Carbon Monoxide Poisoning in Florida During the 2004 Hurricane Season

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Background: During August–September 2004, four major hurricanes hit Florida, resulting in widespread power outages affecting several million households. Carbon monoxide (CO) poisonings during this period were investigated to identify ways to prevent future poisoning.

Methods: Medical records from ten hospitals (two with hyperbaric oxygen chambers) were reviewed to identify individuals diagnosed with unintentional CO poisoning between August 13 and October 15, 2004. Multiple attempts were made to interview one person from each nonfatal incident. Medical examiner records and reports of investigations conducted by the U.S. Consumer Product Safety Commission of six fatal poisonings from five additional incidents were also reviewed.

Results: A total of 167 people treated for nonfatal CO poisoning were identified, representing 51 incidents. A portable, gasoline-powered generator was implicated in nearly all nonfatal incidents and in all fatal poisonings. Generators were most often located outdoors, followed by inside the garage, and inside the home. Telephone interviews with representatives of 35 (69%) incidents revealed that concerns about theft or exhaust most often influenced the choice of location. Twenty-six (74%) households did not own a generator before the hurricanes, and 86% did not have a CO detector at the time of the poisoning. Twenty-one (67%) households reported reading or hearing CO education messages before the incident.

Conclusions: Although exposure to public education messages may have encouraged more appropriate use of generators, a substantial number of people were poisoned even when the devices were operated outdoors. Additional educational efforts and engineering solutions that reduce CO emission from generators should be the focus of public health activities.
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Introduction

Portable, gasoline-powered electric generators are a common cause of unintentional carbon monoxide (CO) poisoning following power outages because of natural disasters.[1–3] When used in an enclosed or poorly ventilated area or in proximity to occupied buildings, their exhaust can quickly infiltrate living spaces and incapacitate or kill occupants.[4] Measurements conducted by the United States Consumer Product Safety Commission (CPSC) suggest that the exhaust from a typical 5-kilowatt generator contains a concentration of CO equivalent to the tailpipe emissions of between 252 and 572 idling vehicles.[4,5]

Current preventive measures focus on educating the public about the hazards of CO and the improper use of portable generators.[6] These campaigns reinforce labeling on the devices and information in manuals that warn users not to operate the engines in an enclosed space. However, no published information is available about what constitutes an adequately ventilated location or a safe distance from occupied buildings. In addition, published studies of generator-related poisoning have examined exposures occurring during power outages subsequent to winter storms.[3,7] Patterns of portable generator use during warm-weather power outages and how they may contribute to CO poisoning have not been examined.

During August and September 2004, four major hurricanes hit Florida, resulting in widespread power outages that affected several million households. An

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estimated 18% to 54% of households in Florida used a generator for power after at least one of the hurricanes.[8,9] Public health officials launched an educational campaign across the state in advance of landfall of the storms about the safe use of portable generators and the hazards of CO. Nevertheless, six deaths attributed to CO poisoning occurred within 5 days after landfall of three of the storms. The Florida Department of Health also identified an increase in the number of people treated for CO poisoning at hospitals participating in posthurricane disease surveillance.

This study was designed to examine the characteristics and sources of CO exposure in these fatal and nonfatal CO poisoning cases, and to describe the placement and use of portable generators associated with poisoning incidents. Factors contributing to the decision about generator placement, including the history of generator ownership and experience, and awareness of the potential hazard posed by CO as delivered by public health messages, were a focus of the investigation.

Methods

To identify incidents of CO poisoning, the authors reviewed all medical records from participating hospitals in which a person received a diagnosis of unintentional CO poisoning (International Classification of Diseases, Ninth Revision code 986) during August 13–October 15, 2004. These dates correspond to the time period between landfall of the first hurricane and 3 weeks after landfall of the last, when active surveillance for CO poisoning was discontinued. Participating hospitals included a network of nine hospitals involved in posthurricane surveillance (one of which had a hyperbaric oxygen [HBO_2] chamber), and another hospital located in central Florida that also had an HBO_2 chamber. Any person diagnosed with unintentional CO poisoning not related to a fire was included as a case.

Records of medical examiners and of investigations of six deaths conducted by the CPSC were also reviewed for basic demographic information and details about generator location; the authors of this study conducted no interviews relative to any of the fatal poisonings.

