HETA 95-0001-2679
Caterpillar Inc.
York, Pennsylvania

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PREFACE

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ACKNOWLEDGMENTS AND AVAILABILITY OF REPORT

This report was prepared by Allison Tepper, PhD and Leo M. Blade, MSEE, CIH. Some of the information and discussion is based on the work and writing of Teresa A. Seitz, MS, CIH. Desktop publishing was done by Kathy Mitchell. All are with the Hazard Evaluations and Technical Assistance Branch, Division of Surveillance, Hazard Evaluations and Field Studies (DSHEFS). Review and preparation for printing was performed by Penny Arthur.

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Health Hazard Evaluation Report 95-0001-2679
Caterpillar Inc.
York, Pennsylvania
March 1998

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SUMMARY

In October 1994, the National Institute for Occupational Safety and Health (NIOSH) received a request from the International Union, United Automobile, Aerospace and Agricultural Implement Workers of America (UAW) for a health hazard evaluation (HHE) at Caterpillar Inc., in York, Pennsylvania. The requestor noted concerns about the possible relationship between cadmium exposures in the brazing area of the oil cooler department (OCD) and sexual dysfunction among five long-term workers in the area. At the time of the HHE request, managers and newly hired workers continued production while most long-term employees were on strike. In May 1995, while the strike continued, NIOSH investigators met with a group of OCD workers at the local union hall. In May 1996, after the strike ended, NIOSH investigators visited the Caterpillar facility to review medical records and Caterpillar environmental and biological monitoring data, conduct a walk-through survey and interview employees, and perform air sampling for airborne metals and fluorides. A return visit was made in August 1996, to conduct biological monitoring for urine cadmium in current and former OCD workers. Because some eligible employees were not identified in August 1996, a second round of biological monitoring was conducted at the local union hall in January 1997.

Medical records for the five employees known to be experiencing sexual dysfunction, all current or former brazers, described a variety of sexual dysfunction symptoms. Upon initial testing, however, all five had testosterone levels below the laboratory's reference range. Urine cadmium levels were above the background range in four workers. Upon follow-up testing one year later, testosterone levels had risen, but were still below the laboratory's reference range in four men. Nocturnal penile tumescence results indicated possible anomalies in erectile function in all five men. Three of the five men had underlying medical conditions — in addition to the low testosterone levels — that could explain the erectile dysfunction.

In data provided by Caterpillar for 154 samples collected in the OCD brazing area from 1974 through January 1996, the median personal breathing-zone (PBZ) airborne cadmium concentration was 1.8 micrograms per cubic meter ($\mu g/m^3$), but measured exposures varied widely, and 33% were equal to or greater than *today's* Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) of 5 $\mu g/m^3$ for an 8-hour time-weighted average exposure (although only 4% of the measured PBZ exposures exceeded the PEL in effect *at the time of the sampling*). Measured PBZ exposures to cadmium steadily declined over the years, except during the period around 1989, as various changes were made affecting the operations and exposure potential, including the eventual phase-out of the use of cadmium-containing materials in the brazing area that was completed by the end of May 1996. In addition to the documented inhalation exposures to cadmium, potential for non-inhalation exposures to OCD workers is suggested by the results of surface-wipe sampling conducted by Caterpillar in 1993 and 1995, which document cadmium on surfaces in the brazing area.

Caterpillar also provided results of PBZ air sampling for other metals and fluorides conducted in the OCD brazing area that suggest historically low inhalation exposures to these substances compared with relevant

occupational exposure criteria. Caterpillar also provided information naming additional substances present in the brazing area, but for which no exposure measurements were made.

Caterpillar also provided results of biological monitoring conducted between August 1993 and February 1995. Creatinine-adjusted urine cadmium levels were above 3 µg/g (micrograms per gram creatinine) in 4 (33%) of 12 long-term workers, but none of the workers recently hired to replace striking employees. Two (5%) of 21 long-term workers, but none of the recently hired workers, had blood cadmium levels above 5 µg/L (micrograms per liter). One long-term worker with past exposure to cadmium had a beta-2-microglobulin level above 300 µg/g creatinine, indicating kidney damage.

The results of the NIOSH air sampling for metals and fluorides conducted in the brazing area in May 1996 indicated that the measured airborne concentrations of all measured substances were well below their relevant exposure criteria. The results of some samples for cadmium revealed "trace" concentrations (below the minimum quantifiable concentration), while for most, cadmium was not detected. The NIOSH air-sampling was conducted near the completion of the phase-out of cadmium-containing materials and, as expected, the airborne cadmium concentrations at that time were lower than those typically measured by Caterpillar over the years.

NIOSH offered urine cadmium testing to all Caterpillar employees who had worked in the oil cooler department for three months or more since 1976. One hundred sixty-two current and former workers participated in the testing. The results for cadmium in urine ranged from "not detected" (less than 0.1 µg/L, unadjusted cadmium) to 19.3 µg/g. Four workers (2%) among those tested by NIOSH had levels at or above 3 µg/g; 98%, however, had levels below 3 µg/g. The four workers with elevated levels included 1 (0.8%) of 132 who had never worked as a brazer and 3 (10%) of 31 who had worked as a brazer. All three brazers with elevated levels worked at least 10 years in this job. A statistical model that considered the joint effects of work as a brazer, cigarette smoking, and age showed a statistically significant association between increased urine cadmium levels and work as a brazer for 10 or more years but not with work as a brazer for fewer years, nor with cigarette smoking or age.

NIOSH investigators were unable to determine whether the occurrence of low testosterone levels and sexual dysfunction among five workers in the oil cooler department was related to exposure to cadmium or other substances found in the workplace. Such a relationship, however, cannot be ruled out given the historically higher levels of exposure to cadmium, a known testicular toxin. Caterpillar's environmental monitoring records showed that brazers in the oil cooler department likely experienced modest *cumulative* exposures to cadmium that steadily declined through the years, but sometimes were exposed to airborne cadmium at levels above the current OSHA cadmium standard. Although only two percent of all workers tested had urine cadmium levels above the background range, 10% of those with a history of brazing had elevated levels. Even after accounting for age and cigarette smoking, work as a brazer for 10 or more years was associated with an increased urine cadmium level. Although Caterpillar has stopped using cadmium in the workplace, previous company sampling data suggests the potential for the presence of cadmium on some surfaces both in and away from the brazing area. Recommendations regarding clean-up of residual contamination and improvements in local exhaust ventilation are included in this report.

Keywords: SIC 3531 (Manufacturing of construction machinery and equipment), cadmium, fluorides, silver, copper, zinc, sexual function, testosterone, erectile dysfunction, biological monitoring, urine cadmium, brazing, soldering.

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INTRODUCTION

In October 1994, the National Institute for Occupational Safety and Health (NIOSH) received a request from the International Union United Automobile, Aerospace and Agricultural Implement Workers of America (UAW) for a health hazard evaluation (HHE) at Caterpillar Inc. in York, Pennsylvania. The requestor noted concerns about the possible relationship between cadmium exposure and urologic and sexual dysfunction among five long-term workers in the oil cooler department (OCD). Until May 1996, cadmium was a constituent of metal-filler alloys used in the brazing operations in this department.

At the time of the HHE request, most long-term employees were on strike and managers and newly hired workers continued production. NIOSH investigators reviewed medical records and Caterpillar environmental and biological monitoring data and on May 3, 1995, met with striking OCD workers at the local union hall. An interim report describing the findings of this phase of the evaluation was sent to company and union representatives on June 21, 1995. Subsequently, the five workers with reported health problems underwent an independent clinical evaluation. When the results of this evaluation confirmed the original finding of unexplained sexual dysfunction, NIOSH investigators decided to conduct a site visit at Caterpillar.

On April 16, 1996, Caterpillar management refused to allow a NIOSH team to enter the facility and subsequently challenged a court-issued inspection warrant. The validity of the warrant was eventually upheld and NIOSH investigators conducted a site visit at the Caterpillar facility on May 6 and 7, 1996. The site visit included a walk-through survey, environmental monitoring for airborne metals and fluorides, and employee interviews. A return visit to the facility was made from August 13 through 15, 1996, to conduct biological monitoring for urine cadmium in current and former OCD workers. A second round of biological monitoring was conducted at the local union hall in January 1997, primarily for eligible workers who were not identified in time for the August 1996 survey.

BACKGROUND

At the York facility, Caterpillar has manufactured parts for its heavy-equipment products since 1953. Oil cooler production at the facility began in late 1964 or early 1965. The OCD, previously in Building B, was moved to Building E in August or September 1989. The main areas in the OCD are machining, brazing, assembly, powder-coating, and air-testing, all contained in a large, high-bay building without partitions separating the production areas.

At the time of the NIOSH site visit in May 1996, OCD workers were working two 10-hour shifts, four days per week. In recent years, they have worked eight-hour shifts. Working 12-hour shifts, six to seven days a week, was reported by workers to have been common prior to the mid-1980s. At the time of the NIOSH site visit, 38 persons worked in the OCD on two shifts, but in past years this number was larger, often about 50. The number of brazers declined from a high of about 36 in the mid-1980s to 8 at the time of the NIOSH site visit (5 on the first shift and 3 on the second). This change was largely due to the introduction of rubber end sheets for oil coolers in 1984. Currently, only about 25% of oil coolers require brazing.

Brazing Techniques and Materials

When oil cooler production began, workers did all brazing by hand. Over time, automated brazing methods were introduced. One method, Sealest torch brazing, was used only during the late 1960s and early 1970s. Currently, four types of brazing are used. Reportedly, employees' assignments often have been rotated among the different brazing operations, although each employee usually has been assigned to just one type during a given workshift.

Induction brazing was introduced in the mid-1980s. The current machine was selected after initial experiments with several different heating units. A bundle of copper tubes is brazed inside a cast-iron shell, following the cleaning of the bundle and shell. A solvent or a degreasing and cleaning solution is used to clean the bundle, and the shell is cleaned with a separate metal-cleaning solution and process (to remove surface impurities). Subsequently, silver-alloy shims and rings are placed in various locations on the bundle. The bundle is placed inside the iron shell, and then both are placed inside an induction heating unit, which melts the silver alloy to create the braze joints.

Quartz lamp brazing was introduced in 1970. It is similar to induction brazing, but quartz lamps are substituted as the heat source.

Three-piece-shell brazing was introduced in the early 1970s. Steel tubes are first cleaned in a degreasing and cleaning solution. Two silver-alloy rings are placed around a steel tube as it is placed in a cast iron hub; then, the combined unit is heated in an induction unit to melt the silver-alloy metal filler. Each tube is joined with two hubs to form a three-piece shell, which is then cleaned, polished, and tested to prepare it for joining with a tube bundle in a subsequent operation. The *three-piece shell prep-and-test* work station is located in the brazing area, but not directly adjacent to the three-piece-shell brazing unit. A dip tank for testing, containing a metal-cutting/drawing solution, is part of this work station.

Hand brazing with a torch and a silver-alloy brazing rod was used for all brazing before the introduction of the automated units described above. While these units replaced hand brazing for most original (as opposed to repair) work, hand brazing continued intermittently for some small runs and small (e.g., 6-inch) oil coolers. Currently, hand brazing is limited to salvage (for repairing leaks). Salvage hand brazing involves the use of a torch and a brazing rod (to provide *additional* metal-filler alloy) to repair joints previously made with silver-alloy rings and/or shims in automated operations.

Each of the automated brazing units has its own salvage area; a separate area is used for large components. Test-and-repair dip tanks containing the metal-cutting/drawing solution are used in these salvage operations. The salvage rate has varied considerably over time, so the frequency of hand brazing from day to day or month to month also may have varied considerably.

