

as automobiles and factories, while failing to address many other important but less obvious ones.

Fortunately, the science of assessing people's exposure to toxic substances has matured. In particular, scientists have developed highly sensitive analytical instruments and portable monitoring devices. Researchers have exploited this equipment in large-scale field studies, designed to gauge just where and how people are exposed to potentially dangerous chemicals.

Getting Personal

In 1980 one of us (Ott), along with Lance A. Wallace of the U.S. Environmental Protection Agency, launched the first serious efforts to assess everyday exposure of the general population to toxic substances. That program, carried out primarily by the Research Triangle Institute in North Carolina and other contract research organizations, later expanded to include some two dozen studies in 14 U.S. states. Using the same methods, researchers sponsored by private industry conducted similar studies in a 15th state (Alaska) and in one Canadian province. Most of these investigations employed monitoring instruments that were small and light enough for people to carry as they went about their normal activities. These devices showed which pollutants existed close by and in what concentration. In some cases, the researchers also made measurements of the food and water con-

sumed. In certain instances, they determined the blood levels of various pollutants from breath samples.

So far these studies of "total human exposure" have examined the prevalence of volatile organic compounds, carbon monoxide, pesticides or dangerous particles in the daily lives of more than 3,000 subjects, a carefully chosen slice of the population meant to be representative of most North Americans living in urban or suburban areas. Chemical analyses of the samples were detailed enough to identify the specific chemicals to which the participants were routinely exposed. For instance, the investigations of volatile organic compounds typically tested for some 30 different chemicals, including many known to cause cancer in people or animals.

It is difficult to know whether the contacts most people have with these substances pose an especially large health risk, because the capacity for low levels of each compound to cause sickness is exceedingly hard to estimate. Still, these studies produced results that were disturbing: most citizens were very likely to have the greatest contact with potentially toxic pollutants not outside but inside the places they usually consider to be essentially unpolluted, such as homes, offices and automobiles. The exposure arising from the sources normally targeted by environmental laws—Superfund sites, factories, local industry—was negligible in comparison.

Even in the New Jersey cities of Bayonne and Elizabeth, both of which have

an abundance of chemical processing plants, the levels of 11 volatile organic compounds proved much higher indoors than out. (Concentrations of the other volatile compounds tested were found to be insignificant in both settings.) The chief sources appeared to be ordinary consumer products, such as air fresheners and cleaning compounds, and various building materials.

Could everyday items with which people happily share their homes truly be more of a threat to their health than industrial pollution, even for people whose communities are surrounded by factories? In short, the answer is yes. For example, benzene—a chemical known to cause leukemia in workers continually exposed to high concentrations—is present in gasoline and in some household products. It is also one of about 4,000 chemicals found in tobacco smoke, so living with a smoker raises one's exposure to benzene enormously.

In 1985 Wallace combined all the existing information about how several hundred people located in five different states were exposed to this compound. He found that the average concentration of benzene they inhaled was nearly three times higher than typical outdoor levels. He calculated that some 45 percent of the total exposure of the U.S. population to benzene comes from smoking (or breathing smoke exhaled by others), 36 percent from inhaling gasoline fumes or from using various common products (such as glues), and 16 percent from other home sources (such

EPA
LIMIT

9

6

3

0

PHOTOGRAPHY BY BERND ALIERS; JENNIFER C. CHRISTIANSEN (charts)

