

SOUTH COAST AIR QUALITY MANAGEMENT DISTRICT

THE HEALTH EFFECTS OF AIR POLLUTION ON CHILDREN

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Introduction

Air pollution has many effects on the health of both adults and children. The purpose of this article will be to examine what is known about how air pollution affects health, especially children's.

Over the past several years the incidence of a number of diseases has increased greatly. Asthma is perhaps the most important disease with an increasing incidence, but other diseases, such as allergic reactions, bronchitis and respiratory infections also have been increasing. The cause of these increases may be due at least in part to the effects of air pollution. This review will address the following questions:

1. Why are children more susceptible to the effects of air pollution than adults?
2. Which air pollutants have the greatest impact on the health of children and adults?
3. What can be done to reduce the effects of air pollution on children's health?

Why are Children More Susceptible to Air Pollution Than Adults?

In many health effects research studies, children are considered as if they were small adults. This is not really true. There are many differences between children and adults in the ways that they respond to air pollution. For example, children take in more air per unit body weight at a given level of exertion than do adults. When a child is exercising at maximum levels, such as during a soccer game or other sports event, they may take in 20 percent to 50 percent more air -- and more air pollution -- than would an adult in comparable activity.

Another important difference is that children do not necessarily respond to air pollution in the same way as adults. Adults exposed to low levels of the pollutant ozone will experience symptoms such as coughing, soreness in their chests, sore throats, and sometimes headaches. Children, on the other hand, may not feel the same symptoms, or at least they do not acknowledge them when asked by researchers. It is currently not known if children actually do not feel the symptoms or if they ignore them while preoccupied with play activities.

This probably does not mean that children are less sensitive to air pollution than adults. There are several good studies that show children to have losses in lung functions even when they don't cough or feel discomfort. This is important because symptoms are often warning signals and can be used to trigger protective behavior. Children may not perceive these warning signals and might not reduce their activities on smoggy days.

Children also spend more time outside than adults. The average adult, except for those who work mostly outdoors, spends most of their time indoors -- at home, work, or even at the gym. Children spend more time outside, and are often outdoors during periods when air pollution is at its highest.

The typical adult spends 85 percent to 95 percent of their time indoors, while children may spend less than 80 percent of their time indoors. Children may also exert themselves harder than adults when playing outside.

Perhaps the most important difference between adults and children is that children are growing and developing. Along with their increased body size, children's lungs are growing and changing, too.

The Lung's Important Role in Health

The lung is an extremely complex organ. While most organs in your body are made up of a few different types of cells, the lung contains more than 40 different kinds of cells. Each of these cells is important to health and maintaining the body's fitness.

Air pollution can change the cells in the lung by damaging those that are most susceptible. If the cells that are damaged are important in the development of new functional parts of the lung, then the lung may not achieve its full growth and function as a child matures to adulthood. Although very little research has been conducted to address this extremely important issue, this review will discuss the information that is available.

USC Children's Health Study

Recent results from the Children's Health Study, conducted by investigators at the University of Southern California, suggest that children with asthma are at much greater risk of increased asthma symptoms when they live in communities with higher levels of ozone and particles and participate in three or more competitive sports. Having said all this, the purpose of this review is not to discourage children or adults from normal daily activities and outdoor exercise. Exercise has very important, beneficial outcomes. Appropriate exercise and prudent exposures of children and adults should be encouraged even in an environment that may always contain some amount of air pollution.

Which Air Pollutants Have the Greatest Impact on the Health of Children and Adults?