During the late 1960s and early 1970s, brazing also was done with a slurry mixed by the workers. The slurry was a mixture of powder, flux, and water. The composition of the powder was the same as the ring or shim that was being brazed. Workers filled a rubber bulb with the slurry and squeezed it out around the tubes. Brazing then was done by hand or an automated process. Since that time, the brazing material has been in the form of rings and shims that are inserted into the shells and tube bundles before placement into the automated heating units.

Flux is used to prepare surfaces for brazing. In the OCD brazing operations at this facility, the same flux has been used in all four types of brazing and throughout the period of production.

Brazing components (rings, rods, and shims) made of silver-alloy metal-filler materials containing cadmium were used from the beginning of the production period until the recent phase-out of cadmium-containing products. Cadmium-containing brazing rods were used for hand brazing until July 1993. Cadmium-containing brazing rings and shims were used in the automated brazing processes until May 1996, although a gradual replacement with non-cadmium-containing substitutes began in early 1995. At the time of the first NIOSH visit, only certain quartz-light-brazed parts were made with cadmium-containing braze materials. Since May

1996, no cadmium-containing materials have been used at the plant.

The compositions of the cadmium-containing silver alloys were unchanged throughout the production period. These alloys each consisted of silver, copper, zinc, and cadmium, in varying proportions ranging, approximately, from 10% to 50%, depending on the specific constituent metal and the specific alloy. (The exact proportions of these metals in the brazing alloys are considered proprietary.) The cadmium-free alloy substitutes each consist of silver, copper, and zinc, in addition to either nickel or tin, again in varying proportions ranging from approximately 1% to over 50%, depending on the specific constituent and specific alloy.

In addition to the brazing alloys, a variety of other substances and mixtures, such as degreasing solutions, cleaning solutions, solvents, metal-cutting/drawing solutions, and fluxes have been used in brazing-area operations, as mentioned above. Also, oil cooler assemblies that already have been powder-coated sometimes are returned to the brazing area for salvage work, so constituents of the powder-coating products used also may be present in the brazing area. Table 1 is a *combined* list of the chemical compounds that are constituents of *one or more* of these products. (The trade name identity and specific use of these compounds are considered proprietary.) Brazing-area employees may have had exposure to any or all of these chemical compounds.

Baffle soldering is another type of joining operation found in the brazing area. In this operation, baffle plates are joined to tube bundles with quartz-light heating; each combined assembly, intended for use in a specialized oil cooler application, is joined with a shell in a subsequent brazing operation. The material used to create the solder joints is called "solder paste," and contains a flux-binder composition and, primarily, a metal-filler alloy consisting of tin (the primary constituent), a small percentage of silver, and less than 1% antimony. No cadmium-containing alloys have ever been used with this operation. This operation was not in use during the NIOSH walk-through survey and environmental monitoring.

Ventilation

Local exhaust-ventilation (LEV) systems serving the OCD brazing operations in Building B were in use from no later than 1966 until the OCD was moved to Building E in 1989. According to information included in Caterpillar records of general-area air sampling for cadmium and other substances, "canopy-type" ventilation hoods serving one or two brazing-area work stations were added to the LEV systems in Building B in approximately mid-1984. The LEV systems in Building B were demolished as part of a renovation of the building after the OCD was moved. Because documentation was not retained, further information about these systems or any other ventilation systems serving the OCD prior to 1989 is unavailable.

Local exhaust-ventilation systems serving the OCD brazing operations in Building E have been in use since the start of operations there and were last modified in February 1996, to increase air-flow rates. Each brazing-area work station is served by one of two LEV systems serving the area, and the entire area is served by one of the two central supply-air (or "make-up air") systems and one of the four general (or "dilution") exhaust-ventilation systems that serve the building. The building also has LEV systems serving two other processes, the powder-coating operations and the electrolytic process. The exhaust fan and discharge outlet for each local and general exhaust-ventilation system is located on the roof of the building. The combined total local-exhaust airflow rate is approximately 45,000 cubic feet per minute (ft^3/min, or cfm). Of that total, the flow rates for exhaust fans F-1 and F-2, which serve the brazing-area processes, reportedly are approxi-mately 7,250 cfm and 21,716 cfm, respectively. Earlier (July 1992) system drawings indicate that the nominal design airflow rates for these two fans at that time were the same as the current values, suggesting that the February 1996 modifications were intended to bring the systems' flow rate performance into compliance with design specifications. Any airflow rates that may have been measured prior to February 1996, were not reported.

The two air-handling units (AHUs) for the supply-air systems are also located on the roof, near the center of the building. The AHUs have outside-air inlets, are capable of supplying up to 100% outside air or mixing some recirculated air with outside air, and are equipped with heating capabilities to condition the supply-air mixture during colder weather. The mix of outside and recirculated air is automatically controlled in response to building air temperature and pressure. The units also are equipped with filtration provided by non-reusable, fibrous media rated at 25% to 30% "Dust Spot Efficiency" (as defined in ASHRAE Standard 62-1989); media are changed at 6-week intervals. The AHUs each supply 49,000 cfm to the building, for a combined total of 98,000 cfm of outside- and recirculated-air mixture (except when operating in the 100% outside-air mode). The general exhaust systems are manually controlled and together are capable of exhausting air from the building at a total flow rate ranging between 0 and 145,200 cfm. The supply AHUs' static pressure controls are set to maintain the building's static pressure at or above the outdoor ambient level (which is achieved by the AHUs inducting outside air at a rate equal to or greater than the total rate at which air is exhausted by the local and general exhaust systems) whenever possible. Whenever the total local and general exhaust rate exceeds the combined 98,000-cfm 100% outside-air intake capacity of the supply AHUs, the building's static pressure becomes negative relative to the outdoors, and the deficit of make-up air is offset by air flow through open doors.

The discharge outlets for the local exhaust-ventilation systems are 7½ feet above the roof, and exhausted air is vertically discharged at a high velocity. The discharge outlets for the general exhaust-ventilation systems are approximately 7 feet above the roof. The AHUs' outside-air inlets are close to roof level, to the west of (so usually upwind of) the discharges for the LEV systems serving the brazing area. These two discharges are about 50 and 120 feet away from the nearest AHU, while the discharge for the general exhaust system serving the area is about 40 feet away.

Each automated brazing unit is served by an exhaust-ventilation inlet connected to one of the two local-exhaust ventilation systems serving the brazing area; the units are not fully enclosed by their respective ventilation hoods. Also, each test-and-repair work station is equipped with a canopy-type exhaust-ventilation hood on its "hot tank" (dip tank). In addition, these work stations are equipped with movable exhaust-ventilation hoods connected to the systems with flexible ducting, to allow for better positioning when working on large parts. The movable hoods were added in 1992. The three-piece shell prep-and-test work station's hot tank is equipped with an exhaust-ventilation hood, but its grinding/polishing work table is not equipped with an inlet or hood.

Personal-Protective Equipment, Work Practices, Administrative Controls

Respirators reportedly have been available to workers in the brazing area for an unspecified number of years but have not always routinely been worn. Since January 1992, the company reportedly has required the use of respirators for controlling exposures to cadmium among brazing-area employees. Until late 1992, 3M® 8710 particulate respirators, suitable for protection against dusts and mists, and 3M® 9920 particulate respirators, suitable for protection against dusts, mists, and fumes, were provided. Since late 1992, 3M® 9970 High-Efficiency Respirators have been in use; these disposable particulate respirators are approved for protection against dusts, mists, fumes, and radionuclides. A respiratory-protection program is in place.

Brazing-area employees wear regular work clothes which they individually launder at home. Showers are available in the building, but reportedly are infrequently used. Hand-washing stations, reportedly installed in 1989, are present in the brazing and powder-coating areas and near the electrolytic process. In the past, workers used asbestos gloves when handling parts from the brazing operations.

Employees generally eat lunch in the Building E conference room, located near the office space in the building. Smoking and eating are prohibited in the immediate brazing area, which is defined by a painted yellow line around the area, but are allowed elsewhere in the building. The painted line was added in February 1996.

METHODS

Environmental Evaluation

Caterpillar sent NIOSH the results of environmental monitoring conducted in the OCD. The environmental data consisted of the results from personal breathing-zone (PBZ) and general-area (GA) air sampling and surface-wipe sampling conducted in the brazing area from 1974 through January 1996. These data included sampling results for substances including cadmium, silver, copper, antimony, lead, zinc, fluorides, total particulates, and tin. NIOSH investigators reviewed and summarized this information.

In May 1996, PBZ and GA air samples for metals and fluorides were collected by NIOSH in the brazing area and adjacent areas. Sample durations were representative of an entire 8-hour shift, although the exact durations varied. For metals, 6 PBZ and 12 GA samples were collected, while for fluorides, 6 GA samples were collected. The specific job titles for the PBZ samples and the locations for the GA samples are provided with the sampling results (in Tables 5 and 6). Air samples were collected using portable, battery-powered air-sampling pumps to draw air at measured rates through collecting media appropriate for the suspected air contaminants of interest and the analytical methods employed.

Air samples for metals, including cadmium, were collected and analyzed in accordance with NIOSH Sampling and Analytical Method 7300, "Elements by ICP," with slight modifications to digestion and measurement conditions. The nominal air-sampling rate was 2.5 liters per minute (L/min) and the collection medium for each sample was a cellulose-ester-membrane filter, 37 millimeters (mm) in diameter and 0.8 micrometers (µm) in nominal pore size, in a plastic cassette. The filters were prepared for analysis by microwave digestion in the presence of concentrated nitric acid, in accordance with the Appendix to the method, and the subsequent analytical technique was inductively-coupled (argon) plasma (ICP), atomic-emission spectroscopy. The determination of tin with this technique is not compatible with the determination of several of the other metals of interest, so additional samples designated for tin analyses were collected.

Air samples for fluorides were collected and analyzed in accordance with NIOSH Sampling and Analytical Method 7902, "Fluorides, aerosol and gas by ISE." The nominal air-sampling rate was 2.0 L/min, and the collection media for each sample (held in a three-piece plastic cassette) were a 37-mm-diameter, 0.8-µm-pore cellulose-ester-membrane filter followed in series by a sodium-carbonate-impregnated cellulose pad. The analytical technique was ion-specific electrode (ISE).

Medical Evaluation

Informal discussion among OCD workers led to the discovery of similar health problems among several men. Consequently, in August 1994, five long-term workers from the OCD went to an occupational physician from the George Washington University, Division of Occupational and Environmental Medicine, in Washington, D.C., for evaluation. Upon completion of an initial assessment, the physician referred the men to another medical center for a more complete evaluation and recommended that a NIOSH HHE be requested. Upon receipt of the HHE request, NIOSH investigators requested and received copies of the medical records for these five workers. In September 1995, the five workers went to the Mt. Sinai School of Medicine, Division of Environmental and Occupational Medicine, in New York, New York, for further clinical evaluation. The results of these evaluations were provided to NIOSH investigators in December 1995. The records from both evaluations contained information on cadmium levels in blood and urine, evaluation of male sex hormones, medical histories, and evaluation of erectile function (only in the Mt. Sinai evaluation).

Caterpillar sent NIOSH the results of medical surveillance conducted on current and former workers from the OCD. The medical surveillance data included medical histories, findings of medical examinations, and results of biological monitoring (blood and urine cadmium, and urine beta-2-microglobulin [B2M]) conducted pursuant to the OSHA cadmium standard from August 1993 through February 1995. The NIOSH medical investigator reviewed and summarized this information.

In May 1996, the NIOSH medical investigator conducted individual, confidential medical interviews with OCD employees. Caterpillar provided a list of all employees working in the OCD at the time of the NIOSH investigation. This list included 21 workers (including 5 brazers) on the first shift and 16 workers (including 4 brazers) on the second shift. All workers on the first shift were invited to participate. Second shift workers who arrived at work early also were invited, as were former OCD workers (for whom biological monitoring data for cadmium were available) now working elsewhere in the plant. Workers were asked to describe any health problems or concerns related to work in the department, and were asked about their interest in testing by NIOSH to evaluate cadmium exposure.

