U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES ■ Public Health Service
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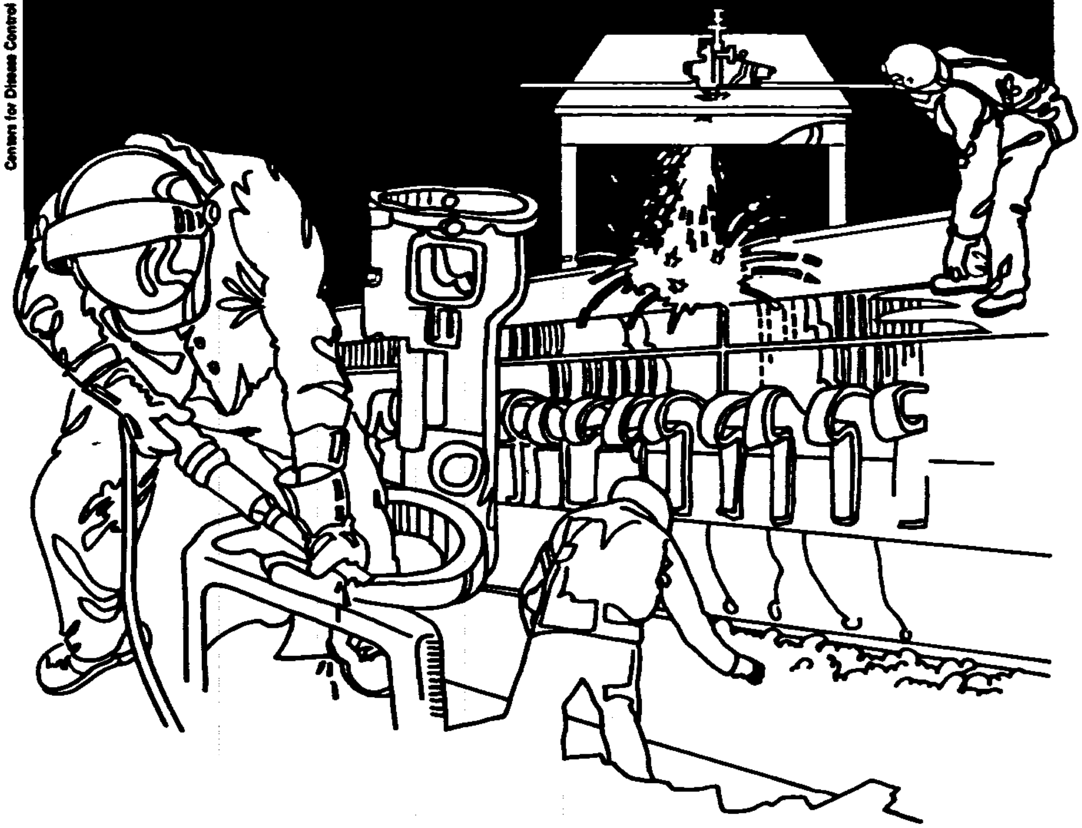

Health Hazard Evaluation Report

HETA 91-009-2108
CARBON/GRAPHITE GROUP
LOUISVILLE, KENTUCKY

PREFACE

The Hazard Evaluations and Technical Assistance Branch of NIOSH conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) of the Occupational Safety and Health Act of 1970, 29 U.S.C. 669(a)(6) which authorizes the Secretary of Health and Human Services, following a written request from any employer and authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found.

The Hazard Evaluations and Technical Assistance Branch also provides, upon request, medical, nursing, and industrial hygiene technical and consultative assistance (TA) to Federal, state, and local agencies; labor; industry and other groups or individuals to control occupational health hazards and to prevent related trauma and disease.

HETA 91-009-2108
APRIL 1991
CARBON/GRAPHITE GROUP
LOUISVILLE, KENTUCKY

NIOSH Investigator:
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I. SUMMARY

In September 1990, the National Institute for Occupational Safety and Health (NIOSH) received a request from a representative of the International Brotherhood of Firemen and Oilers at the Carbon/Graphite Group, Louisville, Kentucky, to investigate possible employee exposures to carbon monoxide (CO). The Carbon/Graphite Group is a manufacturer of calcium carbide and acetylene.

