NIOSH HEALTH HAZARD EVALUATION REPORT:

HETA #99–0177–2828
Boeing Commercial Airplane Group
Oak Ridge, Tennessee

DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

PREFACE

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

HETAB also provides, upon request, technical and consultative assistance to Federal, State, and local agencies; labor; industry; and other groups or individuals to control occupational health hazards and to prevent related trauma and disease. Mention of company names or products does not constitute endorsement by NIOSH.

ACKNOWLEDGMENTS AND AVAILABILITY OF REPORT

This report was prepared by Kevin Roegner and Loren Tapp of HETAB, Division of Surveillance, Hazard Evaluations and Field Studies (DSHEFS). Technical assistance was provided by Kenneth Martinez, Charles Mueller, and Douglas Trout. Field assistance was provided by Joshua Harney, Bradley King, and Robert McCleery. Pulmonary evaluation and analysis was performed by Tina Gomberg and support staff from the Division of Respiratory Disease Studies (DRDS), with further assistance provided by Hector Ortega and David Weissman. Analytical support was provided by Datachem Laboratory and Microbial Specialist, Inc. Desktop publishing was performed by Ellen Blythe. Review and preparation for printing were performed by Penny Arthur.

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Highlights of the NIOSH Health Hazard Evaluation

Evaluation of Synthetic Metal Working Fluid Exposures and Health Effects in the Machine Shop

Employees in the machine shop asked NIOSH to look at breathing, prostate, skin, kidney, and bladder problems and to see if these problems were related to working with a synthetic metal working fluid introduced two years earlier.

What NIOSH Did

Took air samples of fluid mist exposures and bulk samples to see how clean the fluid was.

To see if health problems were likely from the fluid, we asked employees about their health symptoms, looked at medical records, and read the scientific literature.

Asked all machine shop and assembly shop employees to complete a health questionnaire.

Offered breathing tests to employees identified by the survey as possibly having work-related breathing problems.

What NIOSH Found

Fluid mist concentrations were low at the time of the NIOSH study, but had been higher in 1997-1998 (based on company records).

Fluid in the Henry system was very clean, and fluid in the stand-alone machines was a little dirty.

There is no clear evidence in the literature of an association between exposure to machining fluids and prostate problems.

Machine shop employees had more respiratory symptoms than assembly employees

More employees that are exposed to machining fluids (compared to those unexposed) have developed asthma since the synthetic fluid was introduced.

What Boeing Managers Can Do

Continue to increase enclosure and mist collection of machines.

Start a schedule for looking at and changing out mist collector filters.

Begin a medical surveillance program for machine shop employees.

Remove employees with work-related breathing problems away from fluid exposure, and retain pay and benefits for these employees.

What the Boeing Employees Can Do

Not eat or drink at their work stations in the machine shop.

Clean work surfaces at the beginning of each shift.

Let mist settle before opening machine doors to remove/adjust part.

Consider use of a respirator when opening machine doors or using an air gun in machine.

Report breathing problems to the company physician.

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National Institute for Occupational Safety and Health
NIOSH

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February 2001

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SUMMARY

On April 14, 1999, the National Institute for Occupational Safety and Health (NIOSH) received a request for a health hazard evaluation (HHE) from three persons employed at the Boeing Commercial Airplane Group parts manufacturing plant in Oak Ridge, Tennessee. The requesters listed several health effects, including respiratory conditions and skin, kidney, bladder, and prostate problems that they believed were related to exposure to the synthetic metal-working fluid (MWF) used in the machine shop.

NIOSH investigators made three site visits to the Boeing facility to evaluate MWF exposures and employees' health concerns. The exposure assessment included measurements of MWF aerosol and triethanolamine (TEA) exposures, real-time measurements of aerosol exposures, and a microbial characterization of MWF. Because four machinists had been newly diagnosed with asthma in 1998, medical evaluations focused on respiratory effects. The medical evaluation included questionnaires, lung function surveys, and serial peak flow testing on participants determined to have bronchial hyperresponsiveness during the pulmonary function testing.

MWF exposures were measured on 55 workers, representing both machinists and a comparison group of assembly workers. With one exception, all personal exposure values were below the NIOSH Recommended Exposure Limit (REL) of 0.4 milligrams per cubic meter (mg/m^3). The geometric mean (GM) exposures for 42 samples collected on machinists was 0.07 mg/m^3 (geometric standard deviation [GSD], 2.1 mg/m^3). Mass concentrations were significantly lower for workers in the comparison area, 0.02 mg/m^3 (GSD, 2.7 mg/m^3). All TEA exposures were well below the 5 mg/m^3 American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV).

Peak exposures were attributable to activities involving workers placing their head inside the machine. These activities include the insertion of a part to be machined, adjustments to the part placement, and the removal of the part. Activities which generated aerosols, such as the use of the pressurized air gun to clean parts, the application of MWF to the machine during cleaning, or the grinding and polishing of finished parts, also resulted in higher concentrations.

Bacterial activity in the fluid ranged from very low to moderate. A clear disparity, in count and species present, was evident between MWF samples collected in the central system and MWF samples collected

from stand-alone machines. All samples collected in the central system contained only Gram-positive bacteria, and counts were below 10 colony forming units per milliliter (CFU/mL). In contrast, Gram-negative bacteria were identified in the stand alone reservoirs at concentrations of up to 4.7 x 10^5 CFU/mL.

Questionnaire and lung function surveys were offered to all 204 employees working in the machining areas and all 141 of those working in the assembly area. A total of 284 workers (82%) completed the questionnaire. Of the 284 participants in the questionnaire survey, 101 were asked to participate in pulmonary function testing (PFT) because their questionnaire responses indicated work-related respiratory symptoms; 66 participated. Nine of these sixty-six employees were determined to have bronchial hyperresponsiveness (BHR); seven of one hundred and eighty-eight were exposed to MWF (3.7%), and two of ninety-two were unexposed (2.2%). These nine performed 7 to 10 days of serial peak flow measurements. One of the nine (a machinist) had a work-related pattern of peak flow variability, three (all machinists) did not provide sufficient data, three (one machinist and two assembly workers) had a pattern not related to work, and two (machinists) had peak expiratory flow (PEF) changes with no discernable pattern.

Controlling for effects of age and current number of cigarettes smoked, the workers exposed to MWF had almost three times the rate of asthma symptoms (defined by questionnaire), six times the rate of work-related asthma symptoms (defined by questionnaire), and more than five times the rate of one or more work-related respiratory symptoms (as defined by questionnaire) as unexposed workers.

Based on our findings of increased symptoms among exposed individuals, a health hazard exists for employees working in the machine shop at Boeing. Although MWF exposures were below the NIOSH REL of 0.4 mg/m^3, workers in the machine shop reported more respiratory symptoms than assembly shop workers. Exposure to a synthetic MWF appeared to be related to the occurrence of asthma symptoms.

Based on the measurements and observations made during the evaluation, NIOSH investigators offer several recommendations for the control of MWF exposures, and management of workers' health. These include reducing exposures to MWF by using engineering and/or controls, and personal protective equipment. Recommendations also address a medical monitoring program.

Keywords: SIC 3728 (Aircraft Parts and Auxiliary Equipment, Not Elsewhere Classified), metalworking fluids, MWF, endotoxin, Triethanolamine, TEA, asthma, serial peak flow

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INTRODUCTION

On April 14, 1999, the National Institute for Occupational Safety and Health (NIOSH) received a request for a health hazard evaluation (HHE) from three employees at Boeing Commercial Airplanes Group (Boeing) in Oak Ridge, Tennessee. The requesters listed several health effects, including respiratory conditions and skin, kidney, bladder, and prostate problems that they believed were related to exposure to the synthetic metal-working fluids (MWF) used in the machine shop.

NIOSH investigators made an initial site visit to the Boeing facility on May 20, 1999. During this visit, NIOSH investigators held an opening conference with employee and management representatives, conducted confidential interviews with employees, toured the facility, and observed job requirements. During two subsequent visits to the Boeing plant, NIOSH investigators collected air samples to measure MWF aerosol and triethanolamine (TEA) exposures, made real-time measurements of aerosol exposures, collected bulk samples of MWF from the reservoirs of stand-alone machines, and from machines supplied by the central system, administered a questionnaire to machinists and a comparison group of assembly workers, and performed medical evaluations of selected employees who reported respiratory symptoms in a questionnaire survey.

Individuals were notified of their medical test results by letters dated December 15, 1999, (spirometry) and December 16, 1999, (peak flow monitoring). NIOSH reported the preliminary findings of the environmental sampling and medical survey to Boeing management and employees in a letter dated May 25, 2000. This report includes that information, supplemented with additional data analyses and recommendations.

BACKGROUND

Boeing machines a variety of titanium and aluminum commercial airplane parts. Machining is conducted in each of two adjacent machine shops. The "new" machine shop contains 48 machines, and the "old" machine shop contains 14 machines. The types and speeds of machining vary greatly within the shops. Some machines operate at speeds of 300 revolutions per minute (RPM), while others may operate at speeds up to 10,000 RPM. Some of the higher-speed machines had mist collectors installed in 1997. A few additional machines were outfitted with mist collectors in 1998.

Prior to 1990, Boeing supplied MWFs to the machines via individual sumps (stand-alone machines). In 1990, a 60,000-gallon MWF recirculating system, referred to at Boeing as the "Henry filter system," was installed. The Henry filter system was designed to supply MWF to a recently completed machining cell. In December 1990, the Henry filter system received an initial charge of a water soluble MWF at a nominal concentration of 10 percent (%) in water. Boeing encountered technical problems with the soluble MWF, which prompted the company to consider other MWFs. Boeing began using Castrol™ WY4-876A, a synthetic MWF, experimentally in two types of machines (Fadal and Maxim) in July 1996. In May 1997, the Henry filter system was cleaned and charged with Castrol™ WY4-876A. In June 1997, the stand-alone systems also began using the Castrol™ synthetic MWF. In November 1997, a machinist reported shortness of breath that he believed was related to working with the synthetic MWF. In May 1998, the Boeing Safety, Health, and Environmental Affairs organization began receiving additional complaints of respiratory symptoms from machinists, which resulted in the medical evaluation of 12 of 203 employees working in the machining area; the evaluations were performed by an occupational

health physician contracted by Boeing. Eight additional employees were evaluated for MWF-related health concerns prior to our site visit in May 1999. Four of these twenty employees were referred for pulmonary testing; one was found to have objective findings of bronchial hyperresponsiveness and symptoms suggestive of occupational asthma and was treated with asthma medication; two were found to have cough, chest tightness, and/or shortness of breath, which improved away from work (i.e., on weekends, vacations, or when removed from MWF exposure), but no objective findings. However, one of these two employees had seen a private pulmonologist a few months prior to the Boeing pulmonary evaluation, had been diagnosed with asthma after testing for bronchial hyperresponsiveness, and had been put on asthma medications prior to the Boeing evaluation. The remaining employee's symptoms were determined to have been caused by another health disorder. The machinists mentioned above continued to work in the machining area with the recommendation from the Boeing occupational physician that they use a filtering-face-piece respirator while in the machine shop. In addition, two machinists who were not referred to a pulmonologist by Boeing, but were evaluated by their own private physicians, were determined to have asthma by findings of bronchial hyperresponsiveness and symptoms, and treated with asthma medication.

Industrial hygiene data provided by Boeing indicated that MWF exposures in the machine shop, from March 1997 to July 1998, ranged from <0.02 milligrams per cubic meter (mg/m^3) of air to 0.54 mg/m^3. The highest MWF mist concentrations occurred when the synthetic MWF was introduced plant-wide in 1997; and decreased to non-detectable concentrations during the noted time period. These decreases in exposure paralleled Boeing's installation of mist collectors on several machines and increases in airflow to the machine shop's general ventilation systems. The fluid also contains TEA; no air sampling data was available for this fluid component.

Boeing employs 920 employees at the Oak Ridge facility; 600 hourly and 320 salaried. Hourly employees work over three 8-hour shifts: the night shift being staffed only by machinists. Boeing contracts with an occupational medicine physician to provide medical services off-site. Pre-placement medical screening, consisting of a health questionnaire reviewed by the medical director for all Boeing facilities, is conducted. Workers hired for certain jobs, such as painters, chromic acid workers, and hazardous material operators, are given pre-placement physical examinations. Hearing assessment is performed annually. Blood, urine, and pulmonary testing are not routinely performed, with the exception of pre-employment urine drug testing.

METHODS

Exposure Assessment

NIOSH assessed exposure to MWF and TEA aerosols during typical operations over a three-day period beginning on August 31, 1999. Samples were collected during first-shift production on each of the first two days, and during second-shift production on the third day of sampling. Samples were collected over the full work shift. Results from samples collected for less than 8 hours were computed into 8-hour time-weighted average (TWA) values applying the assumption that exposures during the unsampled portion of the shift equaled exposures for the sampled period.

Personal exposure samples were collected in each worker's personal breathing zone (PBZ) to best reflect workers' exposure occurring on the day of sampling. Most of the PBZ samples were collected on machinists. A small subset of samples was collected from workers in the

assembly department, as a means for inter-department exposure comparison. Area samples were collected near the MWF reservoir to estimate exposures for persons who periodically work in that area.

To determine if machine characteristics and engineering controls impact respiratory health effects, we collected information on engineering controls, such as enclosures and mist collectors, and machine characteristics, such as type of machine process (milling vs. non-milling), speed of machine, and central vs. stand-alone sumps.

MWF Aerosols

Samples for MWF aerosols were collected on 37-millimeter (mm) cassettes containing a tared 2-micrometer (μm) pore-sized poly-tetrafluoroethylene (PTFE) filter. A thoracic cyclone was attached to the sampling cassette so that only the thoracic fraction (particles that enter the tracheobronchial region of the lung, generally smaller than 10 μm) of the aerosol would be collected. Filters were connected via flexible Tygon® tubing to sampling pumps calibrated at a nominal flow rate of 1.6 liters per minute (Lpm).

The particulate mass for each air sample was determined by measuring the gross weight of each filter on an electrobalance and subtracting the previously determined tare weight of the filter. The instrumental precision of the microbalance is 0.001 milligram (mg), and the limit of detection (LOD) is 0.01 mg. Samples having values less than the LOD are reported as "none detected" (ND).