Multiple attempts were made to contact one person from each nonfatal incident by telephone. After describing the study and receiving informed consent from an adult member of the household familiar with the incident, the interviewer administered a questionnaire about the source of CO, the location and time line of events, and healthcare seeking. If the source was determined to be a generator, the respondent was asked about its location, operation, and history of ownership, including procurement, experience, training in safe operation, and warning labels. In addition, the interviewer inquired about the presence of CO detectors, and knowledge about the characteristics and potential hazards of CO. Nonidentifying demographic information—including languages spoken in the home, tobacco use, race and ethnicity, and total household income—was collected. Households that could not be reached by telephone were sent a letter describing the investigation and requesting their participation.

Consent scripts and survey questionnaires were translated into Spanish and administered to a respondent in a Spanish-speaking household by a native Spanish speaker.

Statistical analyses were conducted during 2005–2006 using Stata version 8.2 (Stata Corporation, College Station TX, 2005) and SAS version 9 (SAS Institute, Cary NC, 2005). Dichotomous data were analyzed using the chi-square test (>5 observations in all cells) or Fisher's exact test (≤ 5 observations in more than or equal to one cell). All tests were two-sided and an alpha level of $p<0.05$ was considered statistically significant.

This investigation was approved by the Human Subjects Committees at the Florida Department of Health and the U.S. Centers for Disease Control and Prevention.

Results

A total of 167 people diagnosed with nonfatal CO poisoning during the study period were identified, representing a total of 51 exposure incidents. In the six fatal cases representing five incidents the role of CO exposure was confirmed. The number of cases and incidents peaked within 2 days after landfall for all four hurricanes (Figure 1). Figure 2 shows the locations of the fatal and nonfatal poisonings and the tracks of the four major hurricanes affecting Florida. A total of 154 people were treated and released from the emergency department; 13 (8%) others were hospitalized. Overall, 77 (46%) people were treated with HBO_2; further details about the clinical presentation and medical treatment of these people have been published elsewhere.[10]

Multiple attempts were made to contact a victim or representative of all 51 nonfatal poisoning incidents. However, respondents at 2 (4%) households refused to participate, and no respondent could be contacted at 14 households (27%). Overall, interviews with respondents representing 35 of the 51 incidents (69%) were completed.

Demographic Characteristics

Table 1 summarizes the demographic characteristics of individuals with nonfatal and fatal poisoning. The mean ($\pm$SD) number of people diagnosed with CO poisoning per incident was 3 ± 2 (range 1–8). This number did not differ significantly between households that were interviewed and those that were not. According to the 35 respondents, English was the primary language spoken in 27 (77%) households, followed by Spanish (14%), Haitian Creole (6%), and Vietnamese (3%). Twelve respondents (34%) reported that a second language was spoken in the home.

Source of CO and Location of Devices

The findings presented here use information from interviews with the 35 households to confirm the use and location of CO sources in this group. Thus, these results update those released earlier, which relied ex-

