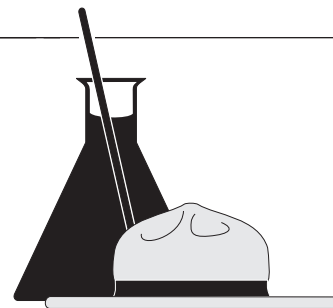




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EXPOSURE OF SNOWMOBILE RIDERS TO CARBON MONOXIDE

Emissions Pose Potential Risk

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SNOWMOBILE travel (fig. 1) has become pervasive recreation in several national parks. During winter 1993-94, more than 87,000 tourists visited Old Faithful in Yellowstone National Park (Wyoming, Montana, Idaho) by snowmobile alone. Experts had predicted it would take 10 years for winter tourism to reach the 1993-94 level; however, it took only three (Wilkinson 1995; Thuerner 1996). Voyageurs National Park in Minnesota also experiences significant snowmobile traffic, with an estimated 30,000 snowmobiles entering annually (Wilkinson 1995). Snowmobile travel is also gaining popularity in many other national parks, such as Mount Rainier, Olympic, Grand Teton, and North Cascades (Wilkinson 1995).

Presently, no federal laws regulate the exhaust from snowmobile engines. The typical snowmobile operates on a small, two-stroke engine (around 400-650 cc). The two-stroke engine is less expensive than its four-stroke counterpart and provides a high power:weight ratio. However, it also produces relatively high emissions of carbon monoxide (CO) and unburned hydrocarbons (UHC) (White et al. 1993). Additionally, snowmobile engines are not equipped with pollution control equipment. Therefore, the typical snowmobile produces significantly more CO and UHC than a modern automobile.



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Figure 1. Snowmobile travel is gaining popularity in national parks, including Grand Teton National Park, Wyoming, the site of the recent emissions study.

HEALTH HAZARDS

Carbon monoxide is a colorless and odorless gas that results from incomplete combustion. It is considered dangerous because it binds to the hemoglobin in blood (forming carboxyhemoglobin) and renders the hemoglobin incapable of transporting oxygen. The amount of carboxyhemoglobin and thus the

effect on health is a combination of the concentration of CO in the air and the time of exposure. When exposure is discontinued, the CO that combined with the hemoglobin is spontaneously released, and the blood of healthy individuals is cleared of half of its CO in 3-4 hours. The effects on health range from neural-behavioral effects at 2-3% carboxyhemoglobin to headaches and fatigue at 10% carboxyhemoglobin to respiratory failure and death. Reduced blood-oxygen levels from CO exposure are particularly dangerous to the elderly, people with cardiovascular disease or other circulation problems, anemic individuals, fetuses, young infants, and pregnant women (U.S. Environmental Protection Agency 1991).

The National Ambient Air Quality Standard (NAAQS) for CO is 35 ppm (parts per million) for 1 hour and 9 ppm for 8 hours. This standard was established to keep blood levels of carboxyhemoglobin below 3%. However, some evidence sug-

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gests adverse health effects can occur at lower exposure levels, and the standards have been criticized (Watson 1995; Greek and Dorweiler 1990).

EMISSION STUDIES

The increase in popularity of the snowmobile and its polluting emissions have increased concern that snowmobile pollution in parks is reaching significant levels. As a result, several researchers have conducted investigations to determine whether this concern is justified. All of their studies focused on measuring the amount of CO in areas frequented by snowmobiles.

During winter 1994-95, National Park Service employees monitored ambient levels of CO at the west entrance station to Yellowstone National Park. The purpose of their study was to determine if National Ambient Air Quality Standards for CO were being exceeded. During winter 1994-95, no NAAQS exceedences occurred during the NPS monitoring study at the west entrance station. However, in-

data gathered at the west entrance in Yellowstone, namely that tourists may be exposed to significant levels of CO. However, a violation of national standards is not expected under present traffic populations due to the siting criteria used to determine compliance with National Ambient Air Quality Standards.

In yet another informal study, Yellowstone National Park rangers fitted with sampling equipment drove from West Yellowstone, Montana, to Old Faithful in typical snowmobile tourist fashion. The 1-hour CO samples that they collected were as high as 36 ppm. This was a very informal investigation that nevertheless illustrates the exposure of snowmobile tourists to significant levels of CO.