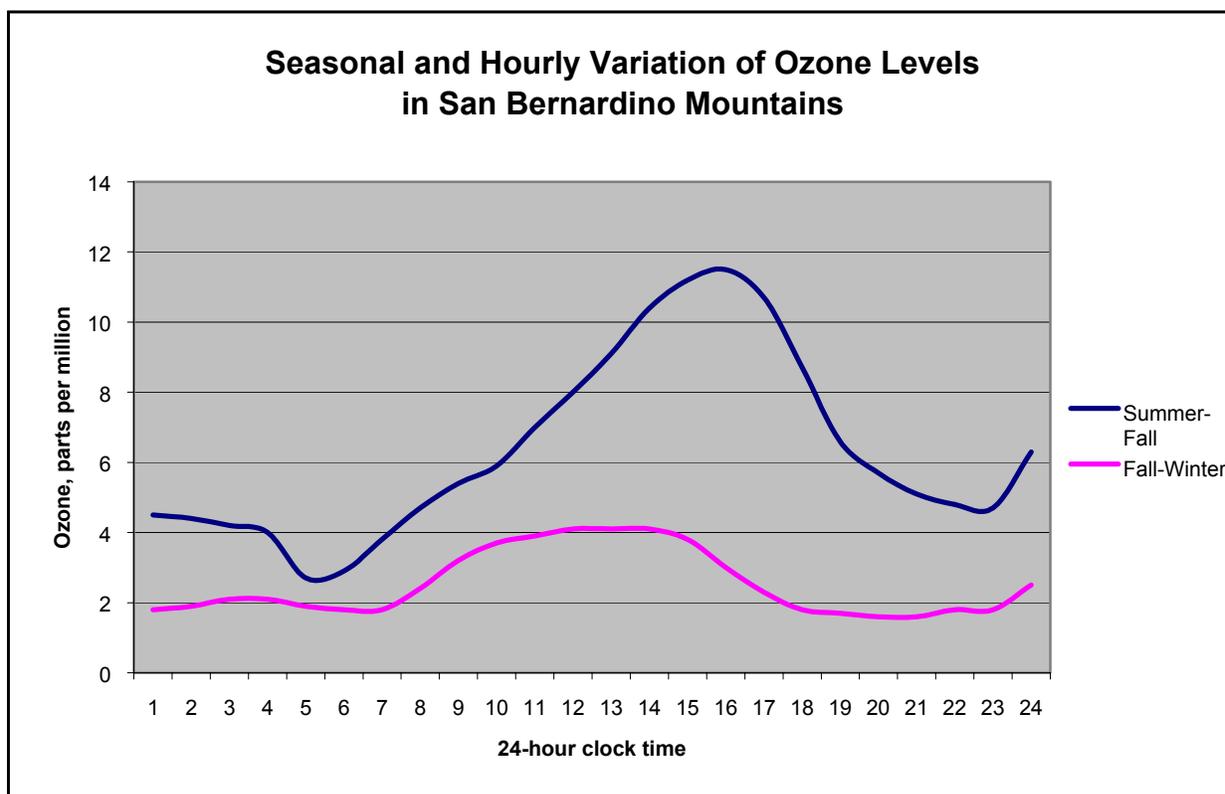
Ozone

Ozone is one of the most important air pollutants affecting human health in regions like Southern California.

Ozone (O₃) is a molecule built of three atoms of oxygen linked together in a very energetic combination. When ozone comes into contact with a surface it rapidly releases this extra force in the form of chemical energy. When this happens in biological systems, such as the respiratory tract, this energy can cause damage to sensitive tissues in the upper and lower airways.

Ozone formation

Because ozone forms as a product of solar energy and photochemical reactions of pollutants, it is not surprising that the highest concentrations of ozone in the atmosphere occur when sunlight is most intense. Thus, ozone generally reaches peak levels during the middle of the day in the summer months. These types of air pollution patterns are called diurnal and seasonal variations. The following graph shows that ozone levels in the San Bernardino Mountains are highest in the summer and fall, and peak in the late afternoon.



Ozone Air Quality Standards

Federal and state agencies have set air quality standards for ozone. An ozone level greater than 0.08 parts per million (ppm) averaged over eight hours is considered unhealthy. This level has been set because both laboratory and community studies have demonstrated measurable effects of ozone at or above that threshold.

The effects of ozone on people include:

- irritation of the nose and throat;
- increased mucus production and tendency to cough;
- eye irritation and headaches for some; and
- during severe episodes, chest pain and difficulty taking a deep breath without coughing.

How Ozone Damages Lungs

What happens when you breathe air that is contaminated with ozone? Like oxygen, ozone is soluble in the fluids that line the respiratory tract. Therefore some ozone can penetrate into the gas-exchange, or alveolar, region of the deep lung.

The following photos show how ozone affects the sensitive tissue in the deep lung. The pictures are from the lungs of rats exposed to ozone in a laboratory under carefully controlled conditions. The human lung is similar --although not identical -- to the rat's lung in terms of the types of cells and the overall structure of the alveolar region.



Figure 1

Figure 1 shows a magnified view of the structure of the normal gas-exchange region of the lung. It is called the gas-exchange region because oxygen inhaled from the air is transferred to the hemoglobin in blood in small blood vessels located inside the thin walls separating the alveolar air spaces.

At the same time, carbon dioxide, produced by normal metabolism and dissolved in the blood, is excreted into the air and expired when you breathe out.