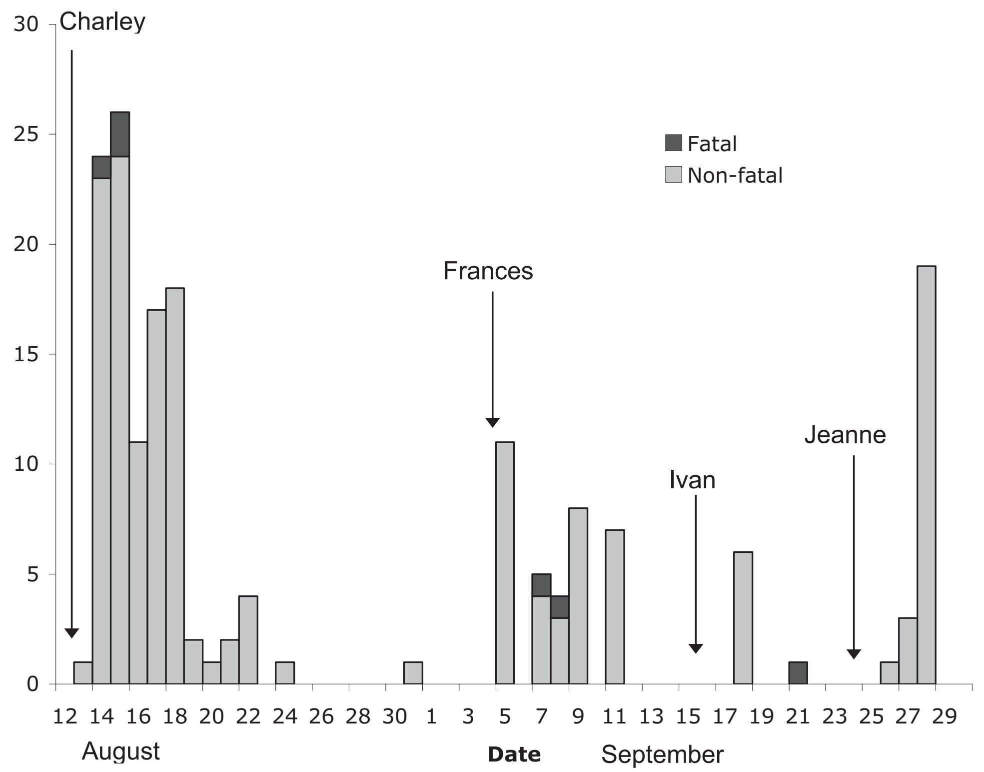

Figure 1. Number of cases of fatal (n=6) and nonfatal (n=167) carbon monoxide poisoning, by date of exposure—Florida, August–September 2004. This figure uses information obtained from household interviews and additional review of medical examiner records to update incident dates depicted in a previously released figure (see reference 10); as a result, the timing of some incidents has been corrected.

clusively on medical records to estimate the use and location of CO sources in all 51 incidents.[10]

Information about the source of CO was available for 48 (94%) nonfatal incidents and for all five incidents with fatalities. Of these, portable generator use was implicated in 46 (96%) nonfatal incidents and in all five incidents with fatalities. In the other two nonfatal incidents, CO exposure was attributed to use of a gasoline-powered saw and of a generator affixed to a recreational vehicle (RV). In one incident (3%), two generators were used.

Table 2 summarizes the location of the generators for the incidents with nonfatal and fatal poisoning. In 22 (48%) of the 46 nonfatal incidents in which a generator was known to be involved, the generators had been operated outside the dwelling, 15 (33%) inside the garage, and 7 (15%) inside the home; the location of the generator was unknown for 2 (4%) incidents. Ambient CO levels were not known for the majority of incidents, but were elevated in three nonfatal incidents.

Location of Incidents

All 35 households that were interviewed reported losing electrical service from the power company after the hurricanes. Fifteen (43%) households were without power for less than 1 week, 10 (29%) for 1–2 weeks, 8 (23%) for 2–4 weeks, and 2 (6%) for more than 4 weeks. Thirty (86%) incidents occurred in the home of the respondent. The remainder occurred in the home of a friend, neighbor, or relative (12%), or in an office or business (3%). Only two incidents occurred in an apartment or multiple-unit house.

Generator Placement and Operation

In interviews, representatives of households with CO poisoning who located their generators outside reported placing it an average of 7 feet from the nearest door or window of the home (range 1–30 ft). Eleven interviewed households placed their generators inside garages; all reported that these structures were attached to the house. Seven (64%) of these households reported that the garage doors were closed.

The decision about generator placement was most often influenced by concerns about theft (43%), exhaust (34%), length of extension cord (26%), desire to keep the device protected from rain and wind (26%), noise (11%), and the need to protect the device from flooding (9%). Nine households (26%) reported other reasons for the location of the generator, including that other people (salesmen) had delivered and set up the device. There was no relationship between demographic characteristics of the household and reported location of the generator. The decision