Because of the increasing concerns about pollution from snowmobiles and the informal data to this effect, we undertook an investigation to quantify and predict exposure to pollution for people who travel on a trail behind another snowmobile.

Our research objectives were to quantify the amount of CO emitted from a snowmobile under steady-state conditions, to quantify the amount of CO an individual is exposed to while driving behind another snowmobile as a function of speed and distance behind that snowmobile, and to develop a model to predict exposure to CO and other pollutants while traveling in the wake of a snowmobile.

STUDY AREA AND METHODS

We performed all emission and exposure testing along a section of snowmobile trail in Grand Teton National Park

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Figure 2. The study took place on flat terrain in Grand Teton National Park and involved a test snowmobile equipped for airflow measurement and exhaust sampling.

(fig. 1, page 1). The trail was ideal for testing. It ran along a valley floor and was relatively flat and straight. Snowmobile traffic was light and did not interfere with controlled test conditions. Additionally, air inversions in this site in winter were strong and permitted us to take the exposure measurements in extremely calm conditions.

To determine the amount of CO emitted from a snowmobile under steady-state conditions, we measured the rate of airflow into the engine and collected bag samples of snowmobile exhaust while traveling at four different speeds over flat terrain (fig. 2). The speeds ranged from 10-40 miles per hour (mph) in order to cover the range of speeds usually occurring on park snowmobile trails. We then measured the CO concentration in each sample bag back at the lab (fig. 3). We used the data to calculate an average mass emission rate of CO for each speed.

To quantify the CO exposure of a following snowmobiler, we took bag samples at five different distances and four different speeds behind a moving snowmobile. We accomplished this by riding a second snowmobile at fixed distances behind the first snowmobile while collecting bag samples (fig. 4). The distances ranged from 25-125 feet. The speeds were the same as used in determining CO emission rates. We also took CO samples in the absence of a lead snowmobile so that we could correct the data for CO from self-exposure. Every effort was made to take exposure data under stable atmo-

National park visitors traveling on snowmobile trails may be exposed to significant levels of carbon monoxide

vestigators did take samples on the snowmobile trail for informational purposes. The 1-hour bag samples taken near the entrance exceeded 35 ppm at two sites and the 8-hour average CO concentration exceeded 8 ppm at one site (Yellowstone National Park 1995). Therefore, concentrations at the west entrance exceeded levels established by the government to protect public health. However, the sampling method and locations used to collect this informal data did not meet guidelines for determining NAAQS compliance. Therefore, the results did not require national or state officials to take action. However, the results are scientifically valid and indicate the potential exposure of snowmobile tourists to significant CO levels.

During winter 1995-96, an informal study was conducted at Flagg Ranch in Grand Teton National Park, Wyoming. The conclusion was the same as that from



Figure 3. Snowmobile exhaust was collected in bags in the field (arrow), diluted, and then analyzed in a laboratory. The canisters contain gases used to calibrate the carbon monoxide analyzer.

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Average carbon monoxide exposure measurements (corrected for self-exposure) at speeds from 10-40 mph and distances of 25-125 feet ranged from 0.5-23.1

bile. This model is valid under stable atmospheric conditions in no or light wind. We will also be able to use this model to predict exposure to the unburned hydrocarbons including air toxics present in snowmobile exhaust when information becomes available. This will provide useful

information on exposure to pollutants other than CO without requiring more expensive testing.

IMPLICATIONS

The major implication of this research is that national park visitors traveling on snowmobile trails may be exposed to significant levels of CO. Although the steady-state exposure data from one snowmobile does not indicate average

spheric conditions. We wanted to predict the maximum exposure possible for individuals that follow another snowmobile.

RESULTS

The average steady-state CO emissions ranged from 9.9 g/mile (99 g/hr) to 19.9 g/mile (795 g/hr) (Table 1, page 10). The current national CO emission standard for new cars is 3.4 g/mile (Black 1991). However, automobile emissions are measured while the vehicle is driven according to a prescribed driving schedule. Therefore, the CO emission standard for automobiles represents the average CO emitted from a vehicle under a variety of driving conditions including acceleration and idling. We measured CO snowmobile emissions under steady-state driving conditions only. Therefore a comparison of the CO emissions that we measured with automobile emissions would be improper. To compare the snowmobile emission results in our study with automobile emission standards, we must know the steady-state CO emissions from an automobile.

