Letter to the Editor

Occupational Carbon Monoxide Poisoning Associated with Diesel Motor Operation in an Air-raid Shelter in June 2015, Jinan City, China—An Epidemiological Investigation*

CUI Liang Liang[1], ZHOU Jing Wen[1], GENG Xing Yi[1], LI Xin Wei[1], LIU Zhong[1], George A. Conway[2], and ZHANG Ji[1,#]

Occupational carbon monoxide (CO) poisoning related to diesel motor fumes in an air-raid shelter (ARS) was first identified in Jinan City, China, in June 2015. A total of 17 cases were identified, including 14 possible cases of firemen and 3 confirmed cases of water channel clean-up workers. The overall attack rate (AR) of firemen was 42% (14/33). The firemen had a significantly higher AR with a longer exposure and more protracted time of rescue in the ARS ($P < 0.05$). All the cases stated that they did not realize the potentially high level of exposure to CO in the ARS. CO poisoning posed a risk to both patients and service providers. Occupational safety and health education should be promoted and enforced in all workplaces where CO sources exist.

Carbon monoxide (CO) is an odorless, colorless gas produced by incomplete combustion of carbon-based compounds. Exposure to CO can cause various adverse health effects ranging from headache and fatigue to coma and death[1]. Thousands of illnesses and deaths have been documented through CO poisoning surveillance systems and accident investigations each year[2-3]. CO-generating equipment, such as motors and generators powered by fuel combustion, has been identified as the most common source of CO[4-5]. Most CO poisoning events can be attributed to poor ventilation and a lack of effective individual respiratory protection[3,6].

At approximately 14:00 PM on June 2nd, 2015, the emergency department doctor from hospital M reported several CO-poisoned patients who were water channel clean-up workers and firemen who had been exposed to an air-raid shelter (ARS) to the Jinan Municipal Center for Disease Control and Prevention, which triggered this epidemiological investigation. This study was considered to be part of a continuing public health event investigation by the Ministry of Health of Jinan, China, and thus was exempt from institutional review board assessment. All data were kept confidential without patient identifiers.

The objective of this paper was to report the investigation, including the description of the epidemiological characteristics, identification of the risk factors, and the evaluation of the exposure and the risk of poisoning. It aims to assist in the development of strategies to reduce CO occupational poisoning in the future.

After interviewing several patients and other insiders (firemen and directors involved in the rescue), we reenacted the scene and can provide a general description as follows: at approximately 8:00 AM, June 2nd 2015, three male water channel clean-up workers (workers A, B, and C) entered the left branch of the ARS in the Lixia District, Jinan City (Figure 1 and Supplement Figure 1, available in www.besjournal.com). A diesel motor was set up at the end of the left branch (the source of the water channel) and began to pump water out of the ARS at approximately 9:00 AM. After that, workers B and C began to clear the water channel while worker A transported diesel oil from the outside of the ARS. One hour later, workers B and C experienced headache, dizziness, and fatigue while they were 30 m away from the diesel motor. They called to worker A for help several times but received no response. Upon investigation, they found that worker A had fallen unconscious on his return route, approximately 20 m away. Workers B and C shut off

doi: 10.3967/bes2017.105

*This study was supported by the Medicine and Technology Development Plan Project of Shandong Province (2016WS0119).

1. Jinan Municipal Center for Disease Control and Prevention, Jinan 250021, Shandong, China; 2. Deschutes County Health Services Department, Bend OR 97703, USA

the diesel motor, evacuated the ARS, and sought to emergency assistance. At approximately 10:40 AM, team I, consisting of eight firemen from the Lixia District Fire Brigade, arrived at the scene to rescue worker A, while workers B and C were sent to hospital M. A total of 25 firemen from team II (eight members), team III (eight members) and team IV (nine members) arrived in groups to assist in the rescue. Finally, worker A was successfully rescued from the ARS at 14:50 PM, over 10 handovers between 33 firemen, and was sent to hospital M at 15:20 PM. During the rescue, several firemen also became ill and were admitted to hospital M. It was a sunny day with an average temperature (*AT*) of 26.6 °C (range: 19.2-30.6 °C), a relative humidity (*RH*) of 51%, and a wind speed of 3.5 m/s on June 2nd 2015, in Jinan City.

