CARBON MONOXIDE:

a firefighting hazard

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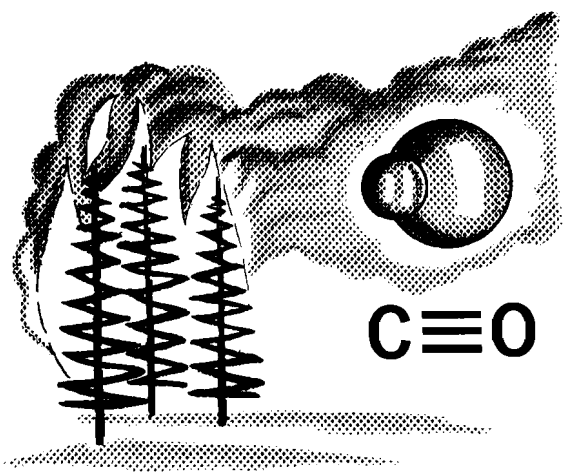


CARBON MONOXIDE (CO) is a highly toxic, nonirritating gas. One of the products of combustion, it is invisible, odorless, tasteless, and slightly lighter than air. But smoke, another combustion product, is visible. And when smoke is present, it is highly likely that CO and other noxious gases are also present. Therefore, the old adage "Where there's smoke, there's fire" might well be reworded to "Where there's smoke, there's carbon monoxide."

Available evidence indicates that CO concentrations high enough to have adverse effects on firefighters are likely to be common in many wildland fire control operations. In fact, technological advances in firefighting equipment may be contributing to increased exposure. Bulldozers with heat shields and protective blankets, fire-resistant clothing and other protective devices, such as face and neck shields—all encourage entry into areas where significant concentrations of CO are most likely to be found.

Carbon monoxide is the most common and widely distributed air pollutant—total emissions of CO exceed those of all other pollutants combined. Although there are a number of natural sources of CO, these contribute little to CO pollution. Most of the atmospheric CO is the result of the incomplete combustion of carbonaceous materials, such as coal, oil, vegetation, and their products. Internal combustion engines, generation of power and heat from burning fuel, and some industrial and manufacturing processes produce large amounts of CO. Today, motor vehicles alone account for more than half of the CO emissions in the United States. Wildland fires and the burning of refuse and agricultural wastes are also major sources.

Carbon monoxide poisoning is not new. Man's difficulties with CO probably date back to the time prehistoric man first used fire. Instances of CO poisoning have been found in early Greek and Roman literature. The increased use of coal for domestic purposes in the 1400's brought with it an increase in CO poisoning. The hazard was intensified by the introduction of illuminating gas, and later natural gas, for heat, power, and light.

Until recent years, concern over CO poisoning has been directed mainly toward the rather high concentrations sometimes found in closed spaces, such as homes, offices, factories, and mines. Here the effect of CO is quite obvious. But with the increasing use of motor vehicles with their high CO emission rate, attention is now being focused on the more subtle effects of the relatively low concentrations of CO that can often be found in outdoor situations—particularly in urban areas.

PHYSIOLOGICAL EFFECTS OF CARBON MONOXIDE

Formation of COHb

Carbon monoxide is toxic chiefly because it reacts with hemoglobin (Hb)—the oxygen-carrying part of the blood. Oxygen and CO react with hemoglobin in a similar manner, oxygen to form oxyhemoglobin (O_2Hb) and CO to form carboxyhemoglobin (COHb). But the affinity of hemoglobin for CO is about 210 times its affinity for oxygen, so CO is taken up by the blood in preference to oxygen. Also the COHb itself interferes with the transfer of oxygen to living tissues. Thus the principal effect of CO is to deprive the body of its needed oxygen supply—the symptoms of CO poisoning are similar to those of insufficient oxygen.

For each level of CO concentration in the air, there is an equilibrium COHb level in the blood—that is, a point beyond which the COHb does not increase. Like the moisture content of wildland fuels, approaching their equilibrium value, the increase in COHb is rapid on first exposure, and then changes more and more slowly as the equilibrium level is approached. When concentration of CO is low and the affected person is sedentary, about 60 percent of the COHb equilibrium level is reached after 2 hours of exposure, and 80 percent after 4 hours. Equilibrium is not achieved for an additional 8 hours. The rate at which COHb is formed depends strongly on respiration rate, so for a person engaged in strenuous activity these times would be shorter. The rate also increases with elevation.

