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Case Studies

Airborne Emissions from Carbon Dioxide Laser Cutting Operations

Dawn Tharr, Column Editor

Case 1 Report by C. Eugene Moss and Alan Fleeger

In December 1989, investigators from the National Institute for Occupational Safety and Health (NIOSH) responded to a request to evaluate the potential occupational significance of airborne emissions produced from materials being cut by a carbon dioxide (CO_2) laser. The study was conducted at a facility that primarily produced scientific glassware, but on occasion, cut plastics and metal parts. During the evaluation, the NIOSH investigators collected environmental air samples to characterize the contaminants released during laser cutting events on the fused quartz glassware, different plastics, and metal targets.

Qualitative analytical results of high volume air samples collected during fused quartz cutting indicated the presence of amorphous material. Personal breathing zone samples, collected for the duration of the cutting operation (approximately 2 hours), revealed respirable exposure concentrations to fused silica as high as 2.2 mg/m^3. When extrapolated to an 8-hour time-weighted average (TWA), assuming zero exposure levels for the remaining 6 hours, these samples yielded fused silica concentrations of 0.5 mg/m^3. Results from five area samples indicated extrapolated 8-hour TWA results as high as 0.9 mg/m^3. The Occupational Safety and Health Administration (OSHA) standard and the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV) for fused silica are 0.1 mg/m^3. However, since NIOSH considers fused silica to be a potential carcinogen, workplace exposures are to be reduced to the lowest feasible level.

Air samples collected for trace elements at 2 inches from the source during metal cutting identified very small quantities of chromium, copper, iron, nickel, and zinc on each of the samples collected. Total quantities reported for each compound were just barely above the analytical limit of detection; this suggests that even on a worst-case basis, these levels would not represent a health hazard.

The qualitative samples collected for organic vapor analysis by gas chromatography/mass spectrometry identified ethyl acrylate as the major component produced during laser cutting of four types of plastics. Significant levels of ethyl acrylate were detected when cutting plexiglass, acrylic, and lucite. Short-term area sampling results for ethyl acrylate ranged in concentrations from nondetectable to 149 ppm. These results are above the OSHA short-term exposure limit (STEL) of 25 ppm and the ACGIH STEL of 15 ppm. Two, long-term, area samples (2 hours) detected 0.4 to 1.0 ppm of ethyl acrylate. NIOSH considers ethyl acrylate to be a potential carcinogen and recommends workplace exposure be reduced to the lowest feasible level.

The ethyl acrylate results are within the range where nausea and other more immediate irritative symptoms may occur. At the time of this investigation, the laser operator stated that he became very ill immediately following the first time he cut similar plastic materials. He reported symptoms including fatigue, headache, irritation, nausea, and vomiting. Based on these sampling results, it appears that the cause of his illness could have been a result of the exposure to ethyl acrylate. The exposures encountered during this investigation were irritating enough that the investigators could not remain in the area during the sampling process.

Based on these data, the NIOSH investigators believe that a health hazard did exist from laser operations on the days of measurements from exposure to respirable fused silica and ethyl acrylate.

Case 2 Report by C. Eugene Moss and Teresa Seitz

In February 1990, NIOSH conducted an evaluation to document potential exposures to emission products produced during the cutting of Kevlar® composite material with a carbon dioxide (CO_2) laser.

Kevlar is a lightweight, organic fiber with extremely high tensile strength and resistance of elongation. It is an aromatic polyamide, more commonly referred to as an aramid fiber. It is formed in the reaction of aromatic diamines and aromatic diacid chlorides in an amide solvent, and it consists of long polyamide chains attached to two aromatic rings. Because of its dimensional stability, strength, heat and flame resistance, chemical inertness, and electrical resistivity, Kevlar has found many uses. It is currently used in filter bags for hot stack gases, insulation, protective clothing, tire cord, aerospace composites, and bullet-resistant structures.

A literature search failed to identify data on emissions generated during laser cutting of Kevlar. Thermal degradation products generated during the heating of Nomex®, another aramid fiber, and an unspecified aramid batting (without finish) at approximately 540°C and 575°C were identified as carbon dioxide, water, acetaldehyde, hydrogen cyanide, and methylcyanide. Thermal analysis of aramid fabric which contained an unidentified finish resulted in the evolution of additional decomposition products including aliphatic and aromatic hydrocarbons (including benzene), alcohols, and sev-

eral esters. This emphasizes the fact that auxiliary chemicals applied to the fibers can affect the types of thermal degradation products formed. Although information regarding thermal degradation products of Kevlar composites having an epoxy matrix was not found, data from a material safety data sheet (MSDS) for the epoxy resin lists the following thermal decomposition products: carbon monoxide, carbon dioxide, ammonia, oxides of nitrogen, oxides of sulfur, and/or hydrogen cyanide.