Video Exposure Monitoring (VEM)

Real-time particulate sampling coupled with video recording was performed to evaluate worker exposures to MWFs. Video exposure monitoring (VEM) was conducted on five different workers each operating separate machines on September 1, 1999, to measure relative air contaminant concentrations and improve our understanding of how the worker's individual tasks affect personal exposure to air contaminants.[1]

During machining activities, the Hand-held Aerosol Monitor (HAM) (PPM Inc., Knoxville, Tennessee) was used to measure relative PBZ air contaminant concentrations. In using this instrument, the workplace aerosol is drawn through a sensing chamber. The aerosol scatters the light emitted from a light-emitting diode. The scattered light is detected by a photomultiplier tube. The analog output of this instrument is proportional to the quantity of the scattered light detected by a photomultiplier tube. The quantity of scattered light is a function of aerosol concentration, particle size, and refractive index. Because the calibration of the HAM varies with aerosol properties, the analog output of the HAM is viewed as a measure of relative concentration. The analog output of the HAM is recorded by a data logger. The information collected on the data logger is downloaded to a computer and converted into a spreadsheet for analysis.

VEM can be used to identify sources of worker exposure to air contaminants and to address questions such as: how does exposure vary among the components of a job, what are the shortcomings of a control, and how quickly does the air contamination decay once an operation has stopped.[2,3] While air concentrations are being measured with the HAM, workplace activities are recorded on videotape. The analog output from direct reading instruments can be overlaid on a video recording as a moving bar or graph that has a height proportional to the air contaminant concentration. This technique shows how worker exposures are related to work activities, and it permits control recommendations that are focused upon actual exposure sources.

TEA Aerosols

Samples for TEA aerosols were collected by drawing air through a glass fiber filter. Filters were connected via flexible Tygon® tubing to sampling pumps calibrated at a nominal flow rate of 1.0 Lpm. Samples were shipped and stored under refrigeration prior to analysis. Samples and field blanks were extracted with 2 milliliters (mL) of acetone for 60-minutes and analyzed for TEA by gas chromatography-mass spectrometry (GC-MS).

Microorganisms

Bulk process samples of the MWF in both stand-alone and central system machines were collected in sterile 150 mL specimen vials and shipped overnight in ice-filled containers to a NIOSH contract laboratory for the enumeration and speciation of bacterial and fungal colonies. Separately, bulk process samples were collected in sterile 50 mL specimen vials and shipped overnight in ice-filled containers to a NIOSH laboratory for endotoxin analysis.

Medical

Interviews and Record Review

Interviews with 14 of the 20 employees seen by the occupational medicine clinic physician (contracted by Boeing) because of MWF-related medical complaints, and 2 additional employees with MWF-related medical concerns, were conducted during the initial site visit. The remaining six employees were either unavailable or declined to be interviewed during the visit. Company and personal medical records of the interviewed employees were reviewed.

The Occupational Safety and Health Administration (OSHA) Log and Summary of Occupational Injuries and Illnesses Form 200 (OSHA 200 log) was reviewed for the years 1997, 1998, and 1999 (up until the time of the site visit in May).

Questionnaire and Lung Function Testing

Based on information obtained from the employee interviews, a questionnaire survey was administered to all employees working in the machining areas and, as a comparison group, all those working in the assembly area. The assembly workers were chosen as the comparison group since they do not work with MWF and are located in a separate room from the machine shops. Employees eligible to participate were given an information sheet (Appendix A) describing the study. NIOSH investigators conducted the questionnaire survey (Appendix B) at the Boeing work site on August 9 and 10, 1999. The purposes of the questionnaire were to determine the prevalence of symptoms, to address the question of whether reported symptoms could be related to workplace exposures (in particular MWF exposure), and to identify employees who might have a respiratory disorder (such as occupational asthma) related to workplace exposures. The questionnaire addressed symptoms and their potential relationship to work exposure, demographic factors (age, gender, etc.), medical and work history, and non-occupational exposures which could affect the health symptoms being experienced.

Participants in the questionnaire survey were chosen to participate in pulmonary function testing (PFT) by the following criteria: (1) one or more respiratory symptoms (chest tightness, shortness of breath, cough, and/or wheezing) reported within the 12 months prior to the survey, and (2) one or more questionnaire responses indicating potential work-relatedness of these symptoms ("yes" or "maybe" to any of the questions: "Do you think it [the symptom] is related to work?," "Did/does it [the symptom] improve during time away from

work?," or "Was/is it [the symptom] worse on the first day back to work after time off?"). The purposes of the lung function tests were to identify employees with respiratory disorders (particularly asthma) and to assess if a difference in the prevalence rate of respiratory disorders existed between machinists and assembly workers. An informational meeting was held at Boeing during the week of August 23 to inform workers of the testing procedures and to answer any questions.

PFT was performed during the week of August 31 on the selected participants after informed consent was obtained; testing included standard lung function testing with either bronchodilator administration (if the PFT revealed an obstructive pattern) or methacholine challenge testing (if the PFT pattern was normal). The specific protocols used in this study are discussed in Appendices C, D, and E.

The methacholine challenge test was considered "positive" if there was a 20% or more decrease in the participant's forced expiratory volume in one second (FEV_1) following a dose of 16 milligrams per deciliter (mg/dl) or less of methacholine.[4,5,6,7,8] The bronchodilator test was considered "positive" if there was a 12% or greater improvement in the participant's FEV_1 after administration of the appropriate dose of bronchodilator.[9] Subjects with "positive" results on either of these tests were considered to have bronchial hyperresponsiveness. Those subjects with both bronchial hyperresponsiveness, as determined by lung function studies, and at least one work-related respiratory symptom (cough, shortness of breath, chest tightness, wheezing), as reported on the questionnaire, were considered to have asthma.

Serial Peak Flow Testing

Those participants determined to have bronchial hyperresponsiveness during the pulmonary function testing were asked to perform peak flow measurements five times per day over a 7-day period; the purpose of the serial peak flow measurements was to assess lung function while at work and away from work. Those participants who were found to have a work-related peak expiratory flow pattern were considered to have occupational asthma. Informed consent was given prior to participation. The protocol and participant instructions for peak flow testing are presented in Appendix F.

Statistical Analysis

Statistical analyses were performed using SAS Version 8 (SAS Institute, Inc., Cary, North Carolina). A statistical analysis was done to assess the relationship between reported symptoms or illnesses and potential occupational exposure to MWF. "Exposed workers" were defined as those employees answering 'yes' to the survey question, "Do you work with, or near, metalworking fluids in your current job?" "Unexposed workers" were defined as those answering 'no' to this question. Asthma symptoms were defined as having at least two of four respiratory symptoms (persistent cough, wheezing or whistling in the chest, tightness in chest, or unusual shortness of breath) in the 12 months prior to the survey. Work-related asthma symptoms were defined as having two or more work-related respiratory symptoms; a respiratory symptom was defined as work-related if a positive response was given to one or more of the following questions: "Do you think it [the symptom] is related to work?" or "Did/does it [the symptom] improve during time away from work?" or "Was/is it [the symptom] worse on the first day back to work after time off?" The magnitude of the relationships was assessed by the prevalence ratio (PR); a 95% confidence interval which excluded one, or a significance level of $p \leq 0.05$, was considered to indicate a statistically significant finding. The PR represents the prevalence of the symptom in the exposed group (machine shop

employees) relative to the prevalence in the unexposed group (assembly workers). A PR of one means no association between the symptom/illness and exposure. A PR of greater than one indicates the presence of an association. For example, a PR of two would mean that a person in the exposed group is two times more likely to have reported the symptom than a person in the unexposed group.

EVALUATION CRITERIA

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH field staff employ environmental evaluation criteria for the 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 even though their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a pre-existing 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 criterion. These combined effects are often not considered in the evaluation criteria. Also, some substances are absorbed by direct contact with the skin and mucous membranes, and thus potentially increases 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 Recommended Exposure Limits (RELs),[10] (2) the American Conference of Governmental Industrial Hygienists' (ACGIH®) Threshold Limit Values (TLVs®),[11] and (3) the U.S. Department of Labor, OSHA Permissible Exposure Limits (PELs).[12] Employers are encouraged to follow the OSHA limits, the NIOSH RELs, the ACGIH TLVs, or whichever are the more protective criteria.

OSHA requires an employer to furnish employees a place of employment that is free from recognized hazards that are causing or are likely to cause death or serious physical harm [Occupational Safety and Health Act of 1970, Public Law 95-596, sec. 5(a)(1)]. Thus, employers should understand that not all hazardous chemicals have specific OSHA exposure limits such as PELs and short-term exposure limits (STELs). An employer is still required by OSHA to protect their employees from hazards, even in the absence of a specific OSHA PEL.

A TWA exposure refers to the average airborne concentration of a substance during a normal 8- to 10-hour workday. Some substances have recommended STEL or ceiling values which are intended to supplement the TWA where there are recognized toxic effects from higher exposures over the short-term.

Metal-Working Fluid Aerosols

NIOSH estimates that at least 1.2 million workers in the U.S. are potentially exposed to agents collectively called MWF.[13] Exposure to MWF has been associated with work-related asthma and other respiratory diseases. From 1988 to 1994, MWF were the second most common cause of work-related asthma, after isocyanates, reported to the Michigan Department of Public Health, a state-based surveillance program for occupational asthma.[14]

Of the four types of MWF, straight oils, soluble oils, semisynthetics, and synthetics, the latter three contain water, which can support the growth of microorganisms. Gram-positive and Gram-negative bacteria, as well as fungi, have been cultured from water-based MWF. In addition to the native chemicals in the MWF, contaminants often found in MWF include thermal degradation products of chemicals in the fluids caused by heat generated in the machining process; tramp oil from the machines themselves and the pumps that circulate the fluids; fine metallic particles generated by the machining operations; and small amounts of dissolved metals from the tools and work pieces.[15] Airborne particles, or aerosols, are generated during the course of metal-working operations and can enter the breathing zone of machine operators.[16]

NIOSH recommends that occupational exposures to MWF aerosols be limited to 0.4 mg/m^3 of thoracic particulate mass as a TWA concentration for up to 10 hours/day during a 40-hr work week, measured according to NIOSH Method 0500.[13] The 0.4 mg/m^3 concentration of thoracic particulate mass approximately corresponds to 0.5 mg/m^3 for total particulate mass. The NIOSH REL is intended to reduce respiratory disorders associated with MWF exposures in the workplace.[13] However, concentrations of MWF aerosols should be kept below the REL where possible because some workers have developed work-related asthma, hypersensitivity pneumonitis (HP), or other adverse respiratory effects when exposed to MWFs at lower concentrations. In addition, limiting dermal (skin) exposure is critical to preventing allergic and irritant skin disorders related to MWF exposure. In most metal-working operations, it is technologically feasible to limit MWF aerosol exposures to a thoracic particulate concentration of 0.4 mg/m^3 or less.[13]

Microorganisms

Historically, microbial contamination of MWF has been a problem primarily because of its effects on fluid quality and performance. Fluid degradation from microorganisms may result in changes in fluid viscosity, and the acid products of fermentation may lower the pH of the fluids, causing corrosion of machined parts. Anaerobic bacteria, specifically the sulfate reducers, may produce hydrogen sulfide and other irritant gases. Excessive microbial growth may result in clogged

filters and ports and may interfere with the machining operations.

Water-based MWFs are excellent nutritional sources for many kinds of bacteria and fungi. The predominant species routinely recovered from MWFs are virtually identical to those routinely recovered from natural water systems. Many species that grow in MWFs secrete waste products that serve as a nutritional substrate for organisms that have more restrictive nutritional needs. Well-maintained MWFs should have bacterial concentrations below 10^6 colony forming units per mL (CFU/mL) of fluid.[17]

Some individuals manifest increased immunologic responses to microorganisms, or their metabolites, in the environment. Although excessive microbial contamination of MWFs poses an occupational hazard, there are insufficient data to determine acceptable levels of microbial contamination in the air. In addition, allergic or hypersensitivity reactions can occur even with relatively low air concentration of allergens, and individuals differ with respect to immunologic susceptibilities.

Endotoxin

Bacterial endotoxin is a thermally stable, lipopolysaccharide compound from the outer cell wall of Gram-negative bacteria, which normally occur abundantly in MWFs. Endotoxin can act as a stimulant to the immune system.[18,19] Endotoxin has been associated with respiratory tract symptoms and cross-shift decrements in lung function in several groups of exposed workers.[20] While some exposure guidelines exist for airborne endotoxin,[21,22] insufficient data exist to promulgate guidelines for endotoxin levels in bulk process MWFs.

Triethanolamine

TEA is a colorless, viscous liquid with a slight ammonia odor.[23] TEA is not volatile at ambient temperatures, and, depending on use conditions, is likely to be airborne in greater concentrations as an aerosol than a vapor.[24] Ethanolamines are moderate irritants to the eyes and skin, and have been shown to cause both allergic and contact dermatitis.[25,26] OSHA has not established a PEL for TEA, nor has NIOSH established a REL. The ACGIH has a TLV of 5 mg/m^3 as a TWA.[11]

Asthma, Bronchial Hyperresponsiveness, and Occupational Asthma

Asthma is a condition characterized by reversible airway obstruction, airway inflammation, and airway hyperresponsiveness to a variety of stimuli.[27] The diagnosis of asthma is based on compatible history (i.e., respiratory symptoms of episodic cough, wheeze, shortness of breath, and/or chest tightness) and the presence of reversible airflow obstruction (measured by spirometry with bronchodilator administration) or, in the absence of airflow obstruction, the presence of pharmacologically induced bronchial hyperresponsiveness (BHR).[28]

BHR is the amplification of the normal physiologic airway response to nonspecific irritant stimulation. It is thought to be due to airway inflammation (probably the major factor), alterations in neurologic control of bronchial smooth muscle tone, and changes in bronchial smooth muscle function.[29] BHR is a characteristic feature of asthma; however, BHR may be present in asymptomatic individuals without overt asthma. BHR is measured indirectly by two methods. The most common method, used in the absence of airflow obstruction on baseline PFT, is to measure the change in expiratory air flow rate after the administration of a pharmacologic agent (such as increasing concentrations of methacholine). If airflow obstruction is present on baseline PFT, the

reversibility of airway obstruction in response to administration of a bronchodilator is used as a measure of BHR. Whether BHR is temporary or permanent is not completely understood.[29]

Occupational asthma (OA) is defined as asthma due to causes and conditions attributable to a particular working environment and not due to stimuli encountered outside the workplace. Work-aggravated asthma is preexisting or concurrent asthma that is aggravated by irritants or conditions in the workplace.[16]

The diagnosis of OA should include the diagnosis of asthma and the establishment of a relationship between the asthma and work.[28] Establishing a work-related cause for asthma is often difficult. A detailed occupational history and symptom history (e.g., symptoms better on days-off, worse the first day back at work) is essential. An OA diagnosis should be confirmed by objective measures. The definitive diagnosis of occupational asthma is made by performing a specific bronchoprovocation test using the suspected causative substance. That test, performed in a hospital setting, is not routinely done due to the time, expense, technical difficulties, and potential adverse reactions. Other objective tests may be used to assist in the diagnosis of OA. Measurement of pre- and post-workshift FEV_1 is simple and inexpensive, but is not a sensitive or specific method of identifying workers with OA.[30] Serial FEV_1 measurements can rule out an OA diagnosis if negative, but may not always indicate OA if positive. These measurements would need to be done both at work and at home to avoid missing delayed-onset asthma. Serial peak expiratory flow (PEF) monitoring is relatively simple and inexpensive, but not as reliable as spirometry since it is dependent on the subject's cooperation, and there is no standardized method for interpreting the results.[28] Typically, FEV_1 and PEF rates fall over several days as symptoms caused by OA worsen and improve when exposure to the causative agent ceases or when therapy is initiated.[16] For PEF measurements, a value called the period percent amplitude mean can be used as a measure of PEF variability; it is calculated using the formula: (highest PEF reading – lowest PEF reading)/mean PEF. A period percent amplitude mean of 20% or greater is an indication of greater than normal variability of the airways for the time period in question. The temporal pattern of this variability over workdays and days off work determines work-relatedness.

