

ORIGINAL RESEARCH

## A comparison of carbon monoxide levels during the use of a multi-fuel camp stove

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**Objective.**—The use of camp stoves in an enclosed or poorly ventilated space is clearly not recommended due to the risk of carbon monoxide (CO) poisoning. Instances may arise, however, when use for a limited time is necessary. We sought to find differences in CO levels between various fuels used to power a commercially available camp stove.

**Methods.**—A comparison was made between unleaded gasoline, kerosene, and white gas (Coleman fuel). The stove, fuels, and CO detector were all purchased from local retailers. A 0.4-m<sup>3</sup> space was constructed with a cardboard box. Three trials were performed using each fuel in which water was heated over the stove for 5 minutes. Measurement of the CO level within the box was taken every 30 seconds.

**Results.**—Kerosene created CO levels of 714 (SD = 113.5) parts per million (ppm) at 2½ minutes but was out of the measurable range of >999 ppm within 4 minutes on each of its trials. White gas burned the cleanest, with an average of 212 ppm (SD = 27.8) at 2½ minutes and 348 ppm (SD = 76.0) at 5 minutes. Unleaded gasoline created 305 ppm (SD = 27.1) at 2½ minutes and 464 ppm (SD = 31.6) at 5 minutes.

**Conclusion.**—All of the fuels created a high level of CO in a short period of time. White gas burned the cleanest and would be preferred to unleaded gasoline or kerosene in the event that the unvented use of a camp stove was necessary.

*Key words:* carbon monoxide, camp stoves

### Introduction

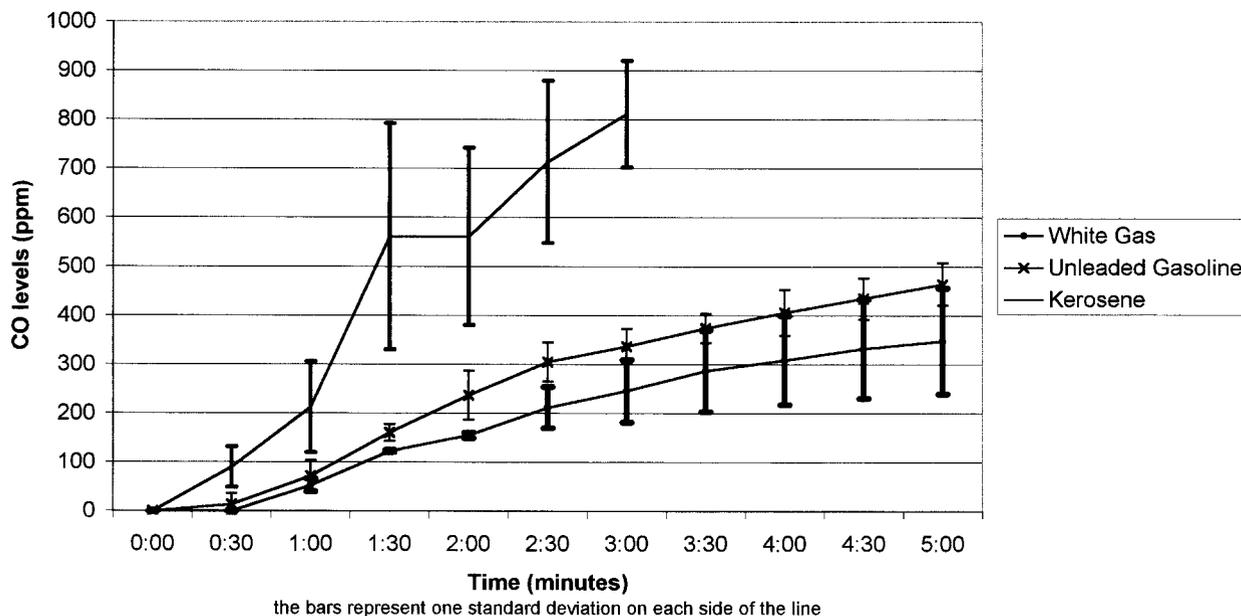
In 1934, Richard E. Byrd headed an ambitious scientific expedition to Antarctica. Due to difficulties negotiating through the ice pack, Byrd was unable to adequately supply an advance weather station before the fall of the winter's night. Rather than give up the base, Byrd elected to man it alone, isolated for the duration of the winter. In the first few days of his stay, he frequently found ice in his ventilation shaft, and only weeks after his support party left, this problem necessitated the choice between freezing to death in his hut and suffering carbon monoxide (CO) poisoning. He was forced to balance his symptoms of headache, nausea, loss of motor control, and confusion against  $-60^{\circ}\text{F}$  weather. His difficulties soon became evident to the rest of the expedition mem-

bers at the coastal station, but it took nearly 2½ months for a relief party to reach him.<sup>1</sup>

While this scenario is unlikely to be repeated, outdoor CO poisonings do occur.<sup>2–4</sup> In especially inclement weather, it may be tempting or even necessary to use an outdoor stove in an enclosed space.<sup>5</sup> From 1990 to 1994, a yearly average of 30 fatal CO poisonings occurred inside tents or campers.<sup>6</sup> Researchers who have examined the use of outdoor stoves in snow caves found a significant increase in the serum CO levels of the participants.<sup>7</sup> The subjects of this study remained symptom free but did show a 6-fold increase in their carboxyhemoglobin levels in an atmosphere in which the ambient CO levels went from a mean of 1.9 parts per million (ppm) to 15.3 ppm. This study examined primarily young males, but pregnant women, children, and patients with preexisting heart disease are at greater risk at relatively lower levels of CO.<sup>8–14</sup> Two studies showed an additive effect of altitude and CO level on symptoms in participants with heart disease.<sup>9,10</sup>

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Comparison of fuels (average values of 3 trials for each fuel).

