdoors, on an average weekday or weekend day. Time-activity diaries can also be used to estimate the breathing rates of individuals, by keeping track of their exercise states such as sleeping, at rest, and light or heavy exercise. The combination of exercise state or breathing rate, the time spent in a microenvironment, and the pollutant concentration in that microenvironment determines the specific dose of a pollutant received. And through the use of appropriate models, scientists can extend data collected for a few hundred or a few thousand individuals to the overall population of a region.

Figure 1 shows a time-activity pattern on a school day for a child who commutes on a school bus from south central Los Angeles to a magnet school on the Westside. In this case the child spends about twelve hours indoors at home, a surprising three hours commuting on a diesel school bus, about seven hours inside school buildings, and the balance of only about two hours outdoors. As this time-activity pattern illustrates, whereas assessment of exposure by traditional air monitoring networks corresponds to, in effect, everyone spending 24 hours a day outside, right next to a monitoring station, in reality almost all adults and children spend more than 90% of their time each weekday indoors or in a vehicle.

Note that in each of the different microenvironments described in Figure 1, different pollutants may be present in differing amounts, including significant differences in air quality between the home location and school location. Given knowledge of time-activity patterns and breathing rates, the remaining informa-

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tion needed to characterize exposure is the specific concentrations of the relevant pollutants in a given microenvironment. The following sections provide examples of how scientists have conducted sophisticated measurements to determine the concentrations of key pollutants in homes, vehicles, schools and other important microenvironments.

Figure 2. Subject wearing personal monitor for measurement of air pollutant concentrations in her personal breathing space.

EXPOSURE MEASUREMENTS

Homes and Personal Monitoring The "gold standard" and ultimate extension of the new paradigm in air pollutant exposure assessment is the measurement of personal breathing space over an extended period (e.g., several days). Such measurements are costly and laborious since they require the recruitment of individual subjects willing to wear a portable air sampling system capable of being taken everywhere throughout a typical day.

Figure 2 shows an example of such a "personal monitoring" system being worn by an adult woman. Inside the backpack is a special pump that can pull air through a set of devices designed to collect samples of particles and gases from the area of the nose and mouth of the person wearing the pack. The pump operates off a battery capable of running at least 48 hours without recharging.

As part of a multi-center study, UCLA researchers conducted a study of indoor, outdoor and personal breathing space in about 100 homes in four southern California communities. Confirming earlier studies of this kind, results showed higher concentrations of fine particles and certain air toxics in personal breathing air than in average indoor air. This corresponds in part to exposures from the "personal cloud" of particles created by activities such as cooking and vacuuming, and the tendency for activities to bring a person in close proximity to indoor sources, where indoor concentrations are highest. Indoor concentrations measured in this research, and similar studies in Los Angeles and other cities, were also higher than outdoor concentrations for pollutants with indoor sources. Such pollutants include chlorinated compounds in air fresheners, cleaning products and moth cakes; aromatic compounds emitted from paints, solvents and building supplies; and aldehydes emitted from consumer products, plywoods and particle boards, or from reactions of ozone with various indoor surfaces.