The composite material in use during this evaluation contained Kevlar fibers in an epoxy matrix. Sheets of the Kevlar composite were placed on a stand and a laser beam was used to cut a series of small holes in the sheet. Although the process was automated, it required periodic monitoring by a laser technician. The technician would set up the operation and return periodically to inspect the work to determine if the size of the holes met specifications. The cutting operation was performed in an area approximately 8 ft. × 10 ft. which was enclosed with a plastic barrier. Local exhaust ventilation consisted of a down-draft system which captured emissions from this process.

Six laser technicians are trained to do this work; however, there is only one operator per shift. Although the laser cutting operation had been performed for approximately 8 months, the type of composite used had been changed, and the new composite was just beginning to be used on a continuous production basis. Prior to this time, work had been performed on a Kevlar–graphite composite material. Reportedly, the odors from the Kevlar–graphite composite were much stronger and resulted in heavier soiling of the plastic barrier than emissions from the new composite material. Health complaints such as eye and skin irritation were also greater with the Kevlar–graphite material. Two half-mask air purifying respirators with organic vapor and high efficiency particulate filter cartridges were available and were worn by the technicians when using the laser to finish the edges of the workpiece after the holes had been cut. This operation takes approximately 5 to 10 minutes. After the parts were completed, they were cleaned by the laser technician using Synasol, an alcohol-based solvent. The laser technician performed this cleaning activity in an area outside the booth that was not supplied with local exhaust ventilation. Rubber gloves were used while cleaning the parts.

Direct-reading measurements for carbon monoxide, hydrogen cyanide, formaldehyde, petroleum hydrocarbons, and oxides of nitrogen were made between 8:45 and 9:15 a.m. and between 12:50 and 1:15 p.m. Formaldehyde and hydrogen cyanide were not detected; the limit of detection (LOD) for both gases was 0.2 ppm. Petroleum hydrocarbons were also not detected; however, the LOD for this class of substances is fairly high at 100 ppm. Carbon monoxide was measured at 30–35 ppm in the morning and at 10 ppm in the afternoon. The current NIOSH Recommended Exposure Limit (REL) for carbon monoxide is 35 ppm as an 8-hour TWA and 200 ppm as a ceiling limit; the ACGIH TLV is 50 ppm with a STEL of 400 ppm. Oxides of nitrogen (nitric oxide and nitrogen dioxide) were measured at 5 ppm in the morning and were not detected in the afternoon (LOD = 0.5 ppm). The current NIOSH REL and ACGIH TLV for nitric oxide is 25 ppm as a TWA over the workshift. The NIOSH REL for nitrogen dioxide is 1 ppm as a 15-minute ceiling limit and the ACGIH STEL is 5 ppm. Although the measurements made during this survey do not distinguish between the different nitrogen oxide forms. Nitric oxide is converted spontaneously in air to nitrogen dioxide.

Time-weighted average air concentrations of hydrogen cyanide (measured as cyanide) in the laser cutting area ranged from 0.03 to 0.08 mg/m^3 in four short-term air samples of 15 to 60 minutes duration. The concentration of hydrogen cyanide in the laser cutting area was 0.05 mg/m^3, as a TWA over the entire workshift. The personal air sample obtained on the laser technician gave a concentration of 0.01 mg/m^3. All hydrogen cyanide concentrations were well below the current short-term exposure guidelines established by NIOSH (5 mg/m^3 as a 10-minute ceiling) and OSHA (5 mg/m^3 as a 15-minute STEL).

Air sampling results for volatile organic compounds (VOCs) indicated the presence of low levels of aliphatic, aromatic, and chlorinated hydrocarbons, alcohols, and aldehydes in samples taken both inside and outside the laser booth. These low levels are not considered a health hazard for employees working in these areas. Based on the types of substances seen and their presence in other areas of the plant, it appears that these VOCs are being volatilized from solvents used in the plant rather than being evolved from the laser cutting operation.

Generation of Kevlar fibers from the laser cutting process does not appear to be a concern, as an air sample obtained a few feet from the laser was largely devoid of fibers. While a yellowish particulate material was collected on the filter, efforts to identify the components by high pressure liquid chromatography (following a chloroform extraction of the filter sample) were not successful.

Results obtained during this survey indicated the need for further monitoring for carbon monoxide and oxides of nitrogen. The levels of nitrogen dioxide measured during the survey may have accounted for the employees reporting eye and skin irritation.

Editorial Note: The Case 1 evaluation was conducted by Gene Moss and Alan Fleeger of NIOSH. The Case 2 evaluation was conducted by Gene Moss and Teresa Seitz of NIOSH. More information may be obtained by contacting the authors at NIOSH, Hazard Evaluation and Technical Assistance Branch, 4676 Columbia Parkway, R11, Cincinnati, Ohio 45226; or telephone 1-800-35-NIOSH.