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PHOTON DYNAMICS LTD., INC.
LONGWOOD, FLORIDA

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I. SUMMARY

On December 3-6, 1989, investigators from the National Institute for Occupational Safety and Health (NIOSH) conducted an investigation at Photon Dynamics, Inc. in Orlando, Florida. This investigation was performed in response to a management request received on July 26, 1989, concerning the occupational significance of airborne emissions produced from materials being cut by a carbon dioxide (CO_2) laser.

During this evaluation, the NIOSH investigators collected environmental air samples to characterize the gases and vapors produced during laser cutting events on different plastic and metal targets. In addition, radiometric/photometric measurements were made on these cutting events.

Qualitative analytical results of high volume air samples collected during fused quartz cutting indicated the presence of amorphous material. Personal breathing zone samples revealed respirable exposure concentrations to fused silica as high as 2.2 milligrams per cubic meter (mg/m^3). When extrapolated to an 8-hour time-weighted average (TWA) basis, assuming zero exposure levels for the remaining six 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. However, since NIOSH considers fused silica to be a potential carcinogen, then workplace exposures are to be reduced to the lowest feasible level.

Air samples collected for trace elements at two inches from the source, 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, which suggest that even on a worst case basis these levels would not represent a health hazard.

The qualitative samples collected for organic vapor analysis 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 non-detectable to 149 ppm. These results are above the OSHA short-term exposure limit of 25 ppm. Two long-term area samples (two 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.

Radiometric results indicate occupational exposure to laser radiation at this facility were below the American National Standard Institute 8-hour maximum permissible exposure limit of 100 mW/cm^2. In addition, plasma-generated optical radiation levels were below appropriate American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values.

Based on these data, the NIOSH investigators believe that a health hazard did exist from laser operations on the days of measurements at Photon Dynamics from exposure to respirable fused silica dust and ethyl acrylate. Recommendations are provided in Section IX to aid in reducing exposures, primarily through the use of ventilation controls.

KEYWORDS: SIC 3231 (Glass Products, Made of Purchased Glass) Laser cutting, quartz, plastics, fumes, fused silica dust, ethyl acrylate.

II. INTRODUCTION

On July 26, 1989, the National Institute for Occupational Safety and Health (NIOSH) received a request from the management of Photon Dynamics, to evaluate airborne emissions from their laser cutting production process in Longwood, Florida. Photon Dynamics primarily produces scientific glassware at this facility, but had, on some occasions, cut plastic and metal parts. NIOSH was asked to identify the emissions produced by the interaction (cutting) of a CO_2 laser with various fused quartz, plastic, and metal products.

On December 3-6, 1989, NIOSH investigators conducted an on-site investigation at the Longwood facility. During this investigation, environmental air samples were collected to characterize the emissions from the laser process. Radiometric/photometric measurements were also collected during the production process. Finally, a qualitative assessment of the local exhaust ventilation system was conducted to determine appropriate recommendations for capturing the emissions.

III. BACKGROUND

Photon Dynamics Ltd, Inc. is a Florida-based company that specializes in unique applications of lasers within the industrial environment. The major emphasis has been developmental work in high speed cutting of quartz material using lasers. Figure 1 shows a typical setup of the glass part being cut by a laser. The laser used was a Photon Sources Inc. Versa-Lase VFA 600 CO_2 laser operating in a continuous mode. This particular class IV laser is rated at 600 watts, operates at an infrared wavelength of 10.6 microns (um), and uses a three inch focusing lens. Figure 2 shows the schematic floor plan of the laser work area.

At the time of these measurements there were four full-time employees working at the facility. However, only one worker was involved continuously with laser cutting. Photon Dynamics shares a building wing with two other companies. The fumes and vapors produced from the laser operations were quite evident to personnel working in these other companies. There had not been any reports of laser beam exposure to any worker and the only concern expressed to NIOSH was the nature of the fume and vapor production.

IV. METHODS AND MATERIALS

A. Environmental

On December 4-5, 1989, the investigators collected a series of environmental air samples to characterize the emissions produced during the laser cutting process. Nine air samples and one bulk sample were collected during the cutting of fused quartz for both qualitative and quantitative identification of silica content. Figure 3 shows the placement of sampling equipment next to the laser cutting event. Five air samples were collected during the cutting of various metal strips for the quantification of trace elements. Three air samples were collected during the cutting of various plastics to qualitatively identify any aldehydes which may have been present. Fifteen air samples were collected during the cutting of four different plastics (acrylonitrile-butadiene-styrene [ABS] plastic; an acrylic resin [Lucite®]; a thermoplastic poly-(methyl methacrylate) polymer [Plexiglas®]; and polycast acrylic plastic) for both qualitative and quantitative identification of organic vapors. The majority of the air samples were collected on a short-term basis (15 minutes) since this was the normal operating time of the laser. It should also be noted that the local exhaust ventilation (LEV) system was poorly designed and had minimal, if any, effect on the collection of environmental air samples.