A possible case was defined as a water channel clean-up worker or fireman who was exposed to the ARS and had the onset of at least two of the following symptoms: headache, dizziness, nausea, or vomiting. A confirmed-case was a possible case with a blood carboxyhemoglobin (COHb) level greater than 10%[7]. A case search was conducted by reviewing the patients' records from hospital M, interviewing the workers and firemen involved in the rescue as well as the directors of the Lixia District Fire Brigade. Data on patient demographics, clinical symptoms, blood test results for COHb (%), and treatments were collected. A total of 17 cases were found to have been hospitalized for anoxic encephalopathy in the neurology department of hospital M. Of them, 14 possible-cases of firemen with a median age of 25 years old (range: 19-35) and three confirmed-cases of workers with a median age of 45 years old (range: 45-47). Among the 33 firemen, the overall attack rate (*AR*) was 42% (14/33), and the *AR* for each team was 75% (6/8) for team I, 13% (1/8) for team II, and 88% (7/8) for team III. No case was identified from team IV.

Treatments of 5 to 10 L/min concentrated oxygen to promote neural functional recovery and a hyperbaric oxygen chamber were given to each case, with no resulting deaths. Fourteen possible-cases of firemen and two confirmed-cases of workers B and C recovered after two weeks of treatment and four weeks of treatment, respectively. Worker A developed delayed neuropsychiatric sequelae during a two-month treatment. Most reported symptoms in the cases at the onset of illness included a headache (82%), dizziness (82%), and nausea (71%). Three workers were tested for blood COHb, and the concentration of COHb from low to high was 25.4% for worker B, 28.4% for worker C and 33.1% for worker A, individually. The 14 firemen who were possible-cases refused to allow testing for blood COHb.

A retrospective cohort study approach was applied, collecting each fireman's duration of exposure in the ARS, the times of rescue and personal protection equipment (PPE) use during the

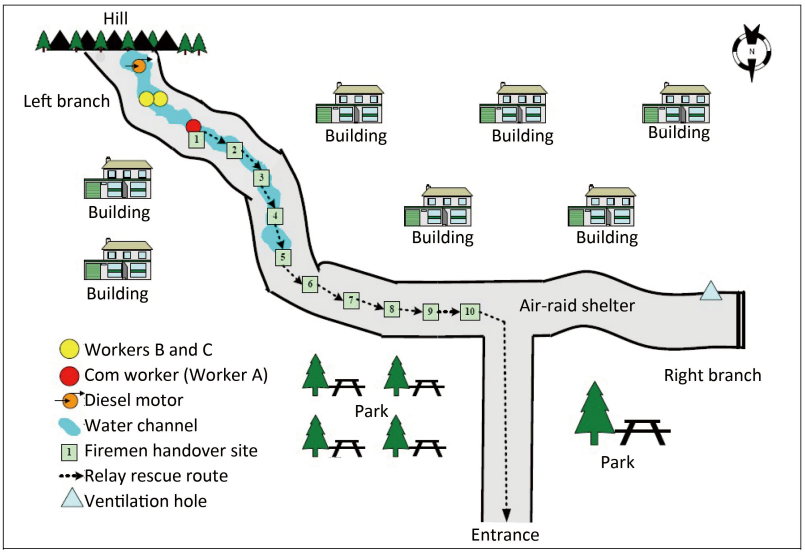


Figure 1. Firemen handover rescue action route in carbon monoxide poisoning accident in the ARS, June 2015, Jinan City. The air-raid shelter had only one entrance 1 m in width and 2 m in height and was built in a central park. Approximately 300 m of the ARS was divided into two branches, the left 200 m long and the right 100 m long, from an intersection 100 m from the entrance.