On November 27-28, 1990, NIOSH investigators conducted an industrial hygiene evaluation of the calcium carbide manufacturing area at the Carbon/Graphite Group. A walk-through examination of the manufacturing process was conducted on November 27, 1990. On the following day, full-shift personal monitoring (12 employees) and general area air monitoring for carbon monoxide was conducted throughout the facility. The exhaust ventilation systems were reviewed, and confidential interviews were conducted with 12 employees to determine the extent to which workers experience symptoms consistent with CO exposure.

Results of personal exposure monitoring using CO dosimeters indicated CO levels of 9 to 82 parts per million (ppm) as full-shift, time weighted averages. Several peaks above 200 ppm CO were observed. These results were found in areas where the CO dosimeter's readings were positively biased by the presence of acetylene gas. However, the high CO reading near a valve in the scrubber area is probably a true value, since the possibility of acetylene interference is minimal in this location. Confirmation of the acetylene interference in the other locations was performed by grab sampling with Tedlar® sampling bags and subsequent analysis by gas chromatography. Carbon monoxide was not found in any grab samples (limit of detection - 1 ppm). The Occupational Safety and Health Administration's Permissible Exposure Limit (PEL) and NIOSH's Recommended Exposure Limit (REL) for CO is 35 ppm for an eight-hour time-weighted average, and 200 ppm for a ceiling exposure concentration. Even with the acetylene interference, most of the dosimeter readings were below the evaluation criteria.

The results of confidential interviews with employees did not reveal complaints compatible with CO exposure. There were reports of specific incidents in the past where employees required medical treatment for short-term CO exposure.

Based on the results of this investigation, a health hazard from CO was not found in the calcium carbide manufacturing area on the days of the NIOSH investigation. Since large quantities of CO are produced as a by-product of the process, a potential hazard for CO exposure is possible during equipment failures or entry into confined spaces. Other possible hazards associated with the process are identified. Recommendations for improving engineering controls, safe work practices, and the use of personal protective equipment are included in Section VII of this report.

KEYWORDS: SIC 2819 (Calcium carbide manufacture), carbon monoxide, acetylene, calcium carbide

II. INTRODUCTION

In September 1990, a representative of the International Brotherhood of Firemen & Oilers Union, Local 320, requested that the National Institute for Occupational Safety and Health (NIOSH) conduct a Health Hazard Evaluation (HHE) at the Carbon/Graphite Group to evaluate employee exposure to carbon monoxide. The request stated that 30 to 40 employees were possibly exposed to carbon monoxide (CO) in areas of the plant where calcium carbide is manufactured and handled.

On November 27, 1990, NIOSH investigators visited the Carbon Graphite Group and conducted an initial walk-through inspection of the calcium carbide manufacturing facility. On the following day, a more thorough inspection of possible exposure sources was conducted, the furnace exhaust systems were reviewed, informal employee interviews were conducted, and air sampling was performed for measurement of carbon monoxide.

III. BACKGROUND

A. Process Description

Calcium carbide is produced by the reaction of high purity quicklime (calcium oxide) and metallurgical coke in an electric-carbide furnace at approximately 5000 ^{o}F.[1] Calcium carbide (CaC_2) forms in a liquid state at the bottom of the furnace, where it is drained ("tapped") from the furnace into cooling molds ("chill cars").

$$CaO + 3C \rightarrow CaC_2 + CO \quad [1]$$

Carbon monoxide (CO) is a reaction by-product that is collected under the cover of the furnace. Large capacity fans are used to draw exhaust gases (predominantly CO) from the furnace cover. Some of the CO may be used to dry coke. The CO is piped to a variable-throat, wet venturi scrubber to remove particulates, and is then flared, producing carbon dioxide.

The cylindrical furnace shell, nominally 35 feet in diameter, consists of reinforced steel side walls and bottom. The interior of the furnace utilizes three self-baking Soderberg electrodes positioned in a delta configuration. The electrodes consist of cylindrical steel casings that are suspended vertically above the furnace. The electrode casings are filled with a specially formulated Soderberg "paste," which consists of anthracite and coal tar pitch, supplied in the form of precast cylindrical blocks.

