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NIOSH HEALTH HAZARD EVALUATION REPORT

HETA 94–0268–2618
Standard Industries
San Antonio, Texas

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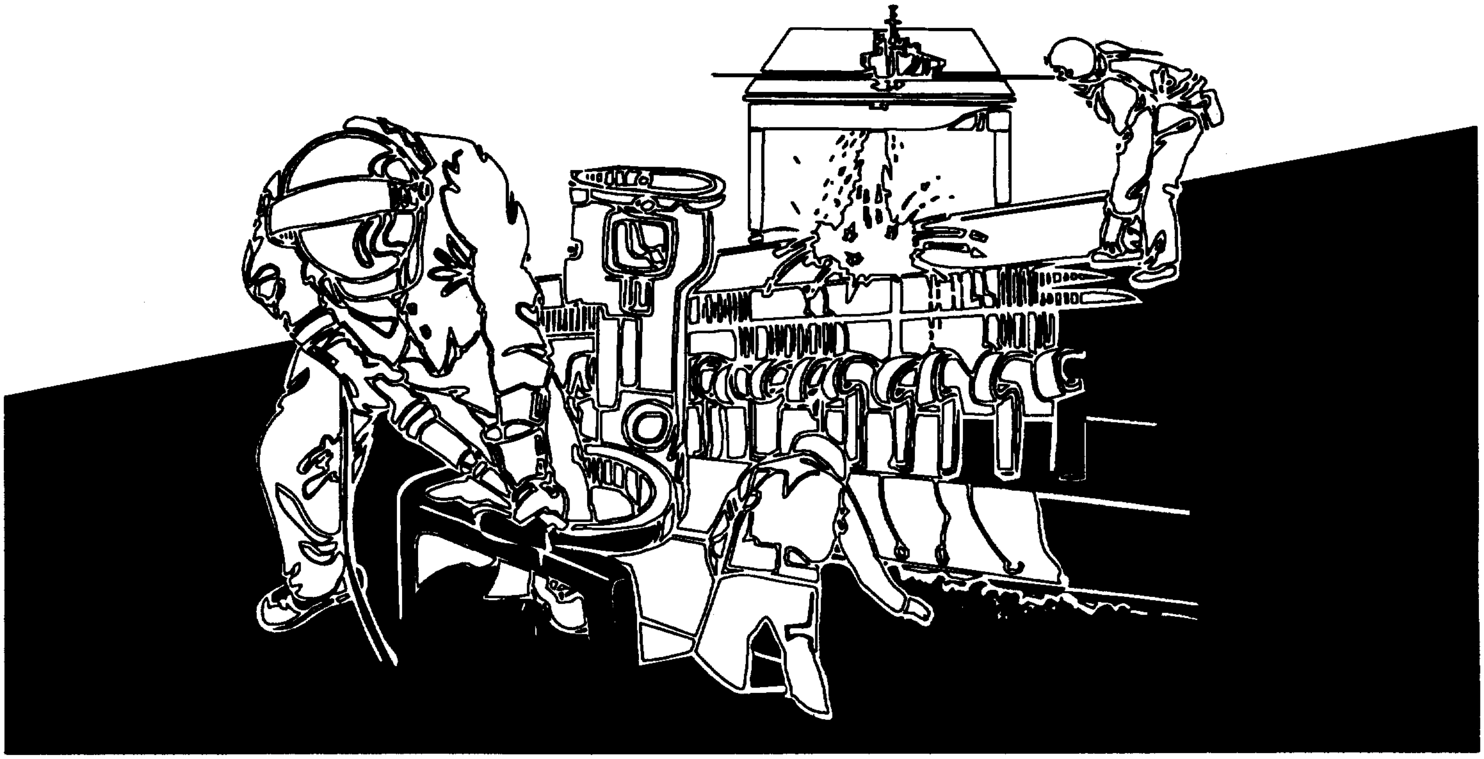

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

PREFACE

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

The Hazard Evaluations and Technical Assistance Branch also provides, upon request, technical and consultative assistance to Federal, State, and local agencies; labor; industry; and other groups or individuals to control occupational health hazards and to prevent related trauma and disease. Mention of company names or products does not constitute endorsement by the National Institute for Occupational Safety and Health.

ACKNOWLEDGMENTS AND AVAILABILITY OF REPORT

This report was prepared by Eric J. Esswein, M.S.P.H., C.I.H., Hazard Evaluations and Technical Assistance Branch (HETAB), Division of Surveillance, Hazard Evaluations and Field Studies (DSHEFS) and Mark F. Boeniger, M.S., C.I.H., Industrywide Studies Branch (IWSB), DSHES. The video assessment monitoring and engineering controls evaluation (Appendices A and B of this report) were prepared by Ronald M. Hall and Kenneth Mead, P.E., Engineering Control Technology Branch, Division of Physical Sciences and Engineering (DPSE). Field assistance was provided by Gregory M. Burr, C.I.H. (HETAB), Aaron Sussell, M.P.H., C.I.H. (HETAB), and Linda M. Ewers, Ph.D. (IWSB). Kevin Ashley, Ph.D. from the NIOSH Methods Research Branch provided expert advice and technical assistance on anodic stripping voltametry techniques. Desktop publishing was done by Kate L. Marlow.

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SUMMARY

In May 1994, the National Institute for Occupational Safety and Health (NIOSH) received a management request to conduct a health hazard evaluation (HHE) at Standard Industries, a battery manufacturing plant in San Antonio, Texas. The request, sent through the Texas Department of Health, asked NIOSH to evaluate the plant and make a determination if on–going improvements to the plant's engineering controls would reduce employee lead exposures. Site visits were made at Standard Industries during the periods July 13–16, 1994, and March 27–31, 1995. Personal breathing zone (PBZ) samples collected in various locations of the plant exceeded the criterion of 50 micrograms of lead per cubic meter ($\mu g/m^3$) of air enforced by the Occupational Safety and Health Administration (OSHA). The highest PBZ exposures were measured in plate pasting operations (range: 68 – 495 $\mu g/m^3$). Exposures in first assembly and pouching ranged from 15–418$\mu g/m^3$ and 31 – 77 $\mu g/m$,^{3} respectively. Surface wipe samples showed a consistent presence of Pb on cafeteria table tops. Significantly increased amounts of lead were present on hand wipe samples obtained from employees finishing lunch compared to hand wipes collected from the same employees before they entered the lunchroom. A unique biological monitoring and sample analysis method (analysis of saliva lead by anodic stripping voltametry) was used to evaluate for the presence of recently absorbed lead in employee saliva samples. Triplicate saliva samples obtained during four consecutive workdays documented a consistent daily increase in saliva lead. Video exposure monitoring identified work practices and housekeeping issues, such as dumping dross into unventilated scrap barrels and floor sweeping with corn brooms, that could increase airborne lead concentrations. Modifications to some engineering controls were suggested to optimize capture efficiencies and enhance performance of the ventilation system. The engineering controls evaluation and video exposure assessment monitoring are compiled in two separate appendices included in this report. The results of this HHE identify the fundamental importance of a good respiratory protection program, the importance of vigilant housekeeping and attention to personal hygiene, and the need for operational maintenance of engineering controls in a plant where lead dust is present.

Engineering controls were appropriate for battery manufacturing, however lead exposures exceeding the current OSHA occupational limits of 50 $\mu g/m^3$ occurred at the facility. Operations and maintenance of engineering controls, housekeeping issues and certain work practices were identified as some of the reasons for overexposures despite the use of engineering controls. Recommendations provided in this report include insuring that local exhaust ventilation systems function as designed, improve the company's respiratory protection program, decontaminate and control Pb on lunchroom surfaces (cafeteria tables and hand contact surfaces), improve hand decontamination to reduce the potential for ingestion of lead, and modify employee work practices to discourage activities which may result in the suspension of lead dust into the workplace atmosphere.

Keywords: SIC 3691 (storage batteries), lead, Pb, battery manufacturing, blood lead levels (BLLs), wipe sampling, respiratory protection, saliva, anodic stripping voltametry (ASV).

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INTRODUCTION

In May 1994, the National Institute for Occupational Safety and Health (NIOSH) received a request for a health hazard evaluation (HHE) from Standard Industries in San Antonio, Texas. The HHE request was sent from Standard Industries through the Texas Department of Health. NIOSH was requested to provide assistance in determining employee exposures to lead and evaluate the local exhaust ventilation system to ensure that on–going engineering control upgrades would be effective in reducing employee exposures to airborne lead. Site visits were made at Standard Industries during the periods July 13–16, 1994, and March 27–31, 1995. Results and recommendations from the initial site visit were sent to Standard Industries in a letter dated March 1995. During a second site visit, additional personal breathing zone (PBZ) and area air samples were collected. Hand and surface wipe samples were obtained and a unique biological monitoring method using saliva was field evaluated. With assistance from the NIOSH Engineering Control Technology Branch (ECTB), the local exhaust ventilation system was evaluated and real–time video monitoring techniques were used to evaluate employee work practices and exposures. A draft ECTB engineering control report and exposure assessment video was presented at a meeting with Standard Industries in September 1995. Suggested recommendations for modifications to the existing engineering controls and selected work practices were provided at this meeting.

BACKGROUND

Standard Industries, established in 1918, is located in southwest Bexar County, Texas, and manufactures lead–acid batteries in a 300,000 square foot (ft^2) plant. Standard Industries is a job shop producing a variety of unique and custom–sized batteries under the name Reliable and other brands. Approximately 150 employees, primarily Hispanic, were employed manufacturing batteries at Standard Industries during the dates of the NIOSH visits. Production at Standard Industries ranges from 2000 to 4000 batteries/day.

While the manufacturing process is typical of lead–acid battery manufacturing, the plant is not highly automated due to the production of uniquely–sized batteries. Lead (Pb) is received in ingot form, is melted, and is used to cast grids. Grids serve as conductors in the battery and the grid framework holds "pellets" of lead paste which is necessary for the electrochemical reaction to occur. Grids are cast in pairs at one of twelve grid casting machines. Seven additional grid casting machines are installed in the plant but were not on–line during either of the NIOSH investigations. Small battery parts, such as post straps and intercell connectors, are cast using a Winkle Machine in a separate area of the plant known as small parts casting.

Powdered lead oxide (which is either purchased commercially or produced on–site) is blended with sulfuric acid and water in a rotary mixer to produce a thick paste. The paste is applied to the grids by a pasting machine to produce cathodic and anodic battery plates. The pasted plates pass through a flash dryer to remove surface moisture. The plates leave the dryer on a short conveyor belt and are gathered by hand, stacked in three–sided bins, and the bins are taken to a drying oven for a 48–hour curing process. As they are needed, bins of cured plates are removed from the oven and stored on the plant floor opposite the plate pouching area. The plate pairs are used in the pouching area where the plates are manually "broken" into single plates over a plate breaking table and then manually loaded onto an automated plate pouching machine. An insulating pouch (a plastic envelope) is mechanically slid over the cathodic plates. In first assembly, anodic and cathodic plates are manually "stacked" or interleaved together into a stack of plates called a cell. Cells are "burned" or welded together in the group burning area using an oxygen–acetylene torch. The welded cells are slid into polypropylene battery cases and any remaining small lead parts (intercell connectors) are attached and electronically welded. Top covers are installed and the batteries are moved to stations to be filled with sulfuric acid. The batteries are wet–charged with an electric current. Final cleaning and drying is performed on the Pow–R–Dry line. Labels and decals are applied in the finishing area.

A variety of engineering controls are used to control lead exposures at Standard Industries. Point of generation controls including enclosure hoods, slot hoods, and downdraft hoods are the primary workstation controls used to capture and remove lead fume and particulates. In some areas, filtered air showers have been installed above employees' workstations to provide an island of clean air. Within the past several years, significant changes to the ventilation system were made such as installation of a new, higher capacity baghouse and newly installed state–of–the–art workstation engineering controls such as downdraft plate breaking tables, downdraft tamping stations, enclosure hoods for plate stacking and workstation high efficiency particulate air (HEPA) supplied air showers. A central vacuum system is available at some workstations for clean–up around the workstations and to vacuum lead dust from employee's work clothes.

Standard Industries has a written employee respiratory protection program. Employees wear air–purifying half–mask, dual cartridge respirators in grid casting, pasting, pouching, first assembly, Tiegle burning, and the "TBS" cast–on station areas of the plant. Employees who walk or who drive forklifts or floor cleaners through these areas also wear respirators. Safety glasses are worn throughout the manufacturing area of the plant. When employees enter the plant, they arrive in a "clean side" locker room. Before the start of the work shift, employees are issued underwear, socks, coveralls, gloves, and a respirator assigned to that individual employee. Employees dress on the "clean" side then pass through a one–way turnstyle into the "dirty" side of the locker room which leads to the plant floor. At the end of the shift, employees enter the dirty side of the locker room, doff their respirators and send them and their workclothes through chutes leading to the laundry. The employees shower and then enter the locker room clean side where they change back to their street clothes. The respirators, contaminated coveralls, underwear, socks, and gloves fall into laundry bins which are adjacent to several front–loading commercial washing machines and driers. After the clothing is laundered and dried, it is stored for reissue to the employees during their next shift. Respirators are disassembled and the facepieces are washed in one of the two front loading washing machines.

Employee blood lead levels (BLLs) are tracked by Standard Industries as part of a medical monitoring program and were provided to NIOSH by management. Mean BLLs for the first two months of 1995 are listed in Table 1 (below) by department. Units in Table 1 are listed in micrograms per deciliter (µg/dL) of lead in whole blood. NIOSH supports the goal of the U.S. Public Health Service that employee BLLs be kept below 25 µg/dL to prevent symptoms of lead poisoning.

Table 1
Employee Blood Lead Levels (BLLs)
1/1/95 – 3/3/95

Location	Number of Employees	Observations	Mean BLL (µg/dL)	Standard Deviation (µg/dL)
Grid Casting	16	33	30	10
Lead Oxide Mill	4	10	40	8.2
Pasting	13	45	39	8.2
1st Assembly (incl. Pouching)	41	72	31	8.1
Pouching (only)	10	18	30	9.3
2nd Assembly	16	23	35	11
Maintenance	11	43	43	7

METHODS

In July 1994, an opening conference was conducted with NIOSH, Standard Industries management, the Texas Department of Health, and the local union representative. A plant walk–through inspection was performed where six area samples and five personal breathing zone (PBZ) samples were collected to evaluate airborne lead concentrations. Personal breathing zone and area air samples were collected on mixed–cellulose ester filters (37 millimeter diameter, 0.8–micron pore size) using personal sampling pumps connected to sampling trains calibrated on–site to a flowrate of 2.0 liters per minute (Lpm). Samples were collected for a period as near as possible to an entire workshift. PBZ samples were collected in the TBS area (casers/unloaders) and the Tiegel Burning station #3. Area air samples were collected in the locker room and the laundry area to evaluate if airborne lead was present in these areas and presented an exposure hazard to employees after they undressed and entered the showers. Eight wipe samples were collected from 1 square foot (ft^2) areas of cafeteria tables, a railing in the food service line, and the receptionist's desk at the front door. Wash'n Dri™ wipes were given to eleven employees who volunteered to wipe their hands for 30 seconds to test for the presence of lead. Five of the eleven samples were obtained from individuals who reported washing their hands prior to taking a break in the plant cafeteria. Colorimetric indicator swabs were used to evaluate for the presence of lead inside 10 half–mask respirators which had been recently used by employees. Several half–masks which had been cleaned for reissue were also evaluated using the colorimetric swab method.