In a recent study at the University of Tennessee, Sluder (1995) measured steady-state CO emissions from a 1988 Chevrolet Corsica. For speeds ranging from 10-40 mph, the steady-state tailpipe emissions of CO ranged from 0.01 to 0.04 g/mile. These values are approximately 1,000 times smaller than the steady-state snowmobile emissions we measured in our investigation. Therefore, our results support the claim that snowmobiles produce significantly more CO than a present-day automobile.



Figure 4. The study required a constant distance between the emitting snowmobile (front) and the trailing snowmobile that recorded the exhaust concentrations.

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exposures greater than 35 ppm, many factors lead us to believe that CO exposure may be significant.

1. Snowmobile tourists typically travel in large groups. Exposure to CO for the last person in the group will be significantly higher than the concentrations we measured behind only one snowmobile.
2. Our investigation dealt with only steady-state conditions. Snowmobiles emit more CO when under power or accelerating. Therefore, the steady-state emissions we measured are a "best-case" emission volume. Exposure will increase at other than constant speed.
3. Park snowmobile trails force snowmobilers to travel directly behind other snowmobiles. The wake of leading snowmobiles cannot be avoided other than by keeping a large gap between snowmobiles.
4. Many park trails are at high altitude where the effect of CO on unacclimated people is intensified.

Using the emission and exposure data from our investigation, we developed a simple model to predict exposure to CO while traveling in the wake of a snowmo-

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5. In many parks, air inversions are strong and create calm conditions that prevent the rapid dispersion of pollution.

TABLE 1. AVERAGE STEADY-STATE CARBON MONOXIDE EMISSIONS FROM A SNOWMOBILE

Speed (mph)	Average CO Emission (g/mile)
10	9.9
20	10.5
30	10.8
40	19.9

TABLE 2. CARBON MONOXIDE EXPOSURE MEASUREMENTS AT VARIOUS SPEEDS AND DISTANCES. EACH VALUE IS CORRECTED FOR SELF-EXPOSURE AND REPRESENTS THE AVERAGE OF 4-5 INDEPENDENT TESTS

Speed (mph)	Distance (ft)	Average CO Exposure (ppm)
10	25	23.1
	50	2.6
	75	0.5
	100	2.4
	125	5.1
20	25	13.0
	50	5.4
	75	2.4
	100	3.4
	125	1.8
30	25	12.1
	50	5.0
	75	3.5
	100	6.69
	125	3.0
40	25	19.6
	50	11.1
	75	8.6
	100	8.9
	125	8.4

6. Many trips on national park snowmobile trails require several hours of driving, increasing exposure to CO.
7. Exposure data from our study were corrected to disregard self-exposure to CO. We measured as much as 10 ppm of CO from self-exposure under steady-

state conditions. This self-exposure is expected to increase with a tailwind or while decelerating.

SUGGESTIONS

The exposure to pollution from snowmobiles on park snowmobile trails may be reduced by a reduction in the emissions from snowmobiles, a decrease in the numbers of snowmobiles on park trails, and avoidance by snowmobilers of stable weather conditions and high-density traffic where significant exposure may occur.

Reducing the emissions from snowmobiles is the most desirable option. In this way, snowmobilers may continue to enjoy popular destinations without restriction. It is possible to make snowmobiles less polluting. One easily implemented first-step is requiring the use of oxygenated fuels. A recent study on small two-stroke engines (Sun et. al. 1996) concluded that oxygenated fuels can reduce UHC and CO emissions by 10-20%. Additionally, their high octane rating can improve engine performance. During winter 1996-97, Yellowstone National Park snowmobiles were run on oxygenated fuels to evaluate the feasibility of this alternative. Other technological options include switching to a small, four-stroke engine with conventional pollution control equipment, running a two-stroke engine slightly lean with catalytic after-treatment, or using a two-stroke engine with fuel injection (with a redesigned combustion chamber). All of these solutions will increase the cost of snowmobiling.

Decreasing the amount of snowmobilers on park trails is the most controversial solution. However, if emissions from snowmobiles are not reduced voluntarily, this may be the only effective option.

Finally, snowmobile tourists should be warned of the potential exposure to pollution and taught to recognize early signs of excessive exposure. They can decrease their own exposure by traveling in small groups, touring on windy days, turning off the engines of stationary snowmobiles, avoiding popular destinations during peak season, driving far behind other snowmobiles, and by driving off-centerline whenever safe and legal.



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