The mixture of coke and quicklime is continuously conveyed into the furnace at a coke to lime ratio of about 0.6. The fifth floor area of the furnace is equipped with a dust collection system to remove coke and lime dust as it is fed into the furnace. Another collection system (utilizing a bag house) exhausts fugitive dust emissions from the second floor level. Reportedly, carbide impurities or large quantities of fines within the furnace charge can encourage the formation of crusts, impeding the flow of carbon monoxide up through the furnace.

The furnace has three tapholes leading to the center of each electrode zone. When the tapping electrode touches the hot solidified carbide, a circuit is completed and sufficient heat quickly develops to melt the carbide, allowing a flow of liquid carbide to be released from the furnace. Each electrode is tapped in turn, making the operation an almost continuous process. Calcium carbide has very low electrical conductivity, which permits it to be drained directly into iron chill cars.

After cooling for 20 to 24 hours, the solidified calcium carbide pig is broken by dropping it on a breaking table at the mouth of a jaw crusher. The calcium carbide, after final crushing and screening, is packed into drums or is sent to the on-site acetylene generating plant. Acetylene (C_2H_2) is produced by the reaction of calcium carbide and water:

$$CaC_2 + 2H_2O \rightarrow C_2H_2 + Ca(OH)_2 + \text{heat} \quad [1,2]$$

Another use of calcium carbide is as a desulfurizing agent in the steel industry.

Reaction of CaC_2 with water vapor in the air will cause acetylene to be released. The highest levels of acetylene at the facility are likely to be found in areas where CaC_2 is present in a crushed form. In this area the high surface area of crushed CaC_2 permits rapid reaction with water vapor in the air.

The carbide furnace is operated 24 hours per day (three shifts). Approximately 7-9 employees are required per shift to staff the operation, not including maintenance crews who may be working in the area.

B. Alarm System

Area monitors for CO are located on the furnace and at the wet scrubber. The alarm level is set at 35 parts per million (ppm). In addition, employees working in the wet scrubber area are required to wear personal CO dosimeters. The company uses a two-level audible/visible alarm set at 35 ppm (as an action level) and 150 ppm (as a second warning threshold) for the CO personal dosimeters.

C. Previous Evaluations

On October 18, 1989, the Kentucky Division of Occupational Safety and Health Compliance monitored personal CO levels at the Carbon Graphite Group utilizing Draeger long term detector tubes. The time-weighted averages of CO were reported to be 6.3 ppm for a tapper, 4.6 ppm for a control room operator, 5.6 ppm for a helper, and 1.0 ppm for a scrubber & helper.

IV. EVALUATION DESIGN AND METHODS

A. Environmental

Carbon monoxide monitoring was performed with Draeger Model 190 CO dosimeters equipped with selective filters, Draeger CO indicator tubes (5/c, #CH25601), and grab samples (SKC Tedlar® sample bags) for CO and acetylene (C_2H_2).

The grab samples taken in Tedlar® sample bags were analyzed by the Mine Safety and Health Administration (MSHA) on November 29, 1990. Samples of air were withdrawn from each of the Tedlar® bags using a gas syringe and injected into a gas chromatograph equipped with two packed columns: a 10 foot, 5 angstrom molecular sieve and a 5 foot Porapak R® connected to a 12 foot Porapak T®. The oven was operated at 76 °C, and a thermal conductivity detector was used. The detection limits for this method are 1 ppm CO and 1 ppm acetylene.

Twelve CO dosimeters were worn by employees, one dosimeter was used as an area monitor, and one dosimeter was worn by a NIOSH investigator. Eight detector tube readings were taken throughout the day by the NIOSH investigator wearing the CO dosimeter. In addition, bag samples were taken at the crusher, the control room, and in the roadway between the furnace and crusher.

B. Employee Interviews

Private interviews were conducted with 12 employees who work in areas where calcium carbide is manufactured and handled. These included two paste and scrubber workers, three maintenance workers, one tapper, two control room operators, two from the crusher area, a crane operator, and a clean-up person.