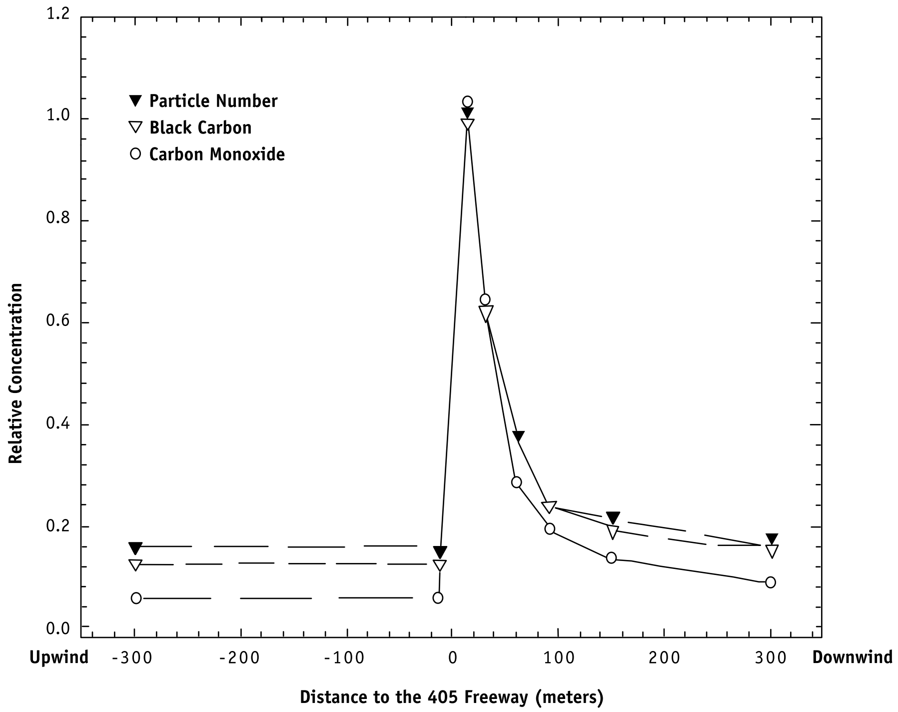

Figure 3. Relative concentrations of black carbon and carbon monoxide, and particle counts, upwind and downwind of the I-405 freeway in west Los Angeles. (Zhu, Hinds, Kim, Siotas, 2002)

Although the average person in California spends about 1.5 hours (or 6% of a day) driving, this time spent in vehicles will typically be the most

Portable Classrooms One-third, or two million, children in California's schools are currently educated in portable classrooms. Both teachers and students have complained about respiratory problems after spending many hours each school day in portables. Studies conducted initially by UCLA researchers, and subsequently by state health agencies, in portable classrooms indicate these complaints arise primarily from poor ventilation, rather than from elevated air toxics concentrations.

Researchers have found that ventilation systems for portable classrooms are poorly maintained, sometimes not properly operated by teachers (or turned off to reduce noise), and are often undersized. In addition, teachers often seal windows with teaching materials or student's assignments and keep doors closed for long periods of time. These factors lead to stagnant air and elevated levels of carbon dioxide from human breath, which in turn can lead to complaints of fatigue and respiratory problems. School administrators, teachers and custodians need to be educated about the importance of proper ventilation in portable classrooms if portables are to be an effective teaching environment.

Near Roadway Exposure Recent studies by UCLA/USC researchers showed (Figure 3) a large spike in concentrations of vehicle exhaust pollutants immediately adjacent to and downwind of the 405 and 710 freeways, with a rapid fall off in concentration on the downwind side of the freeways to near background levels within about 500 feet. These results show that building homes, schools or other structures within about 500 feet of major roadways such as freeways will lead to elevated exposures to deleterious particles and gases for "downwind" occupants. Partly in recognition of these new findings, the legislature recently passed regulations preventing the siting of schools in California any closer than 500 feet of a freeway.

Passenger Cars Using a "chase" car, several studies have investigated in-vehicle exposure to a wide range of

important factor in their overall daily exposure to diesel particulate matter, a key toxic air contaminant.

Table 1. Black carbon concentrations measured inside a passenger car while following various vehicles in Los Angeles. (Fruin, Winer, Rodes, 2004)

Vehicle Followed	Black Carbon Concentration Inside Passenger Car (µg/m³)
Gasoline Passenger Car	~5
Tractor Trailer (Semi) Truck with High Exhaust	13
Delivery Truck with Low Exhaust	21
Diesel Transit Bus with Low Exhaust	90

particles and gases, especially when following diesel vehicles. One of these studies has shown highly elevated levels (compared to background) of ultrafine particles within the cabin of the chase car while driving on congested roadways. Concern about ultrafine particles (smaller than 100 nanometers in diameter) is growing in the health effects community as evidence accumulates that such particles can penetrate cell membranes, including the blood-brain barrier, and may be contributing significantly to the elevated morbidity and mortality observed in vulnerable populations following high exposures to particulate matter.

A recent analysis of the experimental data from one chase car study, by a UCLA doctoral student, indicates that although the average person in California spends about 1.5 hours (or 6% of a day) driving, this time spent in vehicles will typically be the most important factor in their overall daily exposure to diesel particulate matter, a key toxic air contaminant. Table 1 shows the average concentrations of black carbon, a marker of diesel exhaust particulate matter, experienced by a passenger car occupant following different vehicles and exhaust configurations. The clear message is to avoid following diesel vehicles closely, especially those with low exhaust (and especially those emitting black smoke).

Diesel School Buses In the past five years, scientists have conducted two studies of children's exposure in diesel school buses in Southern California. The most recent and comprehensive of these studies, conducted by UCLA/UC Riverside researchers, investigated not only the school bus microenvironment but also bus stops and a school loading/unloading zone. As illustrated in Figure 4, these scientists measured a wide range of particle and gaseous pollutants using real-time instruments to capture the dynamic behavior of the exhaust from nearby vehicles, as well as of the moving bus platform itself. A range of buses was studied, including high-emitting as well as more representative conventional diesel buses, a diesel bus with a particle trap, and a bus fueled with compressed natural gas (CNG). Researchers videotaped surrounding traffic on each run and, as shown in Figure 5, later correlated spikes in concentrations of black carbon and other key pollutants with the emissions of other diesel vehicles in close proximity to the school bus, including other caravanning school buses and diesel trucks traveling immediately ahead of, or alongside, the instrumented school bus. As shown in Fig. 5, spikes in black carbon concentrations aboard the school buses studied exceeded 40 to 50 µg/m³, far higher than ambient concentrations of black carbon in Los Angeles away from traffic, typically in the range of 1 or 2 µg/m³.