Environmental samples for silica identification were collected during two different processes, both which used fused quartz as the bulk material. The two processes sampled included the cutting of various shapes out of bulk plates and piercing a series of holes through a long tube of scientific glassware. A bulk sample of the shavings and two high volume air samples were collected during these processes for qualitative silica analysis. The shavings and high volume samples were analyzed using NIOSH Method 7500 via X-ray powder diffraction (XRD) to determine the silica type (amorphous or crystalline) [1].

Two personal breathing zone and five area respirable air samples were collected for silica using polyvinyl chloride (PVC) filters (five micron (um) pore size) connected in series via a cyclone to a battery powered pump which was calibrated at a flow rate of 1.7 liters per minute (lpm). The samples were to be quantitated based on the qualitative identification of silica type. NIOSH analytical method 7500 [1], utilizing XRD for the analysis, would be employed should the silica be determined to be crystalline. NIOSH method 600 [1], utilizing gravimetric techniques for the analysis, would be employed if the silica is determined to be amorphous.

The environmental samples for trace elements were collected during the cutting of aluminum, brass, copper, galvanized and stainless steel strips. Two personal breathing zone and three area air samples were collected on 0.8 um cellulose ester filters connected to a battery powered pump calibrated at a flow rate of 2.0 lpm. The samples were analyzed for trace elements by NIOSH analytical method 7300 [1], utilizing a scanning inductively coupled plasma emission spectrometer for the analysis.

The environmental air samples for organic vapor analysis were collected during the cutting of various plastics. A total of fourteen samples were collected for qualitative and quantitative identification of emissions from the cutting of four different materials (ABS plastic, lucite, plexiglass, and polycast acrylic). A group of three area air samples, one for qualitative identification purposes and two for quantitative analysis, were collected for each of the four types of plastics. Two additional long-term personal breathing zone samples were collected for quantification purposes.

The air samples collected for organic analysis were collected on standard charcoal tubes connected via Tygon® tubing to a battery powered pump calibrated at a flow rate of 0.1 lpm. The qualitative samples from each of the sample groups were first scanned utilizing a gas chromatograph equipped with a flame ionization detector (GC-FID). The samples were then further analyzed by a GC-mass spectrometer detector to identify those compounds present. The other samples were then quantitated based on the qualitative analysis via NIOSH method 1500 [1] utilizing GC-FID.

The environmental air samples for aldehydes were also collected during the cutting of the plastics. A total of three area samples were collected on ORBO 23 tubes connected via a battery powered pump calibrated at a flow rate of 0.05 lpm. The samples were qualitatively screened for aldehydes utilizing a GC-FID.

B. <u>Radiometric</u>

The following equipment was used to measure levels of radiant energy produced by the various processes:

1. Luminance or brightness levels were measured with a Spectra Mini-Spot photometer having a one degree field of view. The values were obtained in units of footlamberts (fL) which were converted to candela per square centimeter (cd/cm^2). The luminance of a source is a measure of its brightness when observed by an individual without eye protection, regardless of the distance from the source.

2. An International Light radiometer, model 730A, with specially calibrated detectors was used to evaluate the ultraviolet (UV) radiation levels. One detector was designed to read the actinic UV radiation (200 to 315 nanometers [nm]) in biologically effective units of microwatts per square centimeter (uW/cm^2), while the other detector measured near UV (320-400 nm) in units of milliwatts per square centimeter (mW/cm^2) with no biologic weighting factor.

3. An Eppley model 901 calibrated thermopile with a quartz window was used to measure irradiance in units of mW/cm^2 over the wavelength range from 200 to 4500 nm.

4. Calibrated laser power instrumentation was available from Photon Dynamics, Ltd. which documented the laser power level used during cutting events.

All equipment used in this evaluation to document exposure to optical radiation fields had been calibrated within six months either by NIOSH or the respective manufacturer.

V. EVALUATION CRITERIA

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH field staff employ environmental evaluation criteria for assessment of a number of chemical and physical agents. These criteria are intended to suggest levels of exposure to which most workers may be exposed without experiencing adverse health effects. It is, however, important to note that not all workers will be protected from health effects if their exposures are maintained below these levels. A small percentage may experience health effects because of individual susceptibility, a preexisting medical condition, and/or a hypersensitivity allergy.

In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects, even if the occupational exposures are controlled at the level set by the evaluation criteria. Also 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 about chemical and physical agents become available.