V. EVALUATION CRITERIA

The primary sources of environmental evaluation criteria for the workplace are the following: 1) NIOSH Recommended Exposure Limits (RELs) 2) the Occupational Safety and Health Act (OSHA) Permissible Exposure Limits (PELs), and 3) the American Conference of Governmental Industrial Hygienists' (ACGIH) Threshold Limit Values (TLVs).[3,4,5] The OSHA standards also may be required to take into account the feasibility of controlling exposures in various industries where the agents are used; the NIOSH RELs, by contrast, are based primarily on concerns relating to the prevention of occupational disease.

A time-weighted average (TWA) exposure refers to the average airborne concentration of a substance over the course of normal 8- to 10-hour workday. Some substances have a short-term exposure limit (STEL) or ceiling (C) values where there are recognized toxic effects from high short-term exposures. The environmental evaluation criteria are intended to protect workers continually exposed up to 40 hours/week for a working lifetime without experiencing adverse health effects.

Not all workers will be protected from adverse effects even if their exposures are maintained below the evaluation criterion. A small fraction may experience health effects as the result of individual susceptibility, a medical condition, or hypersensitivity (allergy). In addition, some substances may act in combination with other workplace exposures to produce health effects, even if the occupational exposures are controlled to a level set by the evaluation criteria. Some substances are absorbed by direct contact with the skin and mucous membranes, and thus potentially increase the overall exposure. Finally, evaluation criteria may change over the years as new information on the toxic effects of an agent become available. In evaluating the exposure levels and the recommendations for reducing these levels found in this report, it should be noted that industry is legally required to meet those levels specified by an OSHA PEL.

A. Carbon Monoxide

CO is a colorless, odorless, tasteless gas produced by incomplete burning of carbon-containing materials. On inhalation, carbon monoxide acts as a metabolic asphyxiant, causing a decrease in the amount of oxygen delivered to the body tissues. CO combines with hemoglobin (the oxygen carrier in the blood) to form carboxyhemoglobin, which reduces the oxygen-carrying capacity of the blood. The initial symptoms of CO poisoning may include headache, dizziness, drowsiness, and nausea. These initial symptoms may advance to vomiting, loss of consciousness, and collapse if prolonged or high exposures are encountered. Coma and death may follow if high exposures continue without intervention.[6]

Carbon monoxide combines reversibly with the oxygen-carrying sites on the hemoglobin molecule with an affinity ranging from 210 to 240 times greater than that of oxygen; the carboxyhemoglobin thus formed is unavailable to carry oxygen. Initially the victim is pale; later the skin and mucous membranes may be cherry-red in color. Loss of consciousness occurs at about the 50% carboxyhemoglobin level. The amount of carboxyhemoglobin formed is dependent on concentration and duration of CO exposure, ambient temperature, health and metabolism of the individual, breathing rate, level of physical activity, and barometric pressure. The formation of carboxyhemoglobin is a reversible process. Recovery from acute poisoning usually occurs without sequelae unless tissue hypoxia (oxygen deficiency) was severe enough to result in brain cell degeneration.[6,7]

A variety of cardiovascular effects are associated with carbon monoxide. Carbon monoxide is especially serious for persons with chronic heart or lung disease. The reason for this is that the carbon monoxide in the blood reduces the amount of oxygen available to an already damaged heart muscle. Carbon monoxide at low levels may initiate or enhance deleterious metabolism in the heart of individuals with restricted coronary artery blood flow. Breathlessness upon exertion, rapid or irregular heart rhythm, throbbing or fluttering of the heart (palpitation), and chest pain may be present. Excess fluid in the lung tissues (pulmonary edema) may occur. The victim may develop pneumonia. Exposure to 50 ppm for 90 minutes may cause aggravation of angina pectoris (heart pain). The clinical effects of CO exposure are aggravated by heavy labor, high ambient temperature, and altitudes above 2000 feet.[6,7,8,9] Table 1 lists the evaluation criteria for CO.[3,4,5]

B. <u>Calcium Carbide</u>

CaC_2 will react with water vapor or moisture of the skin, eyes, and respiratory tract. Generally, the heat of reaction is not enough to cause harm, but the residual calcium hydroxide which is formed can exert an irritant effect. Contact with moist skin and mucous membranes has been reported to cause ulcerations. Dry CaC_2 may cause dermatitis. CaC_2 can be particularly hazardous to the eyes.[1,2] In the United States, there is no specific exposure criteria for CaC_2.