RESULTS

Exposure Assessment

Metalworking Fluids

Personal exposure results for MWF mists are summarized in Tables 1, 2, and 3. Due to the distribution of the exposure values, geometric means (GM) and geometric standard deviations (GSD) are used as measures of average and variability of the exposure values. Fifty-five MWF exposure samples were collected during three days of sampling. Of these, 43 samples were collected on machinists (36 in the new machine shop and 7 in the old), 6 were collected on assembly workers, and 6 samples were collected on persons in "other" job categories. With one exception, all personal exposure values were below the NIOSH REL of 0.4 mg/m^3. The sample that exceeded the REL was collected on a machinist who worked at the debur station. This sample had a particulate mass concentration of 1.84 mg/m^3, which was notably higher than exposures of other machinists. This result was omitted from subsequent analyses because the elevated mass concentration was judged to be a result of metal dust from deburring activities rather than MWF exposure. An accumulation of metal

dust was observed on the filter during visual inspection after sampling.

Exposures measured in the new (GM, 0.07 mg/m^3 [GSD, 2.1]) and old (GM, 0.07 mg/m^3 [GSD, 1.8]) machine shops were not statistically different and were therefore grouped for analyses. The GM for these 42 PBZ samples collected in the machine shops was 0.07 mg/m^3 (GSD, 2.1). Mass concentration exposure values were significantly lower for workers in the assembly area, GM of 0.02 mg/m^3 (GSD, 2.7). Based on statistical analysis, machinists working on machines with mist collectors had lower exposures to MWF than machinists working on machines without mist collectors (i.e., mist collectors helped to reduce exposure levels). No difference was found in exposure levels of MWF when comparing shifts, or when comparing machines' degree of enclosure.

One area sample was collected at the railing around the central reservoir pit, and a second area sample was collected in the pit. The thoracic mass concentrations for these samples were 1.21 and 4.29 mg/m^3, respectively.

VEM

Machine Fadal #5,5-axis

VEM was performed for approximately one hour on the worker operating the Fadal #5,5-axis machine. In that time interval, one metal part was machined. The Fadal #5,5-axis machine is closed on all sides. Operator access is provided through a sliding plexiglass door located on the front of the machine. During those times when no operator interaction was required by the machining process (i.e., under computer control), the worker was observed using a pneumatic grinder to debur and polish previously machined parts.

A semi-quantitative assessment of the concentrations measured with the HAM over a representative 20-minute interval indicates that the worker is exposed to the highest MWF concentrations when using the pressurized air gun and when applying MWF to the interior of the machine during the workday end clean-up activities. The average MWF concentration was 0.19 and 0.18 mg/m^3, respectively. These activities may require the worker to place his head inside of the machine. At one point, the use of the air gun during the metal part removal resulted in a peak concentration of 1.32 mg/m^3. Grinding parts outside of the machine resulted in a mass concentration average of 0.12 mg/m^3; this exposure is likely due to MWF and metal dusts. Other worker activities that were not associated with the machining process (excluding grinding) accounted for only 9% of the total particulate exposures. This is contrasted with the part removal and air gun application activities which a accounted for 47% of the total particulate exposures. Application of MWF during clean-up accounted for 24% of the exposures. Exposures to grinding outside of the machine accounted for 20% of the total. Figure 1 presents the HAM concentration responses during the machining activities at Fadal #5,5-axis.

Machine Fadal #4,4-axis

VEM was performed for approximately 45 minutes on the worker operating the Fadal #4,4-axis machine. In that time interval, one metal part was machined. As with the Fadal #5,5-axis machine, the Fadal #4,4-axis machine is closed on all sides. Operator access is provided through a sliding plexiglass door located on the front of the machine.

A semi-quantitative assessment of the concentrations measured with the HAM over a representative 11-minute interval indicates that the worker is exposed to the highest MWF concentrations when removing the part from the machine. The average MWF concentration for this task was 0.26 mg/m^3. Some activities

(e.g., removing and installing parts) may require the worker to place his head inside of the machine. These activities resulted in an average concentration of 0.14 mg/m^3. The use of the air gun during the metal part removal and the application of MWF to clean the machine both resulted in an average concentration of 0.1 mg/m^3. A peak concentration over 1.8 mg/m^3 was observed shortly after the shield door was fully opened. Worker activities that were not associated with the machining process accounted for 17% of the total particulate exposures. Part removal and air gun application activities accounted for 45% of the total particulate exposures, while part installation accounted for 18%. Application of MWF during clean-up accounted for 10% of the exposures. Ten percent of the total particulate exposure is attributed to the worker placing his head inside the machine. Figure 2 presents the HAM concentration responses during the machining activities at Fadal #4,4-axis.

Machine 16-28 Modig

VEM was performed for approximately 50 minutes on the worker operating the 16-28 Modig machine. Compared with the other monitored machines, the 16-28 Modig is relatively new and is equipped with a mist collector. During the monitored time interval, a large number of metal parts were machined resulting in the access shield door being opened five times. The operation had a shorter cycle time compared with other observed processes. The machine is closed on all sides. Operator access is provided through a sliding plexiglass door located on the front of the machine.

A semi-quantitative assessment of the concentrations measured with the HAM over a representative 20-minute interval indicates that the worker is exposed to the highest MWF concentrations when removing the part from the machine. The average MWF concentration was 0.63 mg/m^3. This activity requires the worker to place his head inside of the machine. There was no other activity observed in which the worker had direct interaction with the machine. Two out of three peak concentrations during the monitored period were over 2 mg/m^3. However, these exposures only accounted for 24% of the total particulate exposures. Figure 3 presents the HAM concentration responses during the machining activities at 16-28 Modig.

Machine FWC 1956 3B

VEM was performed for approximately one hour on the worker operating the FWC 1956 3B machine. In that time interval, only one metal part was machined. The FWC 1956 3B machine was relatively open compared to other enclosed machines located on the shop floor. Shielding was provided on the front (via a sliding plexiglass door) and back; the sides of the machine were open. Additionally, it was observed that the proper placement of, and subsequent adjustments to, the part in the machine required considerably more time (presumably due to the older age of the machine).

A semi-quantitative assessment of the concentrations measured with the HAM over a representative 15-minute interval indicates that the worker is exposed to the highest MWF concentrations while making adjustments to the positioning of the part in the machine. During this act, the worker's head was located predominantly inside the machine which produced an average MWF concentration 1.26 mg/m^3. The application of the air gun during the metal part removal and standing in front of the machine with the doors open both resulted in average concentrations of 0.7 mg/m^3. The unshielded sides of the machine did provide opportunities for exposure as evidenced by the MWF average concentration of 0.37 mg/m^3 when the worker inspected the machining process from the side. Additionally, because the door shield did not completely cover

the front opening, a peak concentration over 2 mg/m^3 was observed when the worker peered over the door shield. Worker activities that were not associated with the machining process accounted for most of the total particulate exposures, i.e., 64%. Application of the air gun accounted for only 7% of the total particulate exposure, standing in front of the open machine accounted for 5%, and observation of the process from the side of the machine accounted for 8%. Ten percent of the total particulate exposure is attributed to the worker placing his head inside the machine. Figure 4 presents the HAM concentration responses during the machining activities at the FWC 1956 3B machine.

Machine B18-2

VEM was performed for approximately one hour on the worker operating the B18-2 machine. In that time interval, the machining of two parts was sequentially observed and monitored. The B18-2 machine was relatively open compared to other enclosed machines located on the shop floor. Shielding was provided at a ¾ height on all sides of the machine with a front sliding door for access. Additionally, the machine appeared to be operating at a lower RPM speed than the other observed processes.

A semi-quantitative assessment of the concentrations measured with the HAM over a representative 20-minute interval indicates that the worker is exposed to the highest MWF concentrations when adjusting and removing the metal part. The average MWF concentration during these activities was 0.28 and 0.13 mg/m^3, respectively. These activities may require the worker to place his head inside of the work area of the machine to conduct the required activities. MWF concentrations while the worker placed his head in the work area averaged 0.31 mg/m^3. At one point, the worker peered over the edge of the door which produced a peak concentration over 2 mg/m^3. However, the duration of these higher concentration activities was brief, accounting for only a small fraction of the total exposure for the 20-minute assessed time period. Worker activities that were not associated with the machining process accounted for 45% of the total particulate exposures. This is contrasted with the part adjustment and removal activities which accounted for only 22% of the total particulate exposures. Exposures with the worker's head in the machine accounted for 18% of the total. Figure 5 presents the HAM concentration responses during the machining activities at B18-2.

Figures 1 through 5 display the exposure concentrations measured with the HAM during machining activities for five workers on separate machines on September 1, 1999. The figures point to peaks in the exposure concentration data, which are indicative of certain activities by the worker. Most of the major peaks are the result of specific activities which places the worker’s head inside of the machine. These activities include the installation of a part to be machined, adjustments to the part placement, and the removal of the part. Activities which generate aerosols, such as the use of the pressurized air gun to clean parts, the application of MWF to the machine during cleaning, or the grinding and polishing of finished parts, also result in peak concentrations.

Older machines, which are not equipped with complete enclosure, such as the FWC 1956 3B machine, exhibited consistently higher background concentrations during machining than the newer machines that are enclosed, i.e., the 16-28 Modig and the Fadals. The B18-2 did not exhibit higher background concentrations, however, even though the amount of enclosure was similar to the FWC 1956 3B. This could have resulted from the observed fact that the machining appeared to be less energy intensive, i.e., slower RPMs, than that observed on the other processes. Additionally, the older machines require more operator interaction which results in greater opportunities for exposure. Table 4 summarizes the VEM findings.

Triethanolamine

Results of TEA exposure sampling is summarized in Table 5. All PBZ sample results were well below the 5 mg/m^3 TLV for TEA. With the exception of one sample, only trace quantities of TEA were measured in PBZ samples. This indicates that for these samples, TEA was detected at concentrations of less than 0.05 mg/m^3. The only quantifiable exposure was collected on a machinist working at the EZ Trak 11 who had an exposure value of 0.14 mg/m^3. This exposure value is below the TLV, but is notably higher than the exposures measured among all other machinists. We observed nothing that would explain the higher exposure for the EZ Trak 11 machinist.

A TEA concentration of 0.41 mg/m^3 was measured in one area sample collected above the main reservoir for the central system. It is not surprising that a higher concentration was measured above the main reservoir since the fluid is covered by only a mesh grate and a mist was visible above the system.

Bulk MWF Samples

Bulk MWF sampling results are summarized in Tables 6–9. In general, indicators of bacterial activity in the fluid ranged from very low to moderate. A clear disparity, in count and species present, was evident between MWF samples collected in the central "Henry filter system" and MWF samples collected from stand-alone machines. Bacteriological activity in the central system was <10 CFU/mL of fluid, and only *Bacillus* genus (Gram-positive) bacteria were identified. In contrast, bacteriological activity in samples collected from stand-alone systems typically ranged from 10^2 to 10^5 CFU/mL, with *Alcaligenes* and *Pseudomonas* genera (Gram-negative) being most prominent.

This disparity is further evidenced in the endotoxin analyses of samples collected from the same locations. Endotoxin concentrations in samples obtained from the central system were all <10 endotoxin units per milliliter (EU/mL) of MWF. Eleven of fourteen (79%) samples collected from stand-alone machines were in the 10^2 to 10^3 EU/mL range. The other three samples had only 1 EU/mL. Fungi were not found in any sample collected at Boeing.

The differences in bacteriological activity between the central and stand-alone systems are indicative of the differences in the way MWF in the two types of systems are monitored and maintained. According to persons at the Boeing plant responsible for maintaining the fluids, fluid concentration in stand-alone machines is measured and corrected every shift. Typically, de-ionized water may need to be added to replace what may have been lost to evaporation during the previous shift. At the time of the NIOSH survey, there was no schedule in place for monitoring and maintenance of MWF in stand-alone machines beyond these concentration corrections. The MWF contained in the central system is checked weekly for pH, concentration, bacteria count, fatty acid percent, and hardness. These parameters are consistently measured and maintained within specified control limits.

Medical

Employee Interviews and Record Reviews

Of the 16 employees interviewed during the first site visit, 15 were machinists and 1 was an assembly worker. Within the preceding 2 years (since Castrol was introduced), 14 of these workers reported having at least one work-related respiratory symptom (cough, shortness of breath, wheezing, and/or chest tightness), and 10 reported having a rash.

Company medical records of the 16 interviewed employees showed that 2 machinists had been newly diagnosed with asthma through company-initiated pulmonary consultations in 1998. Personal medical records of these 16 employees revealed 2 additional machinists who were diagnosed with asthma through private physician-initiated pulmonary consultations in 1998. The four employees diagnosed with asthma in 1998 had all been hired by Boeing prior to the introduction of the new synthetic MWF in May 1997. In all four cases, the physicians performing the evaluations mentioned MWF as a potential cause.

OSHA Log Review

The 1997 log had 91 entries, with 1 entry related to respiratory disorders. In 1998, there were 104 entries, including 12 concerning respiratory disorders, and in the first 5 months of 1999, there were 33 entries, 7 of them concerning respiratory disorders. One employee accounted for three of the entries during the time period 1997 to 1999; the rest were all different employees. Two of the respiratory disorders resulted in three days of restricted activity each; the remaining 18 involved no lost time or restricted activity duty.

Questionnaire

A total of 284 of 343 assembly and machine shop employees (82%) completed the questionnaire, including 149 machinists (73% participation), 9 helpers in the machine shop area, 14 maintenance workers, 90 assembly workers (63% participation), 13 salaried workers (mostly engineers), 6 dispatchers, and 3 "other." Of the 284 workers who participated, 188 were MWF "exposed" and 92 were "unexposed," as defined in the Methods section; 4 did not give this information. The prevalence of symptoms and illnesses are given in Table 10. The symptoms most often reported as work-related include: unusual shortness of breath, 95%; rash, 95%; eye, nose, or throat irritation, 93%; tightness in chest, 91%; and persistent cough, 90%. Asthma symptoms (as defined in the Methods section) were reported by 23% of participants.