The walls of a normal alveolus are very thin. There are only two layers of cells and a thin interstitial matrix separating the air in the alveolar space, or lumen, from the fluid inside the blood vessels. The cells that line the healthy alveoli are mostly very broad and very thin, and are called Type I lung cells or Type I pneumocytes. This provides a very large surface area across which gases can be efficiently transported.

Figure 2 shows the effects of breathing 0.2 ppm ozone for 4 hours. In Southern California air pollution levels can approach 0.2 ppm -- a Stage 1 ozone alert -- during the smoggiest summer days. The photo shows evidence of additional cells, called macrophages, and some material that may be fragments of ozone-injured alveolar wall cells inside the alveolar space.

Macrophages are immune system cells that respond to the injury of the delicate cells that line the alveolar lumen. These macrophages play important roles in protecting the lungs from inhaled bacteria,

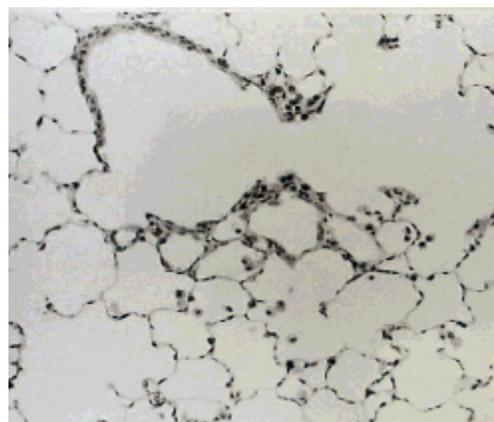


Figure 2

fungi and viruses, and are also important in helping to repair lung tissue injury caused by inhaled pollutants.

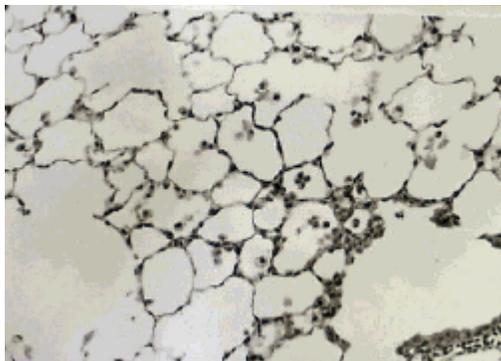


Figure 3

Figure 3 shows more extensive damage following exposure a higher concentration of ozone, 0.6 ppm. The alveolar walls are thicker and there is evidence of cells infiltrating within the walls. There are more macrophages in the alveolar spaces and the thin, Type I cells have been damaged and replaced with thicker Type II, almost cube-shaped cells that are more resistant to the toxic effects of ozone. All of these changes occurred within 48 hours after exposure. If exposure continues for more than three days, the evidence of cell injury seems to be reduced, except for the continuing presence of the Type II cells.

Is Ozone-Related Lung Damage Permanent?

People actually report that the symptoms they feel when first exposed to ozone seem to go away, even though their exposure continues.

Following ozone injury, if the lung is not exposed to ozone for approximately five to seven days, it can for the most part repair itself provided the injury is not too extensive. However, long-term studies with laboratory animals have shown that there may be residual and in some cases permanent damage. This damage might be thought of as accelerated aging of the lung. Thus, frequent exposures to ozone can cause transient damage. The lung's defenses can repair most but probably not all of that damage within a relatively short time in most healthy individuals.

Research and Air Quality Standards

Health scientists probably know more about the effects of ozone on human health than about any other pollutants. This is because ozone is pervasive in the environment. Also there are excellent methods of measuring ozone so the pollutant can be studied using epidemiological methods. The findings of these epidemiological studies can be verified using well-controlled laboratory studies with human volunteers and laboratory animals. Thousands of scientific papers on the health effects of ozone have been published and these have been critically reviewed in documents that provide the scientific basis for National and State Ambient Air Quality Standards. (Ambient refers to outdoor air.)

These so-called Criteria Documents are important because they are extensively reviewed by scientists, public agencies, industry representatives, environmental groups such as the American Lung Association and the Natural Resources Defense Council,

and the public. National and state ambient air quality standards set the goals for healthy air quality in Southern California and across the country.

Based upon the most recent studies, it is now apparent that ozone plays an important role in causing acute health effects, such as heightening asthma symptoms and developing bronchitis symptoms.

The role of ozone in producing long-term or chronic effects is less clear, at least from the available epidemiological studies. However, laboratory animal studies suggest that there can be long-term consequences.