C. <u>Acetylene</u>

Acetylene is classified as a simple asphyxiant. That is, acetylene can cause suffocation by diluting the oxygen in air to a point where it will not support life. In addition, acetylene can be a significant fire or explosive hazard. NIOSH recommends that exposures not exceed 2500 ppm at any time.[3]

VI. RESULTS AND DISCUSSION

The results of environmental monitoring with CO dosimeters are presented in Table 2. An important consideration when interpreting this data is that acetylene is a known positive interference with the Draeger 190 CO dosimeters. A positive interference means that the dosimeters will indicate readings higher than the actual CO levels. Notable levels of acetylene were expected, and were found (3-107 ppm), with the grab bag samples in various locations in the calcium carbide manufacturing facility (see Table 3). Analysis of the grab bag samples indicated that the levels of CO were below the 1 ppm limit of detection. Rain and high relative humidity (68 - 70%) on the day of the NIOSH survey increased the potential for acetylene formation from the calcium carbide. The effect was most evident in the crusher area, which does not have any obvious sources of CO production. However, substantial quantities of crushed calcium carbide are present. The dosimeters indicated high levels of CO in this area, while the indicator tubes and grab bag samples indicated non-detectable levels. 107 ppm acetylene was found near the north crusher well; no CO was present. National Draeger indicates that 10 ppm acetylene causes a $\leq$25 ppm deviation without the selective filter and $\leq$1 ppm deviation with the selective filter.[7] The dosimeter's selective filter, however, did not appear to effectively remove acetylene during this survey.

The dosimeters indicated numerical levels above the criteria only at times when acetylene would be expected to be present. The highest peaks appeared when a potential release of acetylene occurred. An exception is the scrubber area, which does not have any obvious sources of acetylene; calcium carbide is not physically present here. A high level of CO (60 ppm TWA, 403 ppm peak) was found near a leaking valve in this area. Employees working in the scrubber area wear continuous monitors when entering the area. Additionally, they wear supplied air respirators if working on equipment in the area.

Additional area measurements taken with CO dosimeters, indicator tubes, and bag samples can be found in Table 3. According to the Draeger company, the CO indicator tubes also react with acetylene, but with "different sensitivities."[11] The Draeger 5/c CO tube contains a "precleanse layer," which retains some interfering gases (e.g. petroleum distillates, benzene, etc). The actual efficiency of the "precleanse layer" for acetylene is unknown, but is probably concentration dependent.

It should be noted that Draeger® CO long-term tubes (10/a-L) are also significantly affected by acetylene, 100 ppm acetylene causing an indication of 30 ppm when no CO is present.[11]

The CO sampling data gathered in this survey indicate that the levels of CO were below the previously discussed evaluation criteria. In fact, many of the dosimeter CO readings are probably lower than the reported levels. The scrubber area appears to be a potentially hazardous area for CO exposure during equipment failures or equipment repair. In fact, high concentrations of CO were recorded in a location near a leaking valve. However, the employees appear to be adequately protected in the event of CO release by the use of supplied air respirators.

The confidential interviews with employees did not indicate symptoms consistent with long-term CO exposure. There were reports of specific incidents in the past where employees required medical treatment for short-term CO exposure.

VII. RECOMMENDATIONS

A. Carbon Monoxide

1. Carbon Monoxide Monitoring - Scrubber Area

The mandatory use of personal CO monitors should be continued in the scrubber area, since the potential for CO exposure exists in the event of equipment failure. The equipment around the scrubber should be monitored on a regular basis for CO leaks. If leaking equipment is found, repairs should be made to the equipment. During maintenance or repair work, the use of supplied air respirators should be continued by workers in this area. The potential for acetylene interference is probably low in this area.