The formation of COHb is a reversible process, and the COHb level in the blood begins to decrease when the victim moves from contaminated to clean air. The reversal process is slow, however. It is estimated that a given COHb level is halved in from 2 to 4 hours.[1] Thus, if the "half-life" period is 3 hours, and the COHb level in the blood is 20 percent after exposure to CO, it would still be 10 percent 3 hours after exposure, and 5 percent after 6 hours.

Symptoms of CO Poisoning

Little is known of the equilibrium COHb levels for high concentrations of CO, possibly because serious effects or death can occur before equilibrium is reached. The effects of high concentrations have been fairly well established, however. Claudy[2] indicates distress can occur after 1 to 2 hours exposure to 400 parts per million (p.p.m.) of CO in the air. At a concentration of 800 p.p.m., headaches, dizziness, and nausea can occur in 45 minutes, with collapse and possible unconsciousness after 2 hours. At a concentration of 12,800 p.p.m., the effect is immediate, and death is likely in 1 to 3 minutes.

The chief effect of low concentrations of CO is on the central nervous system. Alertness, vision, and time perception are affected. Judgment and the ability to do psychomotor tasks—tasks requiring thinking and doing—are impaired. Apparently these effects are more pronounced when the victim is subjected to distractions, or must attend to more than one task—the kind of situation that often faces fireline supervisory personnel, as well as aircraft pilots and operators of motor vehicles and equipment. There is some evidence that people subjected to low concentrations of CO are more likely to have automobile accidents than others.

Exposure Standards

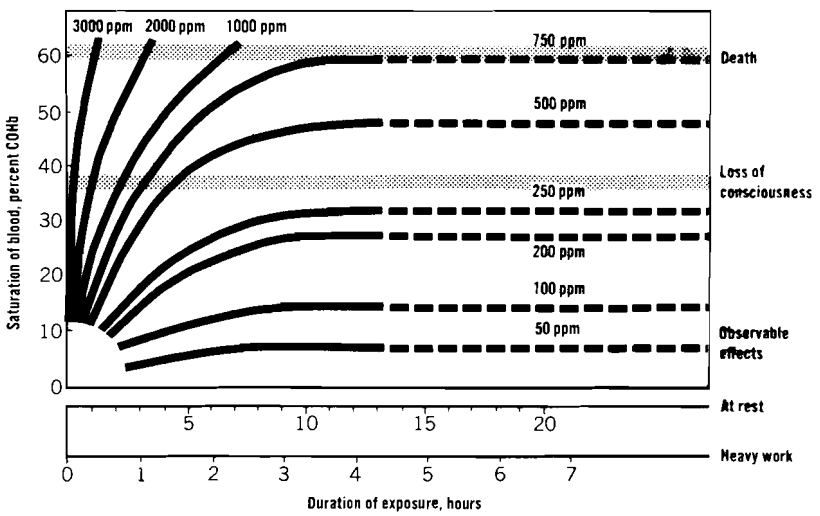
As a result of the increasing evidence of the adverse effects of low concentrations of CO, the 8-hour occupational exposure standard for industry was reduced from 100 p.p.m. to 50 p.p.m. in 1964. The recommended limit for work at elevations from 5,000 to 8,000 feet is now only 25 p.p.m. The California State Department of Health has adopted a concentration of 30 p.p.m. as the "serious" level for 8-hour community exposure. However, some investigators believe these standards may yet be too high. The National Academy of Science advises: "There is no level of CO in ambient air that is known to be without effect."

The normal or "background" COHb blood level is about 0.5 percent. This comes from CO produced by the body metabolism processes and the small amount of CO in unpolluted air. Carbon monoxide effects first become readily apparent when the COHb level reaches about 2 percent—the equilibrium level for a CO concentration of 10 to 12 p.p.m.[3] The effects rapidly become more serious as the COHb level rises:

As COHb levels or duration of exposure increase, health effects become more serious

COHb level, percent	Demonstrated effects
Less than 1.0	No apparent effect.
1.0 to 2.0	Some evidence of effect on behavioral performance.
2.0 to 5.0	Central nervous system effects. Impairment of time interval discrimination, visual acuity, brightness discrimination, and certain other psychomotor functions.
Greater than 5.0	Cardiac and pulmonary functional changes.
10.0 to 80.0	Headaches, fatigue, drowsiness, coma, respiratory failure, death.