The bus route chosen for most attention originated in south central Los Angeles and traveled about half the time on highly congested freeways and half the time on surface streets, to the

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Figure 4. UCLA graduate student operating instruments on diesel school bus. (Fitz, Winer, Colome, 2003)

Brentwood Science Magnet School on the Westside. Remarkably, the child who boarded first on this route, at about 6:05 a.m., spent three hours commuting round trip, and did not leave the returning bus until nearly 5:00 p.m.

Using an inert "tracer" gas injected into the exhaust pipe, this research demonstrated for the first time that all of the buses in this study experienced "self pollution." That is, a portion of the exhaust from the school bus itself entered the cabin, a phenomenon generally not observed in vehicles such as passenger cars. How to minimize or eliminate self-pollution is the subject of on-going research.

Average concentrations of key pollutants were significantly higher aboard the school buses than at bus stops or the school loading/unloading zone, and children spent much more time aboard the buses than at the other two microenvironments. Hence, children's exposure during bus commutes is of greater concern than exposure at bus stops or school loading/unloading zones. Clearly, reducing children's pollutant exposure during bus commutes is an effective way to protect their health, and at the end of this article we suggest strategies for achieving such reductions based on the results of this study.

EXPOSURE MODELS

Scientists have developed a new generation of exposure models in recent years to exploit the data generated in measurement projects like those described above. Because such field studies are expensive and can only investigate a relatively small number of subjects, it is important to build models that can extend these results to larger numbers of susceptible individuals, and even to the entire regional population.

UCLA researchers have developed an individual exposure model (IEM), designed to improve the exposure assessment for thousands of children enrolled in the University of Southern California's long-term longitudinal Children's Health Study (CHS), conducted in twelve communities in California with differing air quality. Due to resource limitations, the CHS assigned the same exposure to every child in a given community, based on a single central monitoring site. By using the IEM to model the exposure of each individual child retrospectively, UCLA School of Public Health researchers were able to estimate the variability in children's exposure within each community, and make this information available to the CHS epidemiologists to improve estimates of health impacts.

UCLA researchers have also recently applied the Regional Human Exposure (REHEX) model to estimate the exposure of the entire regional population to naphthalene, a prototypical polycyclic aromatic hydrocarbon that is a suspected human carcinogen emitted from fuel evaporation, vehicle exhaust and indoor sources. The REHEX model showed that populations near major roadways experienced the highest exposures to naphthalene, with about one million residents experiencing estimated exposures greater than 1000 nanograms per cubic meter.

REDUCING EXPOSURE

Diesel Exhaust Exposures Recently the California Air Resources Board sent the mitigation measures recommended to reduce children's exposure during diesel school bus commutes by the UCLA/UCR school bus study investigators to all 1700 school districts in California, in both English and Spanish. Parents are encouraged to make certain school boards are implementing these measures, particularly those that can be carried out at no cost to the schools. These include placing the buses with the cleanest exhaust on the longest routes; encouraging children to sit in the forward part of the bus when the bus is not full; making sure drivers do not caravan one bus directly behind the other; and making bus drivers turn off their engines immediately upon arriving at a school and only turn their engines on when all students are loaded and the buses are ready to depart. The most important additional measure school boards can take is to require their own bus maintenance mechanics, or mechanics at companies hired to maintain buses, to properly maintain school bus engines to eliminate visible smoke under all operating conditions. Of course all school districts should be encouraged to transition from polluting conventional diesel school buses to cleaner fuel buses and/or buses equipped with particulate trap technologies as soon as possible.

Passenger car occupants can reduce their exposure to diesel exhaust by minimizing, as much as possible, driving behind diesel vehicles, especially diesel school buses and trucks that have low exhausts. Particularly avoid any vehicle emitting visible smoke.