Nine workers reported that they had changed their work area because of respiratory symptoms; all were MWF "exposed" employees. Of the 30 employees who responded "yes" to the question, "Have you ever been told by a medical doctor that you have asthma?," 15 gave a date of diagnosis. Of these 15, 6 were diagnosed after 1996, including 5 MWF "exposed" workers and 1 "unexposed." Two workers were diagnosed with asthma in 1996, the year that the synthetic MWF had been used experimentally (one "exposed" worker, a machinist, and one "unexposed," an assembler who was working in the machine shop at the time). Of the seven diagnosed prior to 1996, two employees had a history of childhood asthma and reported recurrent respiratory symptoms since May 1997 (both work in the machine shop), three have had no respiratory symptoms (two "unexposed" assembly employees and one "exposed" machine shop employee), and two have continued with symptoms (both machine shop employees).

Based on crude analyses of questionnaire responses, MWF-"exposed" workers reported two to three times the prevalence of respiratory symptoms (cough, wheeze, tightness in chest, or shortness of breath), with PRs ranging from 2.03 to 3.15; 95% confidence intervals (CI) for these PRs all exceeded 1 (see Table 11). In addition, there was a significantly higher percentage of "exposed" workers reporting cough with phlegm, irritation of eyes, nose, or throat, and skin rashes than "unexposed" workers; in fact, the prevalence of rash was over three times higher in exposed than unexposed workers (PR = 3.43, CI: 1.79, 6.57). We evaluated factors such as age, gender, smoking history, and hobby history for potential confounding; adjusting for these non-occupational factors did not yield a meaningful change in

the PRs for the exposures. Those employees who reported working in the machine shop in May 1997, when the synthetic MWF was introduced (and when MWF aerosol concentrations had been noted to be greater than they are currently), had 2–3 times the prevalence of respiratory symptoms in the 12 months prior to the questionnaire than those not working in the machine shop at that time.

In our crude analyses, the prevalence of asthma symptoms in exposed workers was over twice that of unexposed workers, and the prevalence of work-related asthma symptoms was six times greater than MWF-"unexposed" workers. After adjusting for the effects of age and current number of cigarettes smoked, MWF-exposed workers had almost three times the prevalence of asthma symptoms (PR = 2.73, CI: 1.50, 5.71) and six times the prevalence of work-related asthma symptoms (PR = 6.28, CI: 2.36, 25.49) as unexposed workers. MWF-exposed workers had more than five times the prevalence of one or more work-related respiratory symptoms (as defined by questionnaire) as unexposed workers (PR = 5.53, CI: 2.74, 13.86).

We found no statistically significant difference in respiratory symptoms between machinists who work on stand-alone machines and machinists who work on machines supplied MWF by the central system. However, stand-alone machinists were more likely to have "flu episodes" than central machinists (p = .008). There was no statistically significant difference in rates of respiratory symptoms between workers working on machines with engineering controls (enclosures, mist collectors) and those without these controls. There was no statistically significant difference in rates of respiratory symptoms between workers performing milling operations and those performing non-milling operations. There was no statistically significant difference in rates of respiratory symptoms by worker machine RPM categories (i.e., 0–5000 RPM, 5000–10000 RPM, and >10000 RPM). Potential confounding factors (age, tobacco use, hobbies) were evaluated when performing these comparisons and did not contribute significantly to the findings.

Lung Function Testing

A total of 101 workers were asked to participate in the PFT: 79 machinists, 15 assembly workers, 2 maintenance personnel, and 5 helpers. Of these, 74 (73%) agreed to participate: 62 machinists, 10 assembly workers, and 2 helpers. Of the 74 PFT participants, 66 (65% of 101) participated in the standard spirometric testing and either the bronchodilator administration or methacholine challenge testing; the other 8 underwent spirometry, but declined further testing. Among these 66 employees, 9 were shown to have BHR based on a "positive" bronchodilator or methacholine response. These 9 employees all had questionnaire-based responses indicating potentially work-related respiratory symptoms. Thus, 9 employees were considered to have asthma, including 7 of the 188 participants exposed to MWF (3.7%) and 2 of the 92 unexposed participants (2.2%). The difference between these ratios was not statistically significant (PR = 1.71; CI: 0.36, 8.08; p = 0.723).

Six employees requested PFT, but did not participate in the questionnaire survey. The lung function tests were performed on those six; five had normal bronchial responsiveness, one elected not to have the methacholine testing. These six workers were not included in the data analyses.

Thus, nine employees were determined to have asthma by this study. Of these nine, two machinists reported a prior history of asthma. Five of the nine employees who worked in the machine shop during May 1997, when the synthetic Castrol was introduced, have developed asthma since that time. Another machinist, who was hired after May 1997, has developed asthma since his date of hire.

Of the four machinists found to have BHR in 1998 (as discussed in the Background section), all participated in the questionnaire and pulmonary function studies including the methacholine challenge or bronchodilator administration. One of the four was found to currently have BHR in our study. All reported that their symptoms had caused them to move to a different work area; three have returned to the machining area, and one remains in assembly.

Including the 4 workers who were diagnosed with asthma in 1998, a total of 12 employees have had evaluations consistent with asthma since 1997. Of these 12, 8 reported working in the machine shop during May 1997.

Serial Peak Expiratory Flow Measurements

The nine employees with BHR, determined from the NIOSH lung function tests, performed 7–10 days of serial peak flow measurements. Of the nine, one had a work-related pattern (machinist), three did not provide sufficient data (all machinists), three showed a pattern not related to work (one machinist and two assembly workers), and two had PEF changes with no discernable pattern (two machinists). Four other employees who had lung function studies suggestive of BHR also participated in the serial peak flow testing. Two of these employees provided insufficient data, one had an inconclusive pattern, and one had changes of PEF in a pattern not suggestive of an occupational cause.

In summary, one machine shop worker had documented occupational asthma, three workers had asthma that was not work related, and five had asthma with insufficient PEF data to determine whether the pattern was consistent with an occupational exposure.

DISCUSSION

The results of this evaluation are consistent with eight previous epidemiologic studies which have shown an association between MWF exposure and respiratory symptoms and/or asthma based on questionnaire responses concerning respiratory symptoms and MWF exposure levels.[14,15,31,32,33,34,35,36] Although exposures to MWF among machinists at Boeing as measured during our survey were below the NIOSH REL, it is known that some workers may experience respiratory health effects related to MWF exposure at such levels.[13]

It is of interest that the nine employees with recently documented asthma reported that their asthma symptoms began after the synthetic MWF was introduced. Four studies have compared synthetic MWF exposure with other types of MWF exposure with regard to health symptoms and effects; all have noted that synthetic MWF exposure has had the highest association with respiratory symptoms and/or objective respiratory findings.[15,37,38,39] Based on the patterns of respiratory symptoms, Greaves *et al.* ranked the relative toxicity of the three MWF aerosols as follows: soluble oils < straight oils < synthetic fluids. In Greaves' study, exposures to synthetic fluids were the lowest in terms of aerosol levels but were associated with the highest prevalence of symptoms. Additionally, asthmatics were three times more likely to have been exposed to synthetic fluids during the two years prior to the onset of their asthma than were workers without asthma. Compared with matched controls, these asthmatics were also more likely to have subsequently transferred into an assembly job by the time of the survey.[15]

Our objective evaluation of pulmonary function in the Boeing employees did not find a meaningful association between current exposure to the synthetic MWF and new-onset asthma defined by respiratory symptoms with bronchial hyperresponsiveness, however, two of three

epidemiologic studies that included methacholine challenge testing have found an association between bronchial hyperresponsiveness and duration of exposure to water-based metal working fluids.[33,34,39] Furthermore, an association between cross-shift FEV_1 decrement and occupational exposure to metal working fluid aerosols has been shown in three of four epidemiological studies.[20,32,35,38]

In this study, MWF exposure could not be definitively concluded to be the cause of the BHR among employees due to several factors. Those factors include plant-specific factors, e.g., the reduction of MWF aerosol levels since May 1997 and the possibility that the MWF used at Boeing may not cause BHR, and factors pertaining to the study, e.g., the low participation rate for the pulmonary function testing, the low number of BHR cases found, the potential interference of the pulmonary function testing from asthma medications, and survivor bias due to transfers. Survivor bias refers to those workers with respiratory problems related to MWF exposure who may have voluntarily transferred from working in the machining area to an area without MWF exposure, and consequently would not have been in the study. The number of workers with work-related respiratory symptoms who became symptomatic after the synthetic MWF was introduced, however, suggests an association between this MWF exposure and the onset of respiratory symptoms in the machine shop employees.

Literature Searches Concerning Prostate Disease and Heart Disease

A literature search on prostate and heart disease was performed to address employee health concerns regarding the possibility of these disorders being associated with MWF exposure. Using Medline®, the terms 'heart disease' and 'prostate disease' were individually matched to MWF (or equivalent terms such as machining fluids, cutting fluids, cutting oils, or MWFs) or specific constituents within the MWF, to determine if studies have been published concerning those topics.

Literature search queries using 'prostate' AND 'metal-working fluids' OR any specific MWF constituent, and their equivalent terms resulted in ten relevant references.

Prostatitis

The causes of prostatitis were examined in related articles. Prostatitis is the most common urological disease in men, afflicting between 25–50% of all adult men.[40] There are four categories of prostatitis: (1) acute bacterial prostatitis, (2) chronic bacterial prostatitis, (3) non-bacterial prostatitis (no infecting organism can be demonstrated), and (4) prostatodynia (a complex of symptoms similar to prostatitis that occurs without objective findings that definitely implicate the prostate gland).[41] The causes of the most common type, non-bacterial prostatitis, are largely unknown.[42] A survey of men ages 20–49 for lower urinary tract and prostatitis symptomatology found that caffeine caused 2–13% of symptoms, while exercise and smoking were not associated with symptoms.[43] The topic of prostatitis and exposure to MWF has not been addressed in the medical literature.

Prostate Cancer

Several studies have looked at the role of occupational exposures and prostate cancer. Of these references, one study (Tolbert et al.) observed a slight association between exposure to straight oils and prostate cancer, but no association with synthetic MWF exposure,[44] and a second study found an association between exposure to

diesel fuel or fumes and prostate cancer, but no association was found between MWF exposure and the disease.[45] Eight of the references examined causes of death among MWF-exposed workers, but none found an increased rate of death due to prostate disease/cancer.[46,47,48,49,50,51,52,53] A literature review in the NIOSH Occupational Exposure to Metal-working Fluids Criteria Document looked at nine studies concerning MWF exposure and risk of prostate cancer;[13] one study found a significant excess of prostate cancer with MWF exposure,[54] one (Tolbert, as mentioned previously) found a slight association, and seven observed no association. Five additional studies looked at the relevance of occupational and non-occupational exposures as risk factors for prostate cancer; radionuclides and farm work did show an association with an increased risk for prostate cancer.[55,56] While early studies with cadmium exposure showed an association with prostate cancer, more recent research did not support this finding.[57,58,59] Prostate cancer is now the most common cancer diagnosed among U.S. men, accounting for 27.5% of all cancer cases in men. Dietary practices, hormonal patterns, and family history are thought to be the primary factors in the etiology of prostate cancer.[60] To summarize these various epidemiologic studies, little evidence currently exists for an association between prostate cancer and metal-working fluids (or the constituents of the Castrol synthetic metal-working fluid used at Boeing).

Heart Disease

Literature search queries using 'heart' OR 'cardiac' AND 'metal-working fluids' OR any specific MWF constituent, and their equivalent terms resulted in no relevant references. Coronary artery disease (CAD) is one of the leading causes of death in the U.S., with an age-adjusted death rate (from ischemic heart disease) of 83 per 100,000 in the year 1997.[61] CAD has many non-occupational risk factors, including smoking, physical inactivity, obesity, high blood pressure, high blood lipid levels, diabetes mellitus, family history of CAD, older age, male gender, blood clotting factors, high blood homocysteine levels, alcohol consumption, and psychological factors.[62] Known or suspected occupational risk factors that can adversely affect the heart include exposure to arsenic, carbon disulfide, carbon monoxide, cobalt, fibrogenic dusts, fluorocarbons, hydrocarbons, lead, nitrates (e.g., nitroglycerin, dinitrotoluene, glycol dinitrate), solvents, cold or hot environments, noise, vibration, and psychological strain (high job demand and low job control).[63]

CONCLUSIONS

Based on our findings of increased symptoms among exposed individuals, a health hazard exists for employees working in the machine shop at Boeing. Although MWF exposures were below the NIOSH REL of 0.4 mg/m^3, workers in the machine shop reported more respiratory symptoms than assembly shop workers. Medical testing from this study did not find evidence of more work-related asthma in the machine shop employees than assemblers; however, the findings of this evaluation suggest that workers currently or previously exposed to the synthetic MWF that was introduced in May 1997 have more work-related respiratory symptoms than those without that exposure at this facility.

In addition, while it was not a focus of this study, the high prevalence rate of skin problems in MWF exposed workers indicates a significant risk of dermal conditions in machine shop workers.

RECOMMENDATIONS

Based on the measurements and observations made during the evaluation, NIOSH investigators offer the following recommendations for the

control of MWF exposures and management of workers' health.

Eating, drinking, and smoking should be prohibited in all work areas. Workers at Boeing were observed eating and drinking at their workstations. This practice greatly increases the possibility for ingesting MWF or metal shavings that may be present in the work area.

Boeing should establish a systematic basis for changing mist collector filters. There was no evidence that Boeing changed the mist collector filters on an established schedule. A few of the mist collectors were outfitted with Magnehelic™ gauges to indicate the static pressure in the system. By knowing the static pressure in the system, the company will know when the mist collector's efficiency is being compromised. One way to accomplish this is to outfit all mist collectors with Magnehelic™ gauges, and to monitor the gauge readings daily, when fluid concentration measurements are obtained.

With the exception of the machines that operate at a very low number of revolutions per minute (and generate little to no mist), Boeing should continue to increase the degree of enclosure on the machines. Where feasible, full enclosure is an excellent exposure control because it isolates the source of the MWF mist from the worker. Varying amounts of enclosure were noted among the different machines operating at Boeing. Some machines were fully enclosed. Other machines were either partially or minimally enclosed. A few machines had been retrofitted with plexiglass covers to increase the degree of enclosure. It is essential that machines outfitted with mist collectors be fully enclosed to optimize the mist collector's effectiveness.

Efforts need to be made to limit dermal exposure to MWF, particularly more concentrated forms. Boeing management and the machinists should work together to devise a system for cleaning work surfaces at least once per shift. MWF aerosols that escape the machines' enclosures will eventually settle on nearby work surfaces. These settled MWF aerosols will concentrate as the water evaporates from the droplet. The irritating nature of the MWF will become more severe as the concentration increases.