Air samples were analyzed for the presence of lead according to NIOSH Method 7105.[1] Samples were analyzed using a Perkin–Elmer Model 5100 Graphite Furnace AA Spectrometer (GFAAS) equipped with background correction. The method was modified to accommodate microwave digestion. The limit of detection (LOD) was reported as 0.01 micrograms (µg) per filter. The limit of quantitation (LOQ) was reported as 0.044 micrograms per filter. Wipe samples were collected using Wash'n Dri™ brand moist towelettes and analyzed according to NIOSH method 9100.[2] The samples were digested in concentrated nitric acid and hydrogen peroxide and analyzed using a Perkin–Elmer 5000 Flame AA Spectrometer. The LOD for the wipe samples was reported as 3 µg per wipe. The LOQ was reported as 9.2 µg per wipe.

In March 1995, NIOSH conducted a follow–up visit at Standard Industries. Industrial hygiene sampling and field evaluation of a biological monitoring technique using saliva were conducted. An evaluation of in–plant engineering controls and video exposure monitoring (VEM) was conducted to evaluate work practices and personal exposures. Forty–four PBZ samples and 48 area air samples were collected. Fifty wipe samples were collected from a variety of environmental surfaces and from employees' hands.

To further characterize lead contamination on surfaces, wipe samples were collected from square foot areas of the facility lunchroom tabletops, the first and second floor conference room tabletops, cutting boards in the kitchen, surface areas on the food service line in the cafeteria, and a few locations in the plant laboratory. Wipes samples were obtained by unfolding the towelette and wiping the surface to be sampled in a serpentine fashion, first left to right, and top to bottom, then left to right again. Masked 12 inch by 12 inch (12" x 12") areas were sampled. When collecting a sample, the pad was folded together after each perpendicular wiping to expose a fresh, uncontaminated surface area of the wipe. Finally, the wipe was folded together and was placed in a clean polyethylene bag, sealed and labeled for laboratory analysis. Polyethylene gloves were worn by NIOSH investigators and the gloves were changed between samples to avoid cross–contamination of samples from the environmental surfaces or contaminating field blanks.

Hand contamination was also evaluated using Wash'n Dri™ wipes. Employees who consented to be tested were asked to open a wipe packet and carefully clean the entire surface of both hands for thirty seconds. A clean polyethylene bag was held out by a NIOSH investigator for the employee to deposit the wipe after they finished wiping their hands.

Because wipe samples collected during the initial NIOSH investigation confirmed the presence of Pb on many environmental surfaces, a table top cleaning study was conducted to evaluate the effect of detergents, abrasive cleansers, and a 3% nitric acid solution to remove lead from various surfaces. Surfaces in the lunchroom, upstairs conference room, and the laboratory were cleaned using a commercially available dishwashing detergent, an abrasive hand cleanser, and a nitric acid solution.

An exploratory study using worker saliva samples as a measure of recent exposure to lead was conducted. The study design involved 12 workers reported by management to work in moderate to high exposure areas within the plant. Three of 12 workers were lost to follow up during the study. One worker terminated employment after one day of participation and two others voluntarily dropped out of the study. Two additional workers were picked up half–way through the study to replace the lost individuals. Therefore, only nine workers participated through the course of the entire study. Of those remaining until the end, five workers (#s 1, 2, 3, 5, 12) were employed in the pasting department, three workers (#s 6, 7, 8) were in pouching, and three workers (#s 10, 13, 14) were in the first and second assembly departments. The workers voluntarily participated and signed an informed consent document that had been approved by the NIOSH Human Subjects Review Board.

Several approaches to collecting and analyzing the biological samples were evaluated in an attempt to more clearly understand the impact of saliva sample collection and sample preparation. Collection and preparation steps tested included pre–rinsing the mouth before collecting the sample and filtration of the saliva samples. Saliva samples were analyzed by both a field portable device that provided immediate results and by laboratory analysis. The relationship between these two methods was examined.

Personal breathing zone air samples, skin wipes, and saliva were collected from the study participants from Tuesday through Friday during one week. Only skin wipes and saliva were collected on the following Monday morning after they were away from work for one to two days. Workers were sampled upon arrival at work before entering the plant (period 1), at mid–day upon breaking for lunch (period 2), and at the end of the work day when preparing to leave the factory (period 3). During each of these times, saliva and wipe samples around the mouth and from the hands of each worker were obtained. The sampling protocol required that the participating worker first wipe both hands thoroughly with a Wash'n Dri™ Towelette and place it into a plastic sample storage bag. After donning a latex glove, they wiped around their mouths with another Wash'n Dri™ Towelette and placed that into a labeled plastic sample storage bag. Each worker would then place a 8–cm long plastic straw between their lips, and expel 1 – 2 milliliters (mL) of saliva into a clean plastic test tube.

Twelve of the saliva samples were collected as described above, but were followed by rinsing the mouth with citric acid before collecting a second and third post–rinse sample. This was done to ascertain whether samples obtained after rinsing the mouth produced any different results from those not preceded by rinsing. If post–rinse saliva results were lower, this might suggest the presence of external particulate contamination in the mouth. Furthermore, a portion of the saliva samples were divided into two equal aliquots which were analyzed by anodic stripping voltammetry (ASV) but one of the samples was first filtered through a 0.45 µm Teflon® filter. This was done in an attempt to remove lead particles of exogenous origin (outside of the body) entering the mouth and otherwise contaminating the saliva sample.

The saliva samples were analyzed on–site using a portable ASV device (PaceScan 1000, Pace Environs, Inc., Cary, N.C.) and were later re–analyzed in a fully equipped laboratory using NIOSH Method 7105, which is based on nitric acid digestion and graphite furnace atomic absorption spectrometry.[1] The ASV analytical methodology entailed recording the original volume of saliva and adding deionized water to bring the saliva sample volume to 5 mL. A proprietary buffer tablet was then added and crushed with a disposable plastic stick, and finally a single–use electrode was placed into the solution. Analysis time is about three minutes and the analytical concentration range is from 2 – 100 µg Pb/L. Samples outside this concentration were serially diluted using dionized water. Calibration standards were periodically run and used to adjust the readings when necessary. The results were reported as the original concentrations adjusted for dilution and calibration factors. All the wipe and PBZ air samples were analyzed in a NIOSH contract laboratory using flame atomic absorption spectrometry after completely ashing the matrix using concentrated nitric acid and 30% hydrogen peroxide on a hot plate (NIOSH Method 7082).[3]

A bulk sample of lead oxide paste used in grid pasting was analyzed for total lead and bio–available lead according to NIOSH Method 7082 (modified for microwave digestion) and ASTM Method D 5517–94.[4] These methods allow for total acid digestion and a milder acid extraction, respectively at pH = 1.5. The latter (mild acid extraction) resembles acidity in the human stomach. Both samples were analyzed using flame atomic absorption spectroscopy. The lead oxide dust was also optically sized using an analytical microscope to describe the physical characteristics of the particles.

An evaluation of the engineering controls used at Standard Industries was conducted. Face velocities and capture distances at workstations were measured using a hot wire thermoanemometer. Pasting, pouching, first assembly, and the TBS areas were evaluated. Additionally, a hand–held aerosol monitor (HAM) connected to a datalogger was worn on an aluminum backpack frame by the workers who agreed to participate in video exposure monitoring. NIOSH investigators used a video recorder to videotape the work practices of the worker being evaluated. Video exposure monitoring is an evaluation process combining real–time sampling with video recording of an observed task. The HAM output signal was recorded with a datalogger and later downloaded to a computer spreadsheet for analysis. The HAM output signal and the video recording are then combined into a single video recording which uses a moving histogram (seen as a bar chart) on the video screen to show relative aerosol concentrations as they occur. The result is a videotape with a moving bar chart showing the influence of work practices on employee breathing zone concentrations of particulate air contaminants. The engineering controls evaluation and the video exposure monitoring results are listed as a separate and more extensive report in appendices of this document.

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)[5], (2) the American Conference of Governmental Industrial Hygienists' (ACGIH®) Threshold Limit Values (TLVs®)[6] and (3) the U.S. Department of Labor, OSHA permissible exposure limits (PELs)[7]. 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 (CFR); 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.

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

Lead

People have used lead since ancient times because of its useful properties, and it was the ancient Romans and Greeks who first discovered its toxic effects. Workplace exposure to lead occurs by inhalation of dust and fume and ingestion of lead–contaminated dust on surfaces. Once absorbed, lead accumulates in the soft tissues and bones. A person's BLL is used as a biological monitoring method for exposure to, and current absorption of lead. Lead is stored in the bones for decades, and health effects may occur long after the initial exposure as the bones release lead in the body.

Numerous studies have documented toxic effects of lead on the nervous system, reproductive system, kidneys, blood–forming system and the digestive system.[8,9,10,11] Lead has been shown to be an animal carcinogen, but there is not yet conclusive evidence that lead exposure causes cancer in humans. Lead poisoning can occur because of chronic exposure or after a short period of very high exposure. The frequency and severity of symptoms associated with lead exposure generally increase with the BLL. Many of the symptoms of excessive lead exposure can easily be confused with other causes; these include weakness, excessive tiredness, irritability, constipation, anorexia, abdominal discomfort (colic), and fine tremors.

The OSHA general industry lead standard (29 CFR 1910.1025 [1978]) established a PEL of 50 µg/m^3 and an action level of 30 µg/m^3 (both 8–hour TWAs).[12] The OSHA standard requires adjusting the PEL for work shifts longer than 8 hours, medical monitoring for employees exposed to airborne lead at or above the action level, medical removal of employees whose average BLL is 50 micrograms per deciliter (µg/dL) or greater, and economic protection for medically removed workers. Medically removed workers cannot return to jobs involving lead exposure until their BLL is below 40 µg/dL. The OSHA interim final rule for lead in the construction industry provides a generally equivalent level of protection to construction workers.[13] The ACGIH TLV for lead is 50 µg/m^3 (8–hour TWA), with a biological exposure indice (BEI) of 30 µg/dL. ACGIH has also designated lead as an *animal carcinogen* and recommends that "...worker exposures by all routes be carefully controlled to levels as low as possible below the TLV."[14] The U.S. Public Health Service has established a national public health goal to eliminate all occupational exposures that result in BLLs greater than 25 µg/dL by the year 2000.[15] NIOSH supports the Public Health Service goal and recommends that to minimize the risk of adverse health effects, employers and workers should continually strive to reduce workplace lead exposures.

Health studies indicate that the OSHA lead standards noted above are not protective for all the known health effects of lead. Studies of adults have found neurological symptoms with BLLs of 40 to 60 µg/dL, decreased fertility in men at BLLs as low as 40 µg/dL, and increases in blood pressure with no apparent threshold to BLLs of less than 10 µg/dL. Fetal exposure to lead is associated with reduced gestational age, birth weight, and early mental development with maternal BLLs as low as 10 to 15 µg/dL.

Lead exposure reduction efforts over the past two decades in the U.S. have resulted in a significant drop in lead exposures. From 1976 to 1991 the mean adult

BLL dropped from 13.1 to 3.0 µg/dL, and in 1991 more than 98 percent of adults had a BLL less than 15 µg/dL.[16] Occupational lead exposures of public health concern continue to occur, however. For example, in 1994 the NIOSH Adult Blood Lead Epidemiology and Surveillance program received reports for 12,137 adults with elevated BLLs ≥25 µg/dL from 23 participating states.

In homes with a family member occupationally exposed to lead, care must be taken to prevent "take home" of lead. Lead may be carried into the home on clothing, skin, or hair, or from vehicles. High BLLs in resident children, and elevated concentrations of lead in the house dust, have been found in the homes of lead–exposed workers.[17] Children of persons who work in areas of high lead exposure should receive a BLL test.

Lead in Surface Dust and Soil

Lead is commonly found in U.S. urban dust and soil due to the past use of lead in gasoline and paints, and also industrial emissions. Lead–contaminated surface dust and soil represent potential sources of lead exposure, particularly for young children. Lead exposure may occur either by direct hand–to–mouth contact, or indirectly from hand–to–mouth contact with contaminated clothing, cigarettes, or food. Previous studies have found a significant correlation between resident children's BLLs and house dust lead levels.[18] There is no federal standard which provides a permissible limit for lead contamination of surfaces in occupational settings. As required by Section 403 of the Toxic Substances Control Act (as amended in 1992) the Environmental Protection Agency (EPA) is in the process of developing health–based residential standards for lead in dust, paint, and soil.

EPA currently recommends the following clearance levels for surface lead loading be met after residential lead abatement or interim control activities: uncarpeted floors, 100 micrograms per square foot (µg/ft ^{2}); interior window sills, 500 µg/ft^2, and window wells, 800 µg/ft^2.[19] These levels have been established as achievable through lead abatement and interim control activities; they are not based on projected health effects associated with specific surface dust levels.

EPA currently recommends a strategy of scaled responses to soil lead contamination, depending upon lead concentrations and site–specific factors. When lead concentrations exceed 400 ppm in bare soil, EPA recommends further evaluation and exposure reduction activities be undertaken, appropriate to the site–specific level of risk. If soil lead concentrations exceed 5000 ppm, EPA recommends permanent abatement of contaminated soil.[19]

RESULTS

Initial Industrial Hygiene Evaluation

Lead sampling results from the initial site visit are listed in Tables 2 and 3. The five PBZ samples ranged from 5 µg/m^3 (Laundry Room Attendant) to 150 µg/m^3, (Machine Operator, Pouching) during the time periods sampled (306–422 minutes). Three area air samples collected in the locker room at the end of the shift when employees were changing clothes and showering were in a range of 4–7 µg/m^3. Area air samples comparing the "clean" and "dirty" sides of the locker rooms were 2 µg/m^3 and 7 µg/m^3, respectively. Hand wipe samples from five employees in the battery finishing area ranged from 110 µg/wipe to 1900 µg/wipe. One hand wipe from an employee in the pouching area showed a lead concentration of 3400 µg/wipe. Five hand wipes from employees (on break) who worked in the paste mixing area and who reported washing their hands prior to break, were in a range of 1100 µg/wipe to 5100 µg/wipe.

