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NIOSH INVESTIGATORS:
C. Eugene Moss, M.S., HP
Charles Bryant, M.S., CIH
John Stewart, B.S.
Wen-Zong Whong, Ph.D.
Alan Fleeger, M.S.P.H., CIH
Bobby J. Gunter, Ph.D., CIH

I. SUMMARY

On December 9, 1987, the National Institute for Occupational Safety and Health (NIOSH) received a request for a Health Hazard Evaluation from the administrator of the Laser Institute at the University of Utah Health Sciences Center in Salt Lake City, Utah. The administrator requested that NIOSH evaluate the smoke produced during laser surgical procedures for potentially hazardous compounds.

Due to the experimental nature of this evaluation it was necessary for the NIOSH investigators to determine the applicability of conventional industrial hygiene techniques. On February 9 and March 10, 1988, preliminary measurements were performed at a local medical laser facility that aided the investigators in gaining experience and in developing a final sampling protocol for use at the medical center. These preliminary measurements are also included as part of this report.

Environmental sampling was conducted at the medical center on April 11-16, 1988 to evaluate occupational exposure to hydrocarbons, polynuclear aromatic compounds (PNAs), formaldehyde, cyanide, and airborne mutagens. A health complaint questionnaire was administered to medical personnel.

Results of the environmental sampling documented detectable levels of ethanol, isopropanol, anthracene, formaldehyde, cyanide, and airborne mutagenic substances.

Ethanol and isopropanol were detected at concentrations of 4.7 parts per million (ppm) and 0.5-16.4 ppm, respectively. Both were below the OSHA and ACGIH evaluation criteria.

Detectable levels of anthracene, a PNA compound, were present in trace quantities.

Detectable quantities of formaldehyde (trace to 0.44 ppm) were found in all but one of the samples. Two short-term samples measured peak concentrations (0.21 ppm and 0.44 ppm) of formaldehyde sufficient to cause irritation in some sensitive individuals.

Cyanide was detected in three of the eleven area and breathing zone samples taken. All levels were below the evaluation criteria. Draeger tubes revealed the presence of hydrogen cyanide at the laser irradiation site at a concentration of 100 ppm.

Solvent extracts of airborne particles generated during laser procedures were found to be mutagenic (Ames test). Whether exposure of operating room personnel to substances that are mutagenic to bacteria poses any genotoxic hazard is not known.

The results of this evaluation indicate the importance of using smoke evacuators as a control measure. Therefore, as part of this evaluation NIOSH investigators undertook a limited study of smoke evacuators and published the findings in a peer-reviewed journal.[1]

Based on the data obtained during this investigation it was determined that exposure to the constituents of the smoke generated during laser surgery presents a potential health hazard. Recommendations are provided in Section VIII which will aid in reducing exposures primarily through the use of smoke evacuators.

KEYWORDS: SIC 8062 (General Medical and Surgical Hospitals), operating rooms, laser surgery, laser smoke, fume, mutagenicity, polynuclear aromatics (PNAs), formaldehyde, cyanide.

II. INTRODUCTION

On December 9, 1988, NIOSH received a request for a health hazard evaluation from the University of Utah Health Sciences Center, Salt Lake City, Utah. The request concerned exposure to smoke generated by medical lasers during laser surgery and animal research procedures. NIOSH investigators conducted environmental surveys at the Health Sciences Center during April 11-15, 1988.

III. BACKGROUND

The word LASER is an acronym for Light Amplification by Stimulated Emission of Radiation. Lasers generate a very intense beam of photons at one wavelength. Since the spread of a laser beam is not large, this property makes the laser a unique surgical device for many applications. In addition to being very precise and easy to use, it also represents a "no touch" therapy where bleeding and edema are minimal. The first laser was built in 1960 and since that time the field has grown rapidly. Today the major lasers used in the medical and surgical fields are the Neodymium-Yttrium, Aluminum Garnet (Nd:YAG), Carbon Dioxide (CO_2), and Argon.

When laser energy is absorbed by human tissue a rapid vaporization of cellular water can occur that may cause disruption of the cell. When lasers are used at high intensities on tissues, a plume of smoke is produced consisting of vaporized material, steam, and particulate matter. Health care workers have expressed concern about the nature and composition of the smoke. While the laser-produced smoke can be suctioned away from the irradiated area by a filtered vacuum system, many health care facilities do not use such a system because of cost, noise, and/or lack of awareness.

IV. METHODS AND MATERIALS

Environmental measurements performed at the medical center facility during surgical procedures on humans were made either in the laser surgical operating rooms or in the laser clinic, depending on the nature of the operation. Environmental measurements were also obtained during irradiation of mice tumors at the animal laser laboratory and the experimental laser laboratory.

The target material used for the preliminary evaluations (February 9 and March 10, 1988) was processed meat (pork). Human and mouse tissue was the target material for the medical center evaluations. The pork was used to test the sampling and analytical methods intended for use at the medical center during laser surgery on humans.

In preparation for the NIOSH evaluation, the medical center had scheduled several different laser operations. Unfortunately, some operations were cancelled for medical reasons. As a result, a decision was made to perform laser smoke evaluations using research animals available from on-going studies being conducted at the medical center. The decision to use animals was based in part upon the need to assess potential exposure to technicians and scientists working with the animals. A total of 16 different laser events involving seven patients and nine animals were evaluated.

Eleven workers were interviewed using a questionnaire to determine the type and extent of health complaints experienced by the medical personnel.

In conducting this evaluation, the NIOSH investigators were permitted to enter the surgical rooms and collect data during the course of the surgical event (when the laser was activated). All personnel involved with these operations were required to wear operating room clothing, including masks, head covers, laser goggles, shoe covers, and surgical gloves. All equipment brought into the operating room was cleaned according to the medical center instructions. Industrial hygiene sampling equipment was positioned as close as possible to the active surgical site (hand held in the employees breathing zone) without interfering with the medical procedure. All operating room personnel were informed of our presence before the operation began.

The same basic data collecting format was used in the animal laser laboratories. Due to the small number of personnel in these laboratories it was possible to position the measurement equipment closer to the surgical site. All of the animals used were female AJ/CR inbred albino mice (20 grams) which had neuroblastomas.

The following types of equipment were used to collect the environmental samples for the evaluation:

A. Fourier Transform Infrared Spectroscopy (FTIR) - Qualitative Organic Analysis

Area samples for organic compounds were collected by drawing air through a Zefluor filter at a flowrate of 1.0 liters per minute (lpm) using calibrated, battery-operated sampling pumps.

For analysis, the Zefluor filters were removed from their cassettes and placed in 20 milliliter (ml) scintillation vials and desorbed with approximately 2 ml of 1,1,2-trichlorotrifluoroethane (Freon-113). An aliquot of this solution was placed on a potassium bromide (KBr) window and allowed to evaporate. A single beam spectrum of the sample-containing window was taken with a Nicolet 60SX (FTIR) using a combined indium actinimide/mercury cadmium telluride detector at 0.5 cm^{-1} spectral resolution and ratioed to a background single-beam spectrum of the window, taken before deposition of the sample.

B. Qualitative Aldehyde Screen

Samples for airborne aldehydes were collected by drawing air through ORBO-23 tubes at a flowrate of 1.0 1pm. Samples were desorbed with 1 ml of toluene in an ultrasonic bath for 60 minutes. Aliquots of the sample extracts were then screened by gas chromatography (GC) with a flame ionization detector (FID) using both a 30-meter DB-WAX (for formaldehyde and acetaldehyde) column and a 30-meter DB-1 GC (other aldehydes) column. This method has a limit of detection (LOD) of 0.5 ug/sample and a limit of quantitation (LOQ) of 1.5 ug/sample.

C. Formaldehyde

The air samples for formaldehyde were collected by drawing air through a glass midget impinger containing 20 ml of a 1% sodium bisulfite solution at a flowrate of 0.5 1pm using calibrated, battery-operated sampling pumps. Analysis was by visible absorption spectrophotometry according to NIOSH Method No 3500. This method has a LOD of 0.2 ug/sample and a LOQ of 0.63 ug/sample.

D. Hydrocarbons

Air samples for hydrocarbons were collected by drawing air through a glass tube containing 150 milligrams (mg) of activated charcoal at a flowrate of 1.0 1pm (qualitative samples) and 0.2 1pm (quantitative samples) using calibrated, battery-operated sampling pumps. The qualitative samples were desorbed with 1 ml of carbon disulfide and analyzed by GC/FID. The quantitative samples were concentrated and analyzed by GC using a mass spectrometer (MS) for major compound identification.

E. Hydrogen Cyanide

Drager* colorimetric detector tubes (1-stroke test for range of measurement of 10-150 parts per million (ppm)) were placed in the laser smoke to document the presence of hydrogen cyanide.

F. Cyanides

Air samples (area and breathing zone) for cyanides were collected via NIOSH Method 7904. Air was drawn through a mixed cellulose-ester filter followed by a glass midget bubbler, containing 15 ml of 0.1 N potassium hydroxide, at a flowrate of 0.5 lpm using calibrated, battery-operated sampling pumps. The samples were analyzed for cyanide by visible absorption spectroscopy. The analytical LOD for this method was 0.1 ug per sample.

G. PNAs

Personal (breathing zone) and area air samples were collected using a sampling train consisting of a Zefluor 2-micron filter (Membrana Co.) and a cellulose acetate O-ring in a cassette, followed by a 7-mm outside diameter glass tube containing two sections of pre-washed XAD-2 resin (100mg/50mg) connected to a battery-operated sampling pump calibrated at a flowrate of 2.0 1pm.