All employees exposed to MWF should be provided with appropriate education and training, and should be encouraged to report all potential work-related health symptoms to appropriate health care personnel.

As part of the safety and health program, Boeing should monitor reported health problems in a systematic manner designed to identify particular job duties, work materials (such as particular MWFs), machines, or areas of the plant which may be associated with particular health effects. Individuals with definite or possible occupational illnesses should be protected from exposures to agents presumed to cause or exacerbate the disease by using engineering (e.g., isolation and ventilation) and/or administrative (e.g., work and hygienic practices, and housekeeping) controls primarily where feasible, and personal protective equipment (PPE) secondarily.

All workers exposed to MWF may benefit from inclusion in an occupational medical monitoring program.[13] Those with the highest risk (i.e., those exposed to MWF aerosols above a designated concentration, e.g., half the REL) should be given priority. In work areas where one or more workers have recently developed asthma, HP, or another serious condition apparently related to MWF exposure, NIOSH recommends medical monitoring regardless of exposure concentration. The Boeing machine shop is one of these areas. Those employees found to have potential work-related health effects should be referred to a physician knowledgeable in occupational medicine.

The components of a medical monitoring program are outlined in the NIOSH Criteria Document.[13]

In some cases, workers may have to be reassigned to areas where exposure is minimized or nonexistent. In such cases, the reassigned worker should retain wages, seniority, and other benefits that might otherwise be lost by such a job transfer.

Concentrations of MWF aerosols in and around the main reservoir "Henry Filter Pit" were considerably higher than any personal exposure concentrations, and well exceeded the NIOSH REL for average full-shift exposures to MWF aerosols. To protect against potential exposure to these high MWF aerosol concentrations, persons who enter the "Henry Filter Pit" should wear a NIOSH-approved respirator that provides protection against mists. Machinists should also consider using a respirator when opening machine doors or using an air gun in the machine. Consistent with NIOSH recommendations and OSHA requirements, respiratory protection should be used per the requirements outlined in the Respiratory Protection Standard, 29 CFR 1910.134.

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Table 1. MWF Mist Exposure Results
Boeing – Oak Ridge Company
HETA 99–0177
August 31, 1999

Job Title	Machine	Sample Time	Volume[1]	Mass Concentration[2]
Machinist	Magnum on Central System	0645–1454	787	0.05
Machinist	Hurco 2	0731–1452	714	0.06
Machinist	Deburr Station	0656–1456	768	1.84
Machinist	Mazak 7	0721–1452	717	0.08
Machinist	B18 4	0701–1454	757	0.20
Machinist	Harding Lathe	0700–1453	757	0.05
Machinist	Fadal 2	0744–1501	712	0.03
Machinist	Maxum 3	0703–1453	757	0.07
Machinist	Maxum 1	0706–1450	738	0.03
Machinist	Maxum 2	0703–1449	760	0.07
Machinist	Matswra	0701–1445	732	0.07
Machinist	Mazak 1	0748–1442	662	0.05
Machinist	B18 2	0648–1449	770	0.14
Machinist	B22 2	0658–1440	742	0.08
Machinist	T10 2	0702–1443	742	0.13
Machinist	Bridgeport 1	0708–1438	702	0.06
Machinist	T35 4	0707–1437	729	0.08
Machinist	Fadal 8	0723–1436	684	ND[4]
Machinist	Cincinnati 51	0650–1433	745	0.20
Assembly		0720–1422	675	0.03
Assembly		0653–1414	706	0.03
NIOSH REL				0.40

[1] Sample volumes are reported in liters of air.
[2] Thoracic fraction mass concentration values reported in milligrams per cubic meter of air (mg/m^3).
[3] Sample mass thought to be largely attributable to metal dust.

[4] "ND" means that the mass collected on this sample was below the analytical limit of detection, 0.02mg/m^3, for this sample set.

Table 2. MWF Mist Exposure Results
Boeing – Oak Ridge Company
HETA 99–0177
September 1, 1999

Job Title	Machine	Sample Time	Volume[1]	Mass Concentration[2]
Machinist	ISC 2130	0648–1437	741	0.07
Machinist	Series 2 Bridgeport	0715–1442	720	0.07
Machinist	EZ Trak 17	0649–1439	738	0.03
Machinist	Cincinnati Slab Mill #2	0642–1427	744	0.03
Machinist	Fadal 5	0732–1452	704	0.07
Helper		0708–1450	744	0.04
Machinist	Mazak 5	0709–1449	731	0.03
Machinist	T10 1	0716–1437	710	0.10
Machinist	OM1 Mill 2	0703–1431	717	0.22
Machinist	SIP 7a	0641–1426	739	0.04
Machinist	T35 1	0653–1423	725	0.04
Tool Setter		0643–1418	720	0.03
Machinist	EZ Trak 7	0727–1417	644	0.09
K-2110		0638–1420	744	0.09
NIOSH REL				0.40

[1] Sample volumes are reported in liters of air
[2] Thoracic fraction mass concentration values reported in milligrams per cubic meter of air (mg/m^3)

Table 3. MWF Mist Exposure Results
Boeing – Oak Ridge Company
HETA 99–0177
September 2, 1999

Job Title	Machine	Sample Time	Volume[1]	Mass Concentration[2]
Machinist	T-35	1455–2150	660	0.06
Machinist	T-35 3	1456–2259	749	0.08
Machinist	Bridgeport 3	1527–2314	729	0.21
Machinist	Maxum 4	1509–2322	794	0.11
Machinist	Mazak 5	1450–2306	767	0.05
Machinist	Fadal 3	1533–2314	747	0.07
Machinist	EZ Trak 17	1458–2318	785	0.09
	Tool Set Area	1504–2215	792	0.03
Machinist	Mazak 7	1514–2307	752	0.05
Machinist	Walter Grinder	1500–2300	768	0.05
Machinist	Honing Machine	1531–2308	740	0.04
Machinist	Parts Maker	1530–2325	751	0.05
Machinist	EZ Track 10	1515–2316	760	0.09
Machinist	Fadal 8	1455–2307	782	0.08
Machinist	Arrow 2	1454–2300	778	0.13
Machinist	Hurco 1	1510–2300	757	0.05
Assembly	Assembly	1503–2305	776	0.01
Assembly	Assembly	1516–2300	718	0.04
Assembly	Assembly	1513–2305	781	ND[3]
Sheet Metal Worker	Sheet Metal Drilling	1448–2304	779	0.04
NIOSH REL				0.40

[1] Sample volumes are reported in liters of air
[2] Thoracic fraction mass concentration values reported in milligrams per cubic meter of air (mg/m^3)
[3] "ND" means that the mass collected on this sample was below the analytical limit of detection, $0.02 mg/m^3$, for this sample set.

Table 4. MWF Summary Concentrations for Specific Tasks and Machines

Activity	Average Concentration (mg/m^3)	Contribution to Total Particulate Exposure
Fadal #5,5-axis		
Non-process associated (door closed)	0.05	9%
Non-process associated (door open)	0.04	0%
Air gun application (door open)	0.19	7%
MWF application (door open)	0.18	24%
Part removal (door open)	0.16	13%
Grinding	0.12	20%
Air gun (door closed – used outside machine)	0.13	27%
Fadal #4,4-axis		
Non-process associated (door closed)	0.09	9%
Non-process associated (door open)	0.1	8%
Air gun application (door open)	0.1	6%
MWF application (door open)	0.08	10%
Part removal (door open)	0.26	39%
Part install (door open)	0.07	18%
Head in machine	0.14	10%
16-28 Modig		
Non-process associated (door closed)	0.08	74%
Non-process associated (door open)	0.12	3%
Part removal (door open)	0.63	24%
FWC 1956 3B		
Non-process associated (door closed)	0.21	45%
Non-process associated (door open)	0.32	19%
Worker inspection from side	0.37	8%
Air gun application (door open)	0.7	7%
Standing in front of machine (door open)	0.7	5%
Head in machine	1.26	16%
B18-2		

Non-process associated (door closed)	0.04	32%
Non-process associated (door open)	0.04	13%
Air gun application (door open)	0.08	10%
Part position adjustment (door open)	0.28	16%
Part removal (door open)	0.13	6%
Part install (door open)	0.03	5%
Head in machine	0.3	18%

Table 5. Triethanolamine Exposure Results
Boeing – Oak Ridge Company
HETA 99–0177
August 31 – September 2, 1999

Job Title	Machine	Sample Time	Volume[1]	Mass Concentration[2]
Assembly	Console assembly	0712–1407	415	< 0.05[3]
Assembly	Console assembly	0713–1412	419	< 0.05
Machinist	Fadal 4	0722–1416	455	< 0.05
Machinist	Fadal 3	0727–1439	432	< 0.05
Machinist	Fadal 1	0716–1442	446	< 0.05
Machinist	Bridgeport	0737–1443	426	< 0.05
Machinist	Mazak 3	0725–1447	442	< 0.05
	Debur	0734–1535	481	< 0.05
Assembly	Assembly	0645–1437	472	< 0.05
Maintenance	MWF Technician	0711–1418	427	< 0.05
Assembly	Assembly	0717–1418	421	< 0.05
	Above Henry Reservoir	0745–1513	448	0.41
Machinist	T35 #2	1512–2259	467	< 0.05
Machinist	EZ Track 11	1506–2312	486	0.14
Machinist	B18 #3	1442–2330	468	< 0.05
ACGIH TLV				5.0
NIOSH REL				none established

[1] Sample volumes are reported in liters of air
[2] Mass concentration values reported in micrograms per liter (mg/m^3)

[3] The limit of quantitation for the analytical method, 19 μg/sample, was used to determine the minimum quantifiable concentrations.

Table 6. Microbiological Results of MWF Bulk Samples
Boeing – Oak Ridge Company
HETA 99–0177
August 31, 1999

Sample Location	Fungi (MEA)		Bacteria (TSA)	
	(CFU/ml)	Taxa Rank	(CFU/ml)	Taxa Rank
Main reservoir of central system	ND		2	Bac
Main reservoir of central system	ND		6	Bac
Central system return stream	ND		4	Bac
T-35 #1(central system)	ND		6.5	Bac
T-35 #2 (central system)	ND		3	Bac
T-35 #3 (central system)	ND		2	Bac
T-35 #4 (central system)	ND		3	Bac
Hurco #1	ND		$1.1x10^4$	PsPu>ComaAci
Mazak #3	ND		$4.0x10^2$	G neg
B-18 #4	ND		$2.0x10^5$	AlcX>G neg>PsFl
Fadal #4	ND		$3.3x10^3$	PsPu
Fadal #6	ND		$3.6x10^4$	PsPs>PsA>PsPu
Mazak #7	ND		$8.1x10^1$	Ps=PsFl>Ps
Milacron 20VC	ND		$5.4x10^3$	ComAci>Ps
OM1 #2	ND		$6.0x10^2$	PsPu>PsA>G neg
Parts Maker	ND		$16x10^2$	PsPu>G neg>Ps

AlcX = Alcaligenes xylosoxidans
ComAci = Comamonas acidovorans
PsFl = Pseudomonas fluorescens
PsPu = Pseudomonas putida
Bac = Bacillus
G neg = Gram-negative
PsPs = Pseudomonas pseudoalcaligenes

Table 7. Microbiological Results of MWF Bulk Samples
Boeing–Oak Ridge Company
HETA 99–0177
August 31, 1999

Sample Location	Fungi (MEA)		Bacteria (TSA)	
	(CFU/ml)	Taxa Rank	(CFU/ml)	Taxa Rank
Main reservoir of central system	ND		$4x10^2$	Bac>G pos
Main reservoir of central system	ND		2	Bac
T-35 #4 (central system)	ND		2	Bac
T-35 #3 (central system)	ND		ND	
T-35 #2 (central system)	ND		2	Bac
T-35 #1 (central system)	ND		ND	
Fadal #4	ND		$3.9x10^5$	AlcX>PsPu
Maxim #3	ND		$1.5x10^5$	AlcX>G neg
B-18 #4	ND		$4.7x10^5$	AlcX>G neg
Mazak #3	ND		$2.1x10^3$	G neg
Parts Maker	ND		$3.6x10^5$	ComAci>G neg

AlcX = Alcaligenes xylosoxidans
ComAci = Comamonas acidovorans
PsPu = Pseudomonas putida
Bac = Bacillus
G neg = Gram-negative

Table 8. Endotoxin Results of MWF Bulk Samples
Boeing – Oak Ridge Company
HETA 99–0177
August 31, 1999

Sample Location	Endotoxin Concentration (EU/ml)[1]
Main reservoir of central system	13.8
Main reservoir of central system	12.3
Central system return stream	12.4
T-35 #1 (central system)	15.5
T-35 #2 (central system)	13.2
T-35 #3 (central system)	12.8
T-35 #4 (central system)	12.8
Hurco #1	$2.4x10^3$
Mazak #3	$7.3x10^2$
B-18 #4	$6.9x10^3$
Fadal #4	$2.7x10^3$
Fadal #6	$2.4x10^3$
Mazak #7	$9.1x10^2$
Milacron 20VC	$1.9x10^2$
OM1 #2	$1.5x10^2$
Parts Maker	$9.5x10^2$

[1] "EU" means endotoxin units

Table 9. Endotoxin Results of MWF Bulk Samples
Boeing – Oak Ridge Company
HETA 99–0177
August 31, 1999

Sample Location	Endotoxin Concentration (EU/ml)[1]
Main reservoir of central system	9.8
Main reservoir of central system	9.8
T-35 #4 (central system)	9.3
T-35 #3 (central system)	9.0
T-35 #2 (central system)	8.5
T-35 #1 (central system)	8.4
Fadal #4	2.0×10^3
Maxim #3	150
B-18 #4	600
Mazak #3	220
Parts Maker	1.3×10^3

[1] "EU" means endotoxin units

Table 10. Symptoms and Illnesses Reported on Questionnaire
Boeing – Oak Ridge Company
HETA 99–0177
August 31 – September 2, 1999

Symptom/Illness	Number (% of 284 participants) who reported symptom/illness	Number (%) of participants who reported symptom and reported it as work-related[1]
Sinus problems	168 (59.6%)	132 (78.6%)
Irritation of eyes, nose, or throat	121 (42.9%)	112 (92.6%)
Unusual tiredness or fatigue	104 (36.7%)	89 (85.6%)
Chest flu or pneumonia	83 (31.4%)	NA[2]
Cough with phlegm	81 (30.3%)	NA
Unusual shortness of breath	74 (26.1%)	70 (94.6%)
Rash or skin irritation	73 (26.1%)	69 (94.5%)
Wheezing or whistling in chest	62 (22%)	55 (88.7%)
Tightness in chest	58 (20.5)	53 (91.4%)
Ache all over	52 (18.4%)	41 (78.8%)
Persistent cough	51 (18%)	46 (90.2%)
Fever, sweats, chills	37 (13.1%)	24 (64.9%)

[1] Answering "yes" or "maybe" to one of the following questions: "Do you think it (the symptom) is related to work?" or "Did/does it (the symptom) improve during time away from work?" or "Was/is it (the symptom) worse on the first day back to work after time off?"
[2] Not applicable (did not ask work-relatedness questions for these symptoms).