Lead on 1 ft^2 surfaces on the tops of tables in the cafeteria were in a range of 47 µg/ft^2 to 1400 µg/ft ^{2}. The lead level in a sample from approximately ten linear feet, of the top surface of a painted metal railing in the cafeteria food service line, revealed 3700 µg/wipe. A 1 ft^2 wipe sample collected on a receptionist's desk at the front door was determined to have 93 µg/ft^2 on the sample.

Follow–up Evaluation and Industrial Hygiene Results

Results of PBZ and area air samples collected during the second site visit are compiled in Tables 4–7. Overall, 75% (33/44) of the samples collected during the second visit exceeded the OSHA PEL of 50 µg/m^3 for workplace exposure to airborne lead. Personal breathing zone samples with the highest concentrations of airborne lead were consistently found in the pasting area. These samples ranged from 68 µg/m^3 (QA/QC person) to 495 µg/m^3 (plate stacker). The mean value for PBZ samples in the pasting area was 291 µg/m^3. The second highest PBZ exposures were measured in first assembly. Samples collected in this area lie in a range from 15 to 418 µg/m^3. The mean value for these samples was 108 µg/m^3. The third highest PBZ concentrations of airborne lead were measured in pouching. These PBZ samples were in a range of 31 to 77 µg/m^3, with a mean value of 50 µg/m^3.

Area samples exceeding the OSHA PEL were found in pasting (2 of 4), pouching (2 of 8), the lead oxide mill (2 of 2), and grid casting (2 of 6). The samples from grid casting were collected while an employee was dry sweeping the floor and when dross was being shoveled into an unventilated scrap barrel. Three area air samples collected in different locations in the lunchroom were each 1 µg/m^3. One area air sample collected in the food preparation areas of the kitchen area was 2 µg/m^3. Area samples collected on each side of the main traffic aisle opposite the grid casting area were 32 µg/m^3 and 34 µg/m^3.

Lead Contamination on Surfaces

Respirators

Thirteen randomly selected and recently used respirators, and one new respirator, were selected to evaluate for the presence of lead on the inside surfaces of the respirator facepiece. Four respirators were checked when employees were on break, one was a new facepiece, and nine were from the laundry and had been washed and were ready for reissue. With the exception of the new facepiece, all the respirator facepieces were determined to be contaminated with residues of lead using Lead Check™ colorimetric indicator swabs (reported minimum sensitivity of 2 µg/swab).

Tabletops

Lead was found to be present on all the tabletops sampled in the employee lunchroom. Table 8 provides results of wipe samples from seven randomly selected tables and various other surfaces in the cafeteria. Two 1–ft^2 sized areas on seven randomly selected cafeteria tables were wiped. The sampling locations were opposite one another and at either end of the tables. To evaluate uniformity of lead contamination and sampling method, the data were evaluated as matched pairs (e.g., sample SITT1a and SITT1b) using Student's t–test for paired samples. Paired samples ranged in concentrations from 160 and 140 µg/ft^2 (samples 6 a & b) to 700 and 770 µg/ft^2 (samples 1 a & b). There was no statistically significant difference in lead concentrations when sample pairs from the same table but opposite sides and at either end of the table were compared ($p = 0.2$, 2–tailed).

To evaluate the ability of acid or detergent to remove lead from table tops, 1 ft^2 areas on four randomly selected tables which had not previously been sampled were cleaned using either a 3% nitric acid solution (prepared by Standard Industries laboratory personnel) or Dawn™ dishwashing detergent. The surfaces of the tables were cleaned for a minute with the nitric acid or the detergent. The tables were wiped clean and then dried using a paper towel and 1 ft^2 areas located opposite from each other were masked and wipe sampled. Two NIOSH investigators each wipe–sampled the same table (locations opposite and at either end from one another) and each investigator obtained one sample from the same table using either the acid or the detergent wash. The results, which are listed in Table

8, confirm a uniformity of contamination on each table and demonstrate a consistency of technique between the investigators. Also, neither cleaning method was completely effective in removing lead from tabletop surfaces.

Another evaluation was performed on the second floor conference table and on a stainless steel laboratory bench in the plant laboratory. Two 1–ft^2 areas on the second floor conference room table and on a stainless steel lab bench were sampled with Wash'n Dri towelettes™. The surfaces were then cleaned using an abrasive cleaning pad and Sani–tough,™ (Sani Fresh, San Antonio, Tx.) a grit–containing hand cleanser used at the plant. After the surfaces were cleaned and dried they were resampled. These serial washings demonstrated a 59% and 98% decrease, respectively in surface lead contamination in the specific situations (the conference room table and the stainless steel laboratory bench) listed in Table 8 .

Surface wipe samples of three plastic cutting boards taken from the kitchen were evaluated for the presence of lead. Lead ranged from a trace amount (quantity between the LOD and the LOQ) to 130 µg/wipe. Wipe samples of the surface on the top of the steam table at the food serving line contained lead at concentrations of 140 and 320 µg/ft^2. Doorknobs on both sides of the door leading from the plant floor, and to the cafeteria were found to have 160 and 90 µgPb/wipe, respectively.

Hand Wipe Samples

Table 9 lists results of six pairs of hand wipe samples obtained from randomly sampled employees after they had washed their hands but before they entered the lunchroom and directly after they finished eating lunch but before returning to their workstations. Paired samples ranged in concentration from 33 and 120 µg/wipe (samples HW6b & 6a, b= before lunch, a= after lunch) to 1300 µg/wipe for both samples (samples HW4a & HW4b). Analysis of hand wipe sample pairs using a matched pairs t–test showed a statistically significant increase (p=0.03) in lead concentration collected on the post lunch hand wipe samples compared to the pre lunch hand wipe samples. The t–test was performed using 1 tail with an *a priori* hypothesis that hand contamination would increase because of the presence of lead on hand contact areas (table tops, door knobs, and the food service line) and previously observed hand contact with these surfaces as workers ate their lunches.

Hand wipe sampling results for the employees in the saliva Pb study upon arriving at work, before lunch and at the end of the work day are shown in Figure 1. A consistent pattern of lead levels was seen. Increasing amounts of lead were present on the skin of the workers' hands towards the end of the work shift. Morning weekday mean concentrations always returned to between 150 and 550 µg/wipe per two hands but were as high as 6,000 to 9,000 µg/wipe per two hands, by the end of the shift. Although the Monday morning concentrations were about half (70 µg/wipe per two hands) the amount seen at the beginning of other work days, the fact that any lead was detected suggests that some lead remained on the workers' hands throughout the weekend or that lead contamination, possibly from workers' cars and other objects, occurred away from work. Figure 2 depicts the effectiveness of hand washing in removing lead from workers' hands. Although there were dramatic measurable reductions of lead on the skin, the average worker still had 530 µg/wipe per two hands obtainable from a Wash'n Dri™ wipe. A hand wipe level of 530 µg Pb/wipe per two hands is roughly equivalent to the amount of lead received via inhalation of an air concentration at the OSHA PEL for a full work shift, accounting for the differences in retention and absorption of lead in each route. If hand–to–mouth transfer of lead is occurring, it could potentially be a significant route of exposure. There were differences in the effectiveness of hand washing between workers. This observation suggests a need for increased employee awareness of the need for adequate hand washing and as a last resort, possibly monitoring this practice.

The results of lead wipes collected around the mouths of employees are presented in Figure 3. The results from days two and three are very similar, with the average end–of–work concentration being 45 µg/wipe. A similar pattern of increasing lead concentration around the mouth is apparent on all four days. Results from days one and four produced correspondingly higher overall mean concentrations. It is unclear why there were several unusually high individual sample results on days one and four. It is not surprising that Pb was present around the mouth, since employees were observed with visible facial hair which can result in a poor respirator facepiece seal. Additionally, deficiencies were identified in the respirator program, specifically cleaning, maintenance, and reuse of cartridges. Observing employees at work revealed that occasionally the employees needed to speak to one another and broke the facepiece seal to communicate.

Analysis of the bulk lead oxide dust revealed that the lead oxide paste used in the plant is 99% lead by weight, and that 83% of the total lead is bio–available as determined by the ASTM Method.[20] The size of the particles ranged from approximately 1.0 to about 20 micrometers (µm) with an average of about 6 µm. The 1 µm particles seemed to be discreet, while the largest, at least in some cases, were clearly agglomerates. Because of the small size of the individual particles, the surface area to mass ratio is expected to be high.

Biological Sampling

Figure 4 shows the blood lead concentrations (provided by management) for the workers participating in the saliva Pb study. The concentrations range from 20 to 45 µg/dL. Extensive installation of new ventilation controls by the company prior to our survey, and reported improvements in the company's respirator use program after our survey, did not produce any significant overall trend in lower BLL concentrations during the five months since the NIOSH field survey. There were small differences in BLLs for six of the nine employees sampled twice. Failure to detect an overall declining trend in BLLs might adequately be explained by the contribution of lead skeletal deposits to the BLL.

A total of 141 saliva samples from twelve workers were collected and analyzed. Of those, 111 samples were analyzed by both ASV on–site and by GFAAS in the laboratory. The ASV and GFAAS data were both log–normally distributed (Shapiro–Wilkes W test) so the data were log transformed before conducting statistical analysis of the data (for the untransformed results, the ASV data mean was 5.1 times lower than the GFAAS mean). Figures 5 and 6 show the results of saliva lead analyzed by GFAAS and ASV methods, respectively. The ASV analytical results were significantly lower than the GFAAS results ($p<.001$, paired t–test).

Analysis of the correlations among environmental measures of lead exposure, blood Pb (BPb), and saliva Pb (SPb) (the GFAAS analysis was used because of the higher confidence in the analytical result) suggest that external lead exposures influenced the saliva results. All environmental measures of exposure were log normally distributed (Shapiro–Wilkes W test) and thus the data were log normally transformed before analysis. When BPb, the natural logarithm of hand lead (lnHand), mouth lead (lnMouth) and air lead levels (lnAir) were compared to lnGFAAS (saliva lead) for each period of measurement, the correlation was strongest between salivaPb and BPb for all but the last period. The correlation of lnAir and lnMouth to lnSPb increased considerably from the first to last period. This finding might be expected if inhalation and the amount of lead around the mouth were contributing to internal exposure, either from exogenous contamination around the mouth or from systemically absorbed lead. The correlation of SPb and lnHand measurements were low (i.e., nonsignificant slope) in the first period and remained low throughout the day. However, this finding should not be necessarily interpreted as indicating that hand–to–mouth transfer is not potentially important, since it is likely that a high inter–and intra–personal variability of this route of exposure might result in the low correlation coefficient and disguise the importance of this important route of exposure in individual cases.

DISCUSSION

The recently installed engineering controls at Standard Industries are state-of-the art design for the battery making industry. Despite the fact that in most instances local exhaust ventilation controls, such as hoods, downdraft tables, and process enclosures, were confirmed to be functional and were operating at adequate capture velocities for the control of lead dusts and fume, PBZ exposures exceeded the OSHA PEL. Observations in each production area help to explain some of these findings.

Grid Casting

The grid casting area uses enclosure hoods to contain fume which may be released by the molten lead. The temperature of the lead in the grid casting posts is kept below 1000°F by design, which was confirmed by NIOSH using a digital thermocouple. Very little, if any fume is generated when the temperature of lead is below 1000°F. The enclosure hoods were initially evaluated using chemical smoke and capture was determined to be adequate. PBZ exposures to Pb in this area were below 50 $\mu g/m^3$. Two area samples exceeding 50 $\mu g/m^3$ were found, however. These levels of lead in air are probably the result of work practices, specifically, dry sweeping the floor and dumping dross into an unventilated scrap barrel.

Pasting Area

Factory walls physically separate the pasting area from the rest of the production areas. Using smoke traces, the pasting area was confirmed to be negatively pressurized with regard to the rest of the facility. The paste mixer is configured with a circular slot hood located around the lip of the mixer. The flash dryer uses an enclosing hood and the plate catching stations are equipped with downdraft hoods. The tamping stations have small downdraft tamping areas. Swinging slot hoods are used in place behind the plate bins at the end of the pasting line. Using chemical smoke to visually identify airflow, the enclosure hoods on the flash dryers and the downdraft hoods on the tamping benches were determined to be operational. The swinging slot hoods appeared to provide capture at the plate stacking bins where pasted plates are deposited after they are removed from the conveyor. The plenum of the circular slot hood on the paste mixer was caked with dried lead oxide. This affected air flow and was confirmed by using smoke tube traces.

Pouching Area

The pouching lines are configured with slot hoods and downdraft hoods. The plate breaking stands are configured to serve as downdraft tables. Chemical smoke was used to confirm air movement and verify capture distance. The controls were appropriate, however, several observations suggest that the systems need increased attention to maintenance. Inspection of a section of flex duct connected to the downdraft plenum at the #1 pouching machine revealed a segment of the duct to be almost completely full of settled lead dust resulting in restricted capture velocity for the control. Several plastic pouches had fallen into the bottom of the plenum and one was blocking the screen at the bottom of the duct. Both of these situations restrict performance of the control by interfering with airflow. The downdraft hoods and tables and the slot hoods at the pouching machines were confirmed to be operational using chemical smoke.

Plate Stacking Areas

The plate stacking areas use four-sided enclosing down draft hoods. Capture velocity was determined to be adequate using chemical smoke. In this area, one overhead air shower at a workstation had been blocked with a piece of cardboard. This is occasionally seen when people find the delivery temperature of the air uncomfortable (the air is not tempered adequately) and disable the control by obstructing the diffusser.

TBS Machine

The TBS machine is configured with a canopy hood over the process (automatic welding). When the automatic welder was used, smoke was visible as it escaped from under the canopy hood. A section of flex duct connects the canopy hood to the branch exhaust duct. According to management, the section of flex duct is necessary because the canopy hood must occasionally be moved out of the way to service the machine. Excessive duct length and the rough surface on the inside of flexible ducting both interfere with the smooth movement of air in this type of duct. Friction loss caused by flex duct contributes to loss of velocity pressure in ventilation systems. As an example: for air at standard temperature and pressure moving through a duct at 4000 feet per minute (fpm), which is the suggested minimum transport velocity for lead dusts, the correction factor assigned to galvanized iron ducting or smooth galvanized ducting is 1.0 and 0.95 respectively. In other words, smooth duct negligibly interferes with the movement of air through ductwork. Calculating the estimated friction loss for a 20 foot section of smooth duct versus flexible duct at a transport velocity of 4000 fpm results in 1.3 inches of friction loss per 100 feet for galvanized (smooth) duct versus 3.1 inches of friction loss per 100 feet for the flexible duct. Capture efficiency can be increased by minimizing or eliminating unnecessary lengths of flexible ducting used in a system. A suggested remedy is listed in the NIOSH ECTB engineering controls report (see appendices A and B).