The filter and tube samples were analyzed for PNAs following NIOSH Method 5506 utilizing high performance liquid chromatography and GC/MS. Standards were prepared by spiking aliquots of a stock solution containing 14 PNAs onto the filters and tubes and desorbing them in the same manner as the field

samples. Retention times of the analytes in the standards were compared to the retention times in the sample chromatograms for analyte identification. Analytes were identified by retention times only and GC/MS was necessary to confirm their identity. The standard analytes and their associated analytical LODs are listed below:

Analyte	LOD (nanograms/sample)
Acenaphthene	100
Anthracene	30
Benz(a)anthracene	30
Benzo(a)pyrene	30
Benzo(b)fluoranthene	30
Benzo(e)pyrene	50
Benzo(k)fluoranthene	30
Benzo(g,h,i)perylene	100
Chrysene	30
Dibenz(a,h)anthracene	50
Fluoranthene	30
Indeno(1,2,3-cd)pyrene	100
Phenanthrene	100
Pyrene	30

H. Airborne Mutagens

Airborne particles were collected on glass fiber filters (type A/E, 4" diameter) with Hi-Vol pumps (General Metal Works) at flow rates between 18.5 and 22 cubic feet per minute (cfm), and on charcoal filter canisters taken from inside the smoke evacuation units. Airborne particulates on the glass fiber filters were extracted with 150 ml of methylene chloride and then with 150 ml of acetone and methanol. Charcoal filter canisters from the smoke evacuators were extracted with the same solvent, but because of their size, a larger volume of solvent (2000 ml) was used. Each extract was filtered and concentrated to a final volume of 0.3 ml or 0.5 ml in dimethylsulfoxide depending on the density of the end products.

Air samples in the surgical operating room were taken approximately 2 ft. above the operative site. A glass fiber filter was also placed in front of the charcoal filtration canisters inside the smoke evacuation unit utilized in the operating room and in the laser outpatient clinic. Control samplers were placed 1/2 ft. above the floor in the hall outside the operating room.

In the animal laser laboratory, air samples were collected 2 in. above the irradiation site (mice tumors) during all experiments. Airborne samples were taken 1 ft. in front of the irradiation site (mice tumors) in the experimental laser laboratory. The difference in sampling distances was due to the accessibility requirements imposed on the sample location in the experimental laser laboratory. The control sampler was placed 1/2 ft. above the floor in the hall outside both laboratories.

Charcoal filter canisters were taken directly from the smoke evacuators to be tested for airborne mutagens. The control charcoal filter canister was run at the same time in a clean room. The *in situ* assay was performed in both the operating room and the laser laboratory. Both experiments were run with their respective controls.

The mutagenicity of extracts from the filters and cannisters were studied in tester strains TA98 and TA100 of *Salmonella typhimurium* with the Salmonella/microsomal micro-suspension mutagenicity test.[2] In this test system, an increased number of bacterial cells (approximate 10^9) was treated with extracts in a small amount of treatment mixture (0.09 ml). The assay was conducted with or without S9 in vitro metabolic activation. After 90 minutes of incubation at 37 degrees Centigrade with shaking, the treatment was further processed using the Ames/plate incorporation test.[3] The colonies, resulting from histidine dependence to histidine independence by reverse mutations, were scored after 2 days incubation at 37 degrees Centigrade. In the *in situ* mutagenicity assay, tester cells (TA98W) were exposed directly to airborne particles in the trapping media during air sampling. Mutation frequencies were determined from treated and control cells after 2, 4, and 6 hour exposures.[4]

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 up to 10 hours per day, 40 hours per week, for a working lifetime, without experiencing adverse health effects. It is, however, important to note that not all workers will be protected from adverse health effects if their exposures are maintained below these levels. A small percentage may experience adverse 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 on the toxic effects of an agent become available.

The primary sources of environmental evaluation criteria for the workplace are: 1) NIOSH Criteria Documents and recommended exposure limits (RELs), 2) the American Conference of Governmental Industrial Hygienist's (ACGIH) Threshold Limit Value (TLVs), 3) the U.S. Department of Labor (OSHA) permissible exposure limits (PELs), 4) applicable American National Standard Institute (ANSI) documents, and 5) current governmental research and articles found in peer-reviewed publications. Often, the NIOSH and ANSI recommendations and ACGIH TLVs are lower than the corresponding OSHA standards. NIOSH, ANSI, and ACGIH TLVs usually are based on more recent information than are the OSHA standards. 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 standard.

A time-weighted average (TWA) exposure refers to the average airborne concentration of a substance during a normal 8- to 10-workday. Some substances have recommended short-term exposure limits or ceiling values which are intended to supplement the TWA, where there are recognized toxic effects from high short-term exposures.

A. Formaldehyde

Formaldehyde and other aldehydes may be released from a variety of common materials including foam plastics, carbonless copy paper, particle board, plywood and textile fabrics. Symptoms of exposure to low concentrations of formaldehyde include irritation of the eyes, throat, and nose, headache, nausea, congestion, asthma, and skin rashes. It is difficult to ascribe specific health effects to concentrations of formaldehyde to which people are exposed, because people vary in their subjective responses and complaints. Irritative symptoms may occur in people exposed to formaldehyde at concentrations as low as 0.1 ppm, but more frequently in exposures of 1.0 ppm and greater. Sensitive children, the elderly, those individuals with preexisting allergies or respiratory diseases, and persons who have become sensitized from prior exposure may have symptoms from exposure to concentrations of formaldehyde between 0.05 and 0.10 ppm. Formaldehyde-induced asthma and bronchial hyperreactivity developed specifically to formaldehyde exposure are uncommon.[5]

Formaldehyde vapor has been found to cause a rare form of nasal cancer in Fischer 344 rats exposed to a 15 ppm concentration for 6 hours per day, 5 days per week, for 24 months. Whether these results can be extrapolated to human exposure is the subject of considerable speculation in the scientific literature. Conclusions cannot be drawn with sufficient confidence from published mortality studies of occupationally exposed adults as to whether or not formaldehyde is a carcinogen. Studies of long-term human occupational exposure to formaldehyde have not detected an increase in nasal cancer. However, the animal results have prompted NIOSH to recommend that formaldehyde be handled as a potential occupational carcinogen and that workplace exposures be reduced to the lowest feasible limit.[6] OSHA has recently reduced its PEL for formaldehyde to 1.0 ppm.[7] In addition, a 15-minute short term exposure limit (STEL) was set at 2 ppm. ACGIH has given formaldehyde an A2 designation, indicating that ACGIH considers formaldehyde a suspected human carcinogen. The ACGIH TLV for formaldehyde is 1 ppm as an 8-hour TWA and 2 ppm as a 15-minute STEL.[8] Formaldehyde is currently listed in the 1989-90 ACGIH "Notice Of Intended Changes" at a proposed ceiling TWA-A2 value of 0.3 ppm. If, after two years no evidence comes to light that questions the appropriateness of the proposed change, the value will be reconsidered for adoption into the

TLV listing.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has developed a rationale, based on personal comfort, that exposure to toxic substances, such as formaldehyde, be limited to 1/10 of the applicable industrial standard. This would suggest that exposure to formaldehyde be limited to 0.1 ppm.[9] This guideline has also been adopted by NASA, and the federal governments of Canada, West Germany, and the United Kingdom.[10] An indoor air formaldehyde concentration of less than 0.05 ppm (0.06 mg/m^3) is of limited or no concern, according to the World Health Organization (WHO).[11]

B. Isopropanol

Isopropyl alcohol causes mild irritation of the eyes, nose, and throat. High vapor concentrations may cause drowsiness, dizziness, and headache. Repeated skin exposure may cause drying and cracking. NIOSH recommends an exposure limit of 400 ppm.[12] The OSHA PEL and ACGIH TLV are the same.[8,13]

C. Ethanol

Ethyl alcohol is an irritant of the eyes and mucous membranes, and causes central nervous system depression. Ethanol is not appreciably irritating to skin, even with repeated or prolonged exposure.[14] The OSHA PEL and ACGIH TLV are 1000 ppm.[8,13]

D. Cyanides

Symptoms of intoxication from cyanides include weakness, headache, confusion and, occasionally, nausea and vomiting. If large amounts of cyanide are absorbed, the workers may collapse instantaneously, often with convulsions, and may die from metabolic asphyxiation. Effects from exposure to low levels of cyanide are probably not incapacitating or serious.[15] NIOSH recommends an exposure limit of 5 mg/m^3.[16] The OSHA PEL is 5 mg/m^3 and the ACGIH TLV is 10 mg/m^3.[8,13]

E. PNAs

PNAs are condensed ring aromatic hydrocarbons normally arising from the combustion of organic matter. Among these polycyclic hydrocarbons are a number of individual PNAs (including benzo(a)pyrene, anthracene, and chrysene) that are known mutagens and carcinogens.[17] Benzo(a)pyrene and chrysene are currently the only individual PNAs with evaluation criteria. The ACGIH considers benzo(a)pyrene and chrysene as suspected human carcinogens and recommends that exposures should be kept to a minimum.[8] NIOSH recommends that chrysene be regarded as an occupational carcinogen.[18] The OSHA PEL for chrysene is 0.2 mg/m^3.[13]

F. Airborne Mutagens

Mutagenic substances may cause genetic alteration in the somatic and/or germ cells. Such cellular alterations may result in premature aging, cancer induction, reproductive failure, developmental defect, or genetic disease. Airborne mutagens can be detected directly with the in situ mutagenicity assay or indirectly with filter collection and subsequent mutagenicity testing (i.e., Ames/Salmonella test). A sample is considered mutagenic if the number of revertants in any of the four concentrations tested (undiluted, 1 to 2, 1 to 4, and 1 to 8) is two fold or greater than the control, and shows a dose-related response.