We hypothesized that the CO level would be dependent on the type of fuel being burned and sought to determine how the use of various fuels changed the ambient level in an enclosed space. We hoped to be able to make some recommendations as to which type of fuel could be most safely burned when conditions necessitate the use of a stove in areas with poor ventilation.

**Methods**

A multi-fuel stove (Sigg Fire Jet, ArNr 3605.20, Sigg AG, Switzerland) was purchased along with 3 types of fuel from a local retailer. We tested white gas (Coleman Co, Wichita, KS), unleaded gasoline, and kerosene. CO levels were measured using a Nighthawk CO detector (Nighthawk, Mebane, NC), which has a range of 0 to 999 ppm.

An unventilated 0.4-m<sup>3</sup> space was constructed from cardboard to simulate a small snow cave. Baseline levels of CO were measured, then 3 trials with each fuel were performed, for a total of 9 trials. In all trials, water was heated over the stove to keep temperature in the model relatively constant. The stove had been used several times prior to initiating our experimental trials. We did not formally randomize the order of the trials. The fuels were burned in order of convenience. The stove was cooled between trials and cleaned when it appeared dirty.

During each trial, the CO level was plotted against time for 5 minutes. If the levels exceeded 999 ppm, the trial was discontinued and the time noted. Between each

trial, the CO level was returned to the baseline level of 0 ppm. Trials were conducted over 2 sessions, both on sunny afternoons with outside temperatures between 55 and 65°F. Measurements were conducted at 400 feet above sea level. No human subjects were placed inside the model, but the CO levels were observed continuously by the primary investigators.

**Results**

White gas caused the lowest rise in CO levels, with an average of 212 (SD = 27.8) ppm at 2½ minutes and 348 (SD = 76.0) ppm at 5 minutes. At no time in any trial of the white gas did the CO levels rise above 500 ppm. Unleaded gasoline caused higher average CO levels, creating 305 (SD = 27.1) ppm at 2½ minutes and 464 (SD = 31.6) ppm at 5 minutes. In one trial, the unleaded gasoline produced a level of 501 ppm at 5 minutes. Kerosene produced the highest CO levels. At 2½ minutes, average levels were 714 (SD = 113.5) ppm. In all 3 trials, CO levels were out of the measurable range of 999 ppm within 4 minutes. The range at 2½ minutes for each of the fuels was from 170 to 253 ppm for white gas, from 267 to 346 for unleaded gasoline, and from 544 to 875 for kerosene. A comparison of average CO levels produced by each fuel is shown in the Figure.

**Discussion**

Byrd’s symptoms of headache, nausea, and confusion during his stay at Advance Base in Antarctica suggest

carboxyhemoglobin levels of 20% to 30%. Studies show that ambient levels of 200 to 500 ppm must be obtained in order to raise serum carboxyhemoglobin acutely to this significant degree.<sup>15</sup> In our study, we found that these levels could be reached rather quickly in the small space that we had.

We used a model of a snow cave because we could easily control the conditions under which it was used. Our model was unventilated and much smaller than usual. We did not feel we could exact a high degree of control in an actual snow cave. A real cave could not be easily ventilated back to the control levels, and even the volume would be subject to change. The volume and ventilation in our model remained constant in all trials. We could rapidly ventilate the model to a baseline of 0 ppm, and the smaller volume allowed us to reach significant levels of CO quickly. While our model was much smaller than an actual snow cave, we felt this was an appropriate method, as we were interested in comparing the fuels rather than in looking at the absolute level of CO produced. It is unlikely that such high levels of CO would be produced as quickly in a carefully built and ventilated snow cave.

We did not randomize the order in which we performed the trials. The stove had been used several times before the data collection phase of the study, and we made sure it was cleaned if it appeared to be burning inefficiently. We do not believe the order of trials significantly affected the data.

The object of this study was to compare CO production by various fuels. We did not test whether different stoves would cause variable levels. It is possible that the type of stove may be significant, and this is an area of possible further study. We found that white gas (Coleman fuel) performed significantly better than the other 2 fuels. We did not test other brands.

During the design of this project, we had several suggestions for various models, such as tents or actual snow caves. We felt that this project had a limited objective, and we wanted to minimize further variables. Future studies are needed to determine the levels of CO produced under actual conditions. While we did not use human subjects, this study suggested that high carboxyhemoglobin levels could be produced within a short period of time by burning fuel in an enclosed space. It would be useful to know what cooking times produce clinically significant CO levels in humans in ventilated tents and snow caves, as extreme situations may arise that would necessitate this risky practice. Future work

could focus on variables such as the type of stove and methods of ventilation. We found significant differences in the ambient levels of CO produced, depending on the fuel, with white gas being the safest in our model.

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