2. Carbon Monoxide Monitoring - Crusher Area

CO monitors should not be used in the crusher area since the strong positive interference of acetylene makes interpretation of the CO dosimeter readings impossible. The crusher area does not have obvious sources of carbon monoxide, except for the possibility of CO being released from pockets within the solidified CaC_2. CO monitoring can be performed in this area with short-term detector tubes, which are not as strongly affected by acetylene. A monitoring device, based on infrared absorption at a selective wavelength (i.e. Wilks Miran®), may also be a viable alternative. Additionally, air sampling for CO and C_2H_2 may be performed by taking air samples in Tedlar® bags with subsequent laboratory analysis.

3. Carbon Monoxide Monitoring - Furnace Area

In the furnace area, CO may be monitored with dosimeters, keeping in mind that interpretation of peaks might be difficult if there are localized releases of acetylene.

4. Carbon Monoxide Area Alarms.

The use of area CO alarms in the furnace and scrubber areas should be continued. Calibration and testing of the alarms should be performed on a regular basis, as specified by the manufacturer.

B. Other Recommendations

1. Engineering Controls - Calcium Carbide Dust

Equipment that produces CaC_2 dust should be enclosed to the extent possible and equipped with exhaust ventilation. The dust laden air should be cleaned in cyclones and/or bag filters before release into the air. Settled dust should be removed with industrial vacuum cleaners or permanent exhaust systems.[1]

2. Personal Protective Equipment

Since the effects of CaC_2 are limited to areas of moisture contact (producing $Ca(OH)_2$), employees should be instructed to wash thoroughly after work. They should change work clothes often enough to avoid wearing heavily contaminated clothing. These recommendations also apply to employees working on the fifth floor of the furnace building, where quicklime and coke are fed into the furnace. Excessive contact with calcium carbide or lime may result in skin, eye, and respiratory tract irritation and damage.[1,2]

Other personal protective equipment includes the use of waterproof gloves (hands protected with Vaseline®), goggles, and NIOSH/MSHA approved respiratory protective equipment used in compliance with OSHA regulations.[1]

3. Other Inhalation Hazards

In addition to CO, the air in the furnace area should be monitored on a regular basis for nuisance dust, calcium oxide and hydroxide, and coal-tar pitch volatiles. The air in the crusher area should be monitored on a regular basis for calcium carbide, calcium oxide and hydroxide, and acetylene.

4. Confined Space Entry

Before entry into confined spaces near the furnace, including interior areas of the furnace during shutdown, and confined spaces where CaC_2 is crushed, carbon monoxide, oxygen, and acetylene levels should be measured. A confined space is an area that has limited openings for entry and exit and unfavorable natural ventilation.[12] Air sampling can be accomplished using a combustible gas meter for acetylene; 2500 ppm acetylene is approximately equal to 10% of the lower explosive limit (LEL). It should be noted that some combustible gas meters will not function in low oxygen areas. Oxygen levels should be measured using an oxygen meter, and CO levels should be measured with both indicator tubes and direct reading instruments. The space should be ventilated before entry if the air samples indicate acetylene levels between 10% and 100% of the LEL, greater than 35 ppm CO, or lower than 19.5% oxygen by volume.[12] Acetylene has a wide explosive range, between 2.5 and 82% by volume.[12] If high levels of CO are indicated, under no circumstances should this be assumed to be acetylene interference. Only air-supplying respirators can be used in the presence of excess CO or insufficient oxygen; air purifying respirators should not be used.

5. Miscellaneous

Notices should be displayed indicating that water should not be used in the event of fire. Non-sparking tools should be used in areas where acetylene might be generated.[1,2] Unnecessary inhalation of acetylene and contact of CaC_2 with water should be avoided.

VIII. REFERENCES

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IX. AUTHORSHIP AND ACKNOWLEDGEMENTS

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1. International Brotherhood of Firemen and Oilers, Local 320
2. The Carbon/Graphite Group
3. OSHA, Region IV

For the purpose of informing affected employees, copies of this report shall be posted by the employer in a prominent place accessible to the employees for a period of 30 calendar days.

Table 1

EVALUATION CRITERIA FOR CARBON MONOXIDE

Carbon/Graphite Group
Louisville, Kentucky

HETA 91-009

NIOSH Recommended Exposure Limit (REL):[3]
35 ppm for an eight hour TWA.
200 ppm Ceiling.