How to Reduce Ozone Exposure

The U.S. Environmental Protection Agency (EPA) has recommended that ozone should not exceed 0.08 ppm averaged over an 8-hr period. When ozone exceeds this level, active children and adults, those with respiratory disease such as asthma, and other people with unusual susceptibility to ozone should limit prolonged outdoor exposure.

Incidentally, personal tobacco smoking during periods of high ozone exposure doubled the risk of asthmatic individuals needing to go to the emergency room for treatment of asthma symptoms.

Carbon Monoxide

Carbon monoxide (CO), a colorless, odorless gas, is a byproduct of combustion.

When inhaled, carbon monoxide reacts very rapidly with hemoglobin in the blood, preventing uptake and transport of oxygen. Because carbon monoxide readily and firmly attaches to hemoglobin, it stays in the blood for a relatively long time. Thus, during an exposure carbon monoxide concentrations in blood can rise in a matter of minutes, then stay high for hours.

Who is Most Sensitive to the Health Effects of Carbon Monoxide?

Most of the health effects directly associated with carbon monoxide are most likely due to decreases in oxygen delivery to vital organs such as the heart and the brain.

People with heart disease may be especially sensitive to the effects of carbon monoxide. In addition, people with lung diseases that limit efficient use of inhaled oxygen, such as asthma and emphysema, may also be susceptible. Even in people without heart or lung diseases, reduced delivery of oxygen to skeletal muscles, especially during exercise, can reduce the ability to perform strenuous work.

At high levels of carbon monoxide exposure, impaired delivery of oxygen to the central nervous system can reduce the ability to respond quickly to external stimuli. After exposures that convert 5 percent to 10 percent of the circulating hemoglobin to carboxyhemoglobin (COHb), people's ability to recognize and react to flashes of light in a test system are reduced. At 10 percent to 30 percent carboxyhemoglobin, nausea,

headaches, unconsciousness, and sometimes death can result. The severity of symptoms increases with the concentration of carboxyhemoglobin.

Air Quality Standards for Carbon Monoxide

Both the EPA and the State of California have set air quality standards for carbon monoxide based on the results of epidemiological and laboratory findings. Ambient levels of carbon monoxide should not exceed 9 ppm, when averaged over an 8-hour interval, and should not exceed 20 ppm in any one-hour period. (The USEPA has a slightly higher 1-hour standard of 35 ppm).

Sources of Carbon Monoxide

The major sources of carbon monoxide pollution are automotive exhaust and emissions from large industrial combustion sources such as electrical power plants. Because these sources produce many contaminants in addition to carbon monoxide -- such as fine particles and nitrogen oxides -- it is often difficult to isolate the health effects of ambient carbon monoxide from those of other pollutants.

In addition to carbon monoxide generated outside, there are also important indoor sources of the pollutant. The most important of these are combustion sources such as gas ovens, gas burners, water heaters, and heating systems. However, in most cases emissions from well-maintained and vented gas appliances are small.

Tobacco smoking is a more significant source of carbon monoxide. Tobacco smoke can contain very high concentrations of carbon monoxide (1,000 ppm to 50,000 ppm). Carbon monoxide levels in the homes of children whose relatives smoke tobacco products can be higher than the carbon monoxide levels outdoors.

Health Effects of Carbon Monoxide

There are hundreds of cases per year of deaths or severe illness due to carbon monoxide poisoning from faulty appliances, indoor emissions of automobile exhaust and industrial exposures. These cases show that carbon monoxide poisoning causes symptoms very similar to those of the flu. In fact, the true number of cases is not really known because many people may have been poisoned slightly and thought that they were just fighting off a cold or the flu. Thus it is very important to make sure that home appliances are well-maintained and that all combustion sources are properly vented to the outdoors.

Epidemiological studies have shown significant association between several health effects and carbon monoxide, although as mentioned earlier it is difficult to completely isolate carbon monoxide's effects from those of other air pollutants.

For example, asthmatic children in Taiwan who were exposed to high levels of traffic-related air pollution -- using carbon monoxide and nitrogen dioxide as marker compounds-- reported more respiratory symptoms than children with lower exposures.

A study of physician office visits in London showed associations between air pollution and doctor visits for asthma and other lower respiratory disease. For children, levels of nitrogen dioxide, carbon monoxide, and sulfur dioxide were associated with increased numbers of medical consultations. However, in adults, the only consistent association was with levels of airborne particles. This suggests that children and adults might respond differently to pollution exposures.