Table 11. Prevalence of Reported Symptoms/Illnesses Among MWF Exposed and Unexposed Employees Boeing – Oak Ridge Company HETA 99–0177 August 31 – September 2, 1999

Symptom/Illness	Number of Exposed (% of 188) reporting symptom/illness	Number of Unexposed (% of 92) reporting symptom/illness	Prevalence Ratio[1] [95% Confidence Interval]
Rash or skin irritation	63 (33.9%)	9 (9.9%)	3.43 [1.79–6.57]
Unusual shortness of breath	64 (34.2%)	10 (10.9%)	3.15 [1.70–5.84]
Irritation of eyes, nose, or throat	100 (53.5%)	19 (20.7%)	2.59 [1.70–3.95]
Tightness in chest	46 (24.7%)	10 (10.9%)	2.28 [1.20–4.30]
Persistent cough	41 (22%)	9 (10%)	2.24 [1.14–4.41]
Cough with phlegm	65 (36.5%)	15 (17.4%)	2.09 [1.27–3.45]
Wheezing or whistling in chest	50 (26.7%)	12 (13.2%)	2.03 [1.14–3.62]
Unusual tiredness or fatigue	81 (43.1%)	23 (25.0%)	1.72 [1.17–2.55]
Pneumonia or chest flu	63 (35.8%)	18 (21.2%)	1.69 [1.07–2.67]
Sinus problems	124 (66%)	43 (47.3%)	1.40 [1.10–1.78]
Ache all over	36 (19.2%)	16 (17.6%)	1.09 [0.64–1.86]
Fever, sweats, chills	24 (12.8%)	12 (13%)	0.98 [0.52–1.88]

[1] Prevalence rate among the MWF-exposed group divided by prevalence among the MWF-unexposed group.

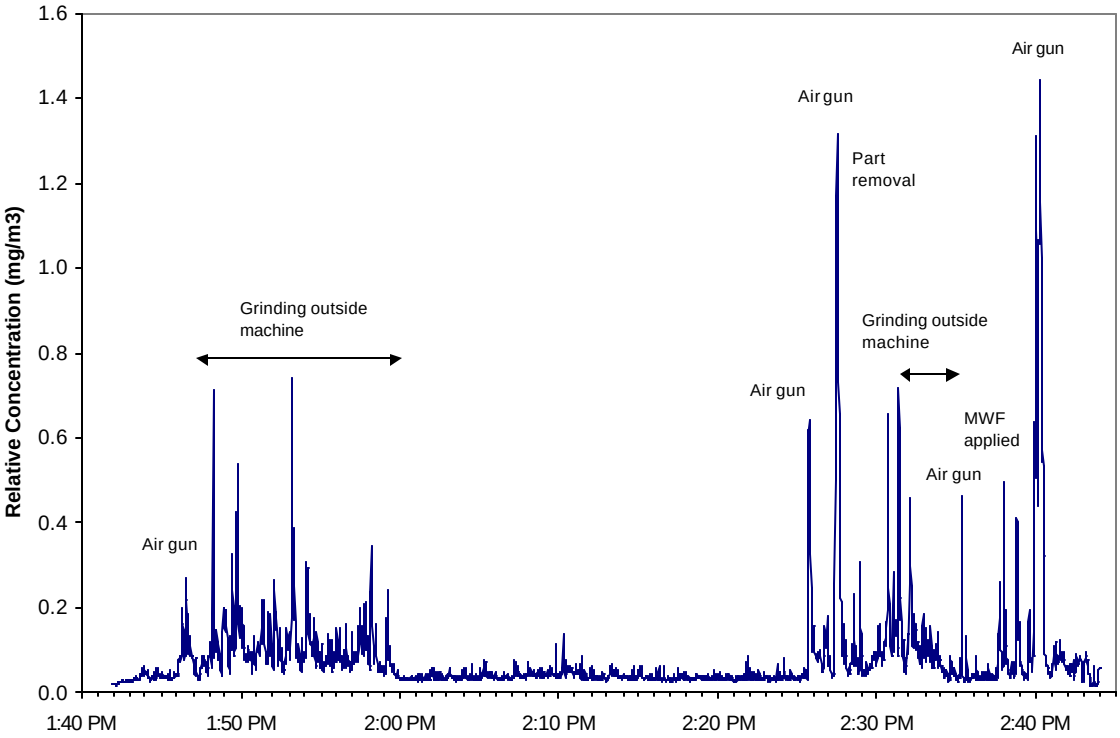

Figure 1. HAM concentration responses during the machining activities at Fadal #5, 5-axis

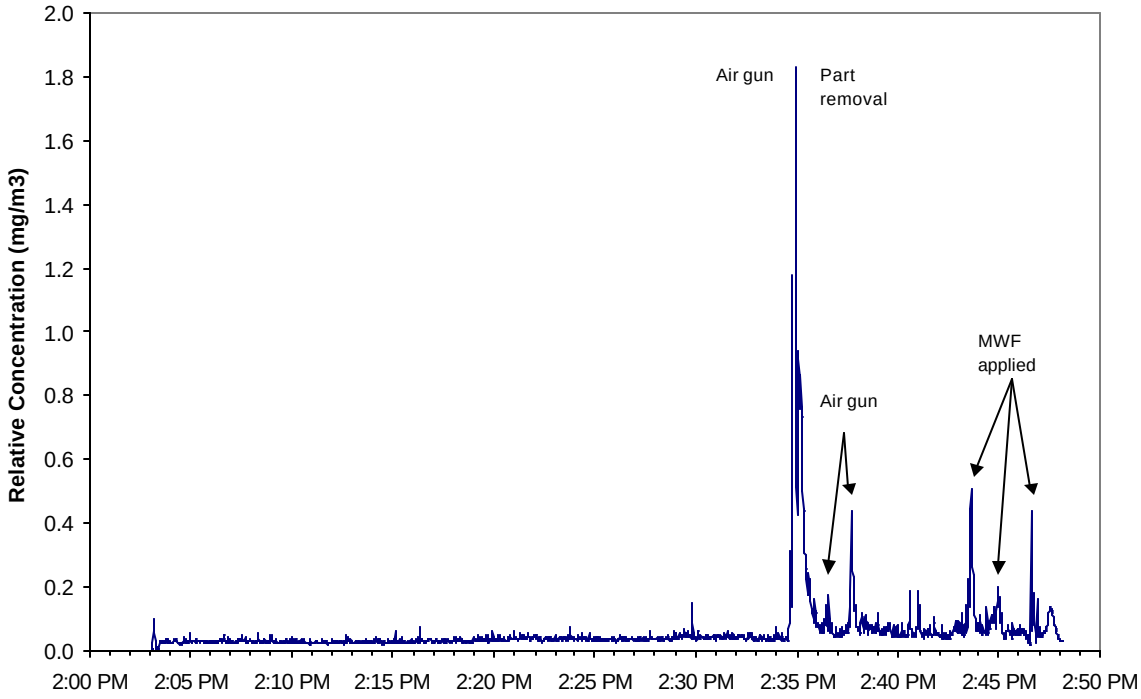

Figure 2. HAM concentration responses during the machining activities at Fadal #4, 4-axis

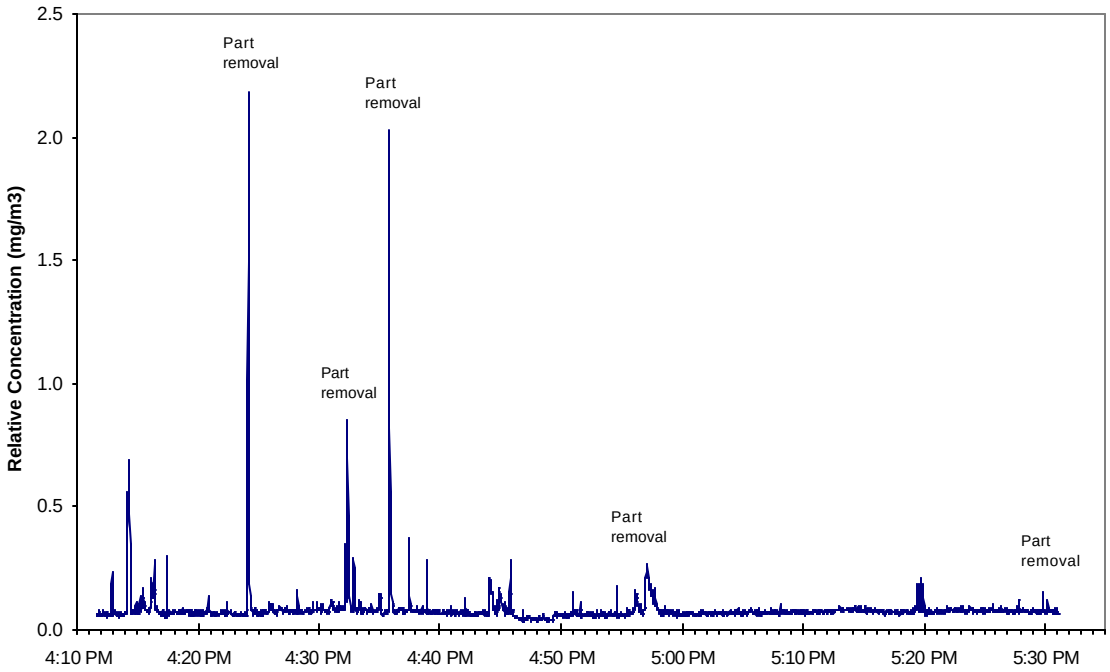

Figure 3. HAM concentration responses during the machining activities at 16-28 Modig.

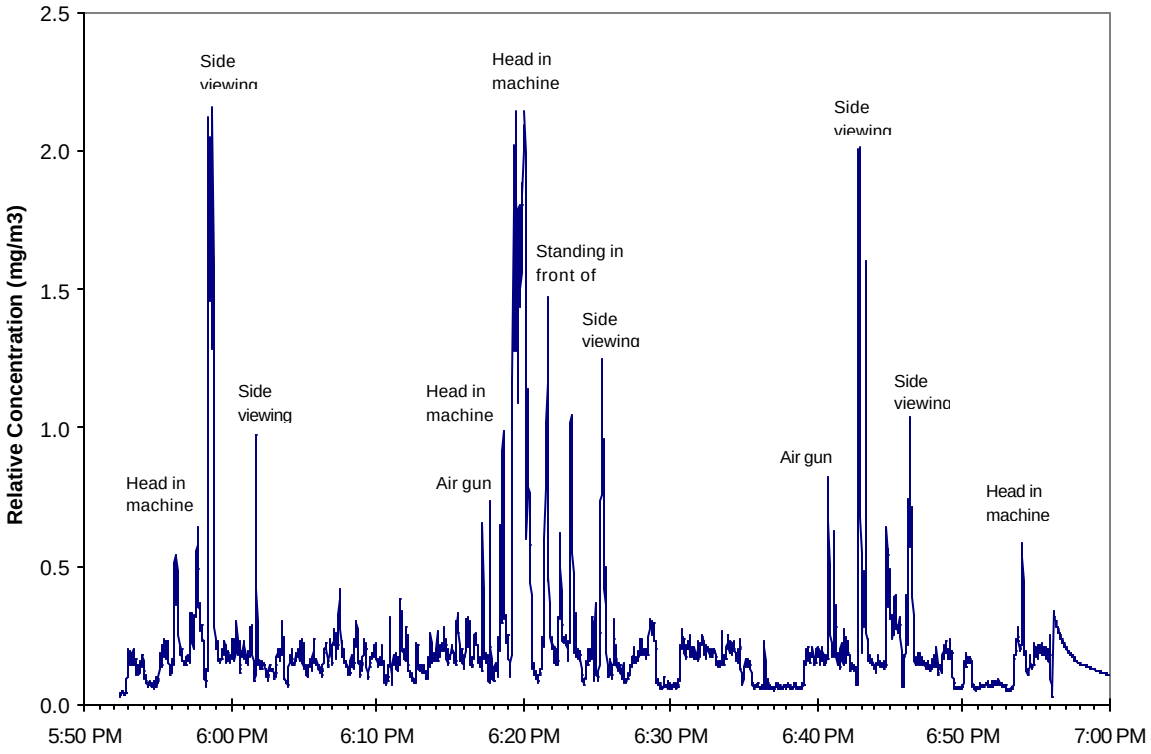

Figure 4. HAM concentration responses during the machining activities at FWC 1956 3B

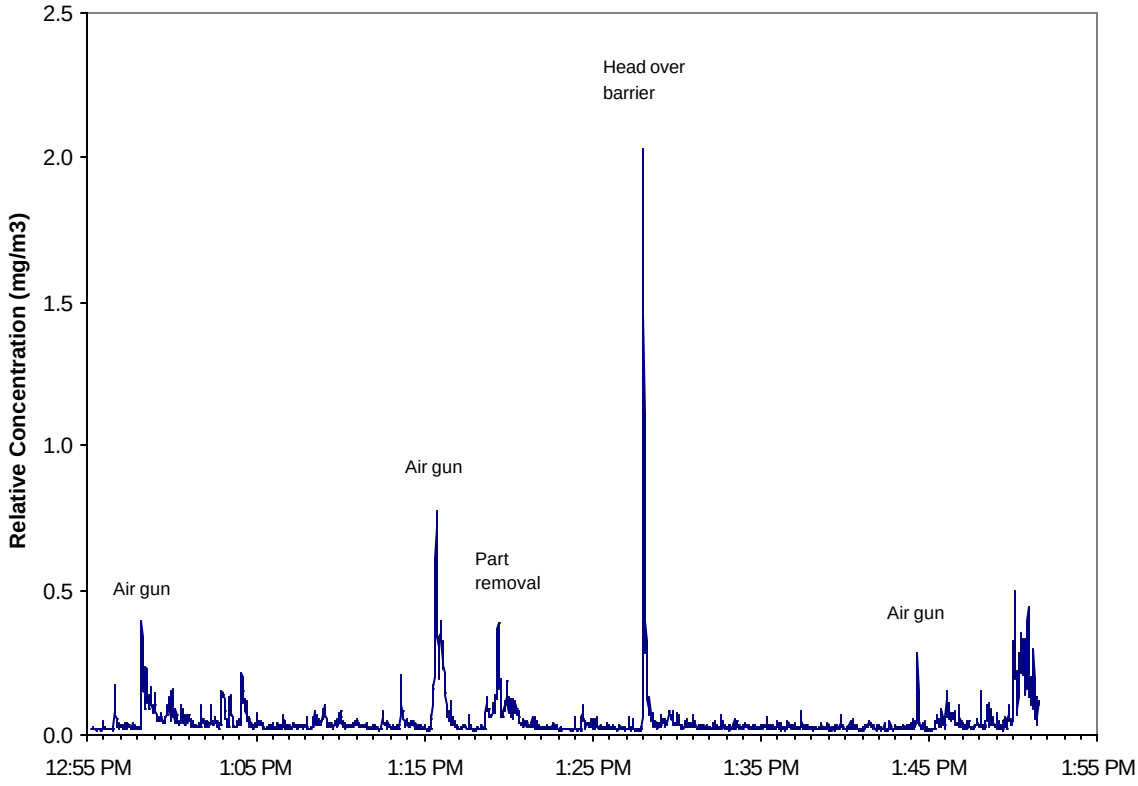

Figure 5. HAM concentration responses during the machining activities at B18-2

Appendix A
INFORMATION SHEET
NIOSH HEALTH HAZARD EVALUATION (HHE) STUDY
BOEING – OAK RIDGE COMPANY, Oak Ridge, TN

WHAT IS NIOSH?
NIOSH is the National Institute for Occupational Safety and Health. NIOSH is an agency of the United States Government, and is part of the Centers for Disease Control and Prevention (CDC).