VI. RESULTS

Results presented in this section and the attached tables are from both the preliminary and medical center facility measurements. Data indicating the operating characteristics of the lasers used for each environmental measurement are given in the Tables.

A. February 9, 1988 (First Preliminary Evaluation)

During both preliminary evaluations, pork chops were purchased from a grocery store and used as the target material to test the sampling and analytical methods to be used in the medical center evaluation.

1. PNAs

Table I presents the results of the air samples taken for PNAs. None of the 14 PNAs which are monitored in the NIOSH standard method were detected in any of the samples.

2. FTIR (Qualitative Organic Analysis)

The results of the Zefluor filter samples taken for FTIR analysis are presented in Table II. The search area of the spectral library indicated that the compounds found on the filters were related to fatty acid esters, based on spectral similarities.

3. Hydrocarbons

Table III lists the hydrocarbon vapors that were identified during irradiation. The air samples indicate that trace amounts of acetone, isopropanol, cyclohexane, toluene, and alkanes were present near the site of irradiation (approximately 15" from target).

4. Qualitative Aldehyde Screen

Table IV presents the results of the samples taken for the qualitative aldehyde scan analysis. Only formaldehyde was detected in concentrations ranging from 0.4 to 0.8 ppm.

B. March 10, 1988 (Second Preliminary Evaluation)

1. PNAs

Table V presents the results of the air samples taken for PNAs. None of the 14 PNAs which are monitored in the NIOSH standard method were detected in any of the samples.

2. Hydrocarbons

Table VI lists the hydrocarbon vapors that were identified during irradiation. The air samples indicate that trace amounts of ethanol, isopropanol, cyclohexane, toluene, MIBK, siloxane, and alkanes were present near the site of irradiation (approximately 2" from target).

3. Qualitative Aldehyde Screen

Table VII presents the results of the samples taken for the qualitative aldehyde scan analysis. Only formaldehyde was detected and at concentrations from 0.2 to 0.5 ppm.

4. Hydrogen Cyanide Screen

Results of the Drager* tube screening samples for hydrogen cyanide are presented in Table VIII. Approximately 100 ppm of hydrogen cyanide was detected at the site of production. This result is 10 times higher than the ACGIH TLV.

C. April 11-14, 1988 (Medical Center and Animal Evaluations)

1. Formaldehyde

The air sampling results for formaldehyde are presented in Tables IX - XI. Formaldehyde was detected in all the samples taken in the operating room, laser clinic, and laser laboratory (Tables IX and X) ranging from trace amounts to 0.44 ppm, TWA over the period sampled. However, it should be noted that some of the samples were taken during very short procedures, lasting only a few minutes. Converting these measurements to 8-hour TWA values would result in much lower concentrations. For example, the sample containing 0.44 ppm would be converted to 0.003 ppm as an 8-hour TWA. None of the short term samples exceeded the OSHA or ACGIH 2 ppm STEL. It was observed that most of the operating room personnel were involved in more than one laser surgery procedure daily. Such increase in exposure time would result in a higher 8-hour TWA.

2. Hydrocarbons

Table XI presents the results of the air samples taken for hydrocarbons. One of the operating room samples contained ethanol at a concentration of 4.7 ppm, well below the evaluation criteria (OSHA and ACGIH) of 1000 ppm.

Two of the three air samples contained isopropanol in concentrations ranging from 0.5 to 16.4 ppm, again well below the evaluation criteria of 400 ppm. The alcohols that were detected may not have been created by the laser interaction with tissue, but rather may be ubiquitous (cleaning solutions) to the health care environment. Trace amounts of C_8-C_{12} aliphatic hydrocarbons were found in two of the three samples. These hydrocarbons would not be expected to cause noticeable effects in most people at the levels detected.

3. Cyanides

Samples (area and breathing zone) for cyanides were taken in the operating room, laser clinic, and laser laboratory (Tables XII and XIII). All samples (range: none detected to 1.53 mg/m^3) were below the evaluation criteria.

4. PNAs

The results of the air samples taken for PNAs are presented in Tables XIV-XVI. Trace amounts of anthracene were detected in three (laser clinic and laser laboratory) of the eighteen samples taken. None of the other thirteen PNAs which are monitored in the NIOSH standard method were detected in any of the samples.

5. Airborne Mutagens

The results in Table XVII show that in the medical center operating rooms, mutagenic substances were detected only in the activated charcoal cartridges located in the smoke evacuation units. The mutagenic responses were found in both TA98 (detects frameshift mutagens) and TA100 (detects primary base-pair substitution mutagens), indicating that the mutagenic agents might induce both frameshift and base-pair substitution mutations. However, the induction of base-pair substitution mutation needs to be further confirmed. Samples of the operating room air did not show any mutagenic activity. It could be concluded, therefore, that smoke evacuation units are capable of removing airborne mutagens generated during laser surgeries when properly positioned in terms of nozzle angle and distance from the irradiated site. In the laser clinic where patients were also treated, extracts of airborne particles (collected on filters) and activated charcoal cartridges from the smoke evacuation units were mutagenic in TA98 and TA100, respectively. It appears that frameshift mutagens were associated with particles which were collected on the filters and that base pair substitution mutagens passed the filters and were collected by the charcoal traps. Again it can be concluded that smoke evacuator units are capable of capturing airborne mutagens (either particulate or gaseous phase).

Table XVIII shows the mutagenicity data collected from using different types of lasers on animals. Airborne particles collected in the laser animal laboratory utilizing CO_2 and YAG lasers were mutagenic. In the experimental fixed beam laser laboratory, mutagenicity was found in the extracts of

airborne particles generated from fixed beam UV 266 and Erbium lasers incident on mice skin. In both cases, mutagenicity was found in TA98 with metabolic activation. The results clearly indicate that airborne particles produced from those laser operations using animals contained indirect-acting frameshift mutagens. Smoke evacuation systems were not used in these studies.

No mutagenic activity was detected with the in situ studies (Table XIX) that were conducted in the operating room of the medical center. This observation could be attributed to the effectiveness of the smoke evacuation devices and/or a low sampling volume during the in situ sampling.

D. Questionaire

A copy of the questionaire used in this evaluation is shown in Appendix I. Selected results from the questionaire are shown in Table XX. It is apparent that some workers perform multiple laser procedures. However, the average length of time per week for laser smoke exposure is smaller because the actual laser beam "on-time" is less than actual procedure time. All respondants said they had not experienced any effects from smoke exposure during or after laser procedures, however at this facility all the respondents had smoke evacuators available for use.

VII. CONCLUSIONS

A. Preliminary evaluations (February 9 and March 10, 1988)

1. No PNAs were detected.

2. Based on the FTIR (qualitative organic) analysis, the major component of the samples is a compound or compounds related to fatty acid esters.

3. Trace amounts of hydrocarbons were detected.

4. The qualitative aldehyde screen revealed detectable levels of formaldehyde ranging from 0.2 to 0.8 ppm.

5. Drager* tube screening revealed hydrogen cyanide concentrations of approximately 100 ppm produced at the site of irradiation.

B. Medical Center and Animal evaluations (April 11-14, 1988)

1. Detectable quantities of formaldehyde were found in all the samples taken in the operating rooms, laser clinic, and laser animal laboratories. Two of the short term (less than fifteen minutes) samples contained peak concentrations of formaldehyde that might cause imitation in some sensitive individuals.

2. Hydrocarbon sampling revealed ethanol, isopropanol (quantifiable levels), and C_8-C_{12} aliphatic hydrocarbons (trace levels). These substances would not be expected to cause noticeable effects in most people at the levels detected.

3. Cyanide was detected in three of the eleven samples taken. All were below the evaluation criteria and would not be expected to produce adverse effects in most people.

4. Detectable levels of anthracene were present in trace quantities.

5. The results of the evaluation (area samples) for airborne mutagens indicate that the lasers used during these evaluations generate mutagenic airborne particles. These mutagenic results were consistent with those in a previous NIOSH report [19] and the study by Tomita et al. [20]

It is not known whether exposure of operating room personnel to agents that are mutagenic to bacteria, or the level and condition of these agents to which workers are exposed, poses any genotoxic hazards. In the meantime, it would be prudent to reduce mutagenically active contaminants by appropriate control measures (i.e. use of smoke evacuation syterns) whenever possible in the operating room.

C. After obtaining the environmental data, NIOSH scientists undertook a limited study of smoke evacuators and published the findings in a peer-review journal. A copy of this article appears in Appendix II. The information contained in this article should be integrated into the overall safety program at the University of Utah, as well as at all health care facilities using lasers.

D. It was observed during this investigation that the amount of smoke produced from irradiated tissue, and not necessarily its components, was a function of the laser irradiance on that tissue. The higher the irradiance, the more smoke, by volume, appeared. This observation indicates that lower irradiance levels may reduce laser smoke emissions. While this technique may reduce exposures, it could be difficult to accomplish considering time, monetary considerations, and quality of health care.

E. Most of the complaints voiced at the test facility focused on the issues of smell, odors, and vision. Many of these complaints occurred when CO_2 and Argon lasers were used to irradiate external body parts. The smoke produced during these procedures was apparently greater than with other laser procedures presently being used at the medical center.