Prenatal Effects of Carbon Monoxide

Carbon monoxide may also have prenatal effects. Pregnant women who were exposed to high levels of ambient carbon monoxide (5 ppm to 6 ppm) were at increased risk of having low birth-weight babies. It has long been known that women who smoke cigarettes during pregnancy have low birth-weight babies, but this is the first study of similar findings in women exposed to environmental carbon monoxide.

Babies exposed to carbon monoxide during the maturation of their organs may suffer permanent changes to those organs. Studies using newborn rats showed that carbon monoxide exposure could cause changes in the heart muscle tissue. This in turn could increase the severity of effects of artery constrictions when they became adults. Other animal studies have shown that long-term carbon monoxide exposure can contribute to a disease called ventricular hypertrophy, in which the cells of the heart's ventricle chambers are enlarged and possibly weakened.

Airborne Particles

Particles, including nitrates, sulfates, carbon¹ and acid aerosols² are a complex group of pollutants.

Unlike ozone, which has a specific chemical composition, airborne particles vary in size and composition depending on time and location. Although the components of particles may have common sources, the types and amounts of particles collected at any one time and location may be unique.

To add to the problem, gaseous pollutants including ozone, sulfur dioxide, nitrogen dioxide and carbon monoxide often are present in the atmosphere at the same time as are particles. It is not always possible to clearly differentiate between the health effects of the gases, the particles, and possibly the combination of particles and gases. This complexity presents a tremendous challenge to the scientific community and to public in trying to understand how inhaled particles affect human health.

The Challenge of Measuring Particle Pollution

Precisely measuring particulate pollution is more difficult and labor intensive than measuring gaseous pollutants such as ozone. For this reason, particle concentrations are not measured on a daily basis in most communities. Frequently, they are measured once every six days.

¹ Both elemental and organic. Elemental carbon is pure carbon from combustion sources, including diesel particulate. Organic carbon is a semi-volatile hydrocarbon from combustion and some evaporative sources.

² Aerosol is the scientific term used to describe particles suspended in a fluid, such as air.

Particle samples are collected on filters that are then weighed. Particle concentrations are reported in terms of micrograms of particles per cubic meter ($\mu\text{g}/\text{m}^3$) of collected air.

Originally, the particle samples were relatively indiscriminate with respect to particle size and often contained very large particles. These large particles contributed a great deal to the weighed particle mass, but might not have been very important with respect to lung health. This is because most of the particles were too large to penetrate through the nasal and head airways to reach the lung. A more health-related sample was needed.

After a great deal of scientific consideration it was decided that particulate matter with aerodynamic diameters³ less than or equal to 10 microns (μm) should be collected. Ambient air quality standards were developed for this material, which is called PM_{10} .

Sources of Particle Pollution

Researchers noted that the sources of relatively large-size particles (greater than 3 microns in aerodynamic diameter) were quite distinct from the sources of particles less than 1 micron in diameter.

The larger, so-called "coarse" particles are mostly produced by mechanical processes, such as automobile tire wear on the road, industrial cutting, grinding and pulverizing processes and re-suspension of particles from the ground or other surfaces by wind and human activities. The chemical composition of coarse particles may be somewhat similar to the chemical composition of soil in that area, along with industrial compounds from activities such as mining or smelting operations. The coarse fraction of urban aerosols also contains bits of plants, molds, spores and some bacteria. Thus the characteristics of the coarse particles may vary greatly in different communities.

In contrast, the smaller or so-called "fine" particles in the urban aerosol come from combustion sources, such as power plants, automobile, truck, bus and other vehicle exhaust or from the reactions that transform some of the pollutant gases into solid or liquid particles. These distinctions may be important because the current air pollution health effects literature suggests, although not with certainty, that for some key health effects the fine particles are more important than the coarse particles. These findings have led EPA to propose a new nationwide $\text{PM}_{2.5}$ standard that would reduce exposure to particles that are 2.5 microns or less in diameter.

Historic Air Pollution Disasters

Epidemiological studies have consistently associated adverse health effects with exposures to particulate air pollution. Early studies implicated particulate and sulfur dioxide pollution in the acute illnesses and premature deaths associated with extremely

³ Aerodynamic diameter is used to define particles' size. Particle deposition on a surface, or in the lung, depends on the particle's aerodynamic and diffusion characteristics. A particle's aerodynamic characteristics depend on its density, shape, actual size, and velocity while its diffusion characteristics are functions of its size and the density of the air in which it is suspended.

severe pollution episodes in Donora, Penn., London, and New York in the 1940s, 1950s, and 1960s. The particle levels in a four-week pollution disaster in London in 1955 were more than 50 times higher than the California standard.⁴ Twenty percent of that aerosol was composed of acid sulfates -- probably sulfuric acid. The number of people hospitalized for lung or heart-related diseases was extraordinarily high, but more importantly there were more than 4,000 premature, or "excess," deaths in the London population.