Source: National Academy of Science and National Academy of Engineering



Acute effects. COHb levels in the blood depend upon the amount of CO in the atmosphere, duration of exposure, and type of physical activity

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CARBON MONOXIDE CONCENTRATIONS IN WILDLAND FIRES

Relatively little is known about the concentrations of CO that can occur in and around wildland fires. But since CO is one of the products of combustion, it is virtually certain that it is present. An estimated 60 pounds of CO are emitted for each ton of burning wildland fuel.[3] During severe burning conditions in southern California chaparral it is not unusual for fires to spread at a rate of 3,000 to 4,000 acres per hour. If 10 tons of fuel per acre are consumed, then 900 to 1,200 tons of CO per hour would be emitted from such fires. Fortunately for firefighters, much of the CO produced is carried aloft in the fire convection column or is diluted by the ambient air. Strong concentrations can be expected in the combustion zone, however. Concentrations as high as 52,000 p.p.m. have been found in burning piles of pinyon pine and juniper trees;[4] concentrations up to 70,000 p.p.m. were found in a smoldering rubble fire.[5]

In their normal activities firefighting personnel are not likely to be exposed to these lethal concentrations—if they were, they would not survive the effects of the fire itself. Available evidence indicates, however, that CO concentrations high enough to have adverse effects are probable in areas where firefighters are likely to be working. Concentration of CO was measured 1 foot and 5 feet above the ground between rows of burning piles of pinyon pine and juniper trees.[4] The sampling points were 12 to 15 feet from the edge of the burning piles. During the peak fire activity the CO concentration generally exceeded 10,000 p.p.m. The concentration decreased rapidly as the fire activity lessened, and an hour after ignition was in the order of 300 to 400 p.p.m. By this time the fire intensity had decreased sufficiently to permit walking between the piles. At the end of 4 hours only a few smoldering logs remained, but the CO concentration was still about 200 p.p.m. Fire conditions in these latter stages were quite similar to direct attack or mop-up conditions in a timber fire.

At the head of a grass fire, CO readings of 50 p.p.m. were obtained in moderately dense smoke about 40 feet from the fire front. The observations were made at a place where a tanker or initial attack crew would usually be operating. The wind speed was about 15 m.p.h., and the fuel loading 2 tons per acre. Since the concentration of CO depends strongly on the amount of fuel burning, heavier fuel loading could be expected to give a higher CO concentration in the same kind of situation.

Carbon monoxide measurements made in light smoke during a 5-acre prescribed burn in chaparral showed concentrations of 30 p.p.m. The measurements were made about 200 feet from the fire front in a 12-m.p.h. wind. Smoke conditions at this point were about the same as those sometimes found in fire camps and chaparral fires in the mop-up stage.

Most experimental work on the effects of low concentrations of CO have been carried out with CO as the only air pollutant. Wildland fires, however, also produce other air pollutants such as carbon dioxide, nitrogen oxides, various aldehydes, and particulate matter. These other pollutants can compound the effects of CO. The concentration of carbon dioxide alone can be high enough in and around a fire to cause minor adverse effects.

The concentration of CO at any point around a wildland fire depends on the quantity of burning fuel, the efficiency of combustion, and the degree of dilution of the combustion products by the ambient air. In general, the strongest CO concentrations can be expected close to the fire and where the smoke is heaviest. Strong winds promote dilution over much of the fire area, but are likely to hold the convection column close to the ground and give higher CO concentrations at the head of the fire. Topographic situations that concentrate or channel the combustion products can also produce high CO concentrations—heads of canyons and ravines are special danger points. Conversely, light winds permit significant CO concentrations over a wider area, and accumulation of CO and other combustion products in areas with poor air circulation. Because of their lower combustion efficiency, slow-burning or smoldering fires produce more CO per pound of fuel than do hot fires. Thus, the CO concentration for the amount of smoke present is likely to be greater in slow burning and smoldering fires.

WAYS TO MINIMIZE THE EFFECTS OF CARBON MONOXIDE

The possibility of CO poisoning is a fire control occupational hazard that cannot be eliminated—only minimized. Exposure of wildland fire control personnel to potentially lethal concentrations of CO, though possible, is likely to be rare. The effects of low concentrations are a more pressing concern. Because low-level CO poisoning impairs alertness, judgment, vision, and some psychomotor functions, it affects fire control operations and fireline safety. To reduce the hazard of CO, these steps can be taken:

• *Train key personnel in the hazards of carbon monoxide.*—Low-level CO poisoning is most likely to have serious consequences if such fire control personnel as fireline supervisors, aircraft pilots, equipment operators, and vehicle drivers are affected. If they recognize that CO can reduce their capability, they can consciously try to compensate for this.