VIII. RECOMMENDATIONS

1. Ventilation controls (smoke evacuation units) should be utilized to minimize the potential for health effects. The smoke evacuation units will also eliminate the emissions that can impair the surgeon's vision.

2. The exhaust outlets of the smoke evacuation units should be vented outside the building to prevent recirculation of any substances that may penetrate the charcoal cartridges. This would also aid in further reducing the odors associated with the laser smoke.

3. Personal protective equipment (gloves and face shields) should be worn when performing maintenance (replacing charcoal cartridges, etc.) on the smoke evacuation units to avoid contact with substances that have accumulated inside the units.
4. Personal protective equipment and adequate ventilation is particularly important when using experimental lasers since smoke and particles may be produced at greater distances from the interaction site than with the lasers currently in use.

5. Further study to examine the advantages and disadvantages offered by utilizing lower irradiance levels to reduce laser smoke emissions is warranted.

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X. AUTHORSHIP AND ACKNOWLEDGEMENTS

Report Prepared by:	C. Eugene Moss, M.S. Health Physicist
	Charles J. Bryant, M.S., CIH Industrial Hygienist
	Wen-Zong Whong, Ph.D. Geneticist NIOSH Morgantown, West Virginia
	John Stewart, B.S. Research Microbiologist NIOSH Morgantown, West Virginia
Field Assistance:	Allan Fleeger, M.S.P.H. Industrial Hygienist Industrial Hygiene Section
	Bobby J. Gunter, Ph.D., CIH Regional Industrial Hygienist NIOSH-Denver, Colorado
Originating Office:	Hazard Evaluations and Technical Assistance Branch Division of Surveillance, Hazard Evaluations, and Field Studies
Report Typed By:	Sharon Jenkins Clerk (Typing)
	Kathy Conway Clerk (Typing)

XI. 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. University of Utah Laser Center
2. NIOSH, Denver Region
3. OSHA, Region VIII

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

PNA Sampling Results in ng/m^3 (Pork Choo Data)
University of Utah Medical Center
Salt Lake City, Utah
HETA 88-101

February 9, 1988

Sample Type	Type Laser	Sampling period	PNAs
Hand Held (15" from meat)	CO_2.30 watt.CW Micro-Blade.f=300 mm beam diameter = 1mm	7 min.	ND
Hand Held (2" from meat)	CO_2.30 watt.CW 125 mm handpiece beam diameter = 0.5mm	5 min.	ND
Hand Held (2" from meat)	CO_2.400 Hz.f=50 mm avg. power = 10 watt peak power = 220 watt pulse duration = 120 us beam diameter = 0.4 mm	6 min.	ND

PNAs = Acenaphthene, Anthracene, Phenanthrene, Fluoranthene, Pyrene, Benz(a)anthracene, Chrysene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(e)pyrene, Benzo(a)pyrene, Indeno(1,2,3-cd)pyrene, Dibenz(a,h)anthracene, Benzo(ghi)perylene.

ND = None Detected.

CW = Continuous Wave

TABLE II

Zefluor Filter Sample/Fourier Transform Infrared Spectroscopy Analysis (Pork Chop Data)
University of Utah Medical Center
Salt Lake City, Utah
HETA 88-101

February 9, 1988

Sample Type	Type Laser	Sampling period	Substance Identified
Hand Held (15" from meat)	CO_2,30 watt,CW Micro-Slade,f=300 mm beam diameter = 1mm	7 min.	Compound or compounds related to fatty acid esters
Hand Held (2" from meat)	CO_2,400 Hz,f=50 mm avg. power = 10 watt peak power = 220watt pulse duration = 120us beam diameter = 0.4 mm	6 min.	

CW = Continuous Wave

TABLE III

Hydrocarbon Sampling Results (Pork Chop Data)
University of Utah Medical Center
Salt Lake City, Utah
HETA 88-101

February 9, 1988

Sample Type	Type Laser	Sampling Period	Substance Identified
Hand Held (15" from meat)	CO_2.30 watt.CW Micro-Blade.f=300 mm Beam diameter = 1mm	7 min.	Acetone‡ Isopropanol‡ Cyclohexane‡ Toluene‡ Alkanes‡

‡ = Substances were present in trace quantities, between the limit of detection (1-5 ug/sample) and limit of quantitation (5-10 ug/sample).

TABLE IV

Qualitative Aldehyde Scan (Pork Chop Data)
University of Utah Medical Center
Salt Lake City, Utah
HETA 88-101

February 9, 1988

Sample Type	Type Laser	Sampling period	Aldehydes Identified*
Hand Held (15° from meat)	CO_2,30 watt,CW Micro-Blade,f=300 mm beam diameter = 1mm	7 min.	Formaldehyde (0.4 ppm)
Hand Held (2° from meat)	CO_2,30 watt,CW 125 mm handpiece beam diameter = 0.5mm	5 min.	Formaldehyde (0.8 ppm)
Hand Held (2° from meat)	CO_2,400 Hz,f=50 mm avg. power = 10 watt peak power = 220 watt pulse duration = 120 us beam diameter = 0.4 mm	6 min.	Formaldehyde (0.4 ppm)

* = Aldehyde scan is limited to the low molecular weight (C_1-C_8) aliphatic aldehydes.

TABLE V

PNA Sampling Results in ng/m^3 (Pork Chop Data)
University of Utah Medical Center
Salt Lake City, Utah
HETA 88-101

March 10, 1988

Sample Type	Type Laser	Sampling period	PNAs
Hand Held (2" from meat)	Nd:YAG.38-74 watt beam diameter = 1.5 mm	5 min.	ND
Hand Held (smoke evacuator exhaust)	"	5 min.	ND
Hand Held (2" from meat)	CO_2.30 watt.CW handpiece.fl = 125 mm beam diameter = 1 mm	5 min.	ND

PNAs = Acenaphthene, Anthracene, Phenanthrene, Fluoranthene, Pyrene, Benz(a)anthracene, Chrysene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(e)pyrene, Benzo(a)pyrene, Indeno(1,2,3-cd)pyrene, Dibenz(a,h)anthracene, Benzo(ghi)perylene.

ND = None Detected.

TABLE VI

Hydrocarbon Sampling Results (Pork Chop Data)
University of Utah Medical Center
Salt Lake City, Utah
HETA 88-101

March 10, 1988

Sample Type	Type Laser	Sampling period	Substance Identified
Hand Held (2" from meat)	Nd:YAG,38-74 watt beam diameter = 1.5 mm	5 min.	Ethanol* Isopropanol* Cyclohexane* Toluene* Alkanes (C9-C12)* MIBK* Siloxane*

* = Substances were present in trace quantities, between the limit of detection (1-5 ug/sample) and limit of quantitation (5-10 ug/sample).

TABLE VII

Qualitative Aldehyde Scan (Pork Chop Data)
University of Utah Medical Center
Salt Lake City, Utah
HETA 88-101

March 10, 1988

Sample Type	Type Laser	Sampling period	Aldehydes Identified*
Hand Held (2" from meat)	Nd:YAG.38-74 watt beam diameter = 1.5 mm	5 min.	Formaldehyde (0.5 ppm)
Hand Held (smoke evacuator exhaust)	"	5 min.	ND
Hand Held (2" from meat)	CO_2.30 watt.CW handpiece.fl = 125 mm beam diameter = 1 mm	5 min.	Formaldehyde (0.2 ppm)

* = Aldehyde scan is limited to the low molecular weight (C_1-C_6) aliphatic aldehydes.

ND = None Detected.

TABLE VIII

Hydrogen Cyanide Samples/Drager Tube (Pork Chop Data)
University of Utah Medical Center
Salt Lake City, Utah
HETA 88-101

March 10, 1988

Sample Type	Type Laser	Number of Strokes	Hydrogen Cyanide
Hand Held (2" from meat)	Nd:YAG.38-74 watt beam diameter = 1.5 mm	1	100 ppm
Hand Held (smoke evacuator exhaust)	"	1	100 ppm
Hand Held (2" from meat)	CO_2.30 watt.CW handpiece.#1 = .125 mm beam diameter = 1 mm	1	100 ppm

TABLE IX

Formaldehyde (Patient Data)
University of Utah Medical Center
Salt Lake City, Utah
HETA 88-101

April 11-14, 1988

Sample Location	Sample Type	Type Laser	Sampling Period	Formaldehyde Concentration (ppm)
Laser Unit # 2 (Skin Lesion)	Area	CO_2.4.0 watt.CW Beam Diameter = 0.2 mm	7 min.	0.013
"	Hand Held	"	13 min.	(Trace)
Operating Room #8 (Graft/PMC Flap)	"	Nd:YAG.15-30 watt.CW Beam Diameter = 0.8 mm	54 min.	(Trace)
Background Level Laser Unit #3	Area	-	318 min.	0.011
Operating Room #8 (Laryngeal Surgery)	Hand Held	Micro-Blade.CO_2.5 watt.CW	11 min.	(Trace)
Laser Unit #3 Vulva (Pre-Cancer)	Hand Held	Argon.2.5 watt.CW Beam Diameter = 3.5 mm	9 min.	0.12
"	Area	"	"	(Trace)
Operating Room #8 (Nasal Procedure)	Hand Held	Argon.4.0 watt.CW	51 min.	(Trace)

Evaluation Criteria:		
	(NIOSH)	LFL
	(OSHA-PEL)	1.0
	(OSHA-STEL)	2.0
	(ACGIH-TLV)‡	1.0
	(ACGIH-STEL)	2.0
	(ASHRAE)	0.1
	(WHO)	0.05

Trace = Substance was present in trace quantities, between the limit of detection (0.2 ug/sample) and limit of quantitation (0.63 ug/sample). This would correspond to an atmospheric concentration range of 0.007-0.023 ppm assuming an air sample volume of 22.5 liters.