Fortunately, major efforts by government agencies, the public, and industries have made it very unlikely there will ever be a similar episode in modern urban communities. However, the lessons learned from these disasters are still relevant. Despite the fact that our levels of airborne particles are much lower than those that occurred during the disasters, EPA estimates that there are still more than 6,000 excess deaths in the United States that could be associated with inhaled particles.

Health Effects of Particulate Pollution

Current ambient levels of PM₁₀ -- 30 to 150 micrograms per cubic meter -- are associated with increases in the numbers of people that die daily from heart or lung failure. Most of these deaths are among the elderly. However there is a strong body of evidence that some children are also adversely affected by particulate matter.

The American Thoracic Society's Environmental and Occupational Health Assembly reviewed current health effects literature. They report that daily fluctuations in PM₁₀ levels have been related to:

- acute respiratory hospital admissions in children;
- school and kindergarten absences;
- decreases in peak lung air flow rates in normal children; and
- increased medication use in children and adults with asthma.

The USC Children's Health Study suggests that children with asthma living in a community with high particle concentrations may have suppressed lung growth. After children moved into cleaner cities their lung growth returned to the normal rate, but they did not recover the lost potential growth, according to John Peters, the study's principle investigator.

It is difficult to positively assign a quantitative risk associated with particulate matter because nearly all studies of its health effects find other pollutants present that may account for some of the effects.

Part of the problem is due to the nature of the data being collected. The levels of particulate matter vary during the course of the day and peak values can be quite high. Few studies have evaluated the effect of these short-term "spikes." However, at least one epidemiological study of children with asthma suggested that changes in symptoms

⁴ The California standard for particulate matter (PM₁₀) is 50 micrograms per cubic meter averaged over 24 hours

and lung function correlate more strongly with 1-hour peaks than with 24-hour average concentrations.

Other studies, primarily with laboratory animals, suggest that the chemical composition⁵ and surface areas of the particles may be more important than particle mass. Scientists are continuing to study the health effects of particles and are developing better methods for measuring the important constituents. It may be possible in the near future to more accurately assess the effects of inhaled particles on human health.

Nitrogen Oxides

Nitrogen oxides are produced during most combustion processes. Mobile sources and power plants are the major contributors in Southern California.

About 80 percent of the immediately released nitrogen oxide is in the form nitric oxide (NO). Small amounts of nitrous oxide (N₂O) are also produced. Nitrous oxide is a "greenhouse" gas that is suspected of playing an important role in global warming.

Nitric oxide reacts with oxygen in the air to produce nitrogen dioxide (NO₂). Further oxidation during the day causes the nitrogen dioxide to form nitric acid and nitrate particles. In the dark, nitrogen dioxide can react with ozone and form a very reactive free radical. The free radical then can react with organic compounds in the air to form nitrogenated organic compounds, some of which have been shown to be mutagenic and carcinogenic.

Health Effects of Nitrogen Dioxide

Nitrogen dioxide is the most important nitrogen oxide compound with respect to acute adverse health effects. Under most chemical conditions it is an oxidant, as is ozone. However, it takes about 10 times more nitrogen dioxide than ozone to cause significant lung irritation and inflammation.

Nitrogen dioxide differs from ozone in that it suppresses the immune system to a much greater degree. As discussed below, some epidemiological studies have shown that children exposed to high levels of ambient nitrogen dioxide may be at increased risk of respiratory infections. Studies with laboratory animals have indeed shown that if mice are exposed first to nitrogen dioxide and later to bacteria at a level that would not infect a healthy control animal, their normal lung defense mechanisms are suppressed and the bacteria are able to infect the host.

⁵ The idea that all particles are equally toxic is not scientifically justified. There are many good examples that can be taken from studies of particles in the workplace. For example, certain types of particles that contain quartz -- a natural mineral composed of silicon dioxide but with a specific crystal structure -- are very potent lung irritants. Repeated exposures to this material can lead to a serious, permanent lung disease called lung fibrosis. Other mineral particles that are fibrous, such as specific forms of asbestos, can cause lung cancer. Other particles such as titanium dioxide do not seem to cause occupational diseases.

Average levels of nitrogen dioxide in the United States range from 0.02 to 0.04 ppm. Levels in major urban areas in Southern California may be higher, but the region has not exceeded the federal standard⁶ for nitrogen dioxide since 1991.