For the August 1996 urine monitoring for cadmium exposure among current and former OCD workers, Caterpillar provided NIOSH with a list of 191 workers who worked in the OCD for 3 months or more since 1976. (In 1976, the company began to maintain electronic work history files.) The information provided included name, current address, date of birth, and job assignments (work area and job title) since 1976. The list included current workers in the OCD, current workers now working elsewhere in the plant, and former workers (retired, on lay-off). All workers on the list were sent a letter inviting them to participate in the testing. Retired and separated employees were contacted by telephone by NIOSH personnel to schedule an appointment. Current employees were scheduled by Caterpillar management during their usual work hours. Participants read and signed an informed consent statement, completed a self-administered questionnaire about work history and cigarette smoking, and provided a urine sample. Participants were asked to wash their hands with soap and water before voiding into the collection cup provided by NIOSH.

Specimens were processed according to procedures established by the analytical laboratory at the National Center for Environmental Health, Centers for Disease Control and Prevention, in Atlanta, Georgia. The urine was poured from the collection cup into two tubes, one each for analysis of cadmium and creatinine. Every tenth sample was split into two equal portions , and sent to the laboratory as blind duplicates along with all other samples. Field blanks, consisting of deionized water, were also prepared each day of testing. Urine samples were stored and shipped on dry ice. Analysis for cadmium was done by Zeeman graphite furnace atomic absorption spectrometry using methods adopted from Pruszkowska et al.[1] Quality control for urine metals analysis was established by analysis of a bench pool as well as Standard Reference Material 2670, Toxic Elements in Freeze Dried Urine, certified for cadmium (produced by the National Institute of Standards and Technology). All measured means and ranges were within the 95%

limits calculated for these pools. The specimens also were analyzed for creatinine, so that a creatinine-corrected cadmium value, which accounts for variations in urine volume, could be calculated.

During the August 1996 biologic monitoring, NIOSH investigators learned that the list of employees provided by Caterpillar was incomplete. Former OCD employees who met the eligibility criteria but were now working in another Caterpillar facility at the York location, and former OCD employees who were on long-term layoff, had been omitted from the list. Caterpillar generated a new list and all workers on the list were sent a letter inviting them to participate in the testing; a return envelope for sending back a reply form was enclosed. Most also were contacted by phone to determine their interest. In January 1997, current employees were scheduled by Caterpillar management during their usual work hours and tested at the workplace; all other participants were tested at the local union hall. Procedures for obtaining consent, administering questionnaires, and collecting urine specimens were as described above.

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 increase the overall exposure. Finally, evaluation criteria may change over the years as new information on the toxic effects of an agent become available.

The primary sources of environmental evaluation criteria for the workplace are: (1) NIOSH Recommended Exposure Limits (RELs)[2], (2) the American Conference of Governmental Industrial Hygienists' (ACGIH®) Threshold Limit Values (TLVs®)[3], and (3) the U.S. Department of Labor, OSHA Permissible Exposure Limits (PELs)[4]. In July 1992, the 11th Circuit Court of Appeals vacated the 1989 OSHA PEL Air Contaminants Standard. OSHA is currently enforcing the 1971 standards which are listed as transitional values in the current Code of Federal Regulations; however, some states operating their own OSHA-approved job safety and health programs continue to enforce the 1989 limits. NIOSH encourages employers to follow the 1989 OSHA limits, the NIOSH RELs, the ACGIH TLVs, or whichever are the more protective criterion. The OSHA PELs reflect the feasibility of controlling exposures in various industries where the agents are used, whereas NIOSH RELs are based primarily on concerns relating to the prevention of occupational disease. It should be noted when reviewing this report that employers are legally required to meet those levels specified by an OSHA standard and that the OSHA PELs included in this report reflect the 1971 values. Refer to Table 2 for the relevant numerical exposure criteria for individual contaminants.

A time-weighted average (TWA) exposure refers to the average airborne concentration of a substance during a normal 8-to-10-hour (hr) workday. Unless differently noted in Table 2, the TWA exposure limits in the PELs and TLVs are applicable to 8-hr exposure periods per workday, whereas those in the RELs apply to exposure periods as long as 10-hr per workday. For cumulative hazards such as cadmium, a methodology for adjusting the applicable exposure limits has been recommended for extended work shifts which exceed the time period specified with a given TWA exposure limit.[5] Some substances have recommended short-term exposure limits (STELs) or ceiling values which are intended to supplement the TWA where there are recognized toxic effects from higher exposures over the short-term. A STEL represents a limit for an average airborne exposure during any 15-minute (min) sampling period, unless a different duration is specified in Table 2.

Cadmium

Exposure to cadmium produces a wide variety of effects involving many organs and systems. Although acute health effects from overexposure to cadmium have been reported, currently, in most occupational settings, chronic effects are of greater concern.

Cadmium poisoning has been reported from acute overexposure to cadmium oxide fumes; the principal symptom is respiratory distress due to chemical pneumonitis and edema.[6] In one situation with a very high level of exposure (40 to 50 milligrams per cubic meter of air [mg/m^3] for 1 hr), death was reported.[6]

Long-term occupational exposure to cadmium is most strongly associated with an increased occurrence of lung cancer, kidney damage, and chronic obstructive lung disease.[7] The total amount of cadmium exposure affects the risk of developing disease. This risk increases as the number of years and the level of cadmium exposure increase.

The kidney is thought to be the organ most sensitive to the toxic effects of cadmium.[8] Kidney damage caused by cadmium exposure occurs when cadmium accumulates in the kidneys. The damage can progress over time and is irreversible. Chronic lung injury develops in workers in relation to the time and level of exposure. Effects on the lung occur quite slowly. The minimum exposure level at which these effects occurs is unknown. The level of exposure linked with lung damage, however, is thought to be above that which causes kidney damage.

NIOSH considers cadmium to be a potential human carcinogen.[9] Two types of cancer have been of concern – lung and prostate cancer. Although the evidence linking overexposure to cadmium with lung cancer is strong, the evidence linking cadmium exposure with prostate cancer is weaker.[10,11]

The OSHA cadmium standard contains a complex scheme for performing and evaluating biological monitoring results (i.e., cadmium in urine and blood, and beta-2-microglobulin in urine).[12] To determine which actions (follow-up monitoring, environmental evaluation, etc.) are appropriate, results of biological monitoring are grouped into three categories (A through C). Cut-off values for each category are given for two time periods, through 1998 and beginning January 1, 1999. The cut-off values separating category A from B, however, do not change between these two time periods. The upper level for category A is 3 µg/g in urine and 5 µg/L in blood, which corresponds with the upper limits (95th percentile) for the background range in the general population (as summarized in Appendix F of the standard). The upper level for category A for beta-2-microglobulin is 300 µg/g creatinine, the level at which kidney function is considered altered. The ACGIH BEI for cadmium is 5 µg/g in urine and 5 µg/L in blood.[3]

Although NIOSH considers cadmium to be a potential human carcinogen, an REL has not been established. The OSHA PEL and ACGIH TLV for 8-hr TWA exposures to airborne cadmium are 5 and 10 µg/m^3 (micrograms [of cadmium] per cubic meter of air), respectively.

The OSHA cadmium standard requires that all workplace surfaces be maintained as free from cadmium as possible.[12] The standard specifies that surfaces contaminated with cadmium should be cleaned by vacuuming, using vacuum cleaners equipped with high-efficiency particulate air (HEPA) filters, or by other methods that minimize re-entrainment of cadmium-containing particulate into the air.

Silver

A local reaction to silver exposure can occur when particles of metallic silver are imbedded in the skin, mucous membranes, and eyes causing discoloration (grey-blue pigmentation) and disfiguration.[6,13] This condition is called argyria. A more generalized argyrosis can occur after prolonged inhalation of soluble silver. Argyrosis of the respiratory tract, causing mild chronic bronchitis, was reported in two workers exposed to silver nitrate.[6] Massive exposure to heated vapor of metallic silver has been reported in one worker, resulting in lung damage with pulmonary edema.[6] Extensive health examinations of 27 silver reclamation workers and a comparison group provided no evidence of negative health effects other than argyrosis of the eye.[13]

The OSHA PEL and NIOSH REL for silver in air (for the soluble compounds, with sampling results expressed as silver, and the metal dust) are each 0.01 mg/m^3 for TWA exposures (8-hr and 10-hr TWAs for the PELs and RELs, respectively). The ACGIH TLVs (for 8-hr TWAs) are 0.01 mg/m^3 for soluble silver compounds (with sampling results expressed as total silver) and 0.1 mg/m^3 for metallic silver particulate.

Reproductive Hormones and Sexual Function

Low levels of the male reproductive hormone testosterone and altered sexual function, primarily impotence, were the major health effects that prompted the HHE request. A brief review of relevant aspects of these topics is given here.

Testosterone is the principal hormone produced by the testes. It functions in the development and maintenance of male sex characteristics (including sexual organs and secondary characteristics such as body hair, voice, and muscle development), the development and maintenance of libido (sexual desire) and potency, and the maturation of sperm.[14] Serum testosterone levels generally decrease with age in adult men after the fifth decade of life, although normal levels have been found in extremely healthy aging men.[14] Serum testosterone levels in an individual are highly variable. In adult men, there is a strong daily rhythm; the difference between the highest levels in the early morning and the lowest levels in the evening and during early sleep can be as great as 30%.[15] Thus, age of the individual and time of day of testing must be considered when evaluating test results.

The relationship between low testosterone levels and occupational exposures has been evaluated for many chemicals. In addition, stress has been shown to be related to lower testosterone levels.[16,17] Of those chemicals relevant to this evaluation, the most information is available for cadmium. The adverse effects of cadmium (given by injection) on the testes of test animals are well-documented. Steinberger and Klinefelter[18] found that exposure to cadmium compounds affected the Sertoli cells, which are important in follicle stimulating hormone (FSH) and testosterone functioning. Ng and Liu[19] and Laskey and Phelps[20] found decreased production of testosterone resulting from cadmium exposure. Caflisch and DuBose,[21] Phelps and Laskey,[22] Pak,[23] and Laskey et al.[24,25] found decreased testosterone levels in rats following cadmium exposure, and Nordberg[26] found similar effects in mice. In a more recent study, however, in which low doses of cadmium were given orally to rats, testosterone levels were not affected by exposure.[27]

Few studies of the effects of cadmium on the human male reproductive system have been reported in the literature. Mason evaluated 77 employees exposed to cadmium fumes generated during the manufacture of copper cadmium alloy.[28] Compared with expected values, exposed workers with evidence of kidney dysfunction showed no significant differences in testosterone, FSH, or luteinizing hormone levels. Favino and colleagues compared levels of testosterone and other androgens in 10 workers with cadmium exposure and 10 unexposed workers from a battery plant.[29] Although they did not find any significant differences between the two groups, the methodology of this study has been criticized (*see below*).