LFL = Lowest Feasible Level. NIOSH regards formaldehyde as a potential carcinogen. NIOSH recommends that workplace exposure be reduced to the lowest feasible limit.

‡ = Included in ACGIH "Notice Of Intended Changes" for 1989-90, currently recommending ceiling TLV value of 0.3 ppm.

TABLE X

Formaldehyde (Mice Tumor Data)
University of Utah Medical Center
Salt Lake City, Utah
HETA 88-101

April 11-14, 1988

Sample Location	Sample Type	Type Laser	Sampling Period	Formaldehyde Concentration (ppm)
Laser Laboratory/ Mice Tumors	Hand Held	CO_2	3 min	0.44
"	"	Nd:YAG.50 watt.CW.Open Beam	4 min	(Trace)
Experimental Lasers/ Mice Tumors	Area	Nd:YAG.Wavelength = 532 nm.10 Hz.78 mJ/pulse Pulse Duration = 10 ns.Beam Diameter = 2.5 mm	5 min	(Trace)
"	"	Nd:YAG.Wavelength = 355 nm.10 Hz.65 mJ/pulse Pulse Duration = 9 ns.Beam Diameter = 1.5 mm	105 sec	(Trace)
"	"	Nd:YAG.Wavelength = 266 nm.10 Hz.60 mJ/pulse Pulse Duration = 8 ns.Beam Diameter = 0.5 mm	220 sec	(Trace)
"	"	Erbium.Wavelength = 2.9 um.8 Hz.30 mJ/pulse Pulse Duration = 250 us.Beam Diameter = 2 mm	4 min	(Trace)

Evaluation Criteria:		
	(NIOSH)	LFL
	(OSHA-PEL)	1.0
	(OSHA-STEL)	2.0
	(ACGIH-TLV)‡	1.0
	(ACGIH-STEL)	2.0
	(ASHRAE)	0.1
	(WHO)	0.05

(Trace) = Substance was present in trace quantities, between the limit of detection (0.2 ug/sample) and limit of quantitation (0.63 ug/sample). This would correspond to an atmospheric concentration range of 0.08-0.26 ppm assuming an air sample volume of 2 liters.

LFL = Lowest Feasible Level. NIOSH regards formaldehyde as a potential carcinogen. NIOSH recommends that workplace exposure be reduced to the lowest feasible limit.

‡ = Included in ACGIH "Notice Of Intended Changes" for 1989-90, currently recommending ceiling TLV value of 0.3 ppm.

TABLE XI

Hydrocarbons
University of Utah Medical Center
Salt Lake City, Utah
HETA 88-101

April 11-14, 1988

Sample Location	Sample Type	Type Laser	Sampling Period	Hydrocarbon Concentration (ppm) Ethanol	Isopropanol	Total Other* Hydrocarbons
Laser Unit #2 (Skin Lesion)	Area	CO_2 4.0 watt.CW Beam Diameter = 0.2 mm	427 min.	ND	0.5	(Trace)
"	Hand-Held	"	17 min.	ND	16.4	(Trace)
Operating Room #8 (Graft/PMC Flap)	"	Nd:YAG 15-30 watt.CW Beam Diameter = 0.8 mm	54 min.	4.7**	ND	ND
Evaluation Criteria:	(NIOSH)			-	400	-
	(OSHA)			1000	400	-
	(ACGIH)			1000	400	-

* = Aliphatics in the C_8-C_{12} range. Decane used for standard.

ND = None Detected.

(Trace) = Substances were present in trace quantities, between the limit of detection (10 ug/sample) and limit of quantitation (30 ug/sample). This would correspond to an atmospheric concentration range of 0.02-0.06 ppm assuming an air sample volume of 83.6 liters.

** = Breakthrough (The amount of analyte found on the sample back sorbent section exceeded 10% of what was found on the front section).

TABLE XII

Cyanide
University of Utah Medical Center
Salt Lake City, Utah
HETA 88-101

April 11-14, 1988

Sample Location	Sample Type	Type Laser	Sampling Period	Cyanide Concentration (mg/m^3)
Laser Unit # 2 (Skin Lesion)	Area	CO_2,4.0 watt,CW Beam Diameter = 0.2 mm	427 min.	ND
"	Hand Held	"	17 min.	0.4
Operating Room #8 (Graft/PMC Flap)	"	Nd:YAG,15-30 watt,CW Beam Diameter = 0.8 mm	54 min.	ND
Background Level Laser Unit #3	Area	-	318 min.	ND
Operating Room #8 (Laryngeal Surgery)	Hand Held	Micro-Slade,CO_2,5 watt,CW	11 min.	ND
Evaluation Criteria:	(NIOSH)			5.0
	(OSHA)			5.0
	(ACGIH)			10.0

ND = None Detected

TABLE XIII

Cyanide (Mice Tumor Data)
University of Utah Medical Center
Salt Lake City, Utah
HETA 88-101

April 11-14, 1988

Sample Location	Sample Type	Type Laser	Sampling Period	Cyanide Concentration (mg/m^3)
Laser Laboratory/ Mice Tumors	Hand Held	CO_2	3 min	1.53
"	"	Nd:YAG.50 watt.CW.Open Beam	4 min	1.05
Experimental Lasers/ Mice Tumors	Area	Nd:YAG.Wavelength = 532 nm.10 Hz.78 mJ/pulse Pulse Duration = 10 ns.Beam Diameter = 2.5 mm	5 min	ND
"	"	Nd:YAG.Wavelength = 355 nm.10 Hz.65 mJ/pulse Pulse Duration = 9 ns.Beam Diameter = 1.5 mm	105 sec	ND
"	"	Nd:YAG.Wavelength = 266 nm.10 Hz.60 mJ/pulse Pulse Duration = 8 ns.Beam Diameter = 0.5 mm	220 sec	ND
"	"	Erbium.Wavelength = 2.9 um.8 Hz.30 mJ/pulse Pulse Duration = 250 us.Beam Diameter = 2 mm	4 min	ND
Evaluation Criteria:	(NIOSH)			5.0
	(OSHA)			5.0
	(ACGIH)			10.0

ND = None Detected

mJ = Millijoule

TABLE XIV

PNA Sampling Results in ng/m³
University of Utah Medical Center
Salt Lake City, Utah
HETA 88-101

April 11-14, 1988

Sample Location	Sample Type	Type Laser	Sampling Period	Anthracene	Other PNAs
Laser Unit # 2 (Skin Lesion)	Area	CO_2,4.0 watt,CW Beam Diameter = 0.2 mm	427 min.	(Trace)	ND
"	Hand Held	"	17 min.	ND	ND
Operating Room #8 (Graft/PMC Flap)	"	Nd:YAG,15-30 watt,CW Beam Diameter = 0.8 mm	54 min.	ND	ND
Background Level Laser Unit #3	Area	-	318 min.	(Trace)	ND
Operating Room #8 (Laryngeal Surgery)	Hand Held	Micro-Slade,CO_2,5 watt,CW	11 min.	ND	ND
Laser Unit #3 Vulva (Pre-Cancer)	Hand Held	Argon,2.5 watt,CW Beam Diameter = 3.5 mm	9 min.	ND	ND
"	Area	"	"	ND	ND
Operating Room #8 (Nasal Procedure)	Hand Held	Argon,4.0 watt,CW	51 min.	ND	ND
Evaluation Criteria:	(NIOSH)			-	‡
	(OSHA)			-	‡
	(ACGIH)			-	‡

Other PNAs = Acenaphthene, Phenanthrene, Fluoranthene, Pyrene, Benz(a)anthracene, Chrysene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(e)pyrene, Benzo(a)pyrene, Indeno(1,2,3-cd)pyrene, Dibenz(a,h)anthracene, Benzo(ghi)perylene.

ND = None Detected.

Trace = Substance was present in trace quantities, between the limit of detection (30 ng/sample) and limit of quantitation (100 ng/sample). This would correspond to an atmospheric concentration range of 35-117 ng/m³ assuming an air sample volume of 854 liters.

‡ = Chrysene and Benzo(a)pyrene are the only individual PNAs with evaluation criteria (see evaluation criteria section in the report for more detail).

TABLE XV

PNA Sampling Results in ng/m^3 (Mice Tumor Data)
University of Utah Medical Center
Salt Lake City, Utah
HETA 88-101

April 12-14, 1988

Sample Location	Sample Type	Type Laser	Sampling Period	Anthracene	Other PNAs
Laser Laboratory/ Mice Tumors	Hand Held	CO_2	3 min	ND	ND
"	"	Nd:YAG,50 watt,CW,Open Beam	4 min	(Trace)	ND
Experimental Lasers/ Mice Tumors	Area	Nd:YAG,Wavelength = 532 nm,10 Hz,78 mJ/pulse Pulse Duration = 10 ns,Beam Diameter = 2.5 mm	5 min	ND	ND
"	"	Nd:YAG,Wavelength = 355 nm,10 Hz,65 mJ/pulse Pulse Duration = 9 ns,Beam Diameter = 1.5 mm	105 sec	ND	ND
"	"	Nd:YAG,Wavelength = 266 nm,10 Hz,60 mJ/pulse Pulse Duration = 8 ns,Beam Diameter = 0.5 mm	220 sec	ND	ND
"	"	Erbium,Wavelength = 2.9 um,8 Hz,30 mJ/pulse Pulse Duration = 250 us,Beam Diameter = 2 mm	4 min	ND	ND
Evaluation Criteria:	(NIOSH)			-	‡
	(OSHA)			-	‡
	(ACGIH)			-	‡

Other PNAs = Acenaphthene, Phenanthrene, Fluoranthene, Pyrene, Benz(a)anthracene, Chrysene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(e)pyrene, Benzo(a)pyrene, Indeno(1,2,3-cd)pyrene, Dibenz(a,h)anthracene, Benzo(ghi)perylene.