• *Shorten tours of duty in "hot-line" situations.*—In most wildland fires, the highest CO concentrations are likely to be found where the smoke is the heaviest, such as at the head of the fire and other areas where the fire is most active. Crews working in these areas should be relieved or rotated to less dense smoke areas at frequent intervals to permit at least partial recovery from CO effects. Short or intermittent tours of duty in hot-line situations are particularly important for supervisory personnel, such as crew bosses and sector bosses, since mistakes and errors in judgment by these people can have far-reaching results. Short tours of duty for equipment operators in dense smoke should also be given special consideration.

• *Provide for close monitoring of supervisory personnel in critical fireline situations.*—If line overhead must be exposed to possible high CO concentrations or to lower concentrations for long periods of time, their actions and decisions should be monitored closely by their supervisors. This will allow correction of errors in judgment that might otherwise result in injuries or death.

•*Limit operation of vehicles by persons likely to be exposed to carbon monoxide.*—Carbon monoxide is very likely to affect driving ability. Operation of motor vehicles by fireline personnel should be kept to a minimum—eliminated entirely if possible. When motor vehicle drivers are exposed to smoky conditions their tour of duty should be shortened, particularly at night, since CO can affect vision.

• *Locate fire camps in smoke-free areas.*—Carbon monoxide poisoning is a reversible process, but the reduction of the COHb level of the blood requires considerable time. Also, the reduction of COHb will proceed only to a point where it is in equilibrium with the existing CO concentration. A fire crew starting its shift with above-normal COHb level will be affected more quickly than usual by CO on the fireline.

Fire camps partially or wholly surrounded by smoldering fires are most likely to have significant levels of CO, since smoldering fires produce more CO for the amount of fuel burning than do more active fires. If it is not feasible to provide smoke-free fire camps for all fire personnel, then such areas should be provided for at least supervisory personnel, aircraft pilots, equipment operators, and motor vehicle drivers.

SUMMARY

Carbon monoxide (CO) is a highly toxic, nonirritating gas. Slightly lighter than air, it is invisible, odorless, and tasteless. Almost all of the atmospheric CO is the result of the incomplete combustion of carbonaceous fuels. Carbon monoxide is generated in quantity by wildland fires.

Carbon monoxide displaces oxygen in the hemoglobin of the blood to form carboxyhemglobin (COHb). The COHb reduces the oxygen-carrying capacity of the blood, and also interferes with the transfer of oxygen to living tissues. The amount of COHb formed depends on the concentration of CO in the air. For each CO concentration level the COHb reaches an equilibrium level after a period of time. The formation of COHb is reversible, and the amount of COHb will decrease when CO concentration decreases. The effects of CO first become apparent when the COHb in the blood reaches the 2 percent level—the equilibrium value for a CO concentration of 10 to 12 p.p.m. of air. The severity of the effects increase rapidly with increasing COHb level, and death will result in a few minutes when the CO concentration reaches 12,000 p.p.m.

The chief effect of low concentrations of CO is on the central nervous system. Alertness, vision, and time perception are affected. Judgment and the ability to do psychomotor tasks are impaired. These effects are more pronounced in persons subjected to distractions, or required to attend to more than one task—as fireline supervisory personnel, aircraft pilots, and operators of motor vehicles and equipment often are.

Relatively little is known about the concentrations of CO in and around wildland fires. But since CO is one of the products of combustion, it is virtually certain to be present. Available evidence indicates lethal concentrations of CO can occur in some areas of wildland fires, and concentrations high enough to cause adverse effects are likely in many areas where fire control operations are carried on.

Exposure of fire control personnel to lethal concentrations of CO is likely to be rare, but the effects of low concentrations are a cause for concern. Because low-level CO poisoning impairs alertness, judgment, vision, and psychomotor functions, it affects fire control operations and fireline safety. To reduce the hazard of CO, these steps can be taken:

1. Train key personnel in the hazards of CO.
2. Shorten tours of duty in "hot-line" situations.
3. Provide for close monitoring of supervisory personnel in critical fire line situations.
4. Limit operation of vehicles by persons likely to be exposed to CO.
5. Locate fire camps in smoke-free areas.

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