Respiratory Protection

Standard Industries has a written respiratory protection policy and uses qualitative fit testing (irritant smoke) to fit test employees. All employees in the production area are required to wear North™ half–mask respirators equipped with HEPA filters. Respirators are cleaned daily by an employee assigned to the laundry. The respirators are first disassembled and the facepieces are washed in a front–loading commercial washing machine with detergent. A close inspection of four respirator facepieces in–use by employees revealed that two facepieces had small tears in the lower inside corners of the facepieces. This damage may be due to aging of the rubber; however, the stress of mechanical agitation from a front–loading washing machine would be expected to aggravate deterioration of the facepiece. The HEPA cartridges were damp wiped with a towel to remove traces of lead on the outside of the cartridge. The cartridges were then turned upside down and tapped on a countertop to dislodge lead dust from the filter so the HEPA filters could be reused.

Lead contamination found on the inside facepieces of employees' respirators could be explained in several ways. The most obvious is that washing the facepieces in a machine used to launder clothing contaminated the facepiece with lead residue. Another explanation is that an inadequate respirator facepiece seal results in lead entering the respirator. This could be due to poor fit or facial hair coming into contact with the sealing surface of the mask. NIOSH investigators observed at least four workers with sufficient facial hair to compromise facepiece seals. In one case, an employee with a full beard was wearing a half–mask respirator. Improperly sized respirators could also account for poor facepiece fit and could allow lead particles to enter the respirator facepiece between the gaps in the seal of the facepiece. It is possible that lead dust passes through the filter itself because of filter damage. While this is an extremely remote possibility in a new HEPA cartridge (because all new HEPA filters are subject to an 0.3 micron aerosol challenge test) the HEPA cartridges used by employees at Standard Industries at the time of the investigation were reused for several weeks to even months at a time. A close inspection of one employee's respirator cartridge revealed a thin, continuous crack around the top joint of the plastic respirator filter cartridge. A knife blade was used to separate the top cap from the cartridge body. The HEPA cartridges consist of two pieces of plastic, a top cap and a bottom piece sealed together. The filter material rests on the bottom piece and is secured with the top cap. When the top cap was removed and the filter was exposed small dents were evident in the top ridges of the filter material. The dents matched exactly with rounded plastic ridges molded inside the top cap. The filter was removed and small tears were visible across the top ridges of the filter. The filter damage appeared to have been caused by repeatedly tapping the filter to dislodge the accumulated lead dust in the filter. Several other respirator cartridges were opened and damage to the filter material itself was also apparent.

Hand Wipe Samples

Appreciable variation in hand wipe samples was found both between workers and for an individual worker during the week. Possibly, a greater increase during the second half of the workshift compared to the first half may be due to the time required for penetration of lead through the glove seam outside the new gloves, or to the excretion of lead in sweat due to recently absorbed lead. Sweat, like saliva, draws from extracellular (plasma) lead. Perhaps the most likely scenario is that the workers may be contaminating their hands more during and directly after lunch through bare–handed contact with contaminated surfaces.

Salivary Lead Monitoring

This study provides important insights into several questions related to the interpretation of lead in saliva as a measure of exposure. Previous to this evaluation, very little was known about the temporal relationship between lead exposure and concentrations of salivary lead in industrial settings. The results of this evaluation of salivary lead should be considered preliminary.

This study documents a notable change in the daily saliva Pb concentrations from the beginning of the workshift until the end of the day. The most plausible reason for this increase would be that a measure of lead in the mouth is rapidly indicating the presence of lead in the workplace and exposure to lead. However, an exact route of exposure (e.g., inhalation or ingestion) and the specific form of lead (particulate lead or plasma lead) are less clear. For instance, not rinsing the mouth prior to collecting the saliva sample may allow inclusion of particulate lead from the interior surfaces of the mouth, and thus, bias accurate measurement of endogenous lead. Rinsing with a citric acid solution reduced the average saliva lead concentration (N=11 sets) to 30% of the non–rinsed concentration, apparently by removal of residual Pb particulates from the mouth. The similarity of the results after the first rinse compared to the results after the second rinse suggests that one or two rinses may be adequate to achieve a stable result. The post–rinse level may represent the true endogenous Pb level present in the extracellular fluid. The five–fold difference in the analytical results from the GFAAS and ASV (Figures 5 and 6) analytical procedures suggested at first, that sample preparation may be important before using the ASV device. It was thought that particulate lead present in a sample may not be "available" to ASV analysis due to a less aggressive digestion procedure compared to GFAAS. However, further laboratory experimentation has shown that the ASV electrodes can become fouled by proteins in saliva, and interfere with ASV analysis.

Whether the greater portion of lead is present as insoluble particulates from an exogenous source (e.g. lead from the workplace environment) or as salivary lead as a consequence of recent exposures is not completely clear. Filtering saliva samples did remove some lead suggesting the lead was present in particulate form. Additional research will be necessary in resolving these issues. Also, there was appreciable variation in the salivary lead results from each worker during the study period. This may be due to problems associated with sample collection and preparation, to normal variations in the magnitude of daily exposure, or to complexities associated with multiple routes of exposure, i.e., ingestion versus inhalation, where the rate of systemic absorption is different, which produces different lag times in uptake and distribution. It was not possible to record every environmental factor contributing to exposure and consequently the study did not identify an exact causal relationship between the salivary concentrations and the events leading to exposure.

The goal of the salivary lead investigation was to measure recently absorbed Pb excreted in saliva. The salivary Pb results obtained using GFAAS and ASV analytical procedures suggest that exposure through the oral route is a contributor to the overall body burden of lead in the workers evaluated. The correlation between saliva and blood lead levels support this. It is possible that with a better understanding of the role of sample preparation, saliva might be used to distinguish between endogenous and exogenous lead and the quantitation of oral ingestion of Pb could be explored. These results indicate the potential of this technique as an exposure monitoring tool and suggest the need for future research.

CONCLUSIONS

The results of workplace environmental monitoring indicate that airborne lead exposures exceed the OSHA 8–hour TWA PEL of 50 µg/m^3 (or the adjusted PELs for work periods exceeding 8 hours in length) in several locations of the plant. Personal breathing zone (PBZ) exposures were highest in the pasting, first assembly, and pouching areas of the plant. Two PBZ exposures in the pasting area (447 and 495 µg/m^3) approached the maximum use limit for half–mask respirators (10 times the PEL or 500 µg/m^3) used at the facility. The concentrations of lead measured in the air and on environmental surfaces point to overexposures to lead despite recent upgrades to the engineering controls. The results of salivary lead and blood lead biological monitoring of exposed workers point to excessive lead exposures in many job categories.

The saliva sampling study, while preliminary, provides important insights into several questions related to the interpretation of lead in saliva and demonstrates the potential utility of this method of exposure assessment. Portable ASV offers several possible attributes over commercial laboratory analysis. Results can be obtained within a few minutes of sample collection and since saliva results may reflect very recent exposure to lead, rapid sample turn–around may be especially helpful in identifying if work activities are related to exposures.

The half–mask respirators which are required as part of the respiratory protection program do not provide adequate protection due to improper maintenance procedures and inappropriate handling of filter cartridges which appears to result in filter and facepiece degradation. Insufficient sealing of the negative pressure respirators was not confirmed, but in some cases this is strongly suspected based on the presence of facial hair on employees wearing respirators. The presence of lead in the facepieces and around employee's mouths, and the presence of lead in saliva samples also point to deficiencies in the respiratory protection program. Enhancements in the respiratory protection program are of critical importance as demonstrated by the condition of the filters and facepieces which were inspected.

Lead contamination on cafeteria tables, food contact surfaces such as cutting boards and dermal contact surfaces in the cafeteria (e.g., food service rail, cafeteria door knobs, and the steam counter at the food serving line) presents increased risk for ingestion of lead by employees. Inadequate hand decontamination also appears to increase the risk for hand to mouth transfer and oral ingestion of lead. The approach needed for control of occupational exposures to lead at Standard Industries is multifactorial because exposures likely involve both inhalation and ingestion routes of exposure. The capital improvements made to the engineering control systems are appropriate and serve to enhance the control of lead dusts and fumes generated during battery building if the controls are appropriately maintained. However, the results of this investigation suggest that even the most extensive improvements and modifications to the local exhaust ventilation system will be insufficient to control lead exposures if plant and personal occupational hygiene issues (improved hand decontamination, decontamination of skin contact surfaces, and control of lead dust on the plant floor) are not aggressively addressed.

RECOMMENDATIONS

The following recommendations are provided in the interests of reducing occupational exposures to lead and reducing employee blood lead levels below 25 µg/dL, the guideline suggested by the U.S. Public Health Service. NIOSH investigators suggest taking a "worst–first" approach towards interventions in the workplace at Standard Industries. The recommendations below are prioritized with this in mind. Additional engineering control recommendations follow in the appendices of this health hazard evaluation.

Respiratory Protection

Significant improvements need to be made in the respiratory protection program at Standard Industries.

- Respirators should not be worn by employees whose facial hair comes in contact with the sealing surface of the negative pressure facepieces. Employees using respiratory protection should be clean shaven to achieve an optimum fit and seal with the facepiece. This should be emphasized as part of annual employee training and should be mandatory as a part of the respiratory protection program at Standard Industries.

- Respirator facepieces should not be washed in the front loading washing machine for several reasons: (a) lead was found to be present on the inside surfaces of facepieces that had been washed and were ready for re–issue to employees. The source of this lead is most likely the washing machine itself as lead contaminated clothing is reportedly washed in the machine; (b) the use of a front loading machine is not recommended for washing facepieces according to North™, the respirator manufacturer. Hand washing, or use of a machine designed specifically to clean facepieces is recommended. The HEPA cartridges are NIOSH certified as a disposable filter and as such, extended use of the filter cartridges is discouraged. Employees should receive training to understand that filter replacement is necessary whenever any change in breathing resistance is noticed by the employee.

- Respirator cartridges should never be tapped or shaken in an attempt to dislodge accumulated dust with the intent to extend service life of the filter cartridge. Realistically, the cartridges can be reused and still retain filter performance characteristics provided the filter is replaced as soon as any change in breathing resistance is noted by the employee. NIOSH certification TC–21C–152 assigned to HEPA cartridges manufactured by North Safety Equipment implies single use for these cartridge filters. Care should be taken when the cartridges are damp wiped to insure the filter material does not become wet.

- Quantitative respirator fit testing should be considered at Standard Industries to determine actual fit factors for employees. The qualitative testing in place at the time of the NIOSH investigation was inadequate. The "rainbow passage," (a section of text to be read by employees that simulates various facial expressions) was not required to be read during fit testing as mandated by OSHA. Recognizing that some employees may not be able to read the English text due to English being a second language, it may be necessary for these employees to repeat the words of the passage as it is read by a reader. Quantitative fit testing is an appropriate strategy to confirm fit of the respirator and insure an adequate facepiece seal under a variety of facial configurations. Additional information can be found in the guidelines provided in DHHS (NIOSH) Publication No. 87–116: ***A NIOSH Guide to Industrial Respiratory Protection.*** A copy of this guide was sent to Standard Industries following the second NIOSH site visit.

- A minimum of three facepiece sizes and two brands of respirators should be made available for employees to choose when selecting their respirators.

Personal Hygiene

- Hand cleansers specifically designed to remove metals from skin surfaces should be investigated for use. Solvent–free, walnut shell–based scrubbers are reported to be highly effective at removing metals and less aggressive on skin surfaces than pumice or plastic bead, grit–based cleansers. Repeated hand washing with aggressive cleansers is not recommended as this has been shown to aggravate or result in skin irritation. Protective water soluble creams applied to clean hands may facilitate easier removal of lead during washing. Inadequate hand decontamination increases the risk of ingestion of lead when eating or smoking.

- Disposable coveralls (worn over the work uniform) are suggested for employees' use in pasting, pouching, and first assembly areas or for other employees whose work uniform has the potential for becoming soiled with lead–containing dust. These coveralls should be removed before employees leave their workstations for breaks or to take lunch. The purpose of disposable coveralls is to reduce lead–containing dusts from entering the cafeteria and becoming resuspended or contributing to surface contamination.

- It may be useful for Standard Industries to consider a periodic surveillance program such as a "clean car day." This could involve using colorimetric indicators swabs to evaluate for the presence of lead on the steering wheels or other dermal contact surfaces in employees' cars. This is suggested to evaluate for the presence of "take home" lead and as surveillance for adequate hand decontamination.

Hygiene

Cafeteria

- The tabletops in the cafeteria are contaminated uniformly with lead. This appears to be related to dermal exposures and possible ingestion exposures to lead. It does not appear that all traces of lead can be completely removed from the tabletops with even aggressive cleaning using an acid solution. Discard the tables or replace the tabletops, or cover the tops of the tables with kraft paper, butcher paper or plastic and replace the coverings daily or as often as needed. Disposable table coverings result in increased plant waste and it is possible that lead dust could become airborne when removing the coverings. Probably a better alternative is to use steel or other smooth surface materials that has been shown to be cleanable. The railing in the cafeteria should be removed. It was shown that the railing in the food service line is a potential source of hand contamination. If a barrier is needed to maintain a service queue at the steam table, posts and pedestals connected together with a thick section of rope is one option for consideration. Employees routinely lean against the railing while they are in the food line and contact with work overalls appears to be the source of lead contamination on the rail. New cutting boards should replace those in the kitchen which were found to be contaminated with lead.

Plant

- An automatic boot wash should be installed outside of the lunchroom and employees encouraged to use this prior to entering the cafeteria for breaks or lunch to control lead dusts entering this area. Additionally, floor mats which remove debris from boot soles (referred to as "walk–off" mats) have been shown to be effective and should be considered for use in the entry to the cafeteria.

- Polyethylene, canvas, or another material should be used as a barrier or liner for the three–sided plate bins which are used for storage and transport of pasted plates to prevent lead–containing dusts from being shed onto the floor in this area. Based on visual observations, the pasted plates which are stored in the bins on the south side of the pouching area appear to shed lead dust onto the plant floor. The results of area air sampling in traffic isles confirm lead to be present in the air with no immediate sources nearby. Based on visual observations, forklift traffic is suspected as a contributing cause of the airborne lead in areas with no known sources. Related to this, the floor cleaner does not appear to completely remove lead dust from the floor. When the residual water from floor cleaning dries, dusts are left which can later become resuspended or moved via foot or forklift traffic. Settled dusts appear to contribute to the problem of lead dust in the air at Standard Industries.

- Resurfacing and sealing the plant floor is recommended in the interests of reducing sources of potentially airborne lead that can contribute to inhalation exposures. Chips, cracks, and unsealed surfaces of the floor interfere with the ability of the floor cleaning machine to effectively remove lead–containing residues from the plant floor. Despite frequent washing, lead dust was confirmed to be present (in suspension or as a wet paste) immediately after the floor cleaning machine made several passes of sections of the floor in the main traffic aisle. When the water evaporates, the dust can be resuspended and contributes to general area exposures in the plant.