Trace = Substance was present in trace quantities, between the limit of detection (30 ng/sample) and limit of quantitation (100 ng/sample). This would correspond to an atmospheric concentration range of 4-12 ug/m^3 assuming an air sample volume of 8 liters.

‡ = Chrysene and Benzo(a)pyrene are the only individual PNAs with evaluation criteria (see evaluation criteria section in the report for more detail).

ND = None Detected.

TABLE XVI

PNA Sampling Results in ng/m^3 (Filter Testing)
University of Utah Medical Center
Salt Lake City, Utah
HETA 88-101

April 11-14, 1988

Configuration	Type Laser	Sampling period	PNAs
No Charcoal	Nd:YAG,30 watt,CW	10 min.	ND
Charcoal	"	"	ND
Pre-Charcoal	CO_2,5 watt,CW	20 min.	ND
Post-Charcoal	Nd:YAG,35 watt,CW	"	ND

PNAs = Acenaphthene, Anthracene, Phenanthrene, Fluoranthene, Pyrene, Benz(a)anthracene, Chrysene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(e)pyrene, Benzo(a)pyrene, Indeno(1,2,3-cd)pyrene, Dibenz(a,h)anthracene, Benzo(ghi)perylene.

ND = None Detected.

TABLE XVII

Mutagenicity of Airborne Particles and Vapors
Collected from Laser Surgery
University of Utah Medical Center
Salt Lake City, Utah
HETA 88-101

April 11-14, 1988

Samples	Particles ug/plate	Air Vol. m^3/plate	Histidine$^+$ revertants/plate TA98 -S9	TA98 +S9	TA100 -S9	TA100 +S9
Glass Fiber Filters from:						
Operating	6.7	0.31	10	11		
Room (OR)	13.4	0.63	9	14	50	61
NIOSH samoler	26.7	1.25	8	12	67	63
OR	29.2	0.23	13	15		
Smoke	58.4	0.45	13	16	52	57
Extractor I[a]	116.7	0.91	14	21	64	63
Laser Clinic	59.5	0.14	24	123*		
Smoke	119.0	0.27	25	145*	66	62
Extractor II[a]	238.0	0.54	34*	143*	74	73
Hall (control)	60.0	0.6	11	18	51	55
	120.0	1.2	9	20	62	76
Charcoal Trap from:						
OR		0.14	16	15		
Smoke		0.27	23	30*	153*	105*
Extractor III[b]		0.54	27	30*	164*	214*
OR Smoke		0.23	17	17		
Extractor I[a]		0.45	24	20	79	54
Laser Clinic		0.14	15	16		
Smoke Extractor II[a]		0.27	24	19	86	88
		0.54	13	13	119*	156*
Charcoal		0.23	7	7		
Control		0.45	10	8	56	57
		0.91	8	10	64	59
Controls:						
Negative			14	13	51	49
Positive[c]				810*		1394*

[a] Glass fiber filter placed in front of charcoal trap for particle collection inside the extractor.

[b] No glass fiber filter

[c] 2.5 ug/plate 2-aminoanthracine

* Positive response

TABLE XVIII

Mutagenicity of Airborne Particles Collected
From Experimental Laser Surgery Using NIOSH Sampler

University of Utah Medical Center
Salt Lake City, Utah
HETA 88-101

April 11-14, 1988

Samples	Particles ug/ plate	Air Vol. m^3/plate	Histidine+ revertants/plate TA98 -S9	TA98 +S9	TA100 -S9	TA100 +S9
Laser Laboratory/Mice Tumors:						
CO_2	126.7	0.04	13	28*		
Laser	253.4	0.08	11	43*	54	68
	506.7	0.16	14	46*	60	71
YAG	192.5	0.024	15	73*		
Laser	385	0.047	14	54*	56	67
	770	0.094	18	64*	84	81
Control	258.4	0.09	11	15	52	56
(Hall)	516.7	0.18	10	20	57	77
Exp. Fixed Beam Laser Lab.:						
YAG	33.3	0.024	10	12		
Laser	66.7	0.047	11	15	49	52
	133.3	0.094	13	21	51	58
UV	32.5	0.024	16	19		
Laser	65.0	0.047	11	26	59	50
(355 nm)	130.0	0.094	13	24	59	67
UV(266 nm)	38.3	0.025	14	21		
and Erbium	76.7	0.049	15	28*	63	62
Laser	153.3	0.099	15	32*	60	65
Controls:						
Negative			14	13	51	49
Positive[a]				810*		1394*

[a] 2.5 ug/plate 2-aminoanthracine
* Positive response

TABLE XIX

Mutagenic Activity of Air and Particulates During Laser Surgery Using *in Situ* Assay System.

University of Utah Medical Center
Salt Lake City, Utah
HETA 88-101

April 11-14, 1988

Post Treatment time (hr)	Reversion Frequency/10^7 Survivors[a]											
	Surgery						Animal Facility					
	-S9			+S9			-S9			+S9		
	CC	CR	OR	CC	CR	OR	CC	CR	OR	CC	CR	OR
2	4.7	5.5	4.4	7.6	4.6	11.3	2.1	4.4	3.9	8.3	5.4	3.4
4	4.4	5.3	5.1	8.1	8.7	7.2	3.6	3.1	6.9	7.0	12.0	4.1
6	2.2	4.9	4.0	10.5	8.7	13.0	4.0	3.8	4.6	8.0	10.4	9.7

[a] TA98 only
CC Recirculating closed system (control)
CR Ambient air from control room
OR Ambient air from operating room

TABLE XX

Selected Results from Questionaire
University of Utah Medical Center

Salt Lake City, Utah
HETA 88-101

April 11-14, 1988

Question	No. Responses	Range of Responses	Average of Responses
Laser procedures per month	8	50-500	191
Hours per week exposed to smoke	10	1-3	1
Most used Laser:			
Nd:YAG	8	-	3
CO_2	8	-	2
Argon	8	-	4
Which Laser creates most smoke:			
Nd:YAG	10	-	1
CO_2	10	-	4
Argon	10	-	0
All	5	-	5
Which operation creates most smoke:			
warts removal	9	-	5
skin area	9	-	6
bronchoscopy	9	-	0
Least desirable property of smoke:			
reduces vision	11	-	2
smell	11	-	7
health issues	11	-	4
Encountered any health problems during last year:			
yes	11	-	0
no	11	-	11

Note: Some individuals gave more than two answers for some questions

APPENDIX I

LASER SURGERY QUESTIONAIRE

INTERVIEW I.D.:_____ DATE:_____

NUMBER YEARS LASER SURGEON/NURSE_____ SEX:_____

NUMBER SURGICAL PROCEDURES INVOLVED WITH ANNUALLY:_____

NUMBER HOURS/WEEK EXPOSED TO LASER SMOKE:_____

WHICH LASERS ARE YOU INVOLVED WITH MOST:_____
LEAST:_____
OTHER:_____

WHAT OPERATIONS ARE YOU MOST INVOLVED WITH:_____
_____

WHICH OF THE OPERATIONS PRODUCE THE MOST LASER SMOKE:_____
_____

WHAT IS THE LEAST DESIRABLE CHARACTERISTIC OF LASER SMOKE:
_____

HOW DO YOU MINIMIZE SMOKE PRODUCED FROM OPERATIONS:_____
_____

WHEN DO YOU USE A SMOKE EVACUATOR?:_____
_____

HAVE YOU EVER HAD ANY OF THE FOLLOWING PROBLEMS DURING OR IMMEDIATELY AFTER PERFORMING OR BEING INVOLVED WITH LASER PROCEDURES:

CHANGE IN SENSE OF SMELL:_____ SKIN RASHES:_____
BLURRED VISION:_____ LUNG PROBLEMS:_____
WATERY EYES:_____ ALLERGIES:_____
SORE THROAT:_____ COUGHING:_____
HEADACHES:_____ FACIAL/NASOPHARYNGEAL
DIZZINESS:_____ WARTS:_____
OTHER SYMPTOMS:_____

HOW MANY DAYS SICK LEAVE DID YOU TAKE LAST YEAR:_____

DO YOU WEAR CONTACT LENSES:_____

WHAT TYPE OF FACE PROTECTION DO YOU USE GENERALLY:_____
WHAT ABOUT IN SPECIAL SITUATIONS:_____

ANY OTHER COMMENTS:_____
_____

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APPENDIX II

Evaluation of a Smoke Evacuator Used for Laser Surgery

Jerome P. Smith, PhD, C. Eugene Moss, MS, Charles J. Bryant, MS, and Alan K. Fleeger, MSPH

Divisions of Physical Sciences and Engineering (J.P.S.) and Surveillance Hazard Evaluations and Field Studies (C.E.M., C.J.B., and A.K.F.), National Institute for Occupational Safety and Health, Cincinnati

A preliminary study was conducted to determine the effectiveness of a smoke evacuation system used in laser surgery. A 30 W medical CO_2 continuous wave (CW) laser was used to make cuts in a pork chop to simulate smoke production during laser surgery. A commercially available smoke evacuation system was used to control the smoke from the simulated surgery. The smoke concentration was measured at 6 in and at 3 and 4 ft from site of laser interaction. The nozzle of the smoke evacuator was located at distances of 2, 6, and 12 in from the surgical site to measure the relative effectiveness of the control. Complete control of smoke was achieved when the nozzle was located at 2 in, but significant amounts of smoke escaped when the nozzle was located at 6 and 12 in. Suggestions for the use of the smoke evacuation system and areas for further study are given.