Impotence is defined as the persistent inability to attain and maintain an erection adequate to permit satisfactory sexual performance.[30] Based on data from a large general population study by Feldman and colleagues, the prevalence of impotence (ranging in severity from minimal to complete) is 52% among men between the ages of 40 and 70.[31] Impotence is associated with aging and many of the suspected causes are age-related. In the Feldman study, the occurrence of impotence was related to several medical conditions (including heart disease, hypertension, and diabetes) and their medications, depression, and various psychological indexes.[31] Other risk factors that have been identified are neurogenic disorders, renal failure, alcohol ingestion, high levels of cholesterol, and low levels of high-density lipoprotein.[30] Although testosterone plays a role in the development and maintenance of libido and potency, studies have shown that many men who report impotence have normal levels of testosterone.[14] Feldman and colleagues found no correlation between impotence and testosterone levels.[31]

The relationship between impotence and occupational exposures or conditions has not been well studied. In a book reviewing the reproductive hazards of chemicals, Barlow and Sullivan noted that for only a few exposures are the data adequate to conclude that a causal relationship to impotence exists.[32] Of the chemicals known to have been used in the OCD, only for cadmium and trichloroethylene are there any reports in the scientific literature of a link with impotence; for both these substances, the evidence is weak. In their study of workers in a battery plant, Favino and colleagues noted that two workers in the exposed group and none in the comparison group reported impotence.[29] Barlow and Sullivan, however, concluded that based on this study "it is not possible to draw any conclusions about the effects of cadmium on testicular and sexual function."[32] Similarly, one case of impotence, among other symptoms, has been reported in a worker with prolonged exposure to trichloroethylene. Although the authors suggested that the symptoms may have been due to the exposure, many alternative explanations are plausible. According to Barlow and Sullivan, "no conclusions about the role of trichloroethylene can be reached."[32] In addition to chemical exposures, there is evidence showing that job-related stress, including unemployment and intermittent employment, is related to impotence.[33]

RESULTS

Environmental Evaluation

Caterpillar PBZ cadmium results. Table 3 contains a summary of Caterpillar's PBZ air-sampling data for cadmium exposures in the OCD brazing area from 1974 through January 1996. The data in the table are stratified by date to illustrate exposures during several time periods delineated by major changes affecting the operations and exposure potential, and to facilitate comparison with the OSHA PEL in effect at the time. Caterpillar PBZ sampling results for cadmium are available for 1974 through January 1996. Therefore, the following five strata of dates were selected to present the Caterpillar data: (1) 1974 through mid-1984; (2) October 1984 through 1988; (3) 1989 (reported separately, due to the uncertainty about some air-sample collection dates relative to the move to

Building E, and the comparatively high measured exposures during that year); (4) 1990 through 1992; and, (5) 1993 through January 1996.

A total of 154 PBZ air samples were collected by Caterpillar, representing the airborne cadmium exposures of at least 34 different employees (including 7 newly hired workers during the mid-1990s strike). The samples were collected over periods of about 6 to 7.5 hours. Collection and analysis methods were NIOSH Method 7048 prior to 1991, and NIOSH Method 7300 ("modified") from 1991 through January 1996. Based on the lowest concentrations reported, the minimum detectable concentrations (MDCs) were assumed to be 1 $\mu g/m^3$ for samples collected prior to 1991, and 0.5 $\mu g/m^3$ for samples collected from 1991 through January 1996. (This reduction in the minimum detectable concentration resulted from the change in sampling and analytical methods.) To allow the calculation of statistical parameters such as medians (geometric means) from the PBZ data, estimated values of 0.7 $\mu g/m^3$ and 0.3 $\mu g/m^3$, respectively, were assigned to the results reported as less than the MDCs; these values represent the respective MDCs divided by the square root of 2, in accordance with the methodology of Hornung and Reed.[34]

For all the data combined over all years, the median airborne PBZ cadmium concentration measured was 1.8 $\mu g/m^3$, below today's OSHA PEL (5 $\mu g/m^3$). However, measured exposures varied widely through the years, ranging from less than the MDC to 580 $\mu g/m^3$; 51 (33%) of the 154 measured exposure levels were equal to or greater than today's PEL, 38 (25%) were detectable but below today's PEL, and 65 (42%) were below the MDC. Six (4%) exceeded the OSHA PEL in effect *at the time of sampling*.

With the exception of results for 1989, the measured median PBZ cadmium exposures steadily declined through the strata of sampling dates shown in Table 3, from 5.1 $\mu g/m^3$ to 0.5 $\mu g/m^3$. Similarly, among the strata with the larger numbers of samples (1974 through mid-1984, 1990 through 1992, and 1993 through January 1996), the proportion of measured exposures that equaled or exceeded today's PEL (60%, 22%, and 5%, respectively) declined through the years, while the proportion that were below the MDC (39%, 46%, and 59%, respectively) increased. These trends suggest a steady decline in PBZ cadmium exposure levels over the years.

For samples collected from 1993 through January 1996, although the median PBZ cadmium concentration measured was 0.5 $\mu g/m^3$ and for 59% of these samples (26 of 44) cadmium was not detected, the measured concentrations for 5% of these samples (2 of 44) exceeded the current OSHA PEL of 5 $\mu g/m^3$, and those for five *additional* samples (for a total of 7 of 44, or 16%) equaled or exceeded the current OSHA action level of 2.5 $\mu g/m^3$. One of the samples for which the measured concentration (of 9.2 $\mu g/m^3$) exceeds the current OSHA PEL represents the exposure of an employee assigned to hand brazing salvage for the quartz-light line on December 19, 1995; on the same date, the measured exposure for another employee assigned to hand brazing salvage for the induction line was 2.5 $\mu g/m^3$, equal to the action level. These exposures occurred well after the reported date that the use of cadmium-containing brazing rods for hand brazing had stopped, but cadmium-containing rings and shims were still in use in the automated brazing operations. Since salvage hand brazing involves the use of a torch and a brazing rod (to provide additional metal-filler alloy) to repair joints previously brazed in automated operations, this information suggests that cadmium-containing brazing fume was created during salvage of cadmium-containing braze joints even when cadmium-free rods were used.

For samples collected prior to 1989, the job descriptions were listed only as "brazer." However, since 1989 the type of brazing was usually specified (e.g., quartz, induction, hand brazing). In general, PBZ cadmium exposures were somewhat higher for workers assigned to hand brazing than for those assigned to automated brazing. Of the exposures for employees reported as engaged in hand brazing, 28% (8 of 29) were not detectable, as compared with 47% (17 of 36), 67% (14 of 21), and 67% (2 of 3) of those for workers reported as engaged only in induction, quartz, and shell brazing, respectively. Conversely, 28% (8 of 29) of the exposures for employees reported as engaged in hand brazing exceeded 5 $\mu g/m^3$, as compared with 11% (4 of 36), 5% (1 of 21), and 0% (0 of 3) of those for workers reported as engaged only in induction, quartz, and shell brazing, respectively. (Many of these samples were collected before the reduction of the OSHA PEL). Because employees' assignments often have been rotated between the different brazing operations, any given brazing employee may have performed all four types of brazing (although each employee usually is assigned to just one type during a given workshift).PBZ air-sampling data are not representative of actual inhalation exposure if the worker whose PBZ is sampled is wearing an effective respirator. However, the information supplied by Caterpillar indicated that respirators were in use by the relevant workers during the collection of only eight of the PBZ air samples (although respirator use was not addressed in the data tables for samples collected in 1995 and January 1996); this is consistent with the information described previously suggesting that respirators have been available to workers in the brazing area for several years but have not always routinely been worn. These include one sample collected in June 1993, for which the measured cadmium concentration (12 $\mu g/m^3$) exceeded the revised PEL and was the highest measured since the PEL was revised; the employee reportedly was wearing a high-efficiency particulate respirator. Two other 1993 samples for which the measured concentration exceeded the OSHA action level were collected while the relevant employees reportedly were wearing respirators; the respirator types were not specifically listed, but the use of high-efficiency particulate respirators reportedly began around the end of 1992.

Caterpillar PBZ results for other contaminants. Table 4 presents a summary of the PBZ air-sampling data for contaminants other than cadmium; Caterpillar reported that a variety of sampling and analytical methods published in various editions of the NIOSH Manual of Analytical Methods were used for these samples. As shown by the data in Table 4, most of these substances frequently were not detected in the air. With the exception of silver, the maximum concentrations reported were all well below the relevant OSHA PELs and NIOSH RELs. One silver concentration (0.015 mg/m^3) exceeding these criteria was measured in the PBZ of the same employee assigned to hand brazing salvage for the quartz-light line on December 19, 1995, who was previously mentioned as having been over-exposed to cadmium on the same day. The silver content of the cadmium-free brazing rods by then in use exceeds that of both the cadmium-containing rods they had replaced and the cadmium-containing rings and shims still in use at that time. The next-highest silver exposure, 0.008 mg/m^3, was measured before 1995, and was below the exposure criteria.

Caterpillar GA air-sampling results. Caterpillar conducted GA air sampling for cadmium, zinc, and fluorides in the OCD brazing area in 1983 and 1984, when the department was still located in Building B; the results were used to assess ventilation effectiveness at two or three operations and/or work stations, named in the records as the "brazing coil," the "brazing station," and the "operator's station." Caterpillar sampling records do not indicate how near to any workers' PBZs any of these GA samples were collected, so the absolute magnitude of the measured air concentrations is not relevant here (cadmium levels were of similar orders of magnitude to the measured PBZ concentrations; levels of the other two contaminants were very low and not noteworthy). However, the records state that installation of (a) canopy hood(s) resulted, and that re-sampling to assess the effectiveness of this improvement was conducted at "machine #18M3456." The results suggest that a large reduction in particulate cadmium emissions was realized from this improvement.

In 1992, Caterpillar collected six short-term ("grab") GA air samples for 1,1,1-trichloroethane in the OCD brazing area, in the vicinity of machine #18M4014 during selected operations, using Dräger® hand-held air pumps and direct-read colorimetric indicator tubes. The Caterpillar sampling records do not indicate if these GA samples were representative of any workers' PBZ exposures during these operations, and the results, which indicate that this solvent was present in measurable concentrations, are notable only because they suggest at least occasional worker exposures in the past.

Caterpillar's surface-wipe sampling data. Caterpillar's surface wipe sampling data indicate that 11 wipe samples were collected in Building E (including 7 in the OCD brazing area and 4 in the conference room) and analyzed for cadmium (using an analytical procedure analogous to that used in recent years for Caterpillar's cadmium air samples). Six samples were collected on June 10, 1993; 4.5 µg of cadmium was measured on a ledge at Tank #TK-123, while no cadmium was detected on top of an oil cooler after patching and brushing or in four samples from the conference room table. The remaining five wipe samples were collected in the OCD brazing area in December 1995. Collection locations and quantities of cadmium measured are as follows: (1) supervisor's desk (E-9-A), none detected; (2) rollmarker near M4008, 0.7 µg; (3) on work table next to M4008, 0.6 µg; (4) on work bench near M1848, none detected; and, (5) on fixture stand near M4151, 5.9 µg. Detection of cadmium on surfaces positively verifies its presence only at the specified sampling locations; the absolute quantities measured cannot be interpreted, but the relative quantities measured at different locations may be useful for comparison with one another.

NIOSH air-sampling results. Tables 5 and 6 contain the results of the NIOSH air sampling for metals and fluorides, respectively, conducted in and near the OCD brazing area on May 7, 1996. At the end of each Table is a *summary* of the most relevant exposure criteria for each substance; please refer to Table 2 for the complete evaluation criteria. The measured airborne concentrations of all substances were well below their relevant exposure criteria. The closest measured concentration to any numerical evaluation criterion was that for silver in the breathing-zone of the three-piece-shell grinder/cleaner/tester; the silver concentration of 5.3 $\mu g/m^3$ was just over half of the NIOSH REL of 10 $\mu g/m^3$.

Traces of airborne cadmium — below the minimum-quantifiable concentration — were detected by the NIOSH sampling at this facility. This includes traces of airborne cadmium detected away from the quartz-light production line, and even outside the brazing area, despite the fact that, according to production information provided by Caterpillar, cadmium-containing alloys were used on the day of the sampling in the brazing area *only* on the quartz-light line (for 25 of 44 units manufactured there that day).