Work Practices

- In grid casting, when the perforated shovel is used to remove dross from the lead pots, the hot dross should not be dumped directly into 55–gallon scrap containers. A chimney effect was apparent as the hot dross hit the bottom of the barrel and a small cloud of lead dust was released into the workplace air. A scrap barrel hood or a hood extension from the dross pot should be available to control lead dust during drossing operations.

- Corn brooms should not be used to dry sweep floors, stairs, or anywhere in the production area. Portable HEPA vacuums are suggested for use instead of dry sweeping. Using suction from the branch line hoses connected to the baghouse is also a possibility.

- Workstation engineering controls should be inspected by the area supervisor on a daily basis to insure that the controls are functioning as designed. Specifically, sliding blast gates should be checked for proper position and flex duct connections (of the shortest length reasonable) should be checked for settled lead dust. Duct obstructions, such as pouches or other debris, should be removed from exhaust plenums to insure optimum capture velocities.

- The use of a canopy hood is not recommended on the pouching line. Canopy hoods are not appropriate for processes using toxic materials where the worker's breathing zone comes under the canopy as air contaminants are directed past the worker's breathing zone in this situation. A slot hood is a more appropriate engineering control for this process.

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Tables 2-3
HETA 94-0268
July 1994
Standard Industries
San Antonio, Texas

Standard Industries
July 14-15,1994

Initial Industrial Hygiene Evaluation

Sample Number	Job Title or Location	Pb (µg)	Time (min)	Volume (l)	Pb (µg/m³)
	PBZ Samples				
SI-11	TBS 2, caser/unloader	34	405	790	43
SI-12	TBS 1, caser/unloader	60	406	792	76
SI-13	Pouching, machine operator	120	422	802	150
SI-14	Laundry room	2.8	316	608	5
SI-15	Tiegle burner	23	306	597	39
	Area Samples				
SI-6	Locker room - dirty side, end of shift	0.73	89	174	4
SI-7	Locker room - dirty side, end of shift	0.94	91	177	5
SI-8	Locker room - dirty side, end of shift	1.3	92	179	7
SI-9	Locker room - clean side	2	532	1037	2
SI-10	Locker room - dirty side	7	527	1001	7

	Wipe Sampling, location, type		**(µg/wipe)**
	Both Hands (taken while employees on break)		
SI-1W	Finishing Area, Battery Cleaner		730
SI-2W	Finishing Area, Battery Cleaner		110
SI-3W	Finishing Area, Wrapper		800
SI-4W	Finishing Area, Cleaner & Decorator		590
SI-5W	Finishing, Fork Lift Operator		1900
SI-6W	Machine Operator, Pouching		3400
		Reported Washing Hands?	
SI-17W	Paste Mixing	Y	1700
SI-18W	Paste Mixing	Y	1600
SI-19W	Paste Mixing	Y	1100
SI-20W	Paste Mixing	Y	5100
SI-21W	Paste Mixing	Y	1700
	Surfaces (1 sq.ft.)		
SI-7W	Cafeteria table, after employee break		230
SI-8W	Cafeteria table, N door leading to plant		47
SI-9W	Railing, cafeteria food service line		3700
SI-10W	Cafeteria table near S exit		430
SI-11W	Cafeteria table, N door leading to plant		720
SI-12W	Cafeteria table, center of cafeteria		440
SI-13W	Cafeteria table adjacent to S exit		1400
SI-14W	Receptionist's desk, plant front door		93

Table 4
HETA 94-0268
March 1995
Standard Industries
San Antonio, Texas

	Standard Industries **March, 28,1995**	**Follow-up Industrial Hygiene Evaluation**			
Sample Number	**Job Title or Location**	**Pb (μg)**	**Time (min)**	**Volume (l)**	**Pb (μg/m^{3})**
	PBZ Samples				
SI-22*	Pouching	85	637	1306	65
SI-23*	Pouching	61	616	1217	50
SI-29*	Pouching	95	613	1226	77
SI-31*	1st Assembly	440	513	1052	418
SI-128*	1st Assembly	27	610	1190	23
SI-28	1st Assembly, Plate Stacking	30	478	920	32
SI-24*	Tiegle Burning	71	606	1212	58
SI-30*	Pasting	180	509	1043	172
SI-33*	Pasting	240	508	1041	230
SI-26*	Pasting	380	503	1031	368
SI-32*	Paste Mixer/driving forklift	290	498	1021	284
SI-27	Pasting, QA/QC	60	431	884	68
	Area Samples				
1AS-1	1st Assy., Ln. 3, under diffusser, casing station	39	501	1002	39
1AS-2	1st Assy., Ln. 4 under diffusser, casing station	13	500	1000	13
1AS-3	1st Assy., Ln. 4, Tiegel Burner	25	500	988	25
1AS-4	1st Assy., Ln. 3, Tiegel Burner	17	499	998	17
2AS-1	2nd Assy., Post Burning, above slot hood	37	467	934	40
GC-A1	Grid Casting, operators station	15	466	932	16
GC-A2	Grid Casting, operators station	15	464	928	16
GC-A3	Grid Casting, operators station	21	460	943	22
PA-A1	Pasting, paste line end, below air diffusser	0.79	514	1028	1
PA-A2	Pasting, paste line end, outside diffusser	40	509	1043	38
PA-A3	Pasting, operator station, head of paste line	93	513	1013	92
PA-A4	Pasting, upper level, at the mixing pot	170	515	1030	165
POU-A1	Pouching, above plate breaking station	37	514	1054	35
POU-A2	Pouching, end of pouch line, PBX height	52	513	1026	51
POU-A3	Pouching, above plate breaking stand	41	512	1050	39
POU-A4	Pouching, midway along pouch line	24	513	1026	23

* > 8 hour workday therefore OSHA PEL in μg/m^{3} = 400 / # hours worked in the day.

Table 5
HETA 94-0268
March 1995
Standard Industries
San Antonio, Texas

Standard Industries
March 29,1995

Follow-up IH Evaluation

Sample Number	Job Title or Location	Pb (μg)	Time (min)	Volume (l)	Pb ($\mu g/m^3$)
	PBZ Samples				
SI-41*	Pouching, (overhead diffusser blocked)	65	611	1191	55
SI-40*	Pouching	37	598	1166	32
SI-44*	1st Assembly	65	588	1176	55
SI-45*	1st Assembly	230	585	1170	197
SI-51*	1st Assembly, Mixing Epoxy	15	489	978	15
SI-50*	Pasting	240	496	992	242
SI-48*	Pasting, plate catcher	300	478	956	314
SI-49*	Pasting, grid loader	290	499	998	291
SI-47*	Pasting, plate catcher	360	507	989	364
SI-46*	Paste Mixer, driving forklift	300	540	1080	278
SI-54	Grid Casting, Line 4	10	439	867	12
SI-55	Grid Casting, Line 8	11	435	859	13
	Area Samples				
SI-43	1st Assembly	22	607	1168	19
SI-25	Pouching, PBZ height near end of line	14	612	1224	11
SI-52	TBS machine, Line 1 plate loader	7.7	552	1104	7
SI-53	TBS machine, Line 1 cell unloader	2.5	554	1108	2
SI-56	Finishing, post burnishing	13	530	1087	12
SI-57	Finishing, middle of line	7.8	529	1058	7
SI-58	Finishing, end of line	6.3	519	1012	6
SI-60	Pow-R-Dry Line	4.1	519	986	4

* > 8 hour workday therefore OSHA PEL in $\mu g/m^3$ = 400 / # hours worked in the day.

Table 6
HETA 94-0268
March 1995
Standard Industries
San Antonio, Texas

Standard Industries **Follow-up IH Evaluation**
March 30,1995

Sample Number	Job Title or Location	Pb (μg)	Time (min)	Volume (l)	Pb ($\mu g/m^3$)
	PBZ Samples				
SI-61*	1st Assembly, group burning	71	508	1016	70
SI-64*	1st Assembly, caser	69	600	1200	57
SI-66*	1st Assembly, plate stacking	200	582	1164	172
SI-68*	1st Assembly	130	650	1300	100
SI-63*	Pouching, line 1	51	607	1214	42
SI-72*	Pasting, plate catcher	360	509	1018	353
SI-70*	Pasting, machine operator	170	517	1034	164
SI-69*	Pasting, plate catcher	350	513	1026	341
SI-73	Pasting, paste mixer	420	470	940	447
SI-71	Pasting, machine operator	280	470	940	298
SI-74	Small parts casting	62	466	932	66
SI-75FF	Grid Casting, lines 1 & 2	39	454	908	43
	Area Samples				
A-30-1	End, Pow-R-Dry line	11	613	1226	9
SI-62	Pouching	48	642	1284	37
A-30-2	Main traffic aisle midway on L	12	612	1224	10
A-30-3	East side aisle, 4th pillar on desk	12	500	988	12
A-30-4	East Side aisle, 6th pillar	11	499	998	11
A-30-5	Main aisle, 1st H pillar	15	467	934	16
A-30-6	Main aisle, midway on R	2.5	466	932	3
A-30-7	Main aisle, L, rack #3 assembly	30	464	928	32
A-30-8	Main aisle, H pillar, right side	32	460	943	34
A-30-9	Finishing, post burnishing	16	514	1028	15
SI-67	Grid Casting , Station 9	35	612	1224	28
A-30-20	Cafeteria, east, near fire exit door	1	448	918	1
A-30-21	Cafeteria, south side, near double doors	0.9	443	875	1
A-30-22	Cafeteria, north wall	0.8	322	644	1
A-30-23	Kitchen, above food preparation area	1.6	489	1002	2
A-30-24	Pouching, end pouching line	52	513	1026	51

* > 8 hour workday therefore OSHA PEL in $\mu g/m^3$ = 400 / # hours worked in the day.

Table 7
HETA 94-0268
March 1995
Standard Industries
San Antonio, Texas

	Standard Industries **March 31,1995**			**Follow-up IH Evaluation**	
Sample Number	**Job Title or Location**	**Pb (μg)**	**Time (min)**	**Volume (l)**	**Pb ($\mu g/m^3$)**
	PBZ Samples				
SI-75*	Pouching	39	623	1246	31
SI-78*	Operator, Pb Oxide Mill	150	596	1192	126
SI-76*	Tiegle Burning	17	624	1248	13
SI-82*	Pasting, breaker	100	505	1010	99
SI-81*	Pasting, machine operator	290	505	972	298
SI-80*	Pasting, plate stacking	490	507	989	495
SI-79	Paste Mixer	330	399	778	424
SI-77*	1st Assembly	130	624	1279	102
	Area samples				
SI-83	Pouching, Line 1	12	546	1092	11
A31-2	1st Floor Conference room, N end of room	13	613	1226	10
A31-3	1st Floor Conference Room, S end of room	12	616	1232	10
A31-4	Pb Oxide Mill, operators station	67	571	1113	60
A31-5	Pb Oxide Mill, weigh station	240	571	1142	210
A31-6	Grid Castng, #9, shoveling dross lines 1&2	140	509	993	141
A31-7	Grid Casting, sweeping with push broom	63	508	991	63
FLS-1	Floor Sweeper, near PBZ, driver's seat	5	389	759	6

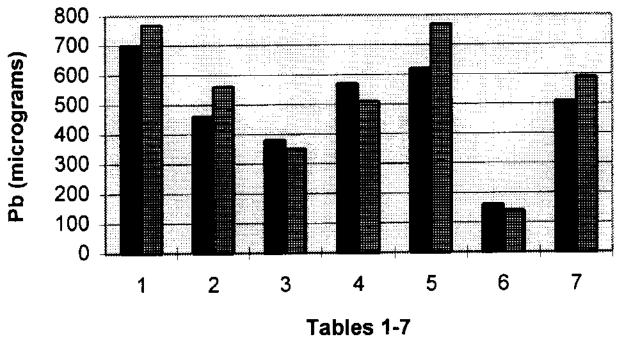
* > 8 hour workday therefore OSHA PEL in $\mu g/m^3$ = 400 / # hours worked in the day.

Table 8
HETA 94-0268
March 1995
Standard Industries
San Antonio, Texas

Cafeteria Tables 1-7 Wipe Sample Pairs

Sample #	Pb (µg/sq.ft.)	Sample #	Pb (µg/sq.ft.)
SI-TT1a	700	SI-TT1b	770
SI-TT2a	460	SI-TT2b	560
SI-TT3a	380	SI-TT3b	350
SI-TT4a	570	SI-TT4b	510
SI-TT5a	620	SI-TT5b	770
SI-TT6a	160	SI-TT6b	140
SI-TT7a	510	SI-TT7b	590

Results of Paired Wipe Samples from Cafeteria Tables (SITT1a- SITT7b)



Notes regarding the data in Table 7:
Cafeteria tables wipe sampling and cafeteria table cleaning investigation are discussed on page 9 of the report. Discussion of second floor conference room and lab bench table cleaning evaluation discussed on pages 9 & 10 of the report.