rescue action by face-to-face interview at the evening of June 2nd, 2015. Three workers' exposure durations were calculated by the time of escape from the ARS after the diesel motor started running. The exposure time sequence of the three workers and 33 firemen (Supplement Figure 1) showed that worker A had a longer exposure time, 335 min, than workers B and C, who spent 85 min in ARS, and the 33 firemen had different levels of exposure with a mean of 30 min (20-100 min). Therefore, the exposure duration variable for the 33 firemen was transformed into a three-level category variable, ≤ 30 min as a low-level, 31-60 min as a middle-level, and > 60 min as a high-level. Risk assessment indicated that the firemen in the more than 30 min exposure group had a significantly higher *AR* than those in ≤ 30 min exposure group [Rate Ratio (*RR*) and 95% Confidence Interval (95% *CI*) in the 31-60 min exposure group: 3.9 (1.7-9.1); *RR* and 95% *CI* in > 60 min exposure group: 4.6 (2.1-10.0)] (Table 1). A significant linear trend for exposure duration to illness was detected using Extended Mantel-Haenszel analysis (χ^2 = 13.22, P < 0.05). Twenty-six (79%) firemen had one prior rescue history and seven had more than two prior experiences. The firemen with two or more rescue actions had a markedly increased *AR vs*. those with only one [*RR* and 95% *CI* for two rescue actions: 2.6 (1.3-5.4); *RR* and 95% *CI* in four rescue actions: 3.3 (1.8-5.8)] (Table 1). A significant linear trend between rescue execution time and illness was detected (χ^2 = 6.85, P < 0.05). Interviews with the firemen showed that PPE was given to each fireman when executing the rescue. However, most of them did not realize the extremely high level of CO exposure; furthermore, some of them occasionally gave their PPE to worker A.

To estimate the CO level when the accident occurred, air quality parameters CO and carbon dioxide (CO_2) in 5 stations at the entrance site and at four inside sites of the ARS at 30 m, 50 m, 70 m, and 100 m away from the entrance were tested separately from 9:30 to 10:30 AM on June 3rd. The mean value was calculated by testing three times for each site and for 5 min at a time. Table 2 shows that the concentration of CO inside the ARS was sharply

Table 1. *RRs* and 95% *CI*[a] of 33 Firemen' Illness in Different Exposure Levels to Air-raid Shelter, Jinan City

Level of Exposures	Illness	Not Ill	Total	AR[b] (%)	*RR* and 95% *CI*
Exposure duration[c]					
≤ 30 min	5	18	23	22	ref
31-60 min	6	1	7	86	3.9 (1.7-9.1)
> 60 min	3	0	3	100	4.6 (2.1-10.0)
Rescue times[d]					
One	8	18	26	31	ref
Two	4	1	5	80	2.6 (1.3-5.4)
Four	2	0	2	100	3.3 (1.8-5.8)

Note. [a]Denotes the rate ratio (*RR*) and 95% confidence interval (95% *CI*). [b]Denotes attack rate. [c]A significant linear trend of exposure duration and illness was observed by Extended Mantel-Haenszel analysis (χ^2 = 13.22, P < 0.05). [d]A significant linear trend of rescue action executing times and illness was observed by Extended Mantel-Haenszel analysis (χ^2 = 6.85, P < 0.05).

Table 2. Concentrations of CO and CO_2 at Five Sites in Air-raid Shelter, Jinan City

Site away from Entrance	CO[c]		CO_2[d]		Environmental Parameters
	PPM[b]	% of Increased	PPM	% of Increased	
Entrance site	1.1	ref	463	ref	*AT*: 24.3 °C *RH*: 57%
30 m	7.2	554.5	996	115.1	*AT*: 16.6 °C *RH*: 72%
50 m	7.0	536.4	952	105.6	*AT*: 15.8 °C *RH*: 74%
70 m	6.2	463.6	1,245	168.9	*AT*: 15.7 °C *RH*: 74%
100 m[a]	7.3	563.6	1,652	256.8	*AT*: 15.5 °C *RH*: 72%

Note. [a]Denotes the cross of right branch and left branch. [b]Parts per million. [c]Tested by hand-held portable carbon monoxide gas infrared detectors (Company: US Interscan; Type: 4140-199.9 m; No: 011032). [d]Tested by hand-held portable carbon dioxide gas infrared detectors (Company: US Interscan; Type: TY-9800A; No: 011058-2).

higher than that at the entrance 24 h after the event occurred. The same trend was also observed for CO_2.

This study is the first reported large-scale investigation of occupational CO poisoning related to a diesel motor in an air-raid shelter in Jinan City, China. A total of 2,770 CO poisoning accidents were documented in Jinan from 2006 to 2014; most were non-occupational poisoning accidents caused by heating and warming of homes. Rarely were the occupational poisoning accidents, and none was related to a diesel motor (Unpublished data, from Jinan Public Health Events Surveillance System). A total of 17 cases were identified in this accident, three confirmed-cases among workers and 14 possible-cases for firemen, the first known CO poisoning of firemen in Jinan. This epidemiological investigation indicated that exposure to a high level of CO, combined with a lack of effective individual respiratory protection, might be the main cause of this CO poisoning accident. Blood carboxyhaemoglobin percentage is the most frequently-used biomarker of CO exposure[7]. In this accident, the blood carboxyhaemoglobin level of the three worker cases exceeded 25%, which is defined as severe CO poisoning.