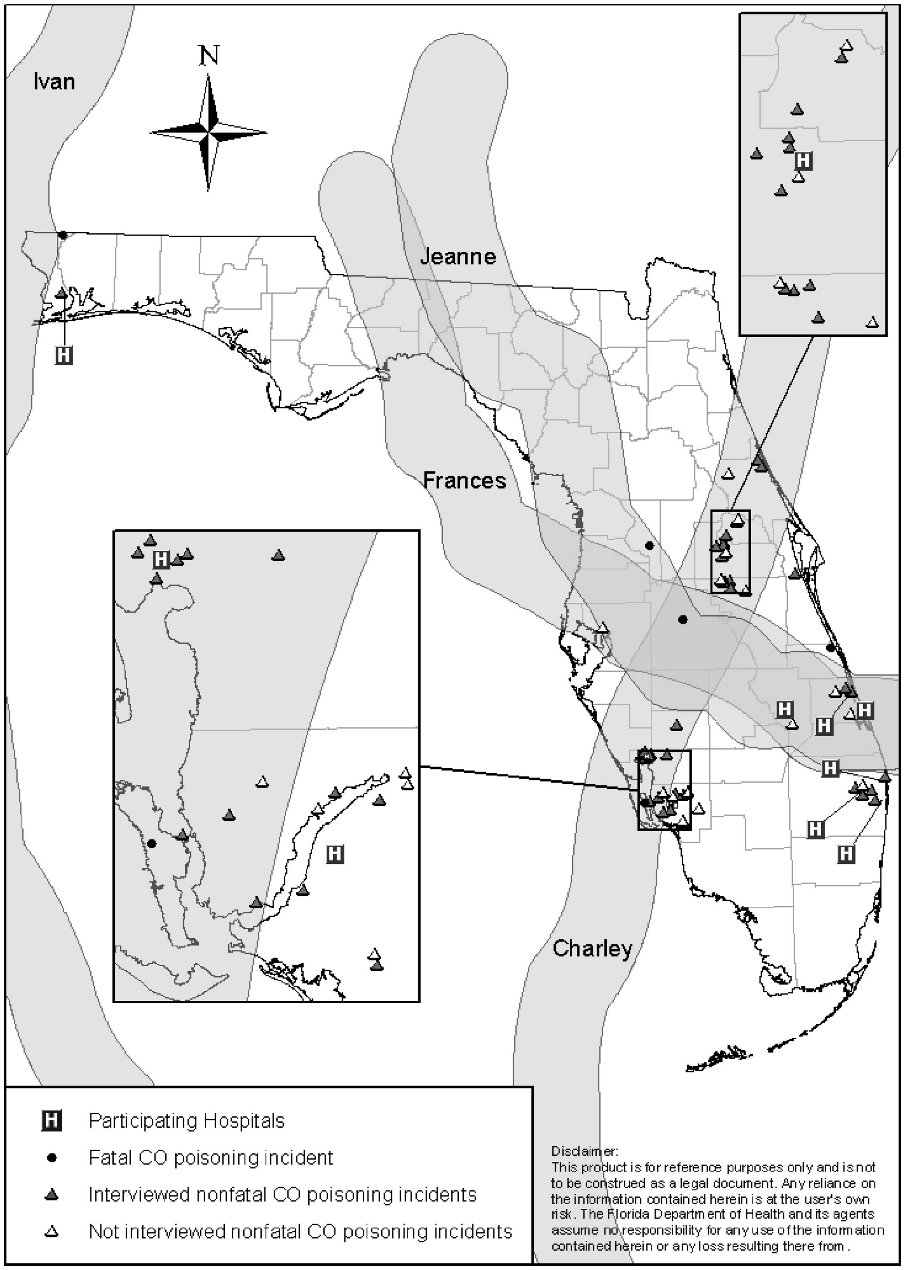

Figure 2. Fifty-mile diameter paths of the major hurricanes affecting Florida in 2004 and the location of nonfatal and fatal carbon monoxide poisonings. Not interviewed nonfatal CO poisonings incidents are depicted using a different symbol because a person involved in the poisoning has not confirmed the location of the incident. Projection/Coordinate System: GCS_North_American_1983; source data: Florida AHCA, NOAA, CO study. Map Date: 8 November 2006; Created by: L. Harduar-Morano, Florida Department of Health, using ESRI ArcMap version 9.1.

about where to place the generator was made by a male in the household in 25 (89%) of the 28 incidents in which this question applied or could be answered. Few people described difficulty with moving their generator(s).