Key words: emission, control, ventilation, fume

INTRODUCTION

Laser surgical procedures allow more precise control of surgical parameters and can reduce patient recovery times. Unfortunately, one of the disadvantages in using lasers for surgical procedures is the production of smoke and fume. Proper control of smoke/fume emissions from laser surgery procedures is needed because of occupational health issues of hospital personnel, comfort of patient, restrictions of the surgeon's field of view, and the smell of the emissions [1]. One more recent health issue concerns the possible presence of HIV and hepatitis B virus in the smoke from surgery. Intact DNA from human papiloma virus (HPV) has, in fact, been observed in the smoke from laser surgery [2]. There are several smoke evacuation systems commercially available that attempt to capture emissions from these procedures. The systems are self-contained suction sources that draw fumes produced from the surgical process into an air cleaning unit. Typically, a hose fitted with a nozzle is attached to the suction source and the nozzle is located as close as possible to the site where the surgery is performed on the patient. One of many questions to be answered in controlling the emissions from these procedures, is, in fact, how close the nozzle should be located to this site. In this article, the results of a preliminary study to answer this question are reported.

MATERIALS AND METHODS

Experiments were performed to estimate the relative degree of emission control with a suction nozzle located at various distances from the laser interaction site. The experiments were performed in a closed room about 10 ft wide and 20 ft long. The room had general ventilation from the heating and cooling system, but no special ventilation other than the smoke evacuator. A 30 W contin-

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Address reprint requests to Dr. Jerome P. Smith, NIOSH, DPSE, MCRB, CRS, 4676 Columbia Parkway (R-8), Cincinnati, OH 45226.

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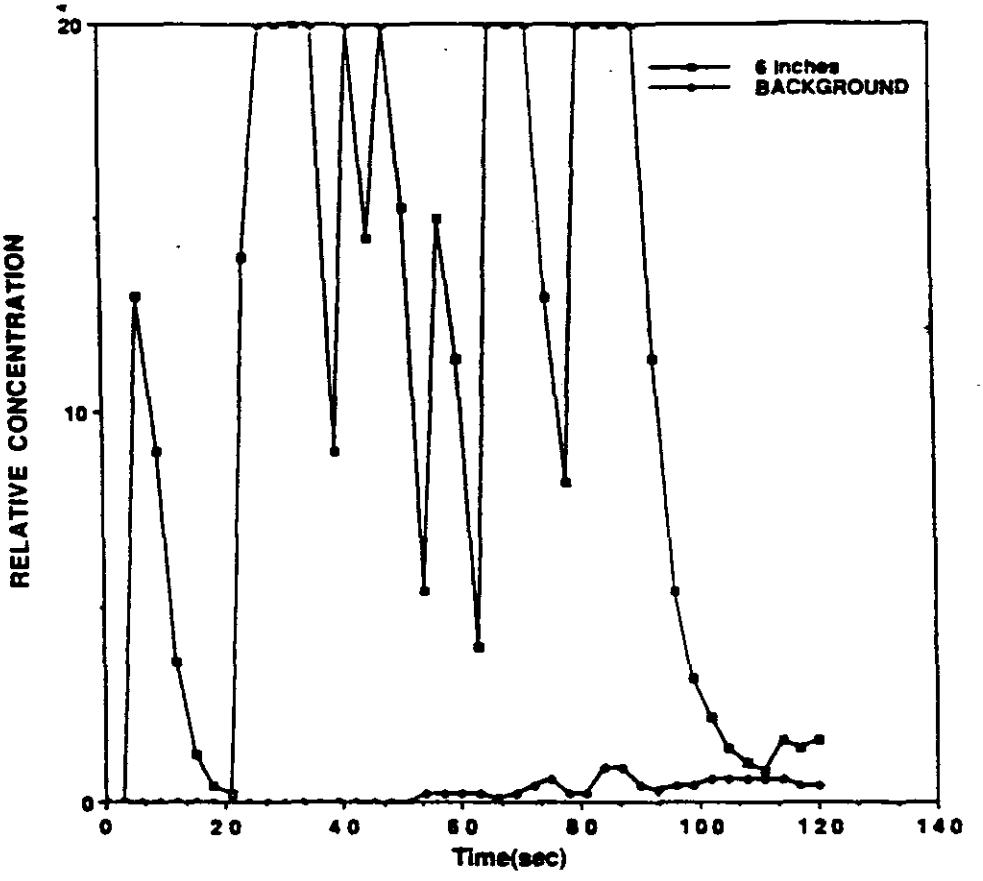

Fig. 1. Smoke concentrations in laser room without smoke evacuation system in operation. Laser in operation for entire period of measurement.

uous wave (CW) CO_2 medical laser system was used that had an articulated arm beam delivery system with a 125 mm focal length lens. The laser spot size ranged from 0.5 to 1.0 mm. The workpiece used to simulate a patient was a pork chop about 6 in long, 4 in wide, and 0.5 in thick. The pork chop was cut by the laser in a manner similar to a surgical event. Since laser surgical procedures can vary widely in the laser-patient configuration and the quantity of smoke produced, the simulation used does not represent any particular operating procedure. The smoke evacuation system used to contain the fumes was a Lase System II (Lase Inc., Cincinnati, OH) smoke evacuation system. This unit has a nominal flow rate of 50 cfm and has HEPA and odor elimination filters. The HEPA filters are rated at 99.97% capture for 0.3 μm particles. The fumes were drawn into the Lase System II through a 1.25 in OD hose with a manufacturer provided oblong shaped nozzle on one end. The nozzle at the end of the hose was mounted at distances of 2, 6, and 12 in from the laser interaction site in order to estimate the effect of distance on control of the fumes.

Three direct reading dust monitors were used to estimate the fume concentrations at various distances from the laser interaction site. A Hand-held Aerosol Monitor (ppm, Inc., Knoxville, TN) (HAM) was mounted 6 in above the laser interaction site to monitor the area where the surgeon and other personnel directly performing the surgery would be located. Air was drawn into the HAM at 1 liter per minute (LPM) with a portable sampling pump.

Two Real-time Aerosol Monitors (MIE, Inc., Bedford, MA) (RAM-1) were used to estimate fume concentrations at 3 and 4 ft from the laser interaction site and were located about 5 ft from the floor of the room. These were used to monitor areas where other personnel might be present in the operating room and were used to estimate background concentrations in various parts of the room. Data from the dust monitors were recorded using a strip chart recorder. The values for the

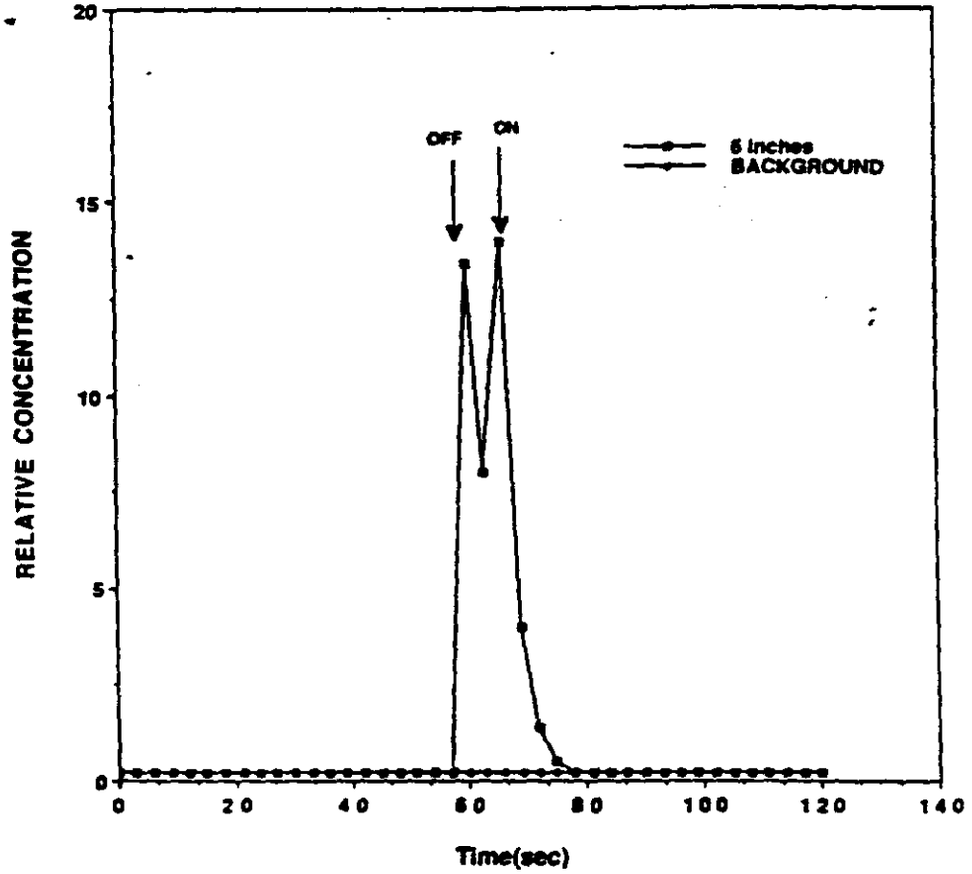

Fig. 2. Smoke concentrations in laser room with nozzle of smoke evacuation system positioned 2 in from laser worksite. Laser on for entire period of measurement but smoke evacuation system was turned off and on.

background concentration in Figures 1–3 are the average of the values given by the two RAM-1's.