Morbidity and mortality of occupational CO poisoning is considered to be preventable through education[6]. Lucas D[8] noted that the principal risk factor in an occupational poisoning accident was working without any protective means. In our report, three workers were exposed to a high-level CO environment in an air-raid shelter without any personal respiratory protection causing them to become poisoned. Air quality testing results 24 h after the accident occurred also found a high concentration of CO still existed inside the air-raid shelter. Therefore, proper occupational safety education and health training needs to be enforced in all workplaces where CO sources exist.

Per a literature review, it appears to be uncommon for service providers, health care professionals, and emergency medical services (EMS) personnel to be accidentally poisoned by CO. Roth D[9] reported an incident of unrecognized CO exposure leading to the hospitalization of 11 EMS personnel, and also found the most frequent CO exposure was to EMS personnel[10]. CO poisoning poses risks to both patients and service providers. In this case, the firemen were exposed to CO mainly because they did not realize an extremely high CO level existed and some of them occasionally gave their own PPE to worker A (a coma case). The risk assessment presented a consistently significantly association between a higher attack rate of poisoning and the longer time exposure and with the repetition of rescues. Another non-negligible fact is that hundreds of CO poisoning accidents occur in Jinan each year, posing an inevitable risk to service providers.

Some limitations should be considered in this study. First, a 24-h delay in the testing of CO inside the air-raid shelter indirectly reflected a high-level CO environment existed but we could not measure the true levels to which the cases were exposed. Second, CO blood carboxyhaemoglobin concentration for the firemen cases was not tested which weakened the evidence of the firemen cases identification. Finally, we retrospectively collected the exposure information from cases and recall bias could not be avoided.

We have reported an epidemiological investigation of a multiple-victim carbon monoxide occupational poisoning accident with 17 cases associated with a rescue operation in an air-raid shelter. Our findings reinforce the importance of occupational education and training for workers with any risk of CO environmental exposure. Specially, a risk assessment of CO poisoning for service providers such as firemen should be considered in rescue actions.

Acknowledgments The authors thank Prof. ZHANG Ying from the Sydney School of Public Health, University of Sydney, Australia for review of the manuscript.

[#]Correspondence should be addressed to ZHANG Ji, MPH, Tel: 86-531-81278877, Fax: 86-531-81278999, E-mail: zhangjicdc@163.com