STEAMY BATHROOM



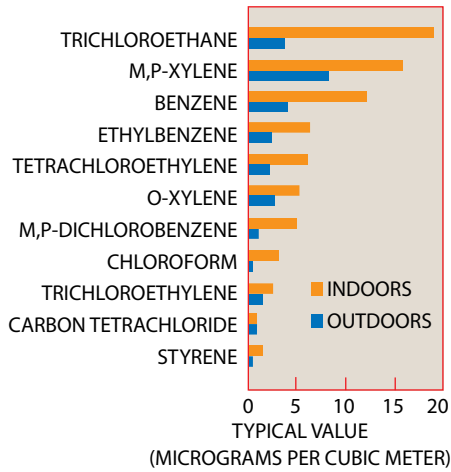
DRY-CLEANED CLOTHES IN CLOSET



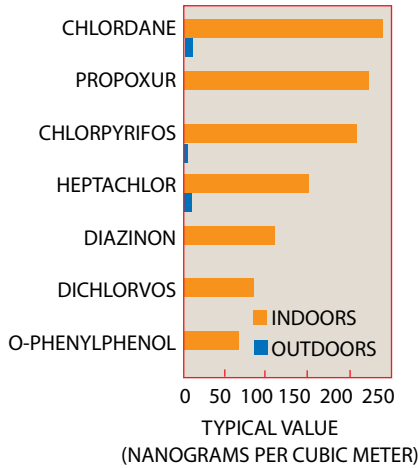
ENCLOSED PARKING GARAGE



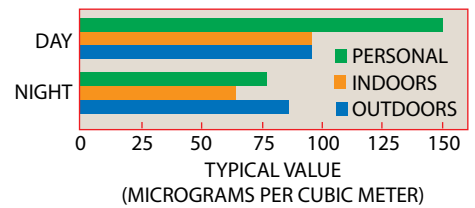
VOLATILE ORGANIC COMPOUNDS



CONCENTRATIONS OF PESTICIDES



CONCENTRATIONS OF 10-MICRON PARTICLES



EXPOSURE STUDIES reveal that people come into contact with toxic volatile organic compounds and pesticides more indoors than outside. Most people's exposure to breathable particles during the day is higher than ambient levels in the air (either indoors or outside), because moving about stirs up a "personal cloud."

as paints and gasoline stored in basements or attached garages). He attributed only 3 percent of the average person's exposure to industrial pollution.

In contrast, government regulators usually consider only the gross amount of benzene released into the general environment, for which the largest share comes from automobiles (82 percent), followed by industry (14 percent) and domestic sources (3 percent). Cigarettes contribute only 0.1 percent of the total. Wallace's work aptly demonstrated that cutting all industrial releases of benzene would reduce health risks by only a tiny fraction. Yet even a modest reduction in cigarette smoking—the smallest source of benzene in the atmosphere—would significantly reduce the likelihood of benzene causing disease.

Many other volatile organic compounds that are quite toxic at high con-

centrations are also more prevalent indoors than out. For example, the chemical tetrachloroethylene (also known as perchloroethylene or "perc"), which has been shown to cause cancer in laboratory animals, is used to dry-clean clothes. Thus, the greatest exposure occurs when people live in a building with dry-cleaning facilities, wear recently dry-cleaned clothes or store such chemically laden garments in their closets. Moth-repellent cakes or crystals, toilet disinfectants, and deodorizers are the major source of exposure to paradichlorobenzene, which also causes cancer in animals. Studies have consistently indicated that almost all exposure to paradichlorobenzene comes from sources inside homes, not from industrial emissions or hazardous-waste sites.

Although assessments of the risks to health are somewhat uncertain, it is clear

that less contact with toxic volatile organic compounds is better than more. Most people can limit potentially harmful exposure by avoiding products that contain such pollutants. But other worrisome vapors are difficult to avoid.

For example, the major sources of exposure to chloroform—a gas that provokes concern because it can cause cancer in animals subjected to high concentrations—are showers, boiling water and clothes washers. It forms from the chlorine used to treat water supplies. Because piped water is something that people simply cannot do without, the only way to minimize household exposure to chloroform is to drink bottled water (or tap water that is run through a good-quality charcoal filter) and to improve ventilation in the bathroom and laundry.

Better airflow can also help lower ex-

PHOTOCOPIER WITH DRY TONER



ENCLOSED SPACE WITH SMOKERS



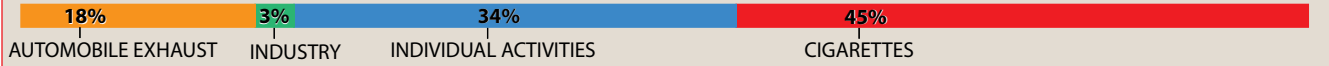
CARPETED HOME



SOURCES OF BENZENE EMISSIONS



SOURCES OF BENZENE EXPOSURE



BENZENE, a volatile organic compound that causes cancer in humans, is quite common. But the sources that produce the greatest quantity of emissions (automobile exhaust and industry)

contribute only modestly to the exposure of the general populace, which faces a considerably greater threat from the benzene released by cigarettes, gasoline vapors and consumer products.

posure to carbon monoxide, a product of incomplete combustion that robs the blood of oxygen and can be particularly harmful to people with heart ailments when inhaled at levels often found indoors. Although studies conducted in the early 1980s in Denver and Washington, D.C., confirmed that carbon monoxide levels rose precipitously when people were in or near motor vehicles, other research has demonstrated that indoor appliances, such as poorly operated gas stoves, grills and furnaces, can also cause extremely unhealthy conditions—even death. Fortunately, outdoor levels of carbon monoxide have steadily declined in the U.S. in concert with the reductions in automobile emissions, as required by federal regulations. Yet further progress will be more difficult, because on the whole the U.S. population now receives greater exposure to carbon monoxide indoors than out.