Generators were most often operated at night (8 PM–12 AM) and overnight (12 AM–7 AM), usually to power refrigerators or freezers (86%), televisions (49%), air conditioners (46%), and fans (46%). A total of 17 households (49%) reported using their generator(s) for ≤ 1 day; 10 (29%) ≤ 1 week; and 8 (23%) for > 1 week.

Generator Ownership and Experience

Twenty-six (74%) of the incidents occurred in households that had not owned a generator before the hurricanes. Moreover, only 13 households (37%) had ever operated a generator before the hurricanes. Twenty-three (66%) households had purchased their genera-

Table 1. Demographic characteristics of nonfatal and fatal CO poisoning cases[a]

	Cases from nonfatal incidents n=167	Cases from fatal incidents n=6
Age in years		
Mean (±SD)	31 (±21)	44 (±12)
Range	<1–79	30–58
≤16 years	52 (31)	—
≥65 years	11 (7)	—
Gender		
Female	87 (52)	1 (17)
Race		
White	76 (45)	6 (100)
Black	36 (22)	—
Hispanic	47 (28)	—
Asian	6 (4)	—

[a]Information is presented as number (percent) unless indicated otherwise.

tor, usually from large home improvement or discount retailers. Nine (20%) households reported borrowing the generator, typically from a friend or neighbor. One (3%) household had rented their generator, while another (3%) reported receiving it at no cost from a federal agency. No household reported purchasing a CO detector while buying the generator, and no household reported being told that they should consider obtaining one.

Recognition of a Problem

In a total of 24 (69%) incidents, the household first suspected CO exposure when someone became ill. In three (9%) incidents, a friend or neighbor alerted household members to the problem. Respondents reported a median period of generator operation of 9 hours (range 3–72 hours) before noticing symptoms. Only 17 of 35 (49%) households immediately left the house when they first realized there was a problem. Ten (29%) households first tried to turn off the generator, while 5 (14%) reported attempting to open doors and windows.

Only four (11%) respondents reported the presence of a CO detector in the household at the time of the poisoning. Of these, only one (3%) reported hearing the device alert during the power outage; this detector was a part of an RV.

Safety Awareness and Perception

Twenty-two (63%) interviewed households reported reading about or hearing CO education messages—most often from television and radio—before they were poisoned. The percentage of households that placed their generator outside was nearly twice as high for those reporting hearing or reading CO prevention messages (59%) compared with households that did not hear or read these messages (31%); however, the difference was not statistically significant (p=0.078). In addition, while CO prevention messages did not specify a recommended distance from the home, generators were placed an average of 7 ft (±7; range 1–30) away from the homes of respondents who reported hearing or reading a message, compared with 5 ft (±4; range 1–10 ft) away from the homes of respondents who reported not hearing or reading a message. The percentage of households that placed their generator outside was higher among those who obtained their generator after the hurricanes (54%) compared with those who owned a generator before the storms (37%). However, the difference was not statistically significant.

Approximately 47% of the respondents reported receiving instruction in how to safely operate a generator; however, most received their information from friends, family, neighbors, or from the owner's manual. No household received information or training from a salesman or store employee. Six of eight (75%) households reporting instruction in safe generator operation placed their generator outside, compared with 11 of 26 (42%) households that did not report instruction; however, the difference was not significant (p=0.11).

Despite their experience with CO poisoning, some respondents still did not understand the nature of CO or the hazards of indoor portable generator use. When asked a series of questions about the properties of CO and where a generator could be safely operated, one thought that a generator could be safely used indoors as long as windows were open. Two believed a generator could be used indoors as long as windows and doors were open and an exhaust fan was running. Four respondents thought that CO has a smell, one said it has a taste, three believed CO is visible, and ten said that it can burn your eyes.