Other NIOSH environmental findings. Observations were made regarding the characteristics and limitations of the LEV systems serving the brazing operations. The automated brazing units are not fully enclosed by their respective ventilation hoods, although observed work practices suggest that more-complete enclosure is possible in each case. Cross drafts were noticed in those areas. Also, when work is removed from the induction-brazing unit and placed on rollers to move it to the adjacent cleaning tank, it continues to evolve fumes into the work area; however, the transfer-roller area is not equipped with a LEV hood. Finally, some workers reported concerns that the movable LEV hoods at the test-and-repair work stations were not effective enough, and not adequately sized for large parts, although no opportunities to observe their use occurred on the days of the NIOSH walk-through survey and environmental monitoring.

Several brazing-area employees were questioned about perceived environmental conditions on the day of the NIOSH air sampling, compared with a "typical" day; most perceived conditions to be "about normal," although one employee working at the quartz-light brazing operation said that it seemed as though the ventilation was "beefed up today." Another employee reported that recently the "man-cooler" fans were removed from the brazing area.

Medical Evaluation

Medical records. Reports from the medical evaluations showed that the five men who underwent extensive evaluation ranged in age from 44 to 59 years and had worked as brazers from 12 to 17 years. Four were working as a brazer at the time of the evaluation. Four men reported symptoms of sexual dysfunction including difficulty achieving and maintaining an erection, decreased sex drive, and premature ejaculation. The onset of symptoms was reported to range from "recently" to 12 years ago. Although urologic symptoms, which generally are related to bladder or prostate problems, were described in the medical records, these were not consistent among the five and were not assessed further. Table 7 shows levels of cadmium in blood and urine and of testosterone in blood. In the initial testing, all five men had testosterone levels below the laboratory's reference range. Four of the five had urine cadmium levels above 3 µg/g; two had levels above 5 µg/g. One of five had a blood cadmium level above 5 µg/L. At the time of the followup testing, approximately one year later, testosterone levels had risen slightly (6-21%) in three workers and substantially (44-92%) in two workers, however, the testosterone levels of four men were still below the laboratory's reference range. Urine cadmium levels stayed essentially the same or fell in three workers, and rose in two workers, with one above 5 µg/g. Blood cadmium levels fell in all five; one remained above 5 µg/L. In all five men, penile duplex doppler results indicated normal blood flow. Nocturnal penile tumescence results indicated possible anomalies in erectile function in all five men. Three of the five men had underlying medical conditions — in addition to the low testosterone levels — that could explain the erectile dysfunction.

Caterpillar's medical surveillance protocol and results. The Caterpillar medical surveillance protocol for cadmium-exposed workers was consistent with the requirements of the OSHA cadmium standard. From the data provided, however, we were unable to determine whether every worker with potential exposure was included in the medical surveillance program. For example, maintenance workers who may have had some cadmium exposure due to work in the brazing area of the OCD, were not included. We do not know, however, whether the levels of their exposure were sufficiently high to trigger the medical surveillance aspects of the cadmium standard. The medical history form used by Caterpillar was that suggested by OSHA in Appendix D of the cadmium standard.[12] This form includes one item related to the sexual and reproductive problems reported by some workers. This item asks, "Have you or your partner consulted a physician for a fertility or other reproductive problem? If Yes, specify who consulted the physician. If yes, specify diagnosis made." Caterpillar provided NIOSH with the forms for 24 long-term employees. Two of the 24 had a positive response to this question. Both indicated that the problem was low sperm count; the dates of this finding were not reported. At the time, neither worker was considered to have current cadmium exposure; one was a machine operator and one was a brazer, although the latter had been in this job for less than a month.

Biological specimens were analyzed for Caterpillar by a commercial toxicology laboratory. Written information provided by Caterpillar indicated that the laboratory maintained a quality assurance program and participated in the Centre de Toxicologie du Quebec (CTQ) cadmium interlaboratory comparison program, as recommended by OSHA.[12] Records provided by Caterpillar showed that 22 of 23 workers had been notified of their laboratory results. The median time between testing and notification was approximately three weeks.

Biological monitoring data are summarized for three groups of workers: long-term workers with past exposure (not exposed at time of monitoring, but previously exposed to cadmium at or above the current action level for at least 60 months) (Table 8), long-term workers with current exposure (Table 9), and newly hired workers (Table 10). The number of reports is different for each measurement due to refusal by some workers to provide specimens and the failure to report all urine measurements in units corrected for creatinine. When an individual was tested more than once, the highest value was used for the summary table. Median urine cadmium levels were higher in long-term workers with past exposure (2.7 µg/g) and long-term workers with current exposure (2.5 µg/g) than in newly hired workers (0.3 µg/g). Urine cadmium concentrations were above 3 µg/g in 4 (33%) of 12 long-term workers, but none of the newly hired workers. Urine cadmium concentrations were above 5 µg/g in 2 (17%) of 11 long-term workers.

Median blood cadmium levels also were higher in long-term workers with past exposure (1.2 µg/L) and long-term workers with current exposure (1.2 µg/L) than in newly hired workers (0.6 µg/L). Two (5%) of 21 long-term workers, but none of the newly hired workers, had blood cadmium levels above 5µg/L.

The median beta-2-microglobulin level was similar in long-term workers with past exposure (48 µg/g), long-term workers with current exposure (50 µg/g), and newly hired workers (48 µg/g). Only one worker, a long-term worker with previous exposure, had a beta-2-microglobulin level above 300 µg/g.

NIOSH interviews with workers. Ten current and former OCD workers participated in the May 1995 meeting with workers at the local union hall. All worked at Caterpillar between 17 and 31 years, and in the OCD between 4 and 26 years. Six had worked as a brazer. Participants in the meeting provided information about the production process and exposure controls. In addition to the health problems described in the health hazard evaluation request, some workers expressed concerns about deaths among current employees; specific causes of death noted were leukemia, prostate cancer, and heart disease.

NIOSH measurement of urine cadmium. Fifteen of the 21 first-shift workers, 2 of the 16 second-shift workers, and 3 former OCD workers were interviewed in May 1996 during the first NIOSH site visit. None of the workers interviewed reported health problems similar to those experience by the five workers whose concerns were described previously. A few workers, however, reported concern about cancer, particularly prostate cancer. Overall, workers (including those who had never worked as a brazer) expressed considerable concern about the potential for cadmium exposure due to the possibility of generalized contamination of the OCD. All said they would be interested in any further testing to be done by NIOSH.

Of the 191 workers initially identified by Caterpillar as eligible for the NIOSH evaluation of urine cadmium, 131 (69%) participated in the testing. Participants included 67 (70%) of 96 active workers, 13 (36%) of 36 retired workers, and 30 (51%) of 59 workers on lay-off. Three workers were deceased. During the test period, NIOSH investigators learned of other workers who wanted to be tested, including 5 workers (1 retired, 3 current) who did not meet the inclusion criteria because they worked in the OCD before 1976 and 16 workers (5 current, 11 separated) who met the criteria but were not on the Caterpillar list. Twenty-two (17%) of the 126 workers newly identified on the second list participated in the testing. Participants included 3 (33%) of 10 active workers, and 19 (16%) of 116 separated workers. Nine additional workers requested to be tested. In all, NIOSH tested 162 current and former Caterpillar workers.

The workers tested by NIOSH ranged in age from 40 to 71 (mean age, 51). Information about cigarette smoking was not provided by 10 individuals; among the remaining 152, 43 (28%) were current smokers, 57 (38%) were former smokers, and 52 (34%) had never smoked cigarettes. Of those tested, 30 (19%) had worked as a brazer since 1976, as determined from work history information provided by Caterpillar.

The results for cadmium in urine ranged from "not detected" (less than 0.1 µg/L, unadjusted cadmium) to 19.3 µg/g (creatinine-adjusted cadmium). Four workers (2%) among those tested by NIOSH had levels at or above 3 µg/g; 98 %, however, had levels below. The 4 workers with elevated levels included 1 (0.8%) of 132 who had never worked as a brazer and 3 (10%) of 30 who had worked as a brazer. All three brazers with elevated levels worked at least 10 years in this job.

The distribution of urine cadmium levels by work as a brazer, cigarette smoking, and age is shown in Figure 1. Based on the distribution of urine cadmium levels among all 162 individuals tested, levels were grouped into thirds as follows (with approximately equal numbers of workers in each group): 1st third (≤ 0.19 µg/g), 2nd (> 0.19 µg/g, ≤ 0.50 µg/g), 3rd (> 0.50 µg/g). Work as a brazer, current and former cigarette smoking, and increasing age were all associated with increasing cadmium levels. Among nonbrazers, the median urine cadmium level was 0.27 µg/g (ranging from "not detected" to 19.28 µg/g). Among brazers, increased urine cadmium levels were seen for those who worked in this job for 10 or more years. The median cadmium level was 0.42 µg/g (ranging from "not detected" to 2.92 µg/g) for those who brazed from 3 months - 4 years, 0.84 µg/g (ranging from "not detected" to 0.84 µg/g) for those who brazed from 5 - 9 years, and 2.53 µg/g (ranging from 1.31 µg/g to 7.31 µg/g) for those who brazed for 10 or more years.

To account for the possible effects of cigarette smoking and age on the association between brazing and urine cadmium levels, multiple linear regression analysis was performed. In these analyses, a value of 0.05 µg/g (equivalent to the limit of detection [LOD] of the analytical method divided by 2) was assigned to the results below the LOD. To ensure that the results were not affected by the choice of an assigned value, the analyses were repeated assigning alternative values (i.e., zero, LOD/√2, LOD) to the values below the LOD.[34] The results were unchanged from those generated by the first method (Table 11). The joint effects of work as a brazer (classified as never, 3 months through 4 years, 5 through 9 years, 10 or more years), cigarette smoking (classified as ever/never), and age (in years) were examined using linear regression techniques. A statistical model that considered the effects of all these variables together showed a statistically significant association between increased urine cadmium levels and work as a brazer for 10 or more years but not with work as a brazer for fewer years, nor with cigarette smoking or age.

Discussion

The primary focus of this health hazard evaluation was the possible relationship between health effects experienced by some workers, namely low testosterone levels and sexual dysfunction, and workplace exposures, particularly cadmium. Also addressed were the possible relationship between these health effects and other exposures, general concerns about exposures to cadmium and other substances, and workers' concerns about cancer. Each of these issues is discussed below.

Are low testosterone levels and sexual dysfunction related to cadmium or other workplace exposures?

The health hazard evaluation was triggered by the documented occurrence of sexual dysfunction and low testosterone levels among five long-term workers, all of whom were current or former brazers in the OCD. To evaluate this issue, NIOSH investigators reviewed available medical information, interviewed workers, reviewed and conducted environmental monitoring for cadmium and other substances, and conducted biological monitoring for cadmium.

The review of available medical information confirmed that five workers had testosterone levels below the reference range of the analytical laboratory. Although testosterone levels were higher for all workers upon repeat testing one year later (after being away from the workplace because of the strike), the increase was small and probably within the range of normal variability for three workers, and the levels for four workers remained unusually low. No population-based, age-appropriate comparison data are available to determine whether the occurrence of low testosterone levels in five men from a relatively small group of brazers is unusual. Moreover, it was not possible to definitively determine whether the low testosterone levels were due to workplace exposure to chemicals. Cadmium exposure causes testicular damage in laboratory animals, and brazers in the OCD were exposed to cadmium. For most workers, the cumulative level of exposure over their careers can be characterized as modest (based on a median exposure level of 1.8 $\mu g/m^3$ between 1974 and 1996). This is consistent with the fact that renal effects, which have been shown to be related to cumulative exposure in other cadmium-exposed workers, were absent in all but one OCD worker (based on Caterpillar's medical surveillance data). At times, however, exposures of some individuals were well above current limits. (This issue is discussed more fully below.) Whether episodic high exposures are related to low testosterone levels among OCD brazers is unknown. Although this type of relationship between exposure and some health outcomes has been suggested, this has not been well studied.[35] These issues could not be evaluated in the context of this health hazard evaluation because of the relatively small number of workers with substantial exposure to cadmium and the timing of the evaluation, particularly with regard to the historical nature of the exposure. The low testosterone levels also could be due to other occupational factors. A contributing role for factors other than chemical exposure, such as stress, cannot be ruled out. A labor strike was on-going when the workers first noticed health problems and when they underwent medical evaluation. Evidence shows that strikes, which involve conflict and change, are stressful.[36] Moreover, the possible closure of the plant was an issue during this evaluation, and studies have shown that job insecurity is related to employee health.[37,38]

The review of available medical information confirmed problems of sexual function in five workers. Although the specific problems reported were not the same in all the men, based on nocturnal penile tumescence monitoring, all showed signs of erectile dysfunction. The clinical interpretation of these tests, however, is not standardized.[14,30] Moreover, three of the five men had underlying medical conditions – other than low testosterone levels – that could explain the erectile dysfunction. The frequency of erectile dysfunction in the general population depends on the definition of this condition and is related to age, but has been reported to be as high as 52 percent.[31] Thus, five cases among current and former brazers at Caterpillar may not be unusual. Interviews with workers uncovered no additional cases.