OSHA Permissible Exposure Limit (PEL):[4]
35 ppm for an eight hour TWA.
200 ppm Ceiling.

ACGIH Threshold Limit Value (TLV):[5]
50 ppm for an eight hour TWA.
400 ppm STEL

ppm = Parts per million

TWA = Time-Weighted Average

Ceiling = level not to be exceeded at any time.

STEL = Short-Term Exposure Limit, a 15-minute time-weighted average which should not be exceeded at any time during a work day

Table 2

RESULTS OF MONITORING FOR CARBON MONOXIDE[1]
USING DRAEGER DOSIMETERS, PERSONAL MONITORING

Carbon/Graphite Group
Louisville, Kentucky

HETA 91-009
November 28, 1990

Work Category/ Location	Dosimeter No.	Time (min)	TWA (ppm)	Peak (ppm)
Clean-up/ Furnace	CO-10	470	38	578[2]
Crane Operator/ Furnace	B	474	21	113
Crane Operator/ Crusher	E	448	78[3]	428[3]
Maintenance/ Various	F	429	9	93
Maintenance/ Various	CO-8	437	15	122
Maintenance/ Various	CO-2	438	27	191
Utility Operator/ Furnace	CO-11	410	19	65
Control Room Operator/ Furnace	CO-13	418	13	25
Paste & Scrubber/ Various	CO-9	466	19	737[4]

continued

Table 2 (continued)

RESULTS OF MONITORING FOR CARBON MONOXIDE USING DRAEGER DOSIMETERS, PERSONAL MONITORING

Carbon/Graphite Group
Louisville, Kentucky
HETA 91-009
November 28, 1990

Work Category/ Location	Dosimeter No.	Time (min)	TWA (ppm)	Peak (ppm)
Paste & Scrubber/ Various	L	467	24	839[4]
Tapper/ Furnace	CO-7	412	27	293[5]
Crusher Leader/ Crusher	CO-4	448	82[3]	359[3]
Scrubber, Area Sample 2nd Level	I	475	60[6]	403[6]

1. All of the CO measurements, except in the scrubber area, was probably positively biased by the presence of acetylene.

2. Peak occurred when cleaning up CaC_2 on ground floor of furnace, some water was present.

3. Acetylene was present as a result of the reaction between CaC_2 dust and atmospheric water vapor.

4. The peak occurred during or after a purge at the scrubber. Supplied air respirators were worn when work was performed.

5. Employee was near water trough on tap floor when peak occurred; CaC_2 was present.

6. These area measurements were taken near a leaking control valve, which is housed in a small closet-sized box. Employees would be wearing supplied air respirators if working on equipment in this location. This CO measurement was probably a true value (not biased by acetylene).

Table 3

AREA MEASUREMENTS FOR CARBON MONOXIDE[1]

Carbon/Graphite Group
Louisville, Kentucky
HETA 91-009
November 28, 1990

Time (24 h)	Location	Carbon Monoxide Levels (ppm) Dosimeter	Indicator Tubes
0724	Furnace Break Room	-	ND
0755	Furnace Break Room	8	ND
0800	Scrubber at the Control Valve	30-80	45
0810	Roadway between furnace & crusher	15-29	ND
1025	Fifth floor of furnace	20	5
1036	Crusher floor	50-60	ND
1042†[A]	Crusher Area	150-365	ND
1118†[B]	Control Room	19	ND
1133†[C]	Roadway between furnace & crusher	7-9	ND

ND = Not detectable

1. All of the CO measurements, except for the scrubber control valve, were probably positively biased by the presence of acetylene gas. The CO measurement at the scrubber control valve was probably a true value (not biased by acetylene).

† Air samples also taken with Tedlar® bag, analyzed by gas chromatography.

A. Crusher area at 1042: CO was ND, C_2H_2 was 107 ppm.

B. Control Room at 1118: CO was ND, C_2H_2 was 3 ppm.

C. Roadway between furnace and Crusher at 1133: CO was ND, C_2H_2 was 3 ppm.