Wipe Samples, Cafeteria Tables - cleaning investigation

Sample pairs	Collected by:	Cleaning Agent	Pb (µg/sq.ft)
SI-TT40, 41	AS/EE	3% Nitric acid	530, 540
SI-TT42,43	AS/EE	Detergent	140, 250
SI-TT45,46	EE	3% Nitric acid	2400, 7700
SI-TT47,48	AS	Detergent	160, 120

Second Floor Conference Room and Lab Bench Tables Cleaning Evaluation

Location	Action	Pb (µg/sq.ft)
Table	initial wipe	220
Table	sani tough + abrasive pad	90
Lab bench	first wipe	7600
Lab bench	sani tough + abrasive pad	380
Lab bench	final wash	110

Lead on Cutting Boards in Kitchen		Pb (µg/sq.ft)
SICB-1	Cutting Board #1-center	8.5
SICB-2	Cutting Board #2-center	19
SICB-3	Cutting Board #3-edge	28
SICB-4	Cutting Board #3-corner	20
SICB-5	Cutting Board #2-opp. side center	25
SICB-6	Cutting Board #1-opp. side center	(Trace)
SICB-7	Cutting Board #3-opp. side	130

Miscellaneous Samples, Cafeteria		Pb (µg/sq.ft)
SI-TT11,12	Top of steam table - serving line	140/320
SI-DK17,18	Doorknob - in/out of cafeteria	90/160

Trace= < limit of quantitation

Table 9
HETA 94-0268
March 1995
Standard Industries
San Antonio, Texas

Hand Wipe Samples

Sample # (before lunch)	Pb (µg)	Sample # (after lunch)	Pb (µg)
HW1B	190	HW1A	280
HW2B	59	HW2A	110
HW3B	260	HW3A	670
HW4B	1300	HW4A	1300
HW5B	530	HW5A	850
HW6B	33	HW6A	120

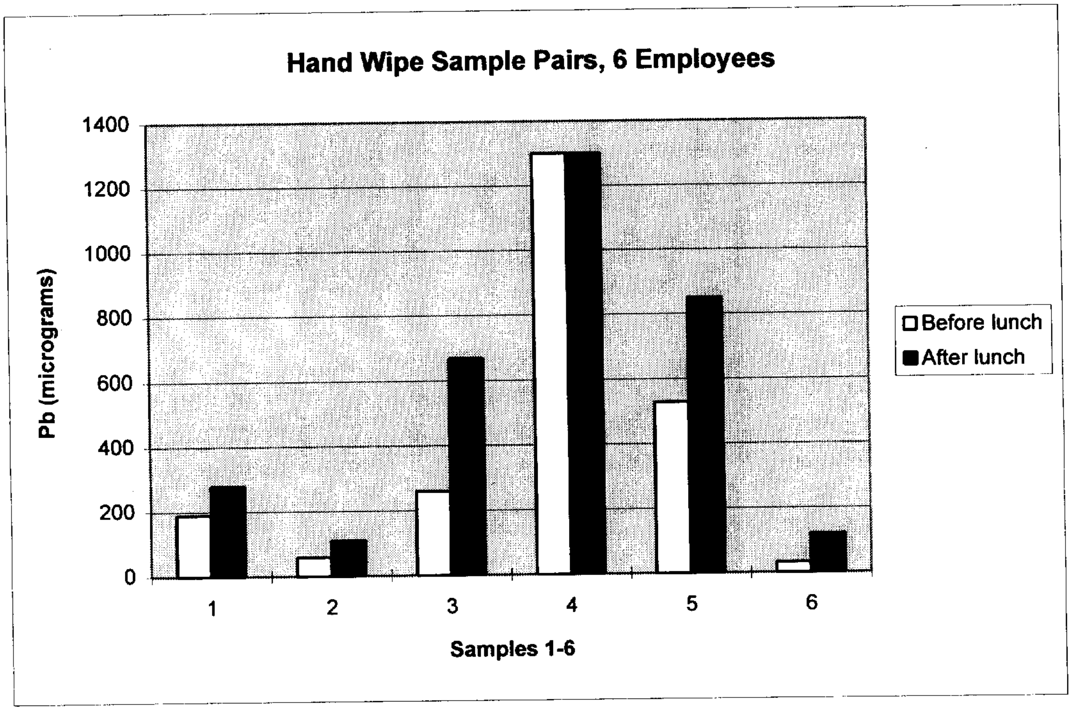


Figure 1
HETA 94-0268
Standard Industries
San Antonio, Texas
March 27-31, 1995

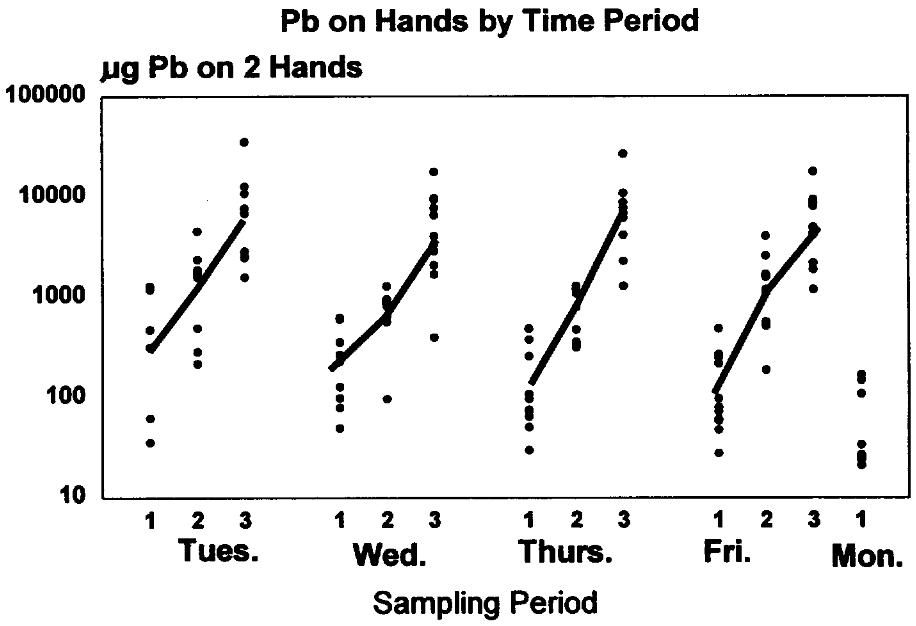


Figure 2
HETA 94-0268
Standard Industries
San Antonio, Texas
March 27-31, 1995

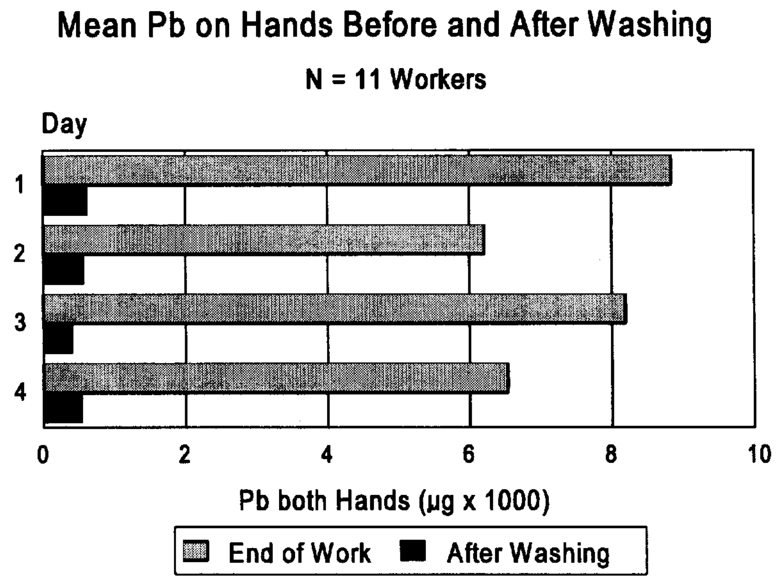


Figure 3

HETA 94-0268
Standard Industries
San Antonio, Texas
March 27-31, 1995

Pb in Skin Wipes Around Mouth

Period 1 = Arrival at Work, 2 = Before Lunch, 3 = End of Work

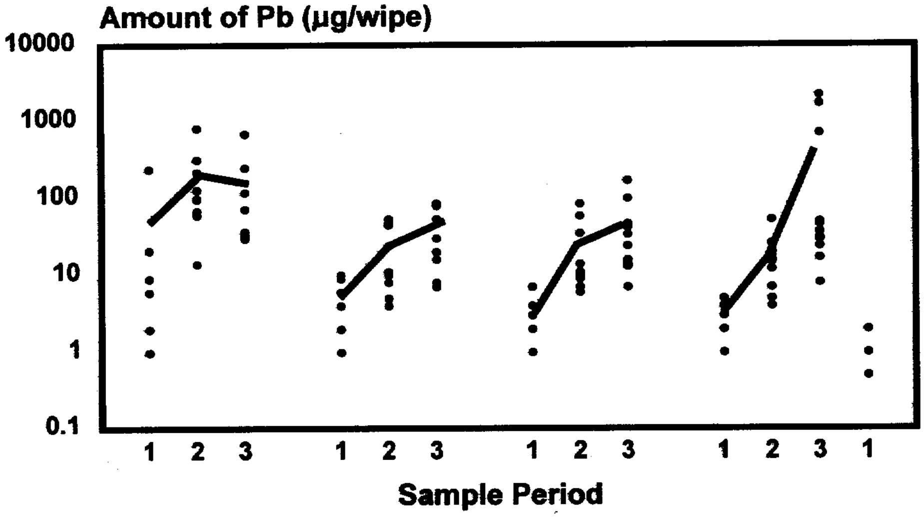


Figure 4

HETA 94-0268
Standard Industries
San Antonio, Texas
March 27-31, 1995

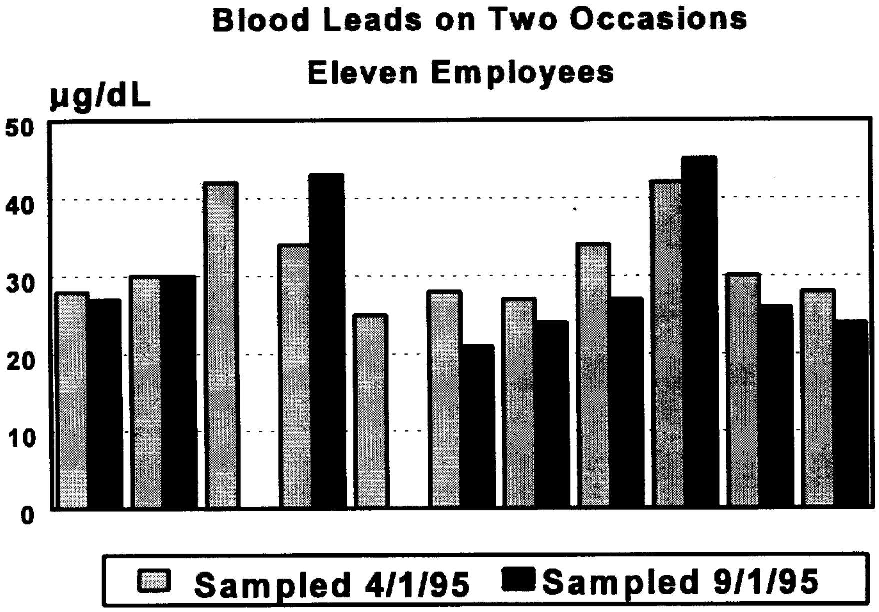
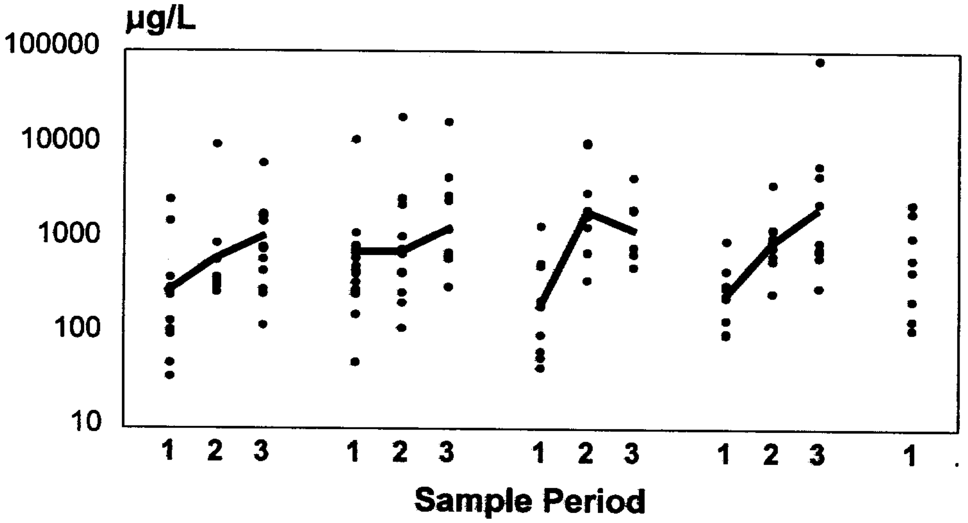


Figure 5
HETA 94-0268
Standard Industries
San Antonio, Texas
March 27-31, 1995

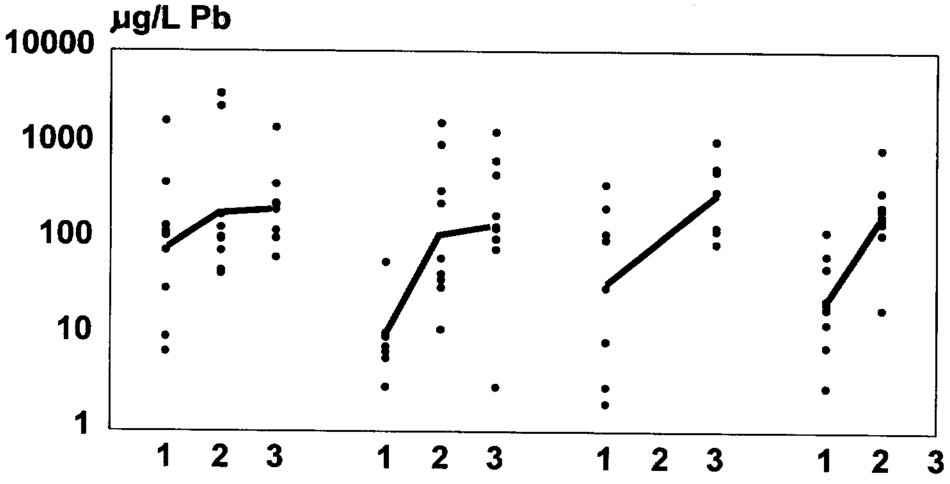
Distribution of GFAAS Saliva Results by Period and Day



nine participants

Figure 6
HETA 94-0268
Standard Industries
San Antonio, Texas
March 27-31, 1995

Distribution of ASV Saliva Pb Results by Sample Period and Day



nine participants

APPENDIX A

Engineering Control Technology Evaluation and Video Exposure Monitoring
HETA 94-0268
Standard Industries
San Antonio, Texas

Ronald M. Hall
Kenneth Mead, P.E

ENGINEERING CONTROL TECHNOLOGY

Standard Industries employs automation, local exhaust ventilation, partial enclosures, clean-air showers, and enclosed ventilation systems throughout the plant in an effort to control worker exposure to lead. In addition, HEPA-filtered half-mask respirators are worn in production areas of the plant.

METHODOLOGY

During the evaluation, each worker sampled wore two air sampling pumps. One sampling pump was used to collect a personal sample from the worker's breathing zone. The other sampling pump pulled air (at 2 Lpm) through the Hand-held Aerosol Monitor (HAM) sensing probe for real-time aerosol concentration analysis. A mixed-cellulose ester (MCE) filter located at the exit of the HAM sensing probe collected the captured aerosol for lead concentration analysis. In this manner, it was possible to verify that the aerosol detected by the HAM contained lead.

Both full-shift air sampling and short-term air sampling for the duration of a specific task were performed. Personal and area samples were collected for lead analysis. These samples were analyzed using a Thermo Jarrell Ash Inductively Coupled Argon Plasma 61E Trace Analyzer according to NIOSH Method 7300MOD.(1) These samples were collected on 37-mm diameter mixed cellulose ester, 0.8-µm pore-size filters using SKC pumps at 2.0 liters per minute (Lpm).