What were past and present levels of exposure to airborne cadmium in the OCD brazing area?

OCD brazing-area employees' assignments often have been rotated among the various brazing-area operations, and many of these employees have lengthy employment histories in the area. In light of this information, the historical Caterpillar environmental exposure information suggests that, in general, brazing-area employees have experienced modest *cumulative* exposures to cadmium by inhalation, as represented by the overall median PBZ airborne-cadmium concentration of 1.8 $\mu g/m^3$ for all brazing-area jobs measured between 1974 and January 1996 in comparison with today's OSHA PEL of 5 $\mu g/m^3$. However, PBZ exposures varied widely during that period, and the data suggest that, over the years, it was not uncommon for any given employee's PBZ exposure to airborne cadmium during a given workshift to greatly exceed the median level for a "typical" brazing-area workshift and also to exceed today's PEL. (Almost all measured exposures [96%] did comply with the PEL in effect *at the time of the sampling*.)

The historical Caterpillar PBZ exposure data suggest that, in general, inhalation exposures to cadmium steadily declined over the years from 1974 through early 1996. The period around 1989 is the only notable exception to this. It is not clear why measured PBZ cadmium exposures during 1989 were much higher than other time periods. The OCD was moved from Building B to Building E during that year, but some samples were collected before the move while others were collected after it. The historical Caterpillar PBZ results also suggest that exposures to cadmium were greatest during hand-brazing operations, as opposed to automated-brazing operations. The following changes in the OCD brazing process materials, operations, and ventilation systems (in the years noted) likely affected airborne cadmium concentrations and PBZ exposure levels: (1) introduction of automated brazing methods (Sealtest torch [late 1960s], quartz-lamp [1970], three-piece-shell [early 1970s], and induction [mid1980s]); (2) installation of "canopy-type" LEV hoods in Building B, the effectiveness of which was demonstrated by the results of the Caterpillar GA air samples for cadmium (1984); (3) move of the OCD to Building E (1989); (4) addition of the movable LEV hoods at the test-and-repair work stations (1992); (5) replacement of cadmium-containing brazing rods with cadmium-free rods for hand brazing use (July 1993); (6) gradual phase-out of all other cadmium-containing brazing alloys (begun early 1995, completed May 1996); and, (7) modifications of the LEV systems to increase air-flow rates (February 1996).

The results of the NIOSH air-sampling in the OCD brazing area on May 7, 1996, indicate levels of airborne cadmium below the minimum-quantifiable concentrations (i.e., "trace" levels), and in many cases below the minimum-detectable concentrations (i.e., "not detectable"). The trace levels detected were below levels measured by Caterpillar, even most recently. This is consistent with the expectations of the NIOSH investigators, due to the phase-out of cadmium-containing brazing alloys that was almost completed by the time of the sampling. In fact, on the day of the NIOSH sampling, cadmium-containing alloys reportedly were used in the brazing area *only* for 25 of 44 units manufactured on the quartz-light line.

As noted, the historical Caterpillar PBZ air-sampling results suggest that exposures to cadmium were greater during hand-brazing operations than during automated-brazing operations. Although the use of cadmium-containing brazing rods for hand brazing in the OCD ended in July 1993, the historical results suggest that hand brazing continued to result in cadmium exposures after that time, during salvage of braze joints made with cadmium-containing brazing alloys, which continued to be used in automated operations until their phase-out was completed (by the end of May 1996). Since brazing-area workers' assignments often have been rotated among the various operations (but usually were limited to just one type of operation during a given workshift), all of these workers likely experienced, at least intermittently over the years, the comparatively higher full-shift cadmium exposures associated with the hand brazing operations.

Several factors, including certain characteristics of the LEV systems serving the OCD brazing operations, could have affected the airborne cadmium levels measured (both by NIOSH and by Caterpillar) since the 1989 move of the OCD to Building E (except item #4 of the following list, which has been applicable only since the addition of the movable LEV hoods in 1992). These factors include: (1) the lack of the greatest possible enclosure of the automated brazing units by their LEV hoods; (2) cross-drafts in the area; (3) the lack of LEV for the transfer rollers between the induction-brazing unit and its cleaning tank; (4) the possibility that the movable LEV hoods are not effective enough and not adequately sized for some very large parts; and, (5) the lack of LEV for the grinding/polishing work table at the three-piece shell prep-and-test work station.

Traces of airborne cadmium detected by the May 1996 NIOSH sampling in the OCD were detected away from the quartz-light production line (the only location where cadmium-containing brazing alloys were in use that day) and even outside the brazing area altogether. The finding of airborne cadmium in unexpected sampling locations may be explained by any of the following factors, or any combination of them, although no definitive conclusions are possible: possible deficiencies in the LEV systems, cross drafts in the work areas, and re-entrainment into the air of previously deposited cadmium. Regarding the latter factor, the presence of cadmium on some surfaces in the brazing area was indicated by the results of Caterpillar's surface-wipe sampling. Additionally, some workers reported concerns about the possibility of re-entrainment of contaminants discharged by the exhaust systems into the supply-air systems' outside-air inlets. Considering the roof-top locations and relative proximities of the supply-air AHUs' OA-inlets to the discharge outlets of the exhaust systems serving the brazing area, this may be possible (given "favorable" wind direction and speed). The non-reusable filters reportedly used in the supply-air AHUs likely would not trap a large portion of any small- to intermediate-sized particles re-entrained in this fashion; therefore, most such particles would enter the SA distribution ductwork. Many such particulates would remain airborne in the ductwork, and immediately be distributed throughout the area served by the SA systems; however, this mechanism also may have resulted in deposition over the years of cadmium-containing particulate in the SA distribution ductwork, and re-entrainment of such dust might occur.

The possibility of the redistribution of cadmium-containing particulates re-entrained by the SA systems suggests the possibility of cadmium exposures, more likely in the past and probably at low levels, to workers outside the brazing area in Building E. The results of the biological monitoring by NIOSH (discussed below), however, suggest that this did not occur at levels that substantially increase cadmium body burdens.

What other factors may have affected overall cadmium exposures of OCD brazing-area employees?

Reportedly, during past years employees frequently worked overtime, often working shifts of up to 12 hours. Although the data provided by Caterpillar were for shorter sampling periods, the air concentrations are expected to be representative of those across the longer shifts; however, longer exposure periods would create greater cumulative exposures at these concentrations and, for cumulative hazards such as cadmium, an adjustment in the exposure limits is recommended for extended work shifts. The Caterpillar PBZ air-sampling results do not specify the lengths of the workshifts on the days of sampling, so this adjustment cannot be made on a sample-by-sample basis. However, it would result in downward adjustments in the TWA exposure limit applicable to some of the sampling results. For example, the current 5 $\mu g/m^3$ PEL, which applies to an 8-hr TWA exposure, would be adjusted to approximately 3 to 4 $\mu g/m^3$ for longer workdays (depending on the actual shift lengths and the adjustment technique chosen from among those currently accepted). A comparison of these values with the PBZ cadmium exposure data in Table 3, however, suggests that these adjustments would not greatly change the conclusions about the magnitude of brazing-area workers' inhalation exposures to cadmium.

Other factors such as the use of respirators and possible exposures by ingestion also must be considered when evaluating overall exposure. Because of these factors, biological monitoring may be a better way of quantitatively assessing *cumulative* exposure. The Caterpillar and NIOSH monitoring data are discussed below.

Respirators, when properly used, likely would have greatly reduced *actual* inhalation exposures to cadmium compared to those suggested by the *measured* airborne concentrations. Although overall rates of respirator use over the years are not known, the company in January 1992 reportedly began issuing respirators for controlling exposures to cadmium among brazing-area employees, and reportedly these have not always routinely been worn. Until late 1992, particulate respirators suitable for protection against dusts and mists, or against dusts, mists, and fumes, were provided, but only the latter type provides effective filtration of brazing fumes. Since late 1992, high-efficiency particulate respirators were provided; this type of respirator, which was in use at the time of the NIOSH visit, also provides effective filtration of brazing fumes. Respirators reportedly were in use by the relevant workers only during collection of as few as 8 of the 154 Caterpillar PBZ air samples for cadmium. Considering this description of historical respirator use in the OCD brazing area, the NIOSH investigators conclude that the Caterpillar PBZ air-sampling data fairly represent typical brazing-area workers' actual inhalation exposures to cadmium — both cumulative and, in most cases, for those workshifts with relatively high full-shift exposures (i.e., exposures well-above applicable median levels) — until 1993 (when increased respirator use, and high-efficiency respirator use, began).

The historical air-sampling data do not reflect exposures to cadmium by routes other than inhalation. The results of Caterpillar's surface-wipe sampling indicate the presence of cadmium on some surfaces in the OCD brazing area, and past hygiene practices may not have minimized the potential for non-inhalation exposures. Possible deficiencies in hygiene practices, such as work-clothes laundering practices, shower and hand-washing station availability and use, and smoking and eating in the brazing area, in the past may have facilitated cadmium exposures by ingestion via hand-to-mouth transfer, in addition to the documented inhalation exposures. The relative importance of ingestion exposures is uncertain, however, since only about 5% of ingested cadmium is absorbed by the body, in comparison with 10% to 50% of inhaled cadmium.[8] Changes have been made in the OCD since 1989 — hand-washing stations were added in 1989, smoking and eating were prohibited in the immediate brazing area, as defined by the painted yellow line added in February 1996, and employees now eat lunch in the conference room — that likely reduced the potential for cadmium ingetsion. However, some possible deficiencies in hygiene practices remain: (1) brazing-area employees wearing and laundering regular work clothes; (2) infrequent use of showers and uncertain hand-washing frequency by brazing-area workers; and, (3) smoking and eating in areas adjacent to the brazing area. Considering these possible deficiencies, as well as the cadmium contamination on some surfaces in the brazing area suggested by the Caterpillar surface-wipe sampling data, the potential for ingestion of cadmium remains despite the reported cessation of the use of cadmium-containing materials in the area.

What do the biological monitoring data tell us about cadmium exposure?

Urine cadmium is generally regarded as a reflection of cadmium body burden.[8] Urine monitoring, both by Caterpillar and NIOSH found only a few workers with current urine cadmium levels above the background range. These results are consistent with the results of historic environmental monitoring done by Caterpillar, which suggest a modest cumulative inhalation exposure to airborne cadmium among brazers. Higher levels of cadmium exposure at times in the past, however, would not necessarily be evident from current biomonitoring results. Limited environmental data and review of exposure controls suggest that cadmium exposure to workers outside the brazing area may have occurred. Statistical analysis of the urine cadmium levels measured by NIOSH shows that long-term work as a brazer relative to other work in the OCD was associated with higher urine cadmium levels. The environmental data and review of exposure controls and hygiene practices also suggest that ingestion of cadmium via hand-to-mouth contamination was possible. The biological monitoring done by NIOSH shows that if such exposure occurred, its contribution was insufficient to substantially increase cadmium body burden above levels found in the general population.