During the 1970s, one of the first studies relating respiratory illnesses and changes in lung function to ambient nitrogen dioxide concentrations reported that children living in areas with high nitrogen dioxide concentrations had greater incidences of lung-related illness than children living in areas with lower concentrations. Since then, other epidemiological studies have suggested that children with asthma are more likely than children without asthma to have reduced lung function and symptoms of respiratory irritation, such as cough and sore throat, when outdoor average nitrogen dioxide concentrations exceed about 0.02 ppm.

Some studies also have suggested that children younger than five years old may be more severely affected by nitrogen dioxide than older children. Several epidemiological studies have suggested that for children, the most important effect of ambient exposure to nitrogen dioxide might be increased susceptibility to respiratory infections and increased severity of responses to inhaled allergens.

Although many epidemiological studies show significant associations between outdoor nitrogen dioxide concentrations and adverse health outcomes, some studies do not corroborate these effects. In part, this is because it is often difficult to fully account for the influences of indoor sources of nitrogen dioxide.

Improvements in Nitrogen Dioxide Measurements

More recent studies have used special devices, called passive dosimeters, that can be worn by children to collect nitrogen dioxide for later analysis. These measurements give epidemiologists the ability to better assess a child's total nitrogen dioxide exposure over the course of the day. These studies show that there can be a great deal of individual variation in exposures, even for children living in the same communities. Thus, it is not surprising that epidemiological studies that do not estimate a nitrogen dioxide dose may reach different conclusions.

However, laboratory studies involving controlled exposures of human volunteers and laboratory animals have demonstrated plausible effects of nitrogen dioxide on human health. For example, if one exposes rats or other animals to nitrogen dioxide, and then examines their respiratory tract tissues, it is very evident that the pollutant can cause short-term injury similar to that seen after ozone exposure.

Long-term exposures to high concentrations of nitrogen dioxide can produce chronic damage to respiratory tract tissue that resembles the lung disease emphysema.

The pollutant's suppression of immune system functions reduces the ability of the host to fight off bacterial and viral infections. Human volunteers who inhaled weakened

⁶ 0.053 ppm as an annual average

influenza virus after being exposed to nitrogen dioxide in laboratories were more susceptible to the infection than a control group that did not inhale nitrogen dioxide.

Other studies show that nitrogen dioxide decreases the body's ability to generate antibodies when challenged by pathogens, and may reduce the ability of the respiratory system to remove foreign particles such as bacteria and viruses from the lung.

Lead

People can be exposed to lead (Pb) through air, food and water. Lead is a toxic heavy metal that causes nerve damage and impairs the body's ability to make hemoglobin, leading to a form of anemia.

Sources of Lead Pollution

Large amounts of lead were emitted to the atmosphere when it was used as a gasoline additive.⁷ The emitted lead could be inhaled. In addition, lead fallout from the air caused widespread contamination of soil, plants, food products, and water.

Lead is often measured in children's blood as an index of environmental exposure. Even low levels⁸ of lead in the blood of children aged 6 to 7 are linked to measurable changes in intelligence quotient and certain perceptual-motor skills. Higher levels of lead exposure can also result in kidney damage and may be related to high blood pressure in adults.

Sulfur Oxides

Most manmade emissions of the gas sulfur dioxide (SO₂) come primarily from the combustion of fossil fuels such as coal, oil, and diesel fuel.

Most of the sulfur in fossil fuel is converted sulfur dioxide, but a small amount is also converted to sulfuric acid. In the atmosphere, gaseous sulfur dioxide can also be converted to sulfuric acid and sulfate-containing particles. Thus, atmospheric concentrations of sulfur dioxide are often highly associated with acidic particles, sulfuric acid particles and sulfate particle concentrations.

The current National Ambient Air Quality Standards for sulfur dioxide are 18 micrograms per cubic meter averaged annually, and 365 micrograms per cubic meter averaged over 24 hours. Southern California does not exceed the national air quality standard because its industries primarily burn low-sulfur fuels such as natural gas. Much of the sulfur oxide air pollution in Southern California is likely to be associated with diesel emissions.

⁷ Lead in the form of tetraethyl lead was added to gasoline in the United States in large amounts from the 1950s until it was banned in the mid-1970s.

⁸ 10 to 30 micrograms per 100 milliliters

Sulfur dioxide is a very water-soluble gas and therefore most of the sulfur dioxide that is inhaled is absorbed in the upper respiratory tract and does not reach the lung's airways. However, the small amount of sulfur dioxide that does penetrate into the airways can provoke important health effects, primarily in individuals with asthma.