It should be pointed out that both the HAM and RAM-1 respond preferentially to particles in the respirable size range (particles less than 3 μm) [3]. Their response also changes with the particle size of the aerosol being monitored. However, the particle size of the smoke should be constant so that relative changes in concentration can be monitored. Since the monitors were not calibrated for the smoke produced in the experiment, the plots produced are on a relative scale to show the level of control rather than absolute gravimetric concentrations.

RESULTS

Figures 1–3 show the effect of placing the smoke evacuation system nozzle at various distances from the laser interaction site.

Figure 1 shows the fume concentrations measured at 6 in from the laser interaction site as determined by the HAM and the room background concentration as determined by the two RAM's when the smoke evacuation system was not in operation. Concentrations near the interaction site could easily exceed 20 (the full-scale range for the monitors) for extended periods of time when the laser was operating. The background concentration in the room also increased from 0 to 1.4 during laser operation. The wide variation in concentration levels observed at 6 in during laser operation was due to two factors. First, as the laser beam came into contact with different parts of the target different amounts of smoke were produced since different parts of the target produce different smoke levels and beam interaction was not constant. Second, transport of the smoke to the HAM is not constant since it is dependent on the air currents in the room, which

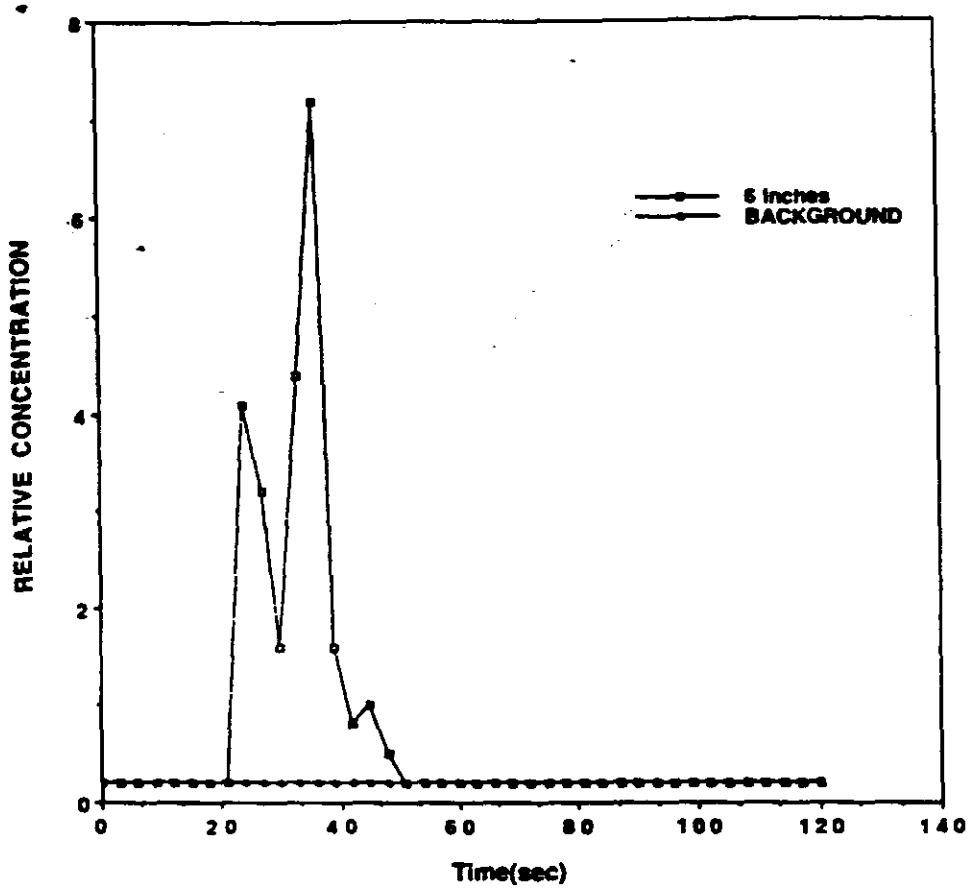

Fig. 3. Smoke concentrations in laser room with nozzle of smoke evacuation system positioned 6 in from laser worksite. Laser and smoke evacuation system left on for entire period of measurement.

are not constant, and this would result in concentration fluctuations. Figure 1 clearly indicates that there is a need to use a smoke evacuation system since high levels of smoke relative to background levels are produced.

The fume concentrations measured with the smoke evacuation system nozzle located 2 in from the laser interaction site is shown in Figure 2. The smoke evacuation system completely collected the fumes from the laser operation when the evacuator was operating. The concentration observed remained at the room background level both at the interaction site and in other areas of the room. When the smoke evacuation system was turned off for a brief period, the concentration at the interaction site increased rapidly to values above 10. However, as soon as the smoke evacuation system was turned on, the levels again decreased to those of the room background. Background levels in the room were not affected by briefly turning off the smoke evacuation system.

Figure 3 shows the fume concentrations observed with the nozzle located about 6 in from the laser interaction site. Collection of fumes was not complete and concentrations as high as 8 were observed 6 in from the laser interaction site. Concentrations of smoke as measured by the HAM fluctuated and decreased after 50 seconds due to variable transport of the smoke to the HAM by air currents in the room. It should be pointed out that both the laser and the smoke evacuation device were operating during the entire time that these measurements were made and still smoke collection was not complete. Background concentrations in the room did not increase measurably during operation of the laser.

The fume concentrations were also measured with the nozzle located 12 in from the laser inter-

action site. The results were qualitatively similar to those shown in Figure 3 except that concentrations higher than 20 were measured at 6 in from the laser interaction site. Background levels in the room also increased from about 0.4 to about 1 during the time the laser was in operation.

The results observed can be compared with those predicted by standard ventilation calculations. The formula for predicting flow rates around circular exhaust openings is $Q = V(10x^2 + A)$ [4], where Q is the volumetric flowrate, V is the air velocity at the center-line of the exhaust opening at a distance x from the opening, and A is the area of the opening. Although the nozzle is not completely circular in shape, this formula can give an approximate air velocity at various distances from the opening since shape will not affect it greatly. If we use $Q = 50$ ft^3/min (the nominal flow rate of the evacuator), V = 150 ft per minute (fpm) (a control velocity for conditions similar to those in an operating room), and A as the area for a 1.5 in round opening, we obtain x = 2.1 in. It should be noted than this formula is only an approximation and will not give a precise value of the velocity at any point. However, it is useful for giving an approximate idea of where adequate control can be maintained. These calculations show that the nozzle must be closer than about 2 in from the laser interaction site to obtain a control velocity of 150 fpm or greater. One hundred fifty feet per minute is a value used for control velocity under conditions similar to those in an operating room.

DISCUSSION

The smoke evacuation system studied is capable of providing what appears to be complete collection of fumes only if the nozzle is within a short distance of the laser interaction site. Positioning of the nozzle of the smoke evacuator at a distance of 2 in from the laser interaction site was found to be adequate. Other studies have also indicated that the nozzle of the evacuator must be close to the site of laser interaction [5,6] to obtain efficient collection. However, the smoke evacuation device should be turned on at the same time or before the laser and run during the entire time the laser is in operation. If the smoke evacuation system were turned off for even a short period, high concentrations could result. These could be controlled rapidly if the device were turned on but exposure could result in the meantime. Perhaps, permitting the smoke evacuation system to operate for 20–30 seconds after the laser was turned off is another possible control measure for situations where continuous operation of lasers is the rule.

Distances of greater than 2 in are likely to result in exposure to high concentrations for personnel working near the laser interaction site and in addition are likely to result in the background concentration in the room being increased. This was certainly found to be the case when the nozzle was at 12 in from the laser interaction site. If the simulated surgery had been carried on for periods of time greater than those used in this study, the background likely would have been increased with the nozzle held closer than 12 in. This would expose personnel located at greater distances from the laser interaction site. Surgical procedures that require the nozzle to be located at distances greater than 2 in may require other means of smoke control. It should be noted that using the smoke evacuation nozzle at distances of 2 in or less from the interaction site may also require adoption of resterilization techniques for the nozzle of the smoke evacuator since it will be close to the surgical site. Although the nozzle is sterile when it is received from the manufacturer, it may become contaminated as surgery proceeds.

Studies are needed to characterize further the controls for laser surgery. The chemical and biological content of the smoke should be determined to assess the hazards presented to personnel. From these results the efficiencies of air cleaners used in the evacuation systems can be determined. It has been determined that filters in smoke evacuators must be able to collect particles efficiently down to 0.1 μm [5]. Complete flow patterns around the nozzle of the smoke evacuation system need to be plotted, and further studies of various operating parameters such as laser power levels, different nozzle designs, and placement of the nozzle are needed. Presence of the surgeon may increase smoke concentration in his/her breathing zone, so this is another area that needs further study. Finally, the present systems are very noisy, another drawback to their use; therefore; other methods of emission control should be investigated.

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