To what other substances were the OCD brazing-area employees exposed?

Airborne concentrations of substances other than cadmium measured by NIOSH in the OCD brazing area in May 1996, suggest relatively low inhalation exposures to these substances, with respect to the applicable occupational exposure limits; only one measured exposure, to silver, was within one-half of any relevant exposure limit. The historical Caterpillar PBZ data reveal a similar pattern, with only measured airborne concentration, again to silver, exceeding any relevant exposure criterion. The one PBZ sample for which the measured exposure exceeded the PEL was collected late in 1995, after the use of cadmium-containing brazing rods had ceased and during the phase-out of the use of cadmium-containing rings and shims; the higher silver content of the replacement brazing alloys may help explain this high measured level. The potential for exposures to these other substances by routes other than inhalation is not readily quantified, but can be qualitatively assessed by considering factors discussed above such as work practices, housekeeping, and PPE used. The results of the Caterpillar GA air samples for 1,1,1-trichloroethane suggest that some level of inhalation exposures to vapors of this compound likely occurred, at least occasionally, around 1992.

The potential exists for past and/or current exposures to other substances (besides cadmium, other metals, and fluorides) that are ingredients of products used in the OCD brazing area. (These substances are listed in Table 1.) Furthermore, the potential for exposures to unidentified decomposition and/or pyrolysis products of some of these substances may exist if the substances are present on surfaces to be brazed with a torch and if they are capable of decomposing due to high temperatures. For example, as previously described, some already powder-coated oil coolers are returned to the brazing area for salvage work; the MSDS for the organic powder-coating product used states, "Hazardous decomposition products are generated during curing and/or burning. Ventilate... properly."

Could cancers occurring among current and former workers be related to workplace exposures?

As in many NIOSH health hazard evaluations, concerns about cancer were expressed by workers. Of the chemicals used in the OCD, only cadmium is known to have a possible relationship to prostate cancer, which was of most concern to workers. As noted earlier, cadmium is recognized by NIOSH as a carcinogen, but the scientific community is divided in its opinion about a link between cadmium exposure and prostate cancer. Prostate cancer is the most common cancer among men in the United States.[39] In estimates for 1997, it accounts for 42 percent of new cases and is the second leading cause of cancer death in men. Between 1989 and 1993, the incidence of prostate cancer increased 50%; the increase is thought to be due in large part to better detection methods. It is estimated that one in every ten men will develop prostate cancer by age 85.[40] Because prostate cancer is relatively common in the general population, the number of cadmium-exposed workers with prostate cancer in the OCD is small, cumulative cadmium exposures have been relatively modest, and exposure data for individuals are limited, it is unlikely that a scientific study at Caterpillar would be able to determine whether the cases that have occurred are related to cadmium exposure at work.

CONCLUSIONS

NIOSH investigators were unable to determine whether the occurrence of low testosterone levels and sexual dysfunction among five workers in the oil cooler department was related to exposure to cadmium or other substances found in the workplace. Such a relationship, however, cannot be ruled out given the historically higher levels of exposure to cadmium, a known testicular toxin.

For brazing-area employees, cumulative exposure to airborne cadmium was modest, and was generally limited to employees working directly as brazers. With the elimination of cadmium from the work process, workers in the oil cooler department are not currently exposed to hazardous levels of cadmium. The settling of cadmium-containing airborne particulates on surfaces in and near the brazing area (and the possible deposition of cadmium in the HVAC equipment), however, suggests that non-inhalation cadmium exposures, such as ingestion via hand-to-mouth contamination, may be continuing to occur.

RECOMMENDATIONS

1. Based on good industrial hygiene practice and the requirements of the OSHA cadmium standard, surfaces in and near the brazing area should be cleaned. Since cadmium reportedly is no longer used in this department, cleanup of residual quantities from surfaces will minimize any potential for future exposures. In accordance with the OSHA standard, surfaces contaminated with cadmium should be cleaned by vacuuming, using vacuum cleaners equipped with high-efficiency particulate air (HEPA) filters, or by other methods that minimize re-entrainment of cadmium-containing particulate into the air. Also, surface-wipe sampling in all areas adjacent to the brazing area should be conducted, in addition to that already conducted by Caterpillar in the brazing area, to assess how widespread cadmium-containing dusts are deposited. After the cleanup of the brazing area and any adjacent areas is complete, additional surface-wipe sampling should be conducted in these areas to assure that no residual cadmium contamination remains.

2. Any accumulations of loose residues inside the SA air-handling equipment should be analyzed for cadmium. If cadmium is present, this equipment should be cleaned.

3. Hygiene practices should be improved, at least until residual cadmium dusts have been fully evaluated and removed as necessary. Hands should be washed before eating, drinking, or smoking during breaks, and only clean surfaces outside the brazing area and immediately adjacent areas should be used for food and beverages. Work clothes should be changed, and workers should shower or wash hands, arms, and faces, before leaving the workplace at the end of each shift.

4. Given the presence of documented adverse health effects among brazers at the facility, for which occupationally related causative factors cannot be ruled out, good industrial hygiene practice suggests that modifications of the local-exhaust ventilation systems should be made to correct the observed deficiencies so that workers' exposures to all airborne contaminants are kept to a minimum. Specifically, the automated brazing units should be more-fully enclosed by their respective ventilation hoods, LEV enclosures should be provided for the parts transfer-roller area near the induction brazing unit and for the three-piece shell prep-and-test work station's polishing/grinding work table, and the effectiveness of the movable hoods at the test-and-repair work stations should be re-evaluated.

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Table 1
Chemical Constituents of One or More Products (Excluding Silver-Alloy Metal-Fillers) Formerly and/or Currently Present in the Brazing Area
Caterpillar Inc., York, PA (HETA 95-0001)

Alkanolamide(s)
Alkanolamine borate(s)
Barium sulfate
Boric acid
CAS# 95-14-7
CAS# 2321-07-5
Dipropylene glycol
Iron oxide
Monoethanolamine
Potassium bifluoride
Potassium hydroxide
Potassium pentaborate
Potassium tetraborate
Proprietary mixture, apparently containing an "oil" and a mixture of mainly aliphatic hydrocarbons
Sodium dodecyl sulfate
Sodium hydroxide
Sodium nitrite
Sodium silicate solution
Titanium dioxide
1,1,1-Trichloroethane (used until 1993)
Trichloroethylene (used from May through December 1993)
Triethanolamine
Water

Table 2 Evaluation Criteria for Selected Metals and Fluorides Caterpillar Inc., York, PA (HETA 95-0001)	
Substance	**Criteria**
Cadmium	REL (dust and fume) -- No numerical REL (Ca)[cancers; renal effects] PEL -- 0.005 mg/m^3 (=5 µg/m^3) TWA [1910.1027] TLV -- 0.01 mg/m^3 (=10 µg/m^3) total particulates, 0.002 mg/m^3 (=2 µg/m^3) respirable particulates, both TWAs (both designated as "A2" carcinogens.)
Nickel	REL (metal, soluble, insoluble, & inorganic) -- 0.015 mg/m^3 TWA (Ca) [cancers; skin effects] PEL -- 1 mg/m^3 TLV -- The 1995-6 intended change for elemental, soluble, insoluble forms of nickel is to 0.05 mg/m^3 TWA, with an A1 designation)
Silver	REL (metal and soluble compounds [as silver]) -- 0.01 mg/m^3 (=10 µg/m^3) TWA [argyria; impregn. of external membrane] PEL -- same TLV -- 0.1 mg/m^3 (=100 µg/m^3) TWA (metal), 0.01 mg/m^3 (=10 µg/m^3) TWA (soluble compounds [as silver])
Copper	REL -- 0.1 mg/m^3 TWA (fume), 1 mg/m^3 TWA (dusts & mists) [upper respiratory irrit.] PEL -- same TLV -- 0.2 mg/m^3 TWA (fume), 1 mg/m^3 TWA (dusts & mists)
Zinc	REL (zinc oxide) -- 5 mg/m^3 TWA, 10 mg/m^3 STEL (fume), 15 mg/m^3 15-min ceiling (total dust) [metal fume fever] PEL (zinc oxide) -- 5 mg/m^3 (fume), 15 mg/m^3 (TL dust), 10 mg/m^3 (respirable dust) TWAs (all) TLV (zinc oxide) -- 5 mg/m^3 TWA (fume), 10 mg/m^3 TWA (dust)
Antimony	REL -- 0.5 mg/m^3 TWA [irritation; cardiovascular and lung effects] PEL -- same TLV -- same
Lead	REL -- <0.1 mg Pb/m^3 TWA, with a "Biological Exposure Indice" [kidney, blood, nervous system effects] PEL -- 0.050 mg/m^3 TWA [1910.1025] TLV -- 0.05 mg/m^3 TWA (designation as an "A3" carcinogen)
Tin	REL (inorganic compounds) -- 2 mg/m^3 TWA [eye, skin irritation] PEL -- none TLV (metal, oxide, inorganic compounds) -- 2 mg/m^3 TWA

Fluorides	REL -- Inorganic fluoride compounds (defined as solids [i.e., in particulate aerosol form] at room temperature, *and* including any gaseous fluorides simultaneously emitted) -- 2.5 mg/m^3 TWA [kidney, bone effects]. REL -- Hydrogen fluoride -- 2.5 mg/m^3 (3 ppm) TWA (2.4 mg/m^3 as F^-); 5.0 mg/m^3 (6 ppm) STEL (4.7 mg/m^3 as F^-) [irritation.; bone effects] PEL -- 2.5 mg/m^3 TWA (F^-); 2.5 mg/m^3 (3 ppm) TWA (hydrogen fluoride) (2.4 mg/m^3 as F^-) TLV -- 2.5 mg/m^3 TWA (F^-); 2.5 mg/m^3 (3 ppm) ceiling (hydrogen fluoride) (2.4 mg/m^3 as F^-)

Table 3
Summary of Caterpillar Personal-Breathing-Zone Air-Sampling Data for Cadmium,
OCD Brazing Area, 1974 through January 1996,
Caterpillar Inc., York, PA (HETA 95-0001)

Dates of sampling	No. Samples	Minimum Airborne Cadmium Concentration ($\mu g/m^3$)	No. (proportion) of sample results reported as "not detected"[†]	Median Airborne Cadmium Concentration ($\mu g/m^3$)	No. (proportion) of sample results equal to or greater than 5 $\mu g/m^3$ *	Maximum Airborne Cadmium Concentration ($\mu g/m^3$)	No. (proportion) of sample results exceeding applicable OSHA PEL[#]	OSHA PEL applicable at the time of sampling ($\mu g/m^3$)[#]
All data, 1974 through January 1996	154	ND[†]	65 (42%)	1.8	51 (33%)	580	6 (4%)	#
1974 through 1992	110	ND	39 (35%)	3.0	49 (45%)	580	4 (4%)	100[#]
1974 through mid-1984	57	ND	22 (39%)	5.1	34 (60%)	120	2 (4%)	100[#]
October 1984 through 1988	5	1	0 (0%)	3.2	1 (20%)	9	0 (0%)	100[#]
1989	11	2	0 (0%)	11.	6 (55%)	580	1 (9%)	100[#]
1990 through 1992	37	ND	17 (46%)	1.2	8 (22%)	140	1 (3%)	100[#]
1993 through January 1996	44	ND	26 (59%)	0.5	2 (5%)	12	2 (5%)	5[#]

† ND = not detected. Airborne concentration was below the minimum detectable concentration (see text).
* This value represents today's OSHA PEL for an 8-hour TWA exposure.
# The OSHA PEL for an 8-hour TWA exposure was changed from 100 $\mu g/m^3$ to 5 $\mu g/m^3$ on December 15, 1992.