For those with asthma, even relatively short-term, low-level exposures to sulfur dioxide can result in airway constriction leading to difficulty in breathing and possibly contribute to the severity of an asthmatic attack.

A number of epidemiological studies have shown associations between ambient sulfur dioxide and rates of mortality (death) and morbidity (illness). However, because sulfur dioxide is often strongly correlated with fine particles and especially sulfate-containing particles, it is difficult to separate the effects of sulfur dioxide from those of the particle compounds.

A study in France found an increase of 2.9 visits to the emergency room for every 20 micrograms per cubic meter increase in atmospheric sulfur dioxide. The results pertained to days when the average sulfur dioxide levels were above 68 micrograms per cubic meter but below the U.S. health standard.

In London, asthma and other lower respiratory diseases in children were most significantly associated with exposures to nitrogen dioxide, carbon monoxide, and sulfur dioxide. In adults the only consistent association was with particulate matter.

Hospital admissions for children with asthma may increase by 20 percent following acute exposure to ozone peaks and possibly with sulfur dioxide. Chronic exposure to increased levels of fine particles, sulfur dioxide, and nitrogen dioxide may be associated with up to threefold increase in nonspecific respiratory symptoms. Thus, recent literature suggests that sulfur dioxide affects adults and children differently and that chronic and acute effects may also be different.

Diesel Emissions

Diesel fuel is burned to power buses, trucks, road-building equipment, trains, boats and ships and electricity-generating equipment. When diesel fuel is burned, the exhaust includes both particles and gases. Diesel emissions are important constituents of ambient air pollution.

What's in Diesel?

Diesel particles consist mainly of elemental carbon and other carbon-containing compounds. Hundreds of compounds have been identified as constituents of diesel particles. These include polycyclic aromatic hydrocarbons (PAHs) and other compounds that have been associated with tumor formation and cancer. In 1998, the California Air Resources Board designated diesel particulate a cancer-causing toxic air contaminant.

Diesel particles are microscopic. More than 90 percent of them are less than 1 micron in diameter. Due to their minute size, diesel particles can penetrate deeply into the lung. There is evidence that once in the lung, diesel particles may stay there for a long time.

In addition to particles, diesel exhaust contains several gaseous compounds including carbon monoxide, nitrogen oxides, sulfur dioxide and organic vapors, for example formaldehyde and 1,3-butadiene. Formaldehyde and 1,3-butadiene have been classified as toxic and hazardous air pollutants. Both have been shown to cause tumors in animal studies and there is evidence that exposure to high levels of 1,3-butadiene can cause cancer in humans.

AQMD's recent landmark research project, the Multiple Air Toxics Exposure Study II, found that diesel particulate is responsible for about 70 percent of the total cancer risk from all toxic air pollution in the greater Los Angeles metropolitan area.

Diesel emissions may also be a problem for asthmatics. Some studies suggest that children with asthma who live near roadways with high amounts of diesel truck traffic have more asthma attacks and use more asthma medication.

Some human volunteers, exposed to diesel exhaust in carefully controlled laboratory studies, reported symptoms such as eye and throat irritation, coughing, phlegm production, difficulty breathing, headache, lightheadedness, nausea and perception of unpleasant odors. Another laboratory study, in which volunteers were exposed to relatively high levels of diesel particles for about an hour, showed that such exposures could cause lung inflammation.

Thus current epidemiological and laboratory evidence suggests that at typical urban concentrations, diesel exhaust may contribute significantly to the health effects of air pollution.

What Can Be Done to Reduce the Effects of Air Pollution on Children's Health?

After reviewing the literature on how children's exposures differ from those of adults, it is evident that:

- children are outdoors more hours per day than most adults;
- they exert themselves to a greater degree while they are outside than most adults; and
- they participate in more organized activities than adults.

There are definite health benefits to having children participate in outdoor activities. However, scientific evidence also suggests that air pollution exposures can injure children's lungs and other organs.

Air quality information in the form of health reports and air quality advisories are now a regular part of life in California. One logical step is to reduce strenuous activities during pollution episodes and try to take advantage of those hours when airborne pollutant levels are lower.

At the public level there is a long-standing commitment to improve air quality. When you look at the air pollution levels in California today you can see that a great deal of progress has been made. There has been a cost for this progress. For instance, some products are more expensive. In return, the lower levels of pollutant exposure compared to 20 years ago should decrease the adverse effect of air pollution on the long-term health of our developing children.

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