Video Exposure Monitoring

Video Exposure Monitoring (VEM) is an evaluation process which combines real-time sampling with a video recording of an observed task. The two signals are combined into a single video recording which uses a moving histogram on the video screen to show exposure concentrations while they occur. VEM was performed to evaluate worker exposures in the casting, pasting, pouching, and assembly areas. The VEM analysis was conducted to improve our understanding of how workers' individual tasks can effect personal exposure to air contaminants.

During a variety of battery manufacturing operations, the HAM was the real-time monitoring instrument used to measure relative air contaminant concentrations. An airborne aerosol is drawn through a sensing chamber and the aerosol scatters light emitted from a light-emitting diode which is then detected by a photomultiplier tube. The quantity of scattered light is a function of aerosol concentration, particle size, and refractive index. The HAM reports the aerosol concentration using an analog output proportional to the intensity of scattered light. Because the laboratory calibration of the HAM varies with aerosol properties, the analog output of the HAM is viewed as a measure of relative concentration.

RESULTS

Personal and area sample results, collected in different areas of the battery manufacturing plant during the engineering control evaluation, were compared for significant differences. Statistical analyses were performed on log transformed data.(2) Analysis of variance (ANOVA) revealed that personal sampling location had a significant affect upon exposures (probability $> F < 0.0001$).(3) A multiple comparison test, Least Significant Difference (LSD), was used to examine the exposure differences between the battery manufacturing areas. Concentration differences are shown in Table I. A significance level 0.05 is the basis for the following discussion. Samples, in the various areas of the plant, were collected on different days, therefore, daily variation in area processes could be a factor in significance.

Air sample lead concentrations (personal and area samples) in the paste machine area were significantly higher than air lead concentrations in the pasted-plate stacking, pouching, casting and drossing, and assembly areas. This indicates that the highest air lead concentrations in the plant (during the engineering control evaluations) were obtained in the paste machine area. The lead concentrations in the pasted-plate stacking, pouching, casting and drossing, and assembly areas were not significant in difference.

Table I
Personal exposures to lead by battery manufacturing operation.

Location	Number of Samples	Geometric Mean (µg/m^3)	Range (µg/m^3)	* Multiple Comparison Test Code
Pasting Machine Area	6	212	151-679	A
Plate Stacking Area (Pasting)	4	46	9-103	B
Pouching Machine Area	6	59	18-128	B
Pouching Stacking Area	3	50	26-121	B
Grid Casting and Dross Area	5	28	9-69	B
First Assembly Area	9	39	4-265	B

* Least Significant Differences (LSD) method: geometric means with different Comparison Test Codes differ significantly.

CASTING AND DROSSING OPERATIONS

Personal and area samples collected in the grid casting area are presented in Table II at the end of this appendix. The employee performing drossing, loading lead ingots in the grid casting machines, and performing clean-up activities had a lead exposure of 69 µg/m^3 during our VEM evaluation. Three full-shift area samples were collected in the casting area to evaluate the amount of airborne lead generated during casting operations. One area sample, collected near a casting machine's melting pot, revealed an air lead concentration of 11 µg/m^3. Another area sample, collected near the lead plate casting exit, revealed a concentration of 9 µg/m^3. Analysis results for the third area sample, collected above an exhaust hood serving a grid casting machine's melting pot, (located near the scrap-lead chute) reported a lead concentration of 69 µg/m^3. This sample result indicated that lead could escape the capture of the melting pot's exhaust hood and release into the general shop area.

VEM was conducted in the grid casting area to identify how the worker's individual tasks affected personal exposure to air contaminants. The filter sample collected at the HAM probe's exit had a lead concentration of 37 µg/m^3, indicating the presence of lead in the aerosol detected by the HAM. Within the grid casting area, the highest relative concentrations were observed when the worker performed drossing and clean-up operations.

During drossing operations, the worker removed the dross from the molten lead pot (at the casting machine) and dumped it in an unventilated drum. The average HAM response during this operation was 0.311 mg/m^3 and the integrated response (concentration multiplied by time) was 32.97 (mg/m^3)(sec) (see Figure 1 for HAM response peaks during this operation). High HAM responses were also seen during clean-up activities. The worker would pick up large pieces of scrap lead off the floor and place them in a chute which feeds the melting pot. The worker manually pushed the material into the melting pot. During this procedure the worker's breathing zone was placed within the capture zone of the exhaust hood of the melting pot. The average HAM response during this operation was 0.308 mg/m^3 and the integrated response was 40.62 (mg/m^3)(sec) (see Figure 1 for HAM response peaks during this operation). High HAM responses were also seen during dry sweeping operations in the casting area. The average HAM response during sweeping was 0.119 mg/m^3 and the integrated response was 20.01 (mg/m^3)(sec). Figure 2 shows the peaks for sweeping operations.

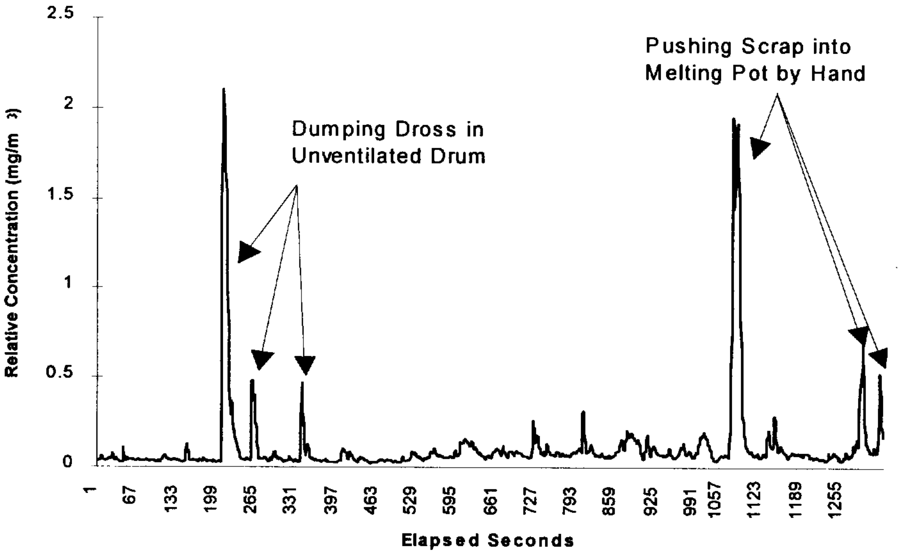


Figure 1. Drossing and Clean-up Operations

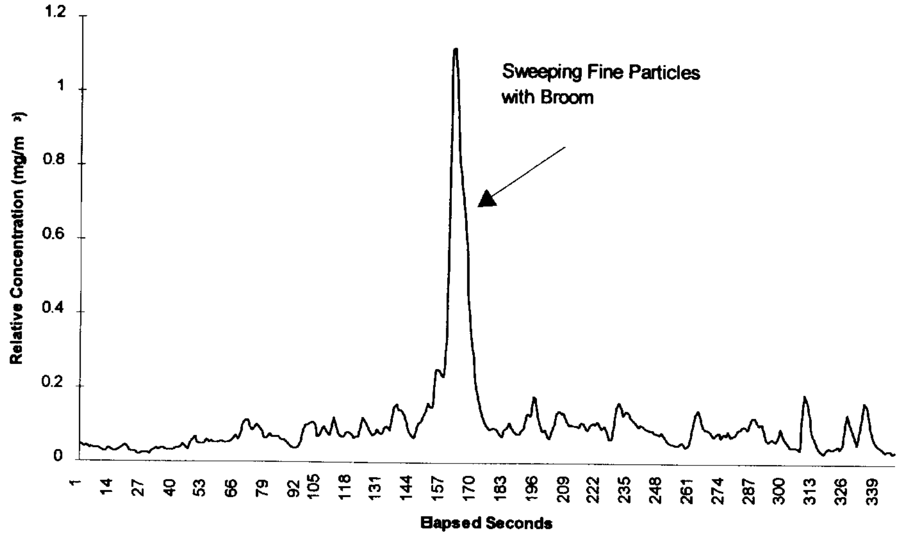


Figure 2. Sweeping Operations

POUCHING OPERATIONS

Personal and area samples collected in the pouching area are listed in Table II. The employee operating and loading the pouching machine with pasted lead plates had a lead exposure of 119 µg/m^3 during our real-time monitoring evaluation. The PBZ sample for the worker stacking the pouched plates into a pallet was 121 µg/m^3 during the evaluation.

Area samples for lead were collected above the conveyor at the pouching machine's exit; above the down-draft hood at the plate breaking station; near the pouching machine operator's breathing zone; and above the pallet where the pouched plates were stacked. The highest concentrations were reported near the pouching machine exit, above the belt conveyor. Concentrations in this area had a geometric mean lead concentration of 114 µg/m^3. Area sample results for samples collected near the plate breaking down draft hood and the pouching operator's breathing zone were 57 µg/m^3 and 18 µg/m^3. The area sample collected above the pouched plate pallet was 26 µg/m^3.

The VEM was used in the pouching area to measure relative air contaminant concentrations and improve our understanding of how the worker's individual tasks can affect personal exposure to air contaminants. A sample was collected at the exit of the HAM probe (near the workers' breathing zone) during clean-up and pouched plate stacking activities. The air lead concentration for this sample was 40 µg/m^3. Another sample, collected at the exit of the HAM probe (near the workers' breathing zone), was collected on the worker operating the pouch machine. This sample revealed an air lead concentration of 26 µg/m^3 during our VEM evaluation.

The worker responsible for stacking the pouched plates in the pouching area had the highest relative concentrations during clean-up and set-up operations (see Figure 3 for relative peak concentrations). During pouching operations, pouches that could not be used were placed in a cardboard box. During clean-up operations, the worker collected the box (full of rejected pouches and other trash) and dumped it into a larger cardboard box. During this task the average HAM response was 0.09 mg/m^3 and the integrated response was 7.55 (mg/m^3)(sec). The worker also generated HAM responses during reel changing operations on the poucher. After the worker removed the old reel, he retrieved a new reel from an adjacent area and placed it on the spool. Next, the worker struck the reel with his shoulder to firmly position the reel on the spool. This shoulder blow caused high HAM responses. The average HAM response during this task was 0.12 mg/m^3 and the integrated response was 5.92 (mg/m^3)(sec). We speculate that the source for these responses were either from dust on the new reel or from dust falling off of the worker's clothing. The HAM's response from the reel replacement activity shows up clearly on the graph in Figure 3.

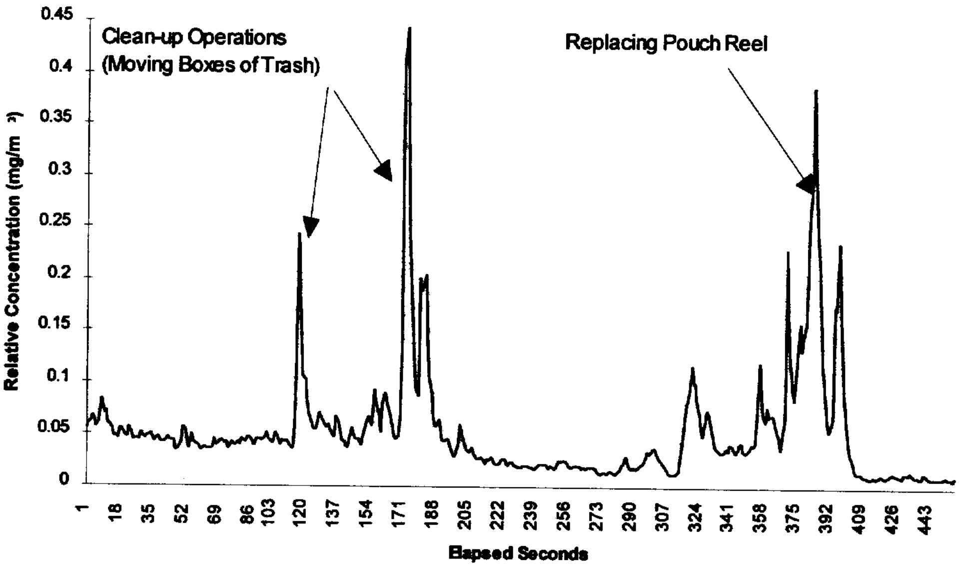


Figure 3. Setup Procedures for Pouch Machine Area

During regular work activities the worker spent most of his time stacking pouched plates in front of the 2 slot ventilation hood. The average HAM response during pouched plate stacking activities was 0.02 mg/m^3 with an integrated response of 15.18 (mg/m^3)(sec). During these activities the worker received peak HAM responses when removing lead plates from defective pouches (see Figure 4). The worker also received high HAM responses when placing pouched lead plates in the storage bin (see Figure 4). However, this operation was not performed regularly and did not account for a significant amount of time during the real-time monitoring evaluation.

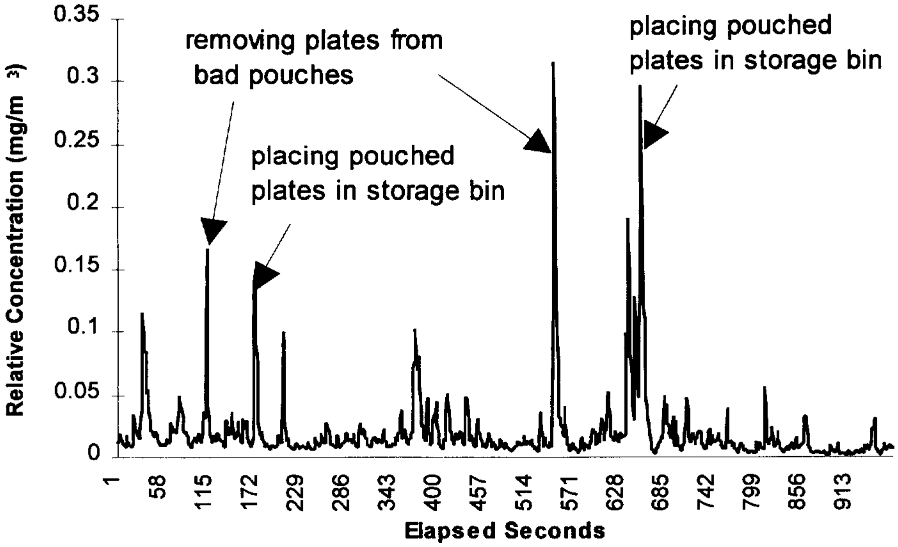


Figure 4. Pouch Stacking Operations

Figure 5 describes HAM responses while running the pouch machine. The worker operating the pouching machine received the highest relative exposures during activities that included retrieving the pasted plates from the storage bin, breaking pasted plates, loading the pouch machine, and running the pouch machine in the pouching area. The average HAM response during the plate retrieving activities (getting pasted plates from the storage bin) was 0.047 mg/m^3 with an integrated response of 7.22 mg/m^3*sec. During pasted plate breaking activities the average HAM response was 0.046 mg/m^3 with an integrated response of 10.8 (mg/m^3)(sec). When loading the pouch machine with pasted plates the average HAM response was 0.054 mg/m3 with an integrated response of 9.08 (mg/m^3)(sec). When working directly in front of the pouching machine, the average HAM response was 0.053 mg/m^3 with an integrated response of 9.78 (mg/m^3)(sec). The worker also received peak exposures when slapping his hands together after handling pasted lead plates (see Figure 5 for peak). However, the time during this activity was low and therefore, was not a major contributor to the overall exposure.