Table 4
Summary of Caterpillar Personal Breathing-Zone Air-Sampling Data for Total Particulates, Fluorides, and Metals, OCD Brazing Area, 1974 through January 1996, Caterpillar Inc., York, PA (HETA 95-0001)

Substance	No. Samples	Proportion of samples reported as "Not detected"	Airborne concentration (mg/m^3)		Current OSHA PEL (mg/m^3)	Current NIOSH REL (mg/m^3)
			Minimum	Maximum		
Total Particulates	85	35%	ND*	2.1	15	NA#
Antimony	3	67%	ND	0.001	0.5	0.5
Copper	101	78%	ND	0.035	0.1	0.1
Fluorides	7	57%	ND	0.05	2.5	2.5
Lead	44	100%	ND	ND	0.05	<0.1
Silver	99	76%	ND	0.015	0.01	0.01
Tin	46	100%	ND	ND	2	2
Zinc oxide	101	65%	ND	0.1	5	5

* ND = not detected. Air concentration was below the minimum detectable concentration (MDC). The MDCs for these samples were not specified.
# NA = not applicable.

Table 5
Results of Air Samples for Metals
Samples Collected on May 7, 1996, at Caterpillar Inc., York, PA (HETA 95-0001)

Operation or Area	Job Title or Area Sample Location	Sample Duration (minutes)	Sample Volume (cubic meters)	Airborne concentration (micrograms per cubic meter, or $\mu g/m^3$)							
				Cadmium	Nickel	Silver	Copper	Zinc	Antimony	Lead	Tin
Shell braze	Brazer	501	1.2	ND	ND	Trace	Trace	Trace	ND	ND	NR
Inducti on braze	Brazer	477	1.2	Trace	ND	Trace	0.24	Trace	ND	ND	NR
Induction braze	Brazer	470	1.2	Trace	Trace	1.9	1.1	4.	ND	ND	NR
Quartz-light braze	Brazer (and tester)	470	1.2	ND	ND	ND	0.21	Trace	ND	ND	NR
3-piece shell braze	AREA Machine #MY-1849	477	1.2	ND	ND	Trace	Trace	Trace	ND	ND	NR
Induction braze (hand repair)	AREA, atop Tank #TK-125	481	1.2	ND	ND	Trace	Trace	Trace	ND	ND	NR
Induction braze	AREA Machine #MY-4008	475	1.1	ND	ND	0.24	Trace	ND	ND	ND	NR
Quartz-light braze	Brazer (also assisting on induction braze)	447	1.1	ND	ND	ND	Trace	ND	ND	ND	NR
Quartz-light braze	AREA Machine #MY-4151	468	1.2	Trace	ND	ND	Trace	ND	ND	ND	NR
Quartz-light braze	AREA Machine #MY-2738	465	1.2	Trace	ND	ND	0.77	Trace	ND	ND	NR
Quartz-light braze (hand repair)	AREA Atop test & repair tank #TK-123	459	1.1	Trace	ND	ND	0.90	Trace	ND	ND	NR
3-piece shell prep. and test	Grinder/cleaner/ tester	418	1.0	ND	ND	5.3	2.3	2.1	ND	ND	NR
3-piece shell prep. and test	AREA, near cleaning Tank #TK-107	447	1.1	ND	ND	Trace	0.23	ND	ND	ND	NR
Kolene #6 Cleaning	AREA, at computer terminal	404	1.0	Trace	ND	Trace	Trace	ND	ND	ND	NR

Table 5
Results of Air Samples for Metals
Samples Collected on May 7, 1996, at Caterpillar Inc., York, PA (HETA 95-0001)

Operation or Area	Job Title or Area Sample Location	Sample Duration (minutes)	Sample Volume (cubic meters)	Airborne concentration (micrograms per cubic meter, or µg/m^3)							
				Cadmium	Nickel	Silver	Copper	Zinc	Antimony	Lead	Tin
Maintenance	AREA, atop work bench	400	1.0	Trace	ND	ND	Trace	ND	ND	ND	NR
3-piece shell braze	AREA Machine #MY-1849	309	0.77	ND	ND	NR	NR	NR	NR	NR	ND
Induction braze (hand repair)	AREA, atop Tank #TK-125	311	0.81	ND	ND	NR	NR	NR	NR	NR	Trace
Quartz-light braze (hand repair)	AREA Atop test & repair tank #TK-123	319	0.80	Trace	ND	NR	NR	NR	NR	NR	ND
Minimum Detectable Concentration‡			1.0	0.08	0.5	0.08	0.08	0.5	0.8	0.5	1.
Minimum Quantifiable Concentration‡			1.0	0.25	1.0	0.25	0.25	1.7	2.5	1.7	3.5
NIOSH Recommended Exposure Limit*				†	15	10	100	5000**	500	<100	2000
OSHA Permissible Exposure Limit*				5	1000	10	100	5000**	500	50	NE
ACGIH Threshold Limit Value*				10	1000	100	200	5000**	500	50	2000

Abbreviations:
ND = Not Detected (concentration was below the Minimum Detectable Concentration)
Trace = Contaminant was detected, and concentration was between the Minimum Detectable Concentration and the Minimum Quantifiable Concentration.
NR = Not Requested (analysis for this metal not requested for this sample)
NIOSH = National Institute for Occupational Safety and Health
OSHA = Occupational Safety and Health Administration
ACGIH = American Conference of Governmental Industrial Hygienists
‡ = Minimum Detectable Concentrations and Minimum Quantifiable Concentrations listed are "typical" for this sample set, and are based upon the typical sample air volume shown. (These parameters vary slightly with sample air volume.)
* = Criteria listed are for full-shift, time-weighted average exposures. Table 2 is a comprehensive listing of relevant criteria for these air contaminants.
† = NIOSH considers this substance to be a suspected human carcinogen, but no numerical REL has been established.
** = Criteria listed are for zinc oxide. No criteria for zinc metal, reported as zinc alone, are available.
NE = None Established

Table 6
Results of Air Samples for Fluorides (Aerosol and Gas)
Samples Collected on May 7, 1996, at Caterpillar Inc., York, PA (HETA 95-0001)

Operation or Area	Area-Sample Location	Sample Duration (minutes)	Sample Volume (cubic meters)	Airborne concentration (micrograms per cubic meter, or µg/m³)		
				Particulate Fluoride (as fluoride [F⁻] ion)	Gaseous Fluoride (reported as F)	Total Fluoride (reported as F)
3-piece shell braze	Machine #MY-1849	368	0.74	7.0	Trace	9.*
Induction braze (hand test/repair)	Above Tank #TK-125	195	0.39	Trace	Trace	Trace
Induction braze	Machine #MY-4008	366	0.73	11.	16.	27.
Quartz-light braze	Machine #MY-4151	370	0.74	Trace	8.6	10*
Quartz-light braze	Machine #MY-2738	363	0.73	Trace	Trace	Trace
Quartz-light braze (test/repair)	Atop test/repair Tank #TK-123	360	0.72	Trace	Not Detected (concentration below Minimum Detectable Concentration)	Trace
Minimum Detectable Concentration‡			0.70	1.	1.	2.
Minimum Quantifiable Concentration‡			0.70	4.7	4.7	9.4
National Institute for Occupational Safety and Health (NIOSH) Recommended Exposure Limit**				2500	2400 (hydrogen fluoride, as F)	2500
Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit**				2500	2400 (hydrogen fluoride, as F)	2500
American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value**				2500	2400†† (hydrogen fluoride, as F)	2500

Abbreviations:
Trace = Concentration is between the Minimum Detectable and Minimum Quantifiable Concentrations
* = Calculated using, for the reported "trace" concentration, a value midway between the Minimum Detectable and Minimum Quantifiable Concentrations.
‡ = Minimum Detectable Concentrations and Minimum Quantifiable Concentrations listed are "typical" for this sample set, and are based upon the typical sample air volume shown. (These parameters vary slightly with sample air volume.)
** = Criteria listed are for full-shift, time-weighted average exposures, unless noted. Table 2 is a comprehensive listing of relevant criteria for the air contaminants.
†† = Ceiling limit, not to be exceeded at any time.

Table 7
Results of Independent Medical Testing of Five Workers
Caterpillar Inc., York, PA (HETA 95-0001)

Worker	Cadmium in Urine (µg/g)*		Cadmium in Blood (µg/L)*		Testosterone (ng/dl)*	
	Time 1†	Time 2‡	Time 1	Time 2	Time 1#	Time 2#
# 1	1.5	4.5	1.8	0.6	232	245
# 2	3.8	3.3	2.0	1.3	233	281
# 3	4.2	4.5	2.0	1.0	155	298
# 4	7.2	10.3	10.4	9.1	249	289
# 5	6.6	2.8	4.5	3.7	245	354

* Explanation of units: µg/L = micrograms per liter; µg/g = micrograms per gram creatinine; ng/dl = nanograms per deciliter
† August 1994, The George Washington University
‡ September 1995, The Mt. Sinai School of Medicine
\# "reference" testosterone range: Time 1, 280-1000; Time 2, 300-1000

Table 8 **Summary of Caterpillar Biological Monitoring (August 1993 - February 1995) for Long-term Workers with Past Cadmium Exposure** **Caterpillar Inc., York, PA (HETA 95-0001)**					
	No. Reports	Median	Minimum	Maximum	No. Elevated[1]
Blood cadmium (microgram per liter [μg/L])	11	1.2	0.5	10.9	1
Urine cadmium (microgram per gram [μg/g] creatinine)	9	2.7	0.5	8.6	3
Beta-2-microglobulin (μg/g creatinine)	11	48	25	874	1

Table 9 **Caterpillar Biological Monitoring (August 1993 - February 1995) for Long-term Workers with Current Cadmium Exposure** **Caterpillar Inc., York, PA (HETA 95-0001)**					
	No. Reports	Median	Minimum	Maximum	No. Elevated[1]
Blood cadmium (μg/L)	10	1.2	0.6	7	1
Urine cadmium (μg/g creatinine)	3	2.5	0.5	4.8	1
Beta-2-microglobulin (μg/g creatinine)	6	50	29	109	0

Table 10 **Summary of Caterpillar Biological Monitoring (August 1993 - February 1995) for Newly Hired Workers with Current Cadmium Exposure** **Caterpillar Inc., York, PA (HETA 95-0001)**					
	No. Reports	Median	Minimum	Maximum	No. Elevated[1]
Blood cadmium (μg/L)	19	0.6	0.5	1.7	0
Urine cadmium (μg/g creatinine)	4	0.3	0.3	0.7	0
Beta-2-microglobulin (μg/g creatinine)	18	48	30	148	0

[1]Blood cadmium >5 μg/L; urine cadmium >3 μg/g ; Beta-2-microglobulin >300 μg/g

Table 11
Analysis of Urine Cadmium Results
by Work as a Brazer, Cigarette Smoking, and Age*
Caterpillar Inc., York, PA (HETA 95-0001)

Variable	Parameter Estimate	Standard Error	p†
Worked as a brazer 10+ yrs	2.61	0.59	0.0001
Worked as a brazer 4-9 yrs	0.26	0.77	0.73
Worked as a brazer 3 mos - 4 yrs	0.10	0.22	0.83
Ever smoked cigarettes	0.45	0.30	0.14
Increasing age	0.03	0.02	0.16

* Urine cadmium measured as creatinine-adjusted cadmium
† a p value less than .05 is considered statistically significant

Figure 1
Distribution of Urine Cadmium Levels (in tertiles)
by Brazing (A), Cigarette Smoking (B), and Age (C)
Caterpillar Inc., York, PA (HETA 95-0001)