WHY IS NIOSH DOING A STUDY AT THE BOEING-OAK RIDGE PLANT?
NIOSH is conducting a study in order to help the company and union evaluate symptoms that have been reported by some workers. We are focusing on certain health effects possibly related to exposure to cooling oil (metalworking fluid) used in the machine shop. The health effects we will be looking at are primarily respiratory (breathing) symptoms.

SCHEDULED DATES OF STUDY:
August 9–10, 1999 for questionnaire and Aug. 30–Sept. 3, for exposure measurements and medical evaluation (involving breathing tests) of selected participants.

WHICH EMPLOYEES DOES NIOSH WANT TO EVALUATE?
NIOSH would like all employees with full-time duties in the machine shop, as well as those employees who divide their time between the machine shop and other areas, to fill out a questionnaire. As a comparison group, we would also like employees who have full-time duties in the assembly area to fill out the questionnaire. Worker participation in the study is voluntary.

WHY IS MY PARTICIPATION IN THIS STUDY IMPORTANT?
A high participation rate among employees will give NIOSH the most accurate information about potential health effects related to cooling oil exposures at Boeing.

WHAT WILL MY PARTICIPATION IN THIS STUDY INVOLVE?
We will be carrying out the study during your regular work hours on August 9–10 and during the week of August 30th. All persons agreeing to participate will be asked to:

- Fill out a questionnaire describing work duties and symptoms you may or may not have experienced

Some participants will also be asked to:

- Wear a personal sampling pump during one work shift for the purpose of measuring the amount of dust/cooling oil to which you are exposed at work.

- Participate in standard breathing tests (spirometry) and possibly peak flow measurements (using a self-administered hand-held breathing meter) to measure your overall lung function and to see if your lung function changes over a work week.

WILL MY PRIVACY BE PROTECTED?
Any personal information you provide will be protected in accordance with the Privacy Act of 1974 and the Freedom of Information Act. A final report summarizing the study's findings will be made available, but will not include participants' names or other personal identifiers.

WHO SHOULD I CONTACT IF I HAVE QUESTIONS ABOUT THE EVALUATION?
NIOSH investigators Kevin Roegner and Dr. Loren Tapp will be present during the

evaluation. At other times, they can be reached at [513] 841–4427.

Appendix B

ID Number_____

Form Approved
OMB No. 0920-0260
Expires 1/31/2001

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
U.S. PUBLIC HEALTH SERVICE
CENTERS FOR DISEASE CONTROL AND PREVENTION
NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH

HETA 99-0177
BOEING, Oak Ridge

This questionnaire is part of a National Institute for Occupational Safety and Health (NIOSH) health hazard evaluation (HHE) regarding workplace exposures and possible health effects related to metalworking fluids (machining fluids). For this HHE, we would like to have participation from Boeing employees in the machining area, as well as a group of employees who do not work with machining fluids. This questionnaire includes questions concerning health symptoms you may have experienced in the last year. Please answer all question as best as you can remember. There are also some questions about your current job and work history. In the next few weeks, we will be contacting some who fill out the questionnaire to offer them standard breathing tests (pulmonary function tests) at Boeing.

All personal information from this questionnaire will be kept confidential to the extent allowed by the federal Privacy Act and the Freedom of Information Act. Group summary results of this evaluation will be provided to employees and management in the form of a final report. The overall results of this survey, without personal identifiers, will be available in a report which will be prepared after the survey is completed.

THANK YOU FOR YOUR PARTICIPATION IN THIS SURVEY

This form is provided to assist in completing a health hazard evaluation conducted by the U.S. Department of Health and Human Services. Public reporting burden for this collection of information is estimated to average 15 minutes per response. Send comments regarding this burden estimate or any other aspect of this collection of information including suggestions for reducing this burden to :

CDC, Project Clearance Officer, 1600 Clifton Road, MS D-24, Atlanta, GA 30333, ATTN: PRA (0920-0260). **(See Statement of Authority below.)**

STATEMENT OF AUTHORITY:
Sections 20(a)(3–6) of the Occupational Safety and Health Act (29 USC 669(a)(6–9), and Section 501(a)(11) of the Federal Mine Safety and Health Act (30 USC 951(a)(11). The identity of the participant will be protected under provisions of the Privacy Act (5 USC). The voluntary cooperation of the participant is required.

BOEING

Oak Ridge, Tennessee

Medical and Occupational History Survey

HETA - 99-0177, August 1999

DEMOGRAPHIC INFORMATION:

1. TODAY'S DATE: __/__/99

(PLEASE PRINT)

2. LAST NAME: _____

3. FIRST NAME: _____

4. MIDDLE INITIAL: _____

5. STREET ADDRESS: _____

6. CITY: _____

7. STATE: _____

8. ZIP CODE: _____

9. TELEPHONE NUMBER: _____ - _____ - _____
(AREA CODE)

10. GENDER: _____MALE _____FEMALE

11. DATE OF BIRTH: _____/_____/_____
(MONTH) (DAY) (YEAR)

12. WHAT IS YOUR CURRENT AGE? _____#Years

13. RACE/ETHNICITY: (CHOOSE ONE)

___AMERICAN INDIAN OR ALASKAN NATIVE
___ASIAN OR PACIFIC ISLANDER
___BLACK (not of Hispanic origin)
___HISPANIC
___WHITE (not of Hispanic origin)
___OTHER (specify) _____

JOB HISTORY:

14. ***WHEN*** DID YOU FIRST START WORKING AT **BOEING, Oak Ridge**?

_____
Month/Year

15. WHAT IS YOUR ***CURRENT*** WORK ***SHIFT***? (CHOOSE ONE)

____ First ____ Second ____ Third

16. HOW MANY **HOURS PER WEEK** DO YOU TYPICALLY WORK AT BOEING?

_____

hours

17. WHAT IS YOUR ***PRESENT*** JOB CLASSIFICATION? (CHOOSE ONE)

___Salaried Employee --> (Specify title) _____
___Machinist
___Assembler
___Maintenance --> HU_____
___Helper --> HU_____
___Dispatcher --> HU_____
___Other (Specify title) _____

18. ***HOW LONG*** HAVE YOU WORKED IN YOUR ***CURRENT JOB***? _____ _____

#Years # Months

19. IN WHAT **AREA** OF THE PLANT DO YOU WORK PRIMARILY? (CHOOSE ONE)

___Fab 1 ___Fab 2 ___ Assembly ___Other (please specify_____)

20. WHAT ***PERCENT*** OF YOUR ***TOTAL WORK TIME*** DO YOU SPEND IN THE PLANT ***MACHINE SHOP AREAS*** (FAB 1 AND FAB 2)?

____ Less than 25%
____ At least 25% but less than 50%
____ At least 50% but less than 75%
____ 75% or more

21. DO YOU WORK WITH, OR NEAR, MACHINING FLUIDS (CUTTING FLUIDS) IN YOUR **CURRENT JOB**?

___No __Yes

22. IN YOUR CURRENT JOB, IF YOU WORK ON ONE OR SEVERAL SPECIFIC MACHINES, PLEASE LIST THE **NAME OF THE MACHINE** AND THE **IDENTIFICATION NUMBER:**

Name and ID# of Machine	**Approximate % (percent) time assigned to machine**
_____	_____
_____	_____

_____ Work around many machines

23. **If you do NOT work with, or near, machining fluids NOW:** HAVE YOU **EVER** WORKED WITH, OR NEAR, MACHINING FLUIDS (CUTTING FLUIDS) AT BOEING?

__No(skip to #25) __Yes —>

23a. **IF "YES" to #23,** please list your **LAST** JOB TITLE, DEPARTMENT, AND MACHINE YOU WERE WORKING ON (OR NEAR) WHICH INVOLVED MACHINING FLUIDS:

JOB	**DEPT**	**MACHINE (NAME, #)**	**WHEN** (Year - Year)
_____	_____	_____	____ - ____

24. IF YOU WERE WORKING IN THE MACHINE SHOP AT BOEING OAK RIDGE IN **MAY 1997 (when Castrol fluid was introduced),** PLEASE LIST YOUR JOB TITLE, DEPARTMENT, AND THE MACHINE YOUR WERE WORKING ON AT THAT TIME:

JOB	**DEPT**	**MACHINE (NAME, #)**
_____	_____	_____

_____ NOT APPLICABLE

HABITS AND HOBBIES HISTORY:

25. HAVE YOU EVER ***SMOKED*** 100 OR MORE CIGARETTES, CIGARS, OR PIPES IN YOUR LIFE?

____ NO (skip to Q.#30) ____ YES (continue)

26. DO YOU ***CURRENTLY SMOKE*** CIGARETTES OR OTHER TOBACCO PRODUCTS?

____ NO (skip to Q. #28) ____ YES (continue)

27. **IF YES**, HOW MANY CIGARETTES **DO YOU** SMOKE **PER DAY**? (20 CIGARETTES = 1 PACK)

_____ **#PACKS** PER DAY _____ **#CIGARETTES** PER DAY

28. **IF NO**, WHEN YOU **DID SMOKE**, HOW MANY CIGARETTES *ON AVERAGE* **DID YOU SMOKE**?

_____ **#PACKS** PER DAY _____ **#CIGARETTES** PER DAY

29. HOW MANY **YEARS** *ALTOGETHER* **HAVE** YOU SMOKED OR **DID** YOU SMOKE?

_____ **#Years** (altogether)

30. In the past 12 months, outside your job at Boeing, have you done any of the following activities (**if "YES", how often):** [**Daily Occasionally Rarely]**

A. **Farming**	___no	___yes–>__daily __occas __rarely
B. **Used two-part (isocyanate) paints**	___no	___yes–>__daily __occas __rarely
C. **Bird-Keeping**	___no	___yes–>__daily __occas __rarely
D. **Been around fumes**	___no	___yes–>__daily __occas __rarely
E. **Welding**	___no	___yes–>__daily __occas __rarely

PLEASE COMPLETE THE FOLLOWING TABLE:

In the past 12 months have you had any of the symptoms listed below?			What month and year did it begin?	Do you think it is related to work?	Have you seen a medical doctor because of this problem?	Did/does it improve during time away from work?	Was/is it worse on the first day back to work after time off?
	No yes		Mo / Yr	No yes unsure	no yes	no yes	no yes unsure
31. Persistent Cough	◯ ◯	If Yes→	___/___	◯ ◯ ◯	◯ ◯	◯ ◯	◯ ◯ ◯
32. Wheezing or whistling in chest	◯ ◯	If Yes→	___/___	◯ ◯ ◯	◯ ◯	◯ ◯	◯ ◯ ◯
33. Tightness in chest	◯ ◯	If Yes→	___/___	◯ ◯ ◯	◯ ◯	◯ ◯	◯ ◯ ◯
34. Unusual shortness of breath	◯ ◯	If Yes→	___/___	◯ ◯ ◯	◯ ◯	◯ ◯	◯ ◯ ◯
35. Fever/Sweat/Chills	◯ ◯	If Yes→	___/___	◯ ◯ ◯	◯ ◯	◯ ◯	◯ ◯ ◯
36. Ache all over	◯ ◯	If Yes→	___/___	◯ ◯ ◯	◯ ◯	◯ ◯	◯ ◯ ◯
37. Unusual tiredness or fatigue	◯ ◯	If Yes→	___/___	◯ ◯ ◯	◯ ◯	◯ ◯	◯ ◯ ◯
38. Rash or skin irritation	◯ ◯	If Yes→	___/___	◯ ◯ ◯	◯ ◯	◯ ◯	◯ ◯ ◯
39. Irritation of eyes, nose or throat	◯ ◯	If Yes→	___/___	◯ ◯ ◯	◯ ◯	◯ ◯	◯ ◯ ◯

40. Sinus problems	◯ ◯	If Yes→	___/___	◯ ◯ ◯	◯ ◯	◯ ◯	◯ ◯ ◯

41. Have the **symptoms** listed in this table caused you to **change your work area**?
G No **G** Yes

HEALTH QUESTIONS:

42. IF YOU REPORTED SYMPTOMS IN THE PREVIOUS TABLE, PLEASE LIST YOUR JOB TITLE, DEPARTMENT, AND THE MACHINE YOUR WERE WORKING ON **AT THE TIME THE SYMPTOMS STARTED:**

JOB	**DEPT**	**MACHINE (NAME, #)**
_____	_____	_____

_____ Not applicable

43. Have you **ever** been told by a medical doctor that you have **asthma**? **G** No **G** Yes

If yes, when was the asthma diagnosed ? ____ /_____(month/year)

Do you still have **asthma**? ----------> **G** No **G** Yes

44. When you **wake up**, do you **cough up phlegm** most days? **G** No **G** Yes

If yes, how often? **G** Less than 3 months per year
G More than 3 months per year

How many years have you had **cough with phlegm**? _____ # years

45. In the past 12 months, have you had a **chest-flu** (fever, cough, aches) or **pneumonia**? **G** No **G** Yes

If yes, how many times? _____# times

Date(s) illnesses began _____(month/year)

THANK YOU FOR PARTICIPATING IN THIS SURVEY. YOUR ANSWERS ARE VERY IMPORTANT TO US, WHETHER YOU HAVE HAD SYMPTOMS OR NOT.