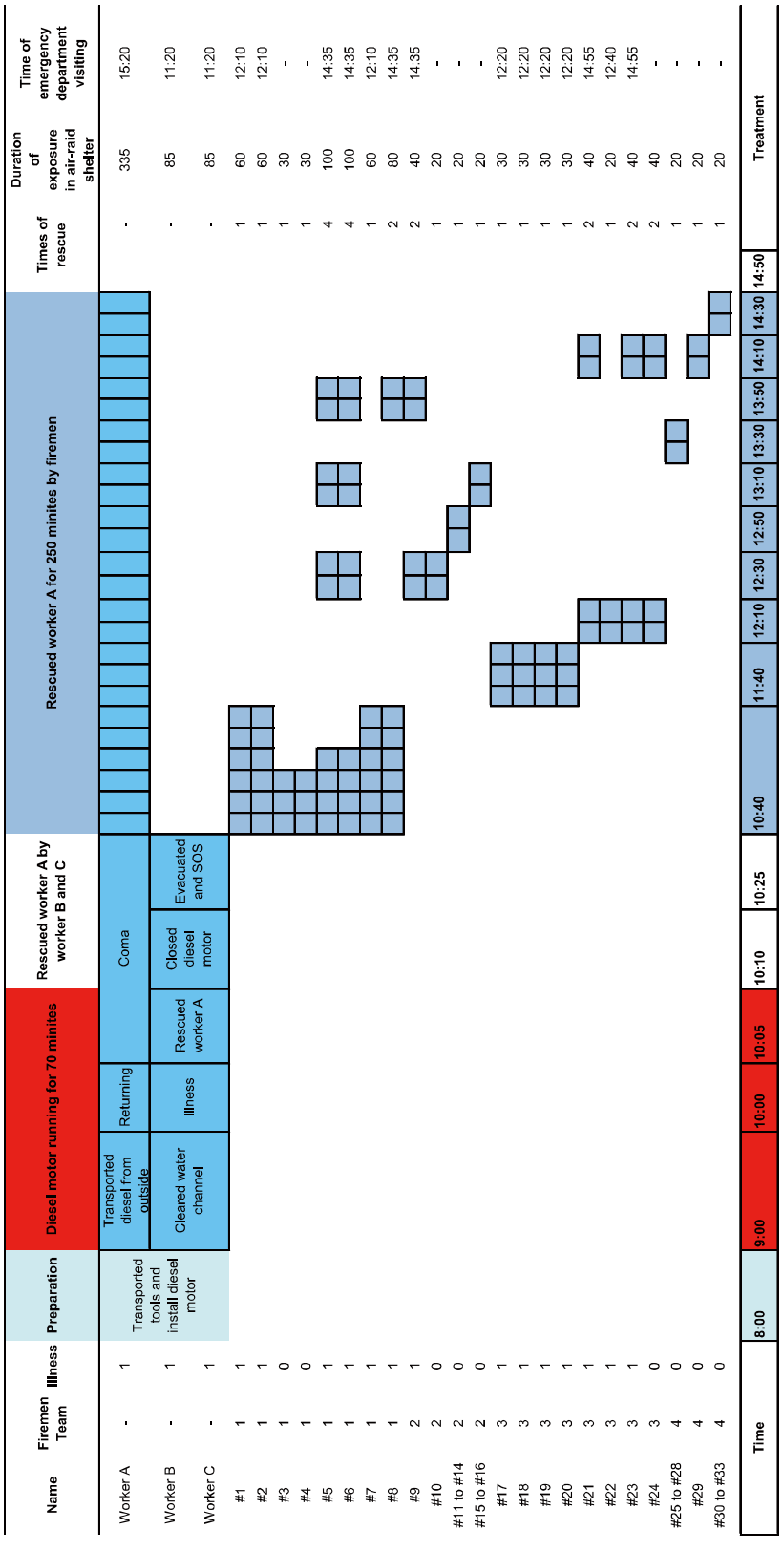
Biographical note of the first author: CUI Liang Liang, female, born in 1980, MPH, majoring in environmental and public health.

Received: May 2, 2017;
Accepted: August 17, 2017

REFERENCES

1. Wu PE, Juurlink DN. Carbon monoxide poisoning. CMAJ, 2014; 186, 611.
2. Braubach M, Algoet A, Beaton M, et al. Mortality associated with exposure to Carbon Monoxide in WHO European Member States. Indoor Air, 2013; 23, 115-25.
3. Iqbal S, Clower JH, Hernandez SA, et al. A review of disaster-related Carbon Monoxide Poisoning: Surveillance, Epidemiology, and Opportunities for Prevention. Am J Public Health, 2012; 102, 1957-63.

4. Environmental Protection Agency (US). Inside air quality. Carbon monoxide (CO). https://www.epa.gov/indoor-air-quality-iaq/carbon-monoxides-impact-indoor-air-quality#Sources. [2017-05-01]
5. Styles T, Przysiecki P, Archambault G, et al. Two Storm-Related Carbon Monoxide Poisoning Outbreaks—Connecticut, October 2011 and October 2012. Arch Environ Occup Health, 2015; 70, 291-6.
6. Henn SA, Bell JL, Sussell AL, et al. Occupational carbon monoxide fatalities in the US from unintentional non-fire related exposures, 1992–2008. Am J Ind Med, 2013; 56, 1280-9.
7. Smollin C, Olson K. Carbon monoxide poisoning (acute). BMJ Clin Evid, 2008; 2008, 2103.
8. Lucas D, Loddé B, Jegaden D, et al. Occupational poisoning by carbon monoxide aboard a gas carrier. Int Marit Health, 2010; 62, 176-9.
9. Roth D, Krammel M, Schreiber W, et al. Unrecognized carbon monoxide poisoning leads to a multiple-casualty incident. J Emerg Med, 2013; 45, 559-61.
10. Roth D, Bayer A, Schrattenbacher G, et al. Exposure to carbon monoxide for patients and providers in an urban emergency medical service. Prehosp Emerg Care, 2013; 17, 354-60.



Supplement Figure 1. Exposure time sequences of three workers and 33 firemen in air-raid shelter, Jinan City.