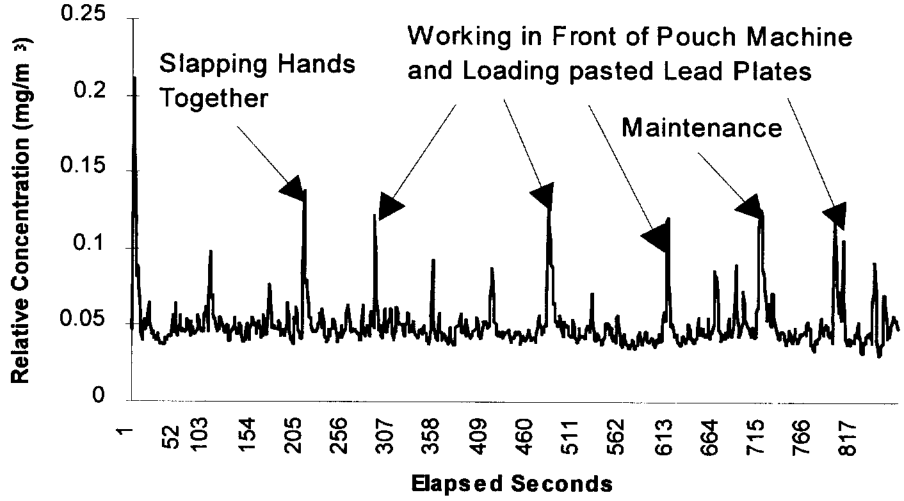


Figure 5. Running Pouch Machine

Ventilation

Table III lists the ventilation measurements obtained in the pouching area (located closest to the assembly area) during real-time monitoring evaluations.

Table III
Ventilation measurements obtained at the pouching machine area.

Location	Air Volume (cfm)	Average Face Velocity (fpm)
Downdraft table at pouch stacking area	210	154
Slot hood at pouch stacking area	500	2860
Canopy hood located over pouching machine	600	147
Downdraft ventilation at pouch machine	No measurement	545
Downdraft table (plate breaking table)	1050	394

Paste Machine Operator

Personal and area samples collected in the pasting machine area are listed in Table II. During our VEM evaluation, the paste machine operator's PBZ concentration was 176 µg/m^3. A consecutive personal sample, installed on the worker after the real-time monitoring, experienced an unexplained pump failure after 40 minutes of sample time. This sample's subsequent analysis reported an unrealistically high lead concentration. Although listed in Table II, this sample is considered to be an anomaly and not representative of actual concentrations, and is not addressed further in this report. Three area samples were collected during the real-time evaluation. All three samples were located at approximate breathing zone height, one on each side of the paste machine and one above the grid loading area at the entrance to the paste machine. The results indicate area lead concentrations of 166.7 µg/m^3 (L. Side), 162.7 µg/m^3 (R. Side), and 151.5 µg/m^3 (entrance). An additional area sample collected above the grid loading area later in the day identified a lead concentration of 185.7 µg/m^3.

We conducted VEM monitoring of operations in the paste machine area to determine which work activities or work areas contributed a greater proportion to the worker's airborne lead exposure. Numerical comparisons were achieved using the relative concentrations reported by the HAM. During the VEM, a filter attached to the HAM's exit port collected airborne particulate for analysis for lead. Laboratory results indicate that the airflow through the HAM had a lead concentration of 681.8 µg/m^3. The paste machine operator conducted several tasks during the evaluation period. For task-analysis purposes, we divided the activities into three categories; (1) paste machine set-up, (2) machine operation, and (3) paste roller repair.

Paste Machine Setup: Due to the multitude of individual tasks associated with paste machine setup, this category was evaluated by identifying the different work areas as opposed to different tasks. A summary of the HAM results vs areas is in Table IV.

Table IV

Summary Statistics For Paste Machine Setup

Code	Area	Count	Average	Sum
1	In/near Toolbox	52	0.165338	8.5976
2	Paste Machine	456	0.164663	75.0862
3	Out of Area	126	0.140606	17.7164
4	Grid Loading	202	0.138277	27.932
5	Camera Off	38	0.172484	6.5544
6	Roller Area	394	0.188299	74.1898
Total		1268	0.165675	210.076

Where:
Code = Category designation used for analysis
Area = Work area description
Count = Number of seconds elapsed for this category
Average = average relative response from the HAM (units are mg/m^3)
Sum = Represents the integrated relative exposure (Count x Average)

Of the six coded areas in Table IV, the exposures received during codes 1, 3, and 5 are related to the retrieval of tools and parts required by the worker. Combined, these codes contributed to only 15.6% of the worker's exposure. We speculate that much of this exposure could be easily eliminated through regular cleaning of tool storage and parts storage areas. Of the remaining three identified areas, the roller area (code 6) is the only area where the proportion of exposure is greater than the proportion of time spent in that area. Much of the activity spent in the roller area required banging and prying on equipment. This activity dispersed lead dust into the air. A thorough wetting of this equipment prior to setup could reduce some of this exposure. An additional concern, which arose after viewing the VEM video tapes, is the potential for lead dust to fall down through the grating from the overhead paste mix area and into the paste machine working area. The ANOVA comparison analysis discussed previously identified the paste machine area as the only evaluated area with significantly higher levels of airborne lead. Any future analysis of the paste machine operations should consider the overhead paste mix area as a possible contributor to the elevated exposures.

Pasting Machine Operation

Pasting machine operations were the largest time segments evaluated. This was done to evaluate exposures created during the normal operation during grid pasting. The individual activities observed during the real-time evaluation was separated into five categories. These are identified with the summary statistics in Table V.

Table V
Paste Machine Operation

Code	Description	Count	Average	Sum
1	Loading Grids	1088	0.122333	133.099
2	Checking Paste Supply	495	0.116441	57.6384
3	In Toolbox	9	0.109933	0.9894
4	Misc. Maintenance	41	0.106985	4.3864
5	Removing Plywood	24	0.180058	4.3214
Total		1657	0.127150	200.435

Where:
Code = Category designation used for analysis
Description = Task description
Count = Number of seconds elapsed for this category
Average = Average relative response from the HAM (units are mg/m^3)
Sum = Represents the integrated relative exposure (Count x Average)

The evaluation of paste machine operations was over 30% longer than the paste machine setup evaluation. However, average concentration during operation is much lower. The result is a lower activity-related total exposure for paste machine operation despite the longer evaluation period. In general, the activity-related concentration for the evaluation appears to roughly coincide with the area-related concentrations recorded during the set up period. The exception to this is during removal of plywood supports sandwiched between layers of grid plates. During this activity, the HAM's measured concentration levels increased significantly. Control solutions to this situation could include substituting plastic grate spacers for plywood, vacuuming the plywood with a ventilation attachment or HEPA filtered vacuum, or using wet methods to wash lead dust from the plywood prior to its removal.

Paste Roller Repair: A machine malfunction in the middle of the paste machine operation lead to the creation of this analysis segment. During paste machine operation, the operator identified a problem with a compression roller on the exit side of the paste machine and began to repair the problem. During this process, the worker retrieved a replacement roller from the toolbox. As the worker removed an outer layer of material (resembling cheesecloth) from the replacement roller, lead dust was visible and was detected by the HAM. The impact of this activity is easily identified on the graph in Figure 6.

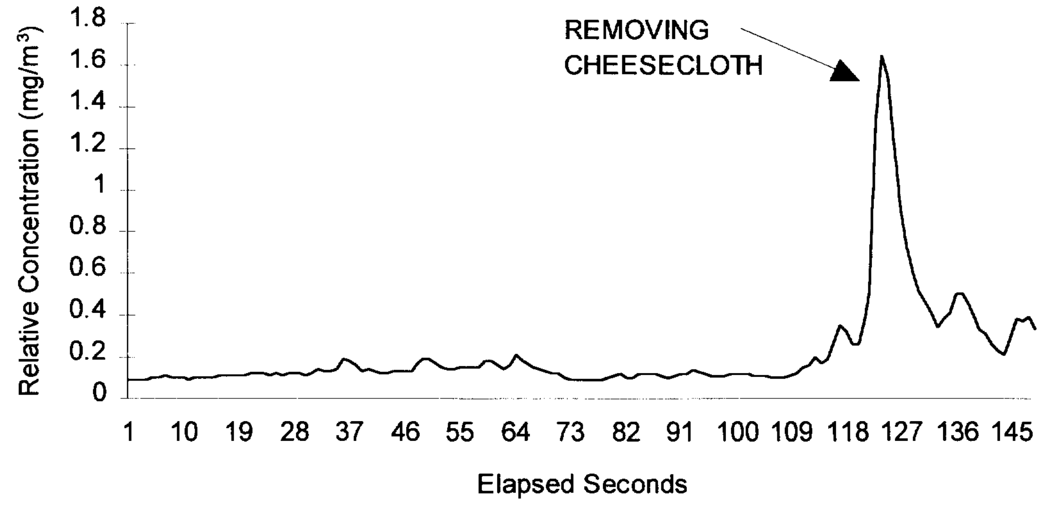


Figure 6. Paste Roller Repair

Although the frequency of this operation is unknown to the NIOSH researchers, a possible control solution to dust-generating repair operations is to require that equipment and parts be wetted down prior to repair. If this became the normal practice during routine repair and troubleshooting tasks, the potential for lead exposure reduction could be substantial. However, precautions addressing electrical and slipping hazards should be incorporated into all wet method recommendations.

Pasted Plate Stacker

The pasted plate stacker is positioned at the end of the conveyor belt exiting from the paste machine drier. Freshly pasted plates advance down the conveyor in a continuous, overlapping line. The stacker manually gathers a group of plates, taps the plates on top of a down draft ventilated surface to square-up the group, then turns and stacks the group of plates into a pallet. The pallet is open in the front and rear with supporting walls on each side. A pivoting local exhaust ventilation system swings into position at the rear opening to create an exhaust flow from the front to the rear of the pallet.

The sample results for personal and area samples collected in the plate stacking area are listed in Table II. During real-time evaluation, the plate stacker's PBZ exposure was 78.4 µg/m³. Two area samples were collected during the real-time evaluation. The height of both samples approximated the breathing zone height. One area sample was above the ventilated pallet, the other was at the work station across from the worker's position, on the opposite side of the conveyor belt. Laboratory results indicate airborne lead concentrations of 65.7 µg/m³ above the ventilated pallet and 8.6 µg/m³ at the adjacent work station. At least one form of ventilation control served both of these sample locations.

We conducted VEM monitoring of the operation in the pasted plate stacking area to determine which work activities contributed a greater proportion to the worker's airborne lead exposure. Numerical comparisons were achieved using the relative concentrations reported by the HAM. Laboratory results for the filter cassette attached to the HAM's exit port indicate that the airflow through the HAM had a lead concentration of 103.4 µg/m³. For the task-analysis, we divided the stacking activities into four categories. These are identified with the summary statistics shown in Table VI.

Table VI
Summary Statistics for Pasted Plate Stacking

Code	Description	Count	Average	Sum
1	Waiting on Plates	343	0.101967	34.9748
2	Gathering Plates	798	0.143240	114.305
3	Turn and Stack	766	0.123764	94.8032
4	Discard Rejects	19	0.135053	2.566
Total		1926	0.128063	246.649

Where:
Code = Category designation used for analysis
Description = Task description
Count = Number of seconds elapsed for this category
Average = Average relative response from the HAM (units are mg/m³)
Sum = Represents the integrated exposure (Count x Average)

Work Practice Observations

One of the benefits of video exposure monitoring is the ability to review video footage of the evaluated task and simultaneously identify work practices that increase employee exposures. This proved to be especially helpful for this operation. As the worker waited for sufficient plates to arrive down the conveyor, he positioned his left hand under the leading plate and flipped it upward forcing the selected group of plates to stand on their bottom edge. This upward flipping motion created a cyclical increase in airborne lead concentrations. Another work practice observed during this operation was the tendency for the worker to bend and fold the reject pasted plates as he removed them from the conveyor belt. This movement created visible lead dust very close to the worker's breathing zone. The effect of both of these activities are visible in the data segment shown in Figure 7.

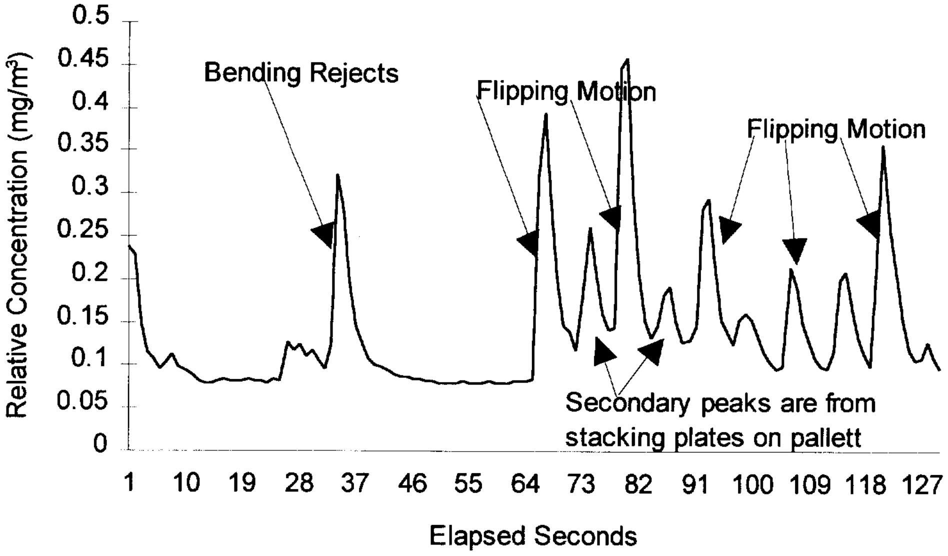


Figure 7. Plate Stacking Segment

Another work practice which appeared to contribute to the worker's exposure was the method of stacking the plates in the pallet. During the real-time evaluation, the worker built up the stack at the rear of the pallet and worked forward. Since the local exhaust ventilation was located at the rear of the pallet, airflow became obstructed as the pallet was filled. Figure 8 shows the last third of the stacking segments (code 3) in chronological order. The graphical trend reveals an increase in breathing zone exposures related to this activity believed to result from the blocked ventilation.