Discussion

After the 2004 hurricanes, a substantial number of households were poisoned with CO by operating por-

Table 2. Location of portable generator (or other CO-producing device) at the time of poisoning

	Number (percent)		
Source and location	Nonfatal incidents n=51	Fatal incidents n=5	Total N=56
Portable generator			
Outside	22 (43)	—	22 (40)
Inside garage	15 (29)	1 (20)	16 (29)
Inside home/business	7 (14)	4 (80)	11 (20)
Unknown location	2 (4)	—	2 (4)
Generator on recreational vehicle	1 (2)	—	1 (2)
Unknown device	3 (6)	—	3 (5)
Other device	1 (2)	—	1 (2)

table, gasoline-powered generators. Many of these were serious poisonings requiring emergency medical attention, HBO_2 therapy, and in some cases, hospitalization. All fatal incidents identified in this study resulted from indoor operation of a portable generator, while most households with nonfatal CO poisonings had placed their generator outside. Many affected households had recently purchased generators, and most respondents reported receiving some information on safe generator use and the hazards of CO. Households often attempted to minimize the risk of harm from generator exhaust when deciding where to locate their generator. CO detectors played little role in the recognition of the hazard; most incidents took place in homes that did not have them.

This investigation suggests that portable generators remain dangerous to people even if the devices are operated outside occupied buildings. At present, manufacturers advise operators not to locate generators indoors or in an enclosed area; however, the companies do not provide specific guidance on what constitutes a safe location for operation of the device. Photographs and audiovisual clips on the websites of leading manufacturers of portable generators illustrate use of the devices in locations unlikely to prevent intrusion of CO into living spaces (e.g., see www.colemanpowermate.com/generators/index.shtml). In addition, the risks for shock and electrocution posed by using nonweatherized devices in wet conditions create a unique set of challenges to the safe operation of portable generators in posthurricane settings.

This investigation suggests that people who reported exposure to messages about the safe use of generators were less likely to operate generators in a place that posed an obvious risk to health. Similarly, new generator owners were less likely to place generators inside their homes or garages. This finding suggests that this group may have received more or better warning information about potential hazards, perhaps from additional labeling on the devices. The finding that people frequently identified concern about exhaust as a reason for the choice of generator location also suggests that the primary messages of prevention campaigns may have beneficially influenced many generator owners. However, this investigation also illustrates that such campaigns, even when comprehensively implemented, are likely to be only partially effective. This suggests the potential role for engineering solutions that minimize CO emissions from portable generators or render them inoperable if CO concentrations reach a threshold level. At the least, generator manufacturers and public health agencies should work together to establish a safe minimum distance from occupied buildings for their operation.

Until then, this investigation provides information about factors affecting placement and use of generators after hurricanes that can be used to strengthen prevention efforts. Although the range of concerns that influenced generator placement is consistent with prior reports,[1] their relative importance differed in this study of warm-weather poisonings. In particular, concerns about theft and protection from weather were more common, suggesting the salience of specific posthurricane social and climatic conditions. Public health agencies should work with retailers and manufacturers to encourage the purchase and use of CO detectors and materials required to secure a portable generator. Prevention messages should emphasize locating generators far away from occupied buildings, and caution users about overnight operation and the importance of seeking fresh air immediately when CO exposure is suspected. Finally, educational interventions that target the generator owner at the point of purchase—through personal training, as well as signage and informational materials—should also be developed.

Limitations

This investigation used a sample of hospitals to collect cases of CO poisoning, and does not represent a complete inventory of cases in Florida during the 2004 hurricane season. Only those treated at participating hospital emergency departments and HBO_2 chambers were included in the study; consequently, it is likely that more severe cases of CO poisoning were differentially identified. In fact, the percentage of people treated with HBO_2 was higher in this investigation than in previous reports.[3,7,11–13] In addition to the method of case selection, this may reflect differences in the sources of CO exposure, greater regional availability of HBO_2, or more frequent use of HBO_2 in postdisaster situations. Households that participated in the interview may also differ systematically from those that were not reachable or that refused to participate; however, according to information in medical records there were no significant differences among these groups in the number or age of people affected, their ethnic composition, or the location of the generator. Finally, households were interviewed approximately 5 months after the final hurricane of 2004. This may have affected recall of certain aspects of the incident.

Conclusion

Use of portable generators after hurricanes is prevalent among households in Florida.[8,9] Sales of portable generators are also rising,[14] primarily because of the increased affordability of the devices and the encouragement of retailers and disaster preparedness campaigns. Although public education messages may have contributed to more appropriate use of portable generators among Florida residents during the 2004 Atlantic hurricane season, a substantial number of people were poisoned even when the generators were operated outside. Additional educational efforts and engineering solutions that reduce CO emissions should be considered to prevent future poisoning.

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