Appendix C
Spirometry

I Background

Spirometry refers to the measurements of exhaled air volume and flow rates from individuals who are coached by trained technicians using either volume-based or flow-based measuring equipment. The important measurements include forced vital capacity (FVC) or the greatest volume of air exhaled from a maximal inspiration to a complete exhalation; the forced expiratory volume in one second (FEV_1) or the volume of air exhaled in the first second of a FVC maneuver; and the ratio between these two values: FEV_1/FVC. These measurements will be made using either a dry rolling-seal spirometer (volume-based system) or a ceramic flow sensor (flow-based system) interfaced to a dedicated computer. All procedures will conform to standard guidelines.[1] At least three maximal expiratory maneuvers or FVC maneuvers will be performed at each session. The selection and interpretation of results will also conform to standard guidelines.[2] Predicted values will be determined from published reference equations.[3]

II Contraindications

(1) Hemoptysis of unknown origin
(2) Pneumothorax
(3) Unstable cardiovascular status including recent myocardial infarction or stroke (within three months)
(4) Known arterial aneurysm
(5) Recent eye surgery (within three months)
(6) Acute disorders that might affect subject performance during testing: e.g., G.I. distress, thoracic or back discomfort or dysfunction.
(7) Recent thoracic or abdominal surgical procedures (within three months)

III Procedure

(1) Subject Preparation
    (A) Informed Consent
    (B) Check height
    (C) Check pre-test questionnaire (see Log for spirometry)
    (D) Subject to be told they may become tired performing these maneuvers and they may feel momentary lightheadedness or chest discomfort.
(2) Test Procedure
    (A) Demonstrate to subject the correct performance of the forced maneuver.
    (B) Have the subject assume the correct position; make sure nose clip is in place.
    (C) Subject should inhale completely; inhalation should be rapid but not forced.
    (D) Subject should place mouthpiece in mouth and close lips around it.

(E) Subject then exhales maximally without holding breath. The subject must be encouraged to blast the air out as rapidly as possible, and to continue exhaling until end-of-test criteria are achieved.[1]

(F) A minimum of three acceptable maneuvers should be obtained.[1]

(G) The two largest FVC values should agree within 200 ml.[1]

IV Log for spirometry

(A) Smoked in the last 2 hours-record and proceed.	YES ____	NO ____
(B) Cold in the last 4 weeks-record and proceed.	YES ____	NO ____
(C) Recent surgery:	YES ____	NO ____
If thoracic/head/abdominal/eye – Stop. Consult physician.		
(D) Suffering from asthma attack, allergy attack or flu now.	YES ____	NO ____
If yes: consult physician.		
(E) Recent MI or stroke.	YES ____	NO ____
If yes: consult physician.		

References

1. Standardization of Spirometry [1995]. 1994 Update. Am J Respir Crit Care Med 152:1107–1136.
2. [1991]. Function Testing: Selection of Reference Values and Interpretative Strategies. Am Rev Respir Dis 144:1202–1218.
3. Knudson RJ, et al. [1983]. Am Rev Respir Dis 127:725–734.

Appendix D
Methacholine Test

I Background

Increased bronchial responsiveness can be seen in conditions such as asthma, smoking-induced chronic obstructive pulmonary disease (COPD), congestive heart failure (CHF), cystic fibrosis, bronchitis, airways disease accompanying ILD and in about 5% of normal individuals.

II Contraindications

(1) Significant airways obstruction: FEV_1 less than Lower Limit of Normal Knudson (95^{th} percentile).
(2) Myocardial infarction or stroke within three months
(3) Known arterial aneurysm.
(4) Uncontrolled systemic hypertension
(5) Inability to perform baseline lung function tests such as spirometry in an acceptable and reproducible manner.
(6) Known allergic response to methacholine.

III Procedure

(1) Subject Preparation
  (A) Informed consent
  (B) Subject can be told that he or she may experience minor symptoms such as cough, chest tightness, headache, sweating, and flushing
  (C) Pre-test questionnaire (See Log for Methacholine)
(2) Test Procedure
  (A) Baseline spirometry (See section for **Spirometry**). Select highest FEV_1 and use as baseline for rest of study.
  (B) If no contraindication
    1) start with 5 breaths of initial concentration of methacholine.
    2) Nebulizer (B&F Medical #61400) at 9 L/min flow rate (compressed air not oxygen)
    3) Inspiratory Capacity Breaths (from FRC to TLC; 5 seconds for inhalation and 5 seconds at TLC) with activation of dosimeter (Rosenthal) for 0.6 seconds after initiation of inspiratory effort.
  (C) Concentrations of methacholine
    1) 0.5 mg/ml– if hx. of asthma or respiratory symptoms
    2) 2.0 mg/ml
    3) 8.0 mg/ml
    4) 32.0 mg/ml
    5) If person has history of asthma or respiratory symptoms (cough, chest tightness, shortness of breath, or wheezing), begin with 0.5 mg/ml.
    6) If no symptoms or history, begin with 2.0 mg/ml.

(D) After inhalation of 5 breaths, perform two spirometry maneuvers at 30 and 90 seconds.
   1) If either FEV_1 is < or = 80% of baseline value, repeat measurement.
   2) If still < or = 80% of baseline, stop test and give bronchodilator. Do repeat spirometry after bronchodilator.
   3) If > 80% of baseline, continue testing.

(E) Proceed to next concentration of methacholine. Test is completed when FEV_1 has declined to < 80% of baseline or all concentrations have been given.
   1) If final FEV_1 is > 85 % of baseline then offer bronchodilator. If yes: check pulse, administer bronchodilator, recheck pulse and release subject.
   2) If final FEV_1 is < or = 85% of baseline, **or** if the individual is symptomatic (cough, shortness of breath, chest tightness, wheezing),check pulse, administer bronchodilator and recheck spirometry. If FEV_1 is now within 5% of baseline FEV_1 **and** subject is free of symptoms, recheck pulse and release subject.

IV Log for Methacholine

(A) Baseline FEV_1 < LLN Knudson: YES – STOP consult physician

(B) Recent (three months) heart attack or stroke – consult physician

(C) History of Arterial aneurysm – consult physician

(D) History of High Blood Pressure – consult physician

(E) Allergies to methacholine – consult physician

(F) Inability to do spirometry YES ____ Stop. NO ____

(G) Smoke in last 2 hours – record and proceed YES ____ NO ____

(H) Cold in last 4 weeks – record and proceed YES ____ NO ____

(I) Medicines in last 12 hours (B-agonist inhalers, ipratropium inhalers, theophylline) – consult physician

(J) Current respiratory symptoms: cough, shortness of breath, wheeze; consult physician; use 0.5 mg/ml starting concentration.

(K) Asthma history: use 0.5 mg/ml starting concentration.

Appendix E
Bronchodilator Administration

I Background

Usually a beta-agonist medication is used for the bronchodilator administration. However, other agents (including anti-cholinergic medications) have been used successfully. For this study, an FDA-approved beta-agonist medication is to be used for the bronchodilator administration.

II Contraindications

(1) Known or suspected adverse reactions to the specific bronchodilator to be used.
(2) Unstable cardiovascular status that might be aggravated by the use of a beta-agonist type medication: e.g., significant arrhythmia, significant tachycardia, and elevated blood pressure.
(3) Resting Pulse > 100 beats per minute

III Procedure

(1) Subject Preparation
    (A) Informed Consent
    (B) Check Pulse
    (C) Subject to be told that they may become tired performing repeated spirometric maneuvers. They will also be told that the administration of the bronchodilator might cause an increase in heart rate, blood pressure, and an increased sensation of tremulousness or jitteriness.
(2) Test Procedure
    (A) Measure pulse rate:
        1) if < or = 100 bpm, proceed with bronchodilator administration.
        2) if > 100 but < 120 bpm, check with physician.
        3) if > 120 bpm do not administer bronchodilator
    (B) The procedure for inhaling the bronchodilator from a metered-dose inhaler (MDI) is demonstrated to the subject.
    (C) The technician holds the MDI 1 to 2 inches from the subject's open mouth.
    (D) The subject exhales below functional residual capacity (FRC) but not all the way to residual volume (RV).
    (E) While the subject is then inhaling slowly from below FRC, the technician will activate the MDI while instructing the subject to continue to inhale slowly to total lung capacity (TLC). The inhalation should take approximately 5 seconds.
    (F) Instruct the subject to then hold their breath at TLC for 5 seconds and then to exhale slowly.
    (G) Wait one minute and repeat steps D through G.
    (H) Wait 10 minutes.
    (I) Repeat the measurement of pulse. Record.
    (J) Repeat spirometry
        1) if FEV_1 has dropped by 15% or patient is symptomatic after methacholine.

2) FEV_1 on spirometry after the administration of the bronchodilator should be > 95% of the baseline spirometry at the beginning of the bronchial challenge test.
3) If it is < 95% of the baseline value, repeat the bronchodilator administration again.
4) If after two bronchodilator administrations, the FEV_1 remains < 95% of the baseline, notify the physician.

IV Log for Bronchodilator:
After Methacholine Test:

(1) Check Pulse
   (A) If pulse is > 100 wait 5 minutes and repeat pulse
   (B) If pulse is < or = to 100 go to next step
(2) Allergies to medications: notify physician if allergy to bronchodilator. If no, go to next step.
(3) History of arrhythmia, fast heart rate, high blood pressure. If yes: Stop. Consult physician.
(4) Check % fall in FEV_1 from baseline
   (A) If 15 % or greater, check pulse, give bronchodilator and repeat spirometry. Check $FEV_{1,}$ pulse and release.
   (B) If symptoms, check pulse, give bronchodilator and repeat spirometry. Check FEV_1, pulse and release.
   (C) If < than 15% fall, offer bronchodilator. If accepted, give bronchodilator, wait 10 minutes, check pulse and release.
(5) Pulse on release should be within 10 beats per minute of pulse before bronchodilator.

Appendix F
Peak Expiratory Flow Rate (PEFR) Testing

The PEFR is defined as the maximum flow which can be sustained for a period of 10 milliseconds during a forced expiration starting from total lung capacity. PEFR is a measure of the initial flows in a forced expiration, and is also a reflection of lung recoil and resistance of the larger airways. Patterns demonstrating a reduction in peak flow measurements when comparing non-workday PEFRs to workday PEFRs will be used to identify subjects with occupationally-related airway reactivity. NIOSH investigators will obtain a determination of the PEFR of each participant using an ENACT Airwatch portable peak flow meter. In addition, participants will be instructed to take their own peak flow measurements for seven consecutive days, including non-work days. They will be asked to obtain measurements five times daily (i.e., upon awakening, shortly after arriving at work, in the middle of the work day [lunchtime or mid-shift break for off-shifts], at the end of the work day, and once four hours after leaving work). Second and third shift workers will be given individual instructions regarding peak flow recording times that will coincide with their sleep-wake cycle. Three exhalations will be recorded each time, and the maximum of the three values will be accepted as the PEFR determination. A participant will be considered as having significant bronchial hyperresponsiveness if the amplitude percent mean ([max – min]/mean) PEFR is greater than 20%.

Immediately before obtaining peak flow measurements, participants will be asked to: (1) record any acute respiratory symptoms (i.e., wheezing, shortness of breath, chest tightness or cough) experienced immediately preceding the PEFR test; and (2) record the time of the most recent use of metered dose inhaler medications prior to PEFR measurement.

Each participant will be asked to complete seven consecutive days of peak flow measurements, and then return the completed logs and peak flow meters in a postage-paid mailer provided by NIOSH.

Data collected from the questionnaire, acute symptom survey, spirometry and serial PEFRs will be analyzed to determine if the following criteria are met to define a case of bronchial hyperresponsiveness related to MWF exposure in the workplace: (1) PEFR measurements are lower on work days compared to days away from work; (2) variation in daily amplitude percent mean >20% is seen on work days and is absent on non-work days; or (3) decreases in PEFR are temporally associated with a discrete exposure episode.

Peak-Flow Measurements Instructions

USE THE PEAK-FLOW METER AT THE TIMES INDICATED ON THE FORM

FROM _____ TO_____

- AT THE APPROPRIATE TIME:

  1. Hold the peak-flow meter as demonstrated.

  2. Take a maximum deep breath in, seal your lips tightly around the sides of the mouth piece and blow out as hard as you can into the meter with a short, sharp puff (as if blowing out a lighted match).

  3. Repeat the procedure 2 more times.

- CHECK THE LINE NEXT TO THE APPROPRIATE SYMPTOMS IF YOU ARE EXPERIENCING **SHORTNESS OF BREATH, WHEEZING, CHEST TIGHTNESS, OR COUGH** AT THIS TIME OR JUST PRIOR TO THE TEST.

- IF YOU HAVE JUST BEEN AWAKENED AT NIGHT BY ANY OF THESE SYMPTOMS:

  1. Record the time.

  2. Take 3 readings on the peak-flow meter as explained above.

  3. Check the appropriate lines for the symptoms experienced.

- MARK THE APPROPRIATE RESPONSE IN THE LAST COLUMN REGARDING THE USE OF ANY ASTHMA MEDICATIONS PRIOR TO TAKING YOUR PEAK-FLOW MEASUREMENT.

If you miss one or more sessions, please resume taking measurements as soon as you can.
DO NOT DROP OUT OF THE STUDY SIMPLY BECAUSE YOU MISSED SOME MEASUREMENTS!!

- *If you have any further questions during or after the study, please contact Dr. Loren Tapp at NIOSH in Cincinnati, Ohio (513/841–4386).*

National Institute for Occupational Safety and Health
Boeing – Oak Ridge, Tennessee
HETA 99–0177
Peak Flow Meter Test Recording

Name_____

Date _____/_____/99

DAY: Sun – Mon – Tues – Weds – Thurs – Fri – Sat (circle one)

WORKSHIFT: **Begin** _____ am/pm **End** _____ am/pm

DID **NOT** WORK TODAY _____

Time of day	***Actual* time**	**At this time(or just prior to) this test, have you had: (check all that apply)**	**Since your last test did you use an Asthma inhaler?**
1) Awakening	____ : ____ a.m. __ p.m.__	___ **wheezing**? ___ **shortness of breath** ? ___ **cough** or **chest tightness**?	_____ YES _____ NO
2) Arrival at work	___ : ____ a.m. __ p.m.__	___ **wheezing**? ___ **shortness of breath**? ___ **cough** or **chest tightness**?	_____ YES _____ NO
3) Lunchtime or mid-shift break	___ : ____ a.m. __ p.m.__	___ **wheezing**? ___ **shortness of breath**? ___ **cough** or **chest tightness**? ___ did you wear a respirator?	_____ YES _____ NO
4) Before leaving work	___ : ____ a.m. __ p.m.__	___ **wheezing**? ___ **shortness of breath**? ___ **cough** or **chest tightness**? ___ did you wear a respirator?	_____ YES _____ NO
5) 4 hours after leaving work	___ : ____ a.m. __ p.m.__	___ **wheezing**? ___ **shortness of breath**? ___ **cough** or **chest tightness**?	_____ YES _____ NO

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