Home Exposures Reducing air pollutants in the home is important because the majority of most people's time is spent there, and many potent sources of indoor pollution are commonly taken for granted. Volatile chemicals are frequently emitted from products such as cleaning agents, solvents, paints, air fresheners, etc., and their use (as well as storage)

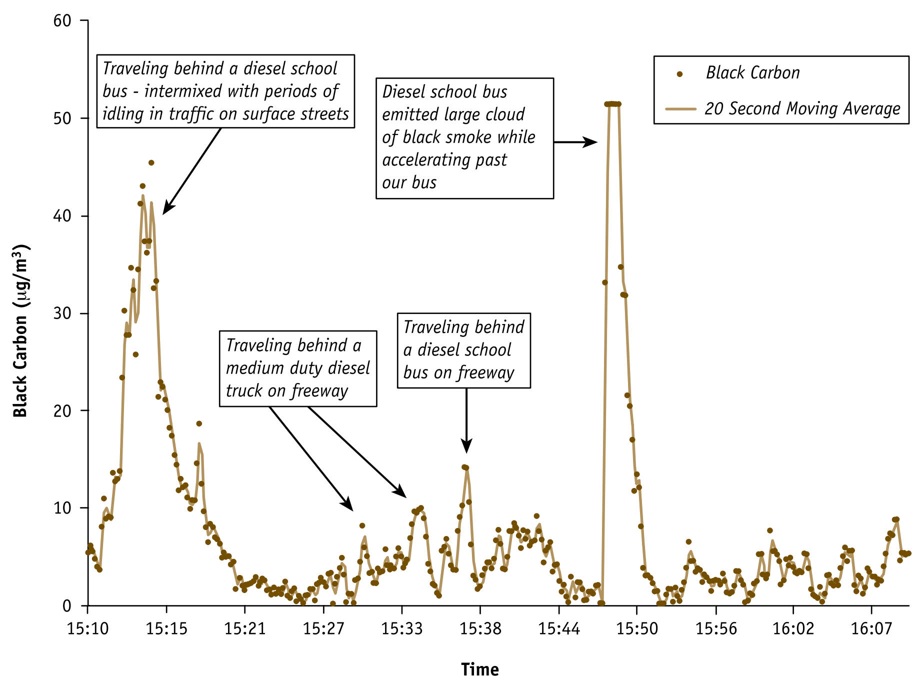

Figure 5. Agreement between videotaped encounters with diesel vehicles and spikes in black carbon concentrations measured on a commuting school bus. (Fitz, Winer, Colome, 2003)

Figure 6. Child wearing personal monitor with separate sampler (left) for in-home monitoring of air toxics and fine particles.

should be minimized, and only under conditions of good ventilation.

An important source of coarse particulate matter exposure in the home is house dust, which may be enriched in toxic metals and pesticides. Housekeeping measures such as door mats, removing shoes, keeping floors clean, and minimizing the use of carpeting are effective at reducing indoor dust levels. In addition, avoiding the use of pesticides on pets or lawns removes a major source of pesticide exposure (often a more important route of exposure than food residues). The major source of fine particles and nitrogen dioxide is combustion, so activities such as cooking, especially with natural gas, should be performed with adequate ventilation. Second-hand tobacco smoke should never be allowed in the home.

FUTURE DEVELOPMENTS

Two main areas need further development to advance air pollutant exposure assessment capabilities. First, more attention needs to be given to gases and particles that have been inadequately measured in personal breathing space or key microenvironments. These include ultrafine particles, polycyclic aromatic hydrocarbons—many of which are particle-bound and are known mutagens or carcinogens—and oxygenated compounds—especially aldehydes that are suspected carcinogens. Second, the development of compact, light-weight, and relatively inexpensive "real-time" samplers—the size of a cell phone, for example—equipped with real-time telemetry capability, remains the ultimate goal of personal monitoring for air pollutants. Replacement of the current expensive, heavy and obtrusive "back-pack" monitoring systems, would facilitate the recruitment of much larger numbers of participants, and the acquisition of more accurate and representative data. Nanotechnology, and continued development of innovative and minaturized pollutant monitors, offer a path to reach this goal.

GRADES

Exposure Assessment Researchers

Consistent with the severity of the air pollution problem in Southern California, the region has one of the highest concentrations in the world of researchers concerned with air quality, including various aspects of pollutant exposure assessment. As a result, a substantial number of specialized monitoring and exposure studies have been conducted over the past decade. This research, which has led not only to a better understanding of human exposure to air pollutants but also initial policy recommendations and regulations for reducing such exposures, merits a good grade. However, as noted above, additional studies are needed for non-

School districts should be encouraged to transition from polluting conventional diesel school buses to cleaner fuel buses and/or buses equipped with particulate trap technologies as soon as possible

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conventional pollutants such as ultrafine particles and certain toxic chemicals that have not been adequately studied. **Grade B+**.

Agencies The various regulatory agencies, including the California Air Resources Board, U.S. EPA, and South Coast Air Quality Management District, deserve substantial credit for supporting the exposure assessment research described above and for implementing initial exposure reduction measures. However, these agencies could do more to implement specific policies to reduce the most important indoor exposures to toxic air pollutants, especially pollutants not regulated under the Clean Air Act but identified as of concern by health effects researchers. **Grade B**

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