Another environmental concern that appears more severe indoors is the danger from fine particles in the air. In one study, researchers used miniaturized monitors to collect minute particles in and around 178 homes in Riverside,

Calif. Respondents carried devices that gathered particles 10 microns or less in diameter, ones small enough to penetrate into the lungs.

Curiously, exposures during the day were about 60 percent greater than expected from the particulate levels measured in samples of air concurrently taken indoors and outside. The higher exposures arose, at least in part, because people do not simply float through the air; rather they tend to stir up “personal clouds” of particle-laden dust from their surroundings as they move about. These investigators showed that most of these fine particles form through combustion—such as smoking, cooking, burning candles or firewood. Finding such pollutants indoors is troubling, because recent epidemiological studies have associated elevated concentrations of fine particles outdoors with premature death.

Even more disturbing were the results from two studies of indoor air contaminants conducted during the late 1980s in Jacksonville, Fla., and Springfield, Mass. In those places, investigators found that indoor air contained at least

five (but typically 10 or more) times higher concentrations of pesticides than outside air—and those residues included insecticides approved only for outdoor use. Evidently, potent chemicals targeted against termites in the foundations of these houses had found their way indoors. Such poisons can be tracked in on people’s shoes, or they may seep through the soil as a gas into homes. Chlordane (which was taken out of products sold for home use in 1988) and some other pesticides contaminating the air indoors caused a greater share of exposure than the amounts found on food.

In addition, people sometimes apply inappropriate pesticides directly to indoor surfaces, unaware that they are causing their own high exposures. And even the most enlightened homeowners are often ignorant of past applications of dangerous chemicals. Pesticides that break down within days outdoors may last for years in carpets, where they are protected from the degradation caused by sunlight and bacteria. This persistence is well demonstrated by measurements of the pesticide DDT (dichlorodiphenyltrichloroethane), which was outlawed

KITCHEN FUMES



COMMON HOUSEHOLD PRODUCTS



OUTDOORS IN THE SUBURBS



in the U.S. in 1972 because of its toxicity. Despite that long-standing prohibition, Jonathan D. Buckley of the University of Southern California and David E. Camann of the Southwest Research Institute found that 90 of the 362 Midwestern homes they examined in 1992 and 1993 had DDT in the carpets.

Indeed, that study showed that the contaminants lurking in people's carpets are not restricted to pesticides. In more than half of the households Buckley and Camann surveyed, the concentrations of seven toxic organic chemicals called polycyclic aromatic hydrocarbons (compounds produced by incomplete combustion, which cause cancer in animals and are thought to induce cancer in humans) were above the levels that would trigger a formal risk assessment for residential soil at a Superfund site.

Small People, Big Problems

The pesticides and volatile organic compounds found indoors cause perhaps 3,000 cases of cancer a year in the U.S., making these substances just as threatening to nonsmokers as radon (a natural radioactive gas that enters many homes through the foundation) or secondhand tobacco smoke. And toxic house dust can be a particular menace to small children, who play on floors, crawl on carpets and regularly place their hands in their mouths. Infants are particularly susceptible: their rapidly developing organs are more prone to damage, they have a small fraction of the body weight of an adult and may

ingest five times more dust—100 milligrams a day on the average.

Before 1990, when the EPA and U.S. Department of Housing and Urban Development established standard methods for sampling dust on carpets, upholstery and other surfaces, it was difficult to quantify the risk to children. Since then, however, improved techniques have allowed scientists to make more concrete statements about the degree of exposure. For example, we can now estimate that each day the average urban infant will ingest 110 nanograms of benzo(a)pyrene, the most toxic polycyclic aromatic hydrocarbon. Although it is hard to say definitively how much this intake might raise a child's chance of acquiring cancer at some point, the amount is sobering: it is equivalent to what the child would get from smoking three cigarettes.

The research also points out that, for small children, house dust is a major source of exposure to cadmium, lead and other heavy metals, as well as polychlorinated biphenyls and other persistent organic pollutants. Carpets are most troublesome because they act as deep reservoirs for these toxic compounds (as well as for dangerous bacteria and asthma-inducing allergens, such as animal dander, dust mites and mold) even if the rugs are vacuumed regularly in the normal manner. Plush and shag carpets are more of a problem than flat ones; floors covered with wood, tile or linoleum, being the easiest to clean, are best.