The primary sources of environmental evaluation criteria for the workplace are the following: 1) NIOSH criteria documents and recommendations, 2) the American Conference of Governmental Industrial Hygienist's (ACGIH) Threshold Limit Values (TLV), and 3) the U.S. Department of Labor (OSHA) occupational health standards. The OSHA standards may be required to take into account the feasibility of controlling exposures in various industries where the agents are used; the NIOSH recommended standards, by contrast, are based primarily on concerns relating to the prevention of occupational diseases. In evaluating the exposure levels and the recommendations for reducing these levels found in these reports, it should be noted that industry is legally required to meet those levels specified by an OSHA standard.

At present there is limited information from OSHA on exposure criteria for workers exposed to physical agents. Criteria for physical agents not covered by OSHA come from either ACGIH, NIOSH, or in some cases from consensus standards promulgated by the American National Standards Institute (ANSI).

A. Fused Silica

Fused silica is a colorless, odorless, noncombustible solid formed by heating amorphous silica (diatomaceous earth) to high temperatures. Fused silica is insoluble in water or acids, except hydrofluoric acid. It has been reported [2] that the processing of amorphous silica by high temperatures alters the silica from the benign amorphous form to the pathogenic, crystalline form, which causes fibrosis in the lungs. Fused silica could be expected to be nearly, if not quite, as fibrotic as that of crystalline silica [3]. The toxicology and regulation of fused silica is currently a topic of active research. The International Agency for Research on Cancer [4] has reviewed the experimental animal and epidemiological data on a variety of crystalline forms of silica and has determined that there is sufficient evidence for the carcinogenicity of crystalline silica to experimental animals and limited evidence for the carcinogenicity of crystalline silica to humans.

The NIOSH REL for respirable fused silica is 0.05 mg/m^3 of air. During testimony on the OSHA PEL Standards (July, 1988), NIOSH stated that the data indicate that silica, amorphous-fused meets the OSHA definition of a potential occupational carcinogen as defined in 29 CFR 1990 [5]. Therefore, NIOSH recommends that OSHA label this substance as a potential occupational carcinogen and exposures be reduced to the lowest feasible level. Prior to the OSHA's recent revision of its PELs, fused silica was not specifically included in the table concerning mineral dusts. In September, 1989, the OSHA final rule limits for fused silica, respirable dust was set at 0.1 mg/m^3 of air. This level of 0.1 mg/m^3 of respirable dust is equivalent to the current ACGIH TLV for silica, amorphous-fused.

B. Ethyl Acrylate

Exposures to ethyl acrylate on a short-term basis have shown it to be a strong irritant to the skin, eyes, mucous membranes, gastrointestinal tract, respiratory system, and a dermal sensitizer. Its odor threshold for a 100% response is 0.005 parts per million (ppm)[3]. Literature references suggests that workers would not tolerate exposures above 25 ppm for any length of time [6] and that prolonged exposure to 50-75 ppm would produced drowsiness, headache, and nausea [3]. In order to minimize the irritant effects, both OSHA and ACGIH have established a short-term (15 minute) exposure criteria of 25 ppm. The 1986 IARC Monographs on the evaluation of the carcinogenic risks of chemicals to humans concludes that there is sufficient evidence for carcinogenicity of ethyl acrylate in experimental animals to consider a carcinogenic risk to humans [7]. This data indicates that ethyl acrylate meets the definition of a potential occupational carcinogen as defined in 29 CFR 1990. Therefore, NIOSH recommends that it be treated as a potential occupational carcinogen and exposures be reduced to the lowest feasible level [8].

C. Radiometric

At present there is limited information from OSHA on exposure criteria for workers exposed to lasers. Criteria for physical agents not covered by OSHA come from either ACGIH, NIOSH, or in some cases from consensus standards promulgated by the American National Standards Institute (ANSI). The criteria used for this evaluation were those published by ANSI in their "Safe Use of Lasers in Health Care Facilities" [9]. Under ANSI Z136.1, the 8-hour maximum permissible exposure (MPE) for CO_2 lasers is 100 mW/cm^2. Another important safety criterion addressed in this standard is the nominal hazard zone (NHZ). The NHZ is defined as that space within which the level of direct, reflected, or scattered radiation exceeds the MPE for that laser. The NHZ perimeter is the envelope of MPE exposure level produced by a specific laser in a given application. The space within the NHZ usually requires control measures to minimize occupational hazards.

Ultraviolet radiation and luminance measurements were also taken into account for the fact that under some laser interactions optical radiation can be produced, in addition to the scattered laser radiation. This so-called "plume" radiation can be independent of the laser radiation and can create deleterious biological effects if absorbed by a worker. This topic of plume radiation has been extensively dealt with in reference 10.