One of us (Roberts), along with several colleagues, has shown that people

can prevent the accumulation of dangerous amounts of dust by using a vacuum equipped to sense when no more particles can be extracted. Other of our studies have indicated that simple preventive acts can help considerably. For example, wiping one's feet on a commercial-grade doormat appears to reduce the amount of lead in a typical carpet by a factor of six. Because lead exposure is thought to affect more than 900,000 children in the U.S., the use of good doormats would translate into a significant boost to public health.

Removing one's shoes before entering is even more effective than just wiping one's feet in lowering indoor levels of the toxic pollutants that contaminate the environs of most homes (such as lead from peeling paint and pesticides from soils around the foundation). By taking such precautions to avoid tracking in dust and using an effective vacuum cleaner—one equipped with a rotating brush and, preferably, a dust sensor—people can reduce the amount of lead and many other toxic substances in their carpets to about a tenth (or, in some cases, to a hundredth) of the level that would otherwise persist.

Unfortunately, most people are unaware of the ubiquity of indoor pollution or of how to reduce it. One innovative initiative by the American Lung Association in Seattle aims to remedy that problem by training volunteers (dubbed "master home environmentalists") to visit dwellings and help residents limit domestic environmental threats.

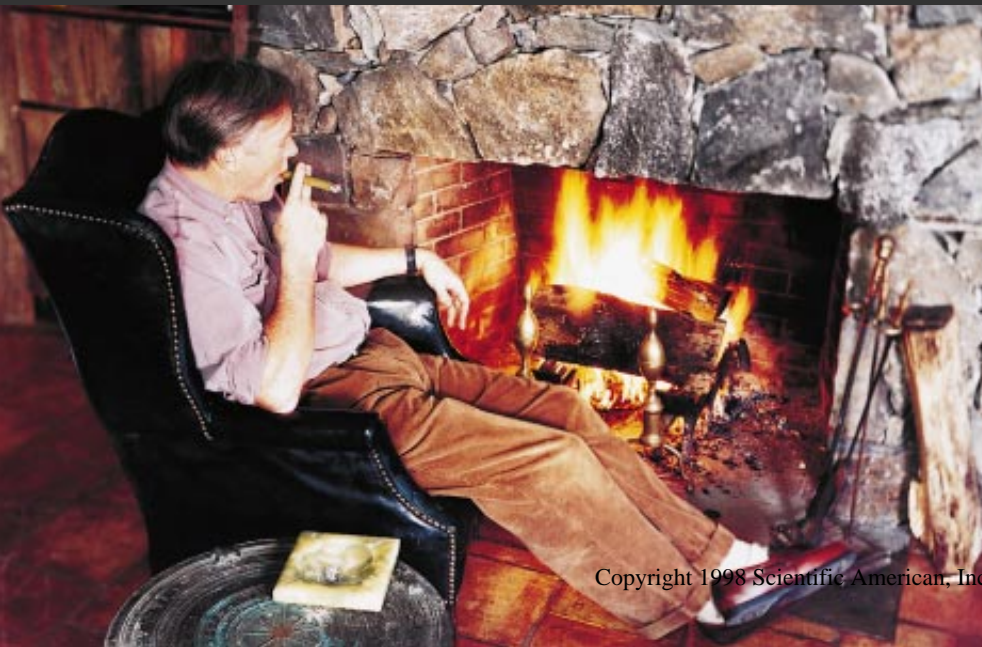
Trouble with the Law

The many findings now available from multiple studies of people's everyday exposure all point to a single conclusion—that the same air pollutants covered by environmental laws outdoors are usually found at much higher levels in the average American residence. This situation has come about, at least in part, because the U.S. has made remarkable progress in improving the quality of outdoor air over the past three decades by controlling automobile and industrial emissions. Of the hundreds of air pollutants covered under existing U.S. laws, only ozone and sulfur dioxide remain more prevalent outdoors.

So it is peculiar that more attention has not yet shifted toward indoor pollution, the main sources of which are not difficult to identify. In fact, they are right under people's noses—moth repel-

TOBACCO SMOKE AND PRODUCTS OF INCOMPLETE COMBUSTION

V.O.C.  BENZENE AND MANY
R.P.  OTHER COMPOUNDS



SURFACE SAMPLER draws in particle-laden air in the same manner as a conventional vacuum cleaner. The instrument collects the dust by circulating the air within a specially designed cyclone. The rotating current of air slows near the bottom of the swirling vortex, and suspended particles drop into a small bottle for later analysis.



COURTESY OF CS-3, INC.

CARBON MONOXIDE MEASURER uses an electrochemical cell as a gas sensor. The small electric current generated by the cell varies with the ambient level of carbon monoxide. By monitoring this current, an internal microcomputer can calculate the concentration of carbon monoxide and record its value at regular intervals.



BETH PHILLIPS



BETH PHILLIPS

PERSONAL SAMPLER records the particles and volatile organic compounds to which the wearer is exposed over the course of several days. Particles are trapped by forcing air through a filter with an electric pump, whereas volatile compounds are collected by letting air diffuse through a membrane onto charcoal disks.

lents, pesticides, solvents, deodorizers, cleansers, dry-cleaned clothes, dusty carpets, paint, particleboard, adhesives, and fumes from cooking and heating, to name a few.

Sadly, most people—including officials of the U.S. government—are rather complacent about such indoor pollutants. Yet if these same substances were found in outdoor air, the legal machinery of the Clean Air Act of 1990 would apply. If truckloads of dust with the same concentration of toxic chemicals as is found in most carpets were deposited outside, these locations would be considered hazardous-waste dumps. In view of the scientific results comparing indoor and outdoor exposure, it would seem that the time is now ripe for a major rethinking of the nation's environmental laws and priorities.

The initial version of the Clean Air Act, written in 1970, focused on outdoor pollution. Even in its 1990 revision,

the law has not changed much. It does not address the fact that Americans spend 95 percent of their time inside: despite all the evidence available today, the act still relies exclusively on measurements taken at outdoor monitoring stations. Many other U.S. laws pertaining to air pollution, hazardous waste, toxic substances and pesticides are similarly flawed, because they do not require accurate information on the levels of exposure people receive.

Although the absolute level of health risk posed by many toxic pollutants may be elusive, scientists can now accurately measure the exposure caused by different sources. Hence, to protect public health best, the broad suite of environmental laws should be reexamined and judged by how effectively they reduce people's total exposure rather than by how they reduce total emissions. That effort would surely be substantial, both to recast a large body of legisla-

tion and to monitor how well the laws work to reduce exposure. But the payoff would be a dramatic reduction in health costs as well as an improvement in the economy and effectiveness of environmental regulation.

Americans concerned about toxic substances do not have to wait for their government to make these far-reaching changes. Reducing exposure normally demands only modest alterations in one's daily routine. Yet people cannot take the simple steps required without adequate knowledge. So increased education is needed. Laws requiring more detailed labeling would also help: If a product contains a dangerous pollutant, should not the manufacturer be required at least to list the chemical by name on the package? Armed with a better understanding of the toxic substances found in common products and in other sources at home, people could then make their own informed choices. SA

The Authors

WAYNE R. OTT and JOHN W. ROBERTS have long studied environmental threats to health. Ott served for 30 years in the Environmental Protection Agency, managing research on air pollution, toxic substances and human exposure. He now does research in the departments of statistics and environmental engineering at Stanford University. Roberts helped to develop the surface samplers used by the EPA to measure pollutants in carpet dust. In 1982 he founded Engineering Plus, a small firm in Seattle specializing in assessing and controlling exposure to dangerous pollutants in the home. He works frequently with the master home environmentalist program in Seattle to help reduce the exposure of families to indoor pollutants.

Further Reading

- NON-OCCUPATIONAL EXPOSURE TO PESTICIDES FOR RESIDENTS OF TWO U.S. CITIES. R. W. Whitmore, F. W. Immerman, D. E. Camann, A. E. Bond and R. G. Lewis in *Archives of Environmental Contamination and Toxicology*, Vol. 26, No. 1, pages 47–59; January 1994.
- EXPOSURE OF CHILDREN TO POLLUTANTS IN HOUSE DUST AND INDOOR AIR. J. W. Roberts and P. Dickey in *Reviews of Environmental Contamination and Toxicology*, Vol. 143, pages 59–78; 1995.
- HUMAN EXPOSURE TO ENVIRONMENTAL POLLUTANTS: A DECADE OF EXPERIENCE. L. A. Wallace in *Clinical and Experimental Allergy*, Vol. 25, No. 1, pages 4–9; 1995.
- HUMAN EXPOSURE ASSESSMENT: THE BIRTH OF A NEW SCIENCE. W. R. Ott in *Journal of Exposure Analysis and Environmental Epidemiology* (available from Princeton Scientific Publishing), Vol. 5, No. 4, pages 449–472; 1995.