VI. RESULTS

A. Environmental

The qualitative analytical results by XRD of the bulk shavings and two high volume air samples, collected during the cutting of the fused quartz, indicated that it was an amorphous material. The results did indicate one peak which does coincide with the quartz primary peak. The presence of quartz, however, could not be confirmed on the basis of only one peak. At least three peaks at the appropriate intensities are required for the identification of crystalline material. Therefore, the final state of the material is assumed to be fused silica. Upon qualitatively identifying the material as amorphous fused silica, a gravimetric analysis was conducted on the remainder of the environmental air samples. Table 1 presents the results. The two personal breathing zone samples, collected for approximately a two-hour period, measured respirable exposure concentrations to fused silica of 1.6 and 2.2 mg/m^3, TWA over the period sampled. Calculating these personal breathing zone sample results over 8 hours, assuming zero exposure levels for the remaining six hours, resulted in 8-hour TWA personal exposure levels to fused silica of 0.4 and 0.5 mg/m^3, respectively. The five area air sample results ranged in concentration from 0.4 to 3.0 mg/m^3, TWA over the sampling period. These area results, calculated on an 8-hour TWA basis, ranged from 0.1 to 0.9 mg/m^3, and are above the NIOSH REL.

The environmental air samples collected for trace elements 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 (LOD). Exposure concentrations, even on a worst case basis when the air sample was collected two inches from the source, did not reveal any levels which would approach any occupational exposure criteria.

The qualitative air samples collected for organic vapor analysis identified ethyl acrylate as the major emission of the four plastics evaluated. There were no aldehydes detected on any of the qualitative aldehyde samples. Table 2 presents the sample results as a group, according to the type of plastic which was being cut at the time of the sample and shows that significant levels of ethyl acrylate were detected when cutting plexiglass, acrylic and lucite. Short-term area sampling results for ethyl acrylate ranged in concentration from non-detectable to 149 ppm. These results are above the OSHA STEL limit of 25 ppm. The two long-term area samples (two hours) detected 0.4 to 1.0 ppm of ethyl acrylate. NIOSH has recommended that exposure to ethyl acrylate be reduced to the lowest feasible level.

B. Radiometric

1. Laser Power

Photon Dynamics Ltd. using its own calibrated thermopile, reported that the laser power measured on the day of measurements was 235 watts. The laser technician indicated that this wattage level was very typical for the cutting events performed at the facility.

2. Luminance

Luminance levels associated with the heated material ranged from 0.67 to 3.3 cd/cm^2. These values were measured with the photometer aimed at the location where the laser beam struck the material. While the recorded levels are close to or slightly exceed the ACGIH TLV of 1 cd/cm^2, the source (laser plume) is not rich in blue wavelengths, and therefore, in the opinion of the investigators, these luminance levels do not constitute a serious optical hazard. However, since these luminance levels can rapidly vary in intensity, it is suggested that yellow/amber tinted laser goggles be worn.

3. Ultraviolet Radiation

Levels of both near and actinic scattered UV radiation were documented during the evaluation at 12 inches from the interaction site of the laser beam and material. The actinic levels (200 to 315 nm) were non-detectable. The maximum levels of near UV (315 to 400 nm) were 25 uW/cm^2. These levels of near and actinic UV radiation are below their respective 8-hour TLVs of 1 mW/cm^2 and 0.1 biological effective uW/cm^2 and, therefore, did not constitute an optical hazard.

4. Scattered Laser Radiation

The scattered CO_2 laser radiation levels from the glass cutting process ranged from 4 to 10 mW/cm^2 at 12 inches from the interaction site. This number could be slightly high since the Eppley thermopile is sensitive to optical wavelengths other than IR wavelengths. All measurements were made at an angle of 45 degrees from the vertical.

The relationship for the irradiance of diffusely scattered laser radiation at a distance R can be expressed as

$$E = \frac{f\, P \cos @}{B\, R^2}$$

where f is the coefficient of surface reflectivity at 10.6 microns, P is the radiant power (in watts) incident upon the target, cos @ is the scatter angle from the normal to the target surface, R is the distance (cm) from the target, and E is the irradiance produced (W/cm^2) [10]. Using values of P = 235 W, f=0.1, @=45 degrees, the estimated scattered irradiance at a distance of 30 cm is about 5.5 mW/cm^2. This is compared with the measured result of 4 to 10 mW/cm^2. It should be noted that the scattered value was not uniformly produced around the glass cutting area. These levels are to be compared to the ANSI maximum permissible exposure level for exposure to CO_2 laser of 100 mW/cm^2.

VII. DISCUSSION

It is appropriate to assume that the environmental samples, collected on a short-term basis, are typical of the laser operator's exposure during a normal work day. During normal operations, the operator's activities center on a) programming the computer to make the necessary cuts, and b) performing the cutting events. At the present time, the cutting of fused quartz is the major product at this facility. The cutting of the various plastics and metals is very experimental and may not be further expanded.

During the course of the investigation, it was mentioned to the NIOSH investigators that the laser operations are to be taken over by the neighboring scientific glassware department. When this change occurs there probably will be an increased amount of fused quartz used per day.

The present sampling results do indicate an overexposure to respirable fused silica dust on an eight-hour basis. The estimated eight-hour sampling results have probably underestimated the true eight-hour exposure, since zero exposure was assumed during the non-sampled period. The eight-hour personal breathing zone sample for the operator is ten times greater than the NIOSH REL, which is based on the analytical LOD. With a possible increase in production, respirable fused silica concentrations can be expected to rise.

During the cutting operations with the fused quartz, a detectable odor was noticed. It is apparent that the source of this odor is the graphite pad which is used as a laser beam stop. Environmental samples, collected for both organics and aldehydes during this process, did not identify this odor. It is hypothesized that a binder or some other compound that was used in the graphite mix is the source of this odor.

The sampling results collected for organic vapors during the cutting of various plastic samples did reveal significant exposures to ethyl acrylate. The measured exposure levels, 50 to 75 ppm, are within the range where nausea and other irritative symptoms may occur [8]. 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. His reported symptoms included fatigue, headache, irritation, nausea, and vomiting. Based on the organic vapor sampling results, it does appear 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 (who did not have any respirators) could not remain in the area during the sampling process.

At the time of this investigation a local exhaust ventilation (LEV) system was present. However, the system was not operating when the environmental samples were collected. The investigators do not believe that the present system, if functioning, is adequate for capturing any emissions from the process. The existing system, as shown in Figures 4 and 5, consisted only of a flexible duct which was connected to the general systems return duct. Upon activating the system, only a very slight air flow was detected across the face of the flex duct. The NIOSH investigators recommended to the operator that the system not be activated during the cutting process to minimize the potential for contaminating the return air system and other occupied areas in the building.

The NHZ for the quartz cutting events was determined to be less than 9 cm. It was noted that at no time during these cutting events was the worker closer than the NHZ to the intersection site. In addition, the worker did wear appropriate laser eye protectors.

VIII. CONCLUSION

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

IX. RECOMMENDATIONS

The following recommendations are offered to reduce potentially significant occupational exposures and safety risks at Photon Dynamics Ltd., Inc.:

1. There is a need to improve the ventilation system in the laser room area. Since several rooms are served by the existing ventilation system, the exhaust from the laser room enters the breathing area of non-laser workers located in distant rooms. It should be noted that immediately after completing this evaluation and reviewing the preliminary findings Photon Dynamics, Ltd. completely revamped the ventilation system. Pictures of this revision were submitted to the NIOSH investigators and are shown in Figures 6 and 7. Although these figures demonstrate vast improvements in the ventilation system, the investigators still believe additional control measures and evaluations may be necessary.

2. If odors and symptoms continue to be a problem for the operator, even after engineering and/or administrative controls are implemented, the use of respiratory protection may still be necessary. However, since this evaluation has identified at least two suspect carcinogens, it may be advisable to use NIOSH certified air-supplied respirators during all laser cutting procedures. The respirator program shall be in compliance with OSHA's 29 CFR 1910.134.

3. In order to insure that the recently installed ventilation system is properly operating, personal breathing zone air samples for respirable silica should be taken in the future by certified industrial hygienists to verify acceptable exposures.

4. It is recommended that yellow/amber tinted laser eye protectors be used to help reduce localized bright levels (i.e. luminance levels) created by the laser beam during glass cutting procedures.

5. The doors leading to the laser room should have the appropriate interlocks and postings (see reference 10).

6. It was noticed during this survey that many wires and cables were laying on the floor of the laser room which created a potential trip/fall situation. It is suggested that attention be given to eliminating this potential safety hazard.

X. REFERENCES

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XII. DISTRIBUTION AND AVAILABILITY OF REPORT

Copies of this report are temporarily available upon request from NIOSH, Hazard Evaluations and Technical Assistance Branch, 4676 Columbia Parkway, Cincinnati, Ohio 45226. After 90 days, the report will be available through the National Technical Information Service (NTIS), 5285 Port Royal, Springfield, Virginia 22161. Information regarding its availability through NTIS can be obtained from NIOSH Publications Office at the Cincinnati address. Copies of this report have been sent to:

1. Photon Dynamics Ltd, Inc. Orlando, Florida
2. NIOSH
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 I

Results of Air samples for Fused Silica
Photon Dynamics
Orlando, Florida
December 4-5, 1989

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Sample Type/Location	Sample Volume (liters)	8-hour TWA (mg/m^3)
Area/operators desk	250	0.91
Personal/NIOSH investigator	211	0.42
Personal/Laser operator	209	0.55
Area/20 inches above source	44	0.22
Area/7 inches above source	44	0.22
Area/20 inches above source	49	0.19
Area/7 inches above source	49	0.07
Evaluation Criteria:*	(NIOSH)	$0.05 mg/m^3$

*NIOSH policy is to treat fused silica as a potential carcinogen. NIOSH recommends that workplace exposure to fused silica be reduced to the lowest feasible level.

TABLE II

Results of Air Samples for Ethyl Acrylate
Photon Dynamics
Orlando, Florida
December 4-5, 1989

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Sample Type/Location /Material	Sample Volume (liters)	Actual TWA (PPM) Ethyl Acrylate
Area/16" above source/ plexiglass	1.6	71
Area/3" above source/ plexiglass	1.6	32
Area/16" above source/ acrylic	1.5	13
Area/3" above source/ acrylic	1.5	149
Area/16" above source/ lucite	1.7	5
Area/3" above source/ lucite	1.7	64
Area/16" above source/ ABS	1.5	ND
Area/3" above source/ ABS	1.5	ND
Personal/NIOSH investigator/all	14.3	0.4
Personal/Laser operator/ all	14.3	1
Evaluation Criteria:	(NIOSH)	LFL
	(OSHA-STEL)	25ppm

ND = None Detected
LFL = Lowest Feasible Level, NIOSH regards ethyl acrylate as a potential carcinogen. NIOSH recommends that workplace exposure be reduced to the lowest feasible level.
PPM = Parts per Million

Figure 1. Typical laser cutting process. Notice the laser induced visible radiation emerging from the holes made in the glass pipe.

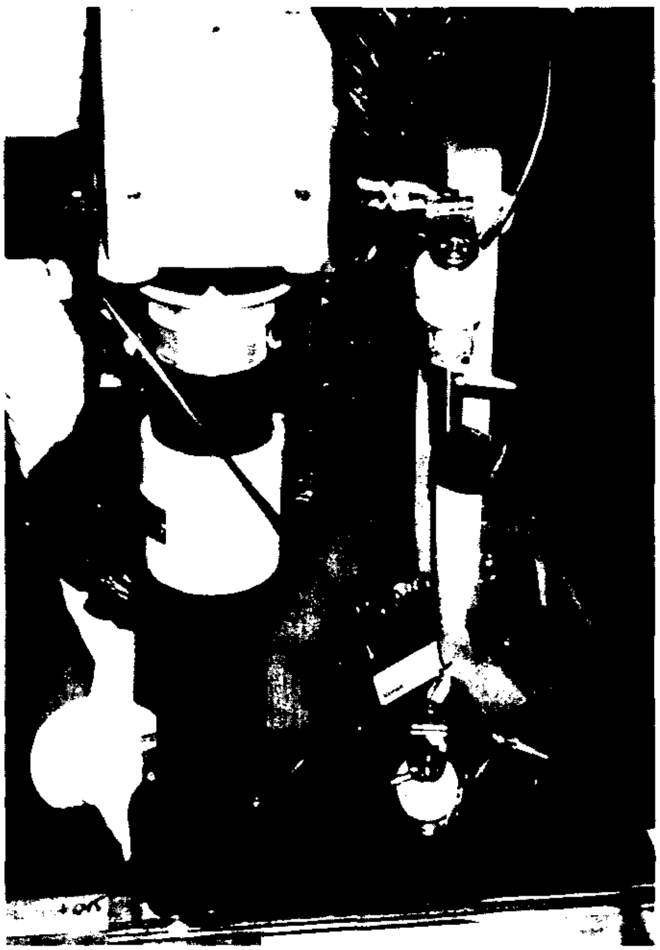

Figure 3. Location of environmental sampling equipment during laser cutting process.

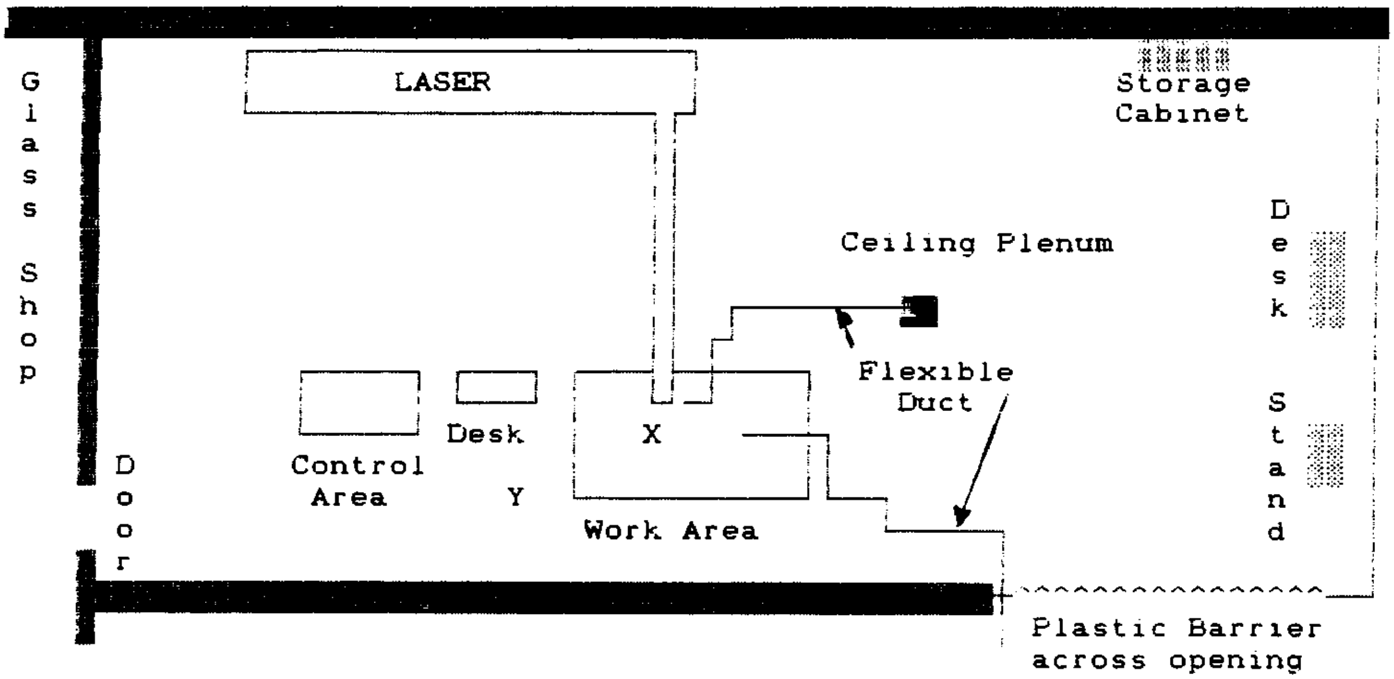

Figure 2. Schematic floor plan of the 24 x 20 foot laser room at Photon Dynamics Ltd. The "X" signifies where the laser beam interacts with the target material. The "Y" is the general location where the worker resides during laser cutting events.

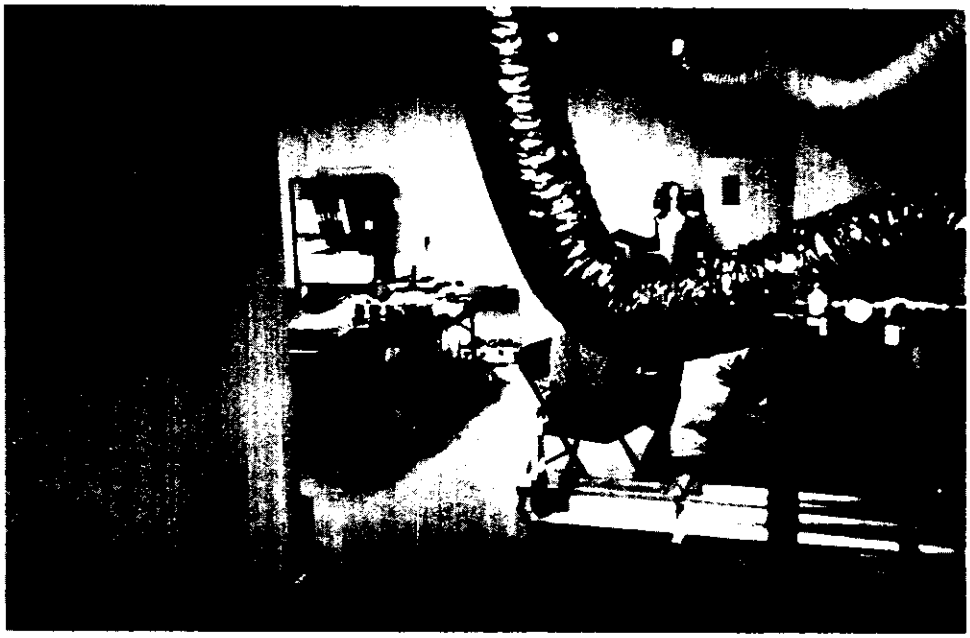

Figure 4. View of exhaust ducts from the laser room.

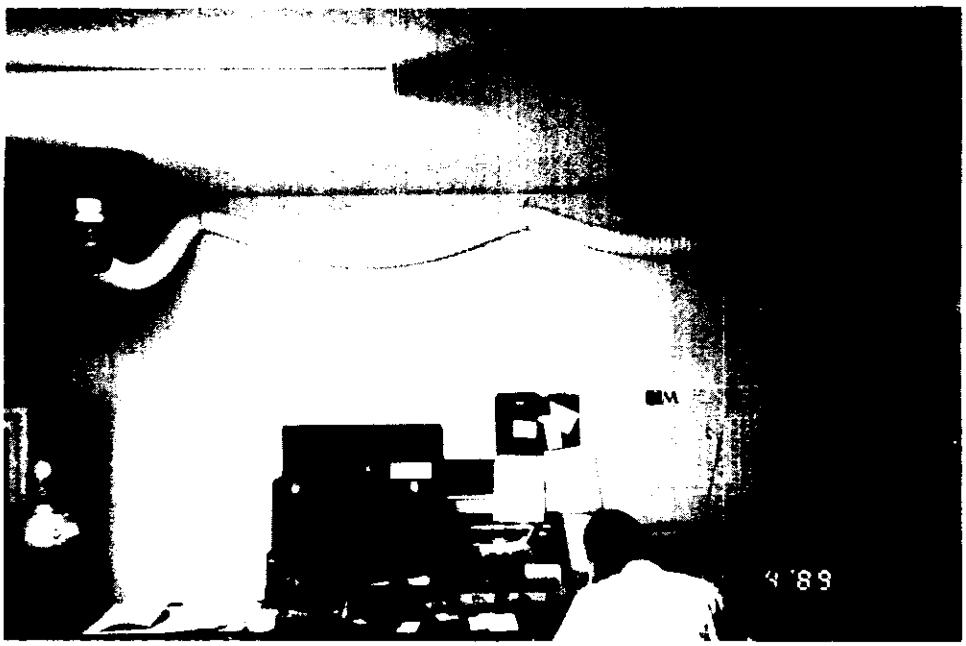

Figure 5. View of exhaust duct from the adjacent work room.

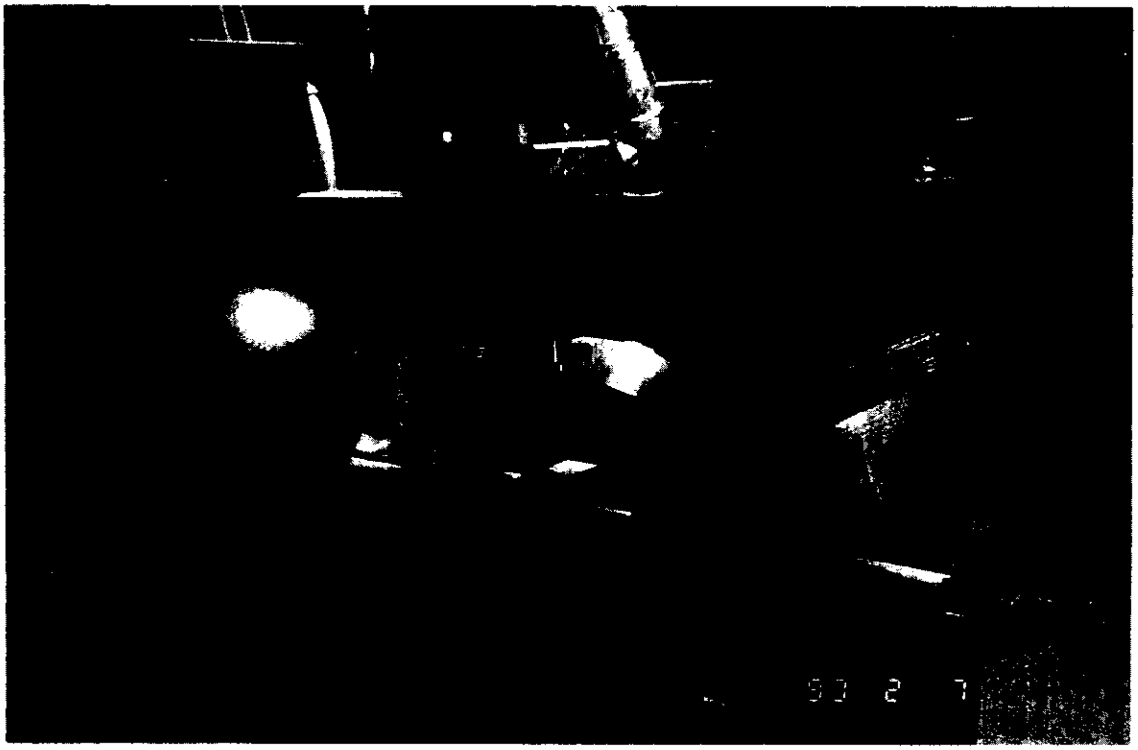

Figure 6. Newly installed laser work chamber at Photon Dynamics **after** NIOSH evaluation. The air intake is on the side and the moveable **front** panel is an appropriate laser barrier.

Figure 7. The three exhaust ducts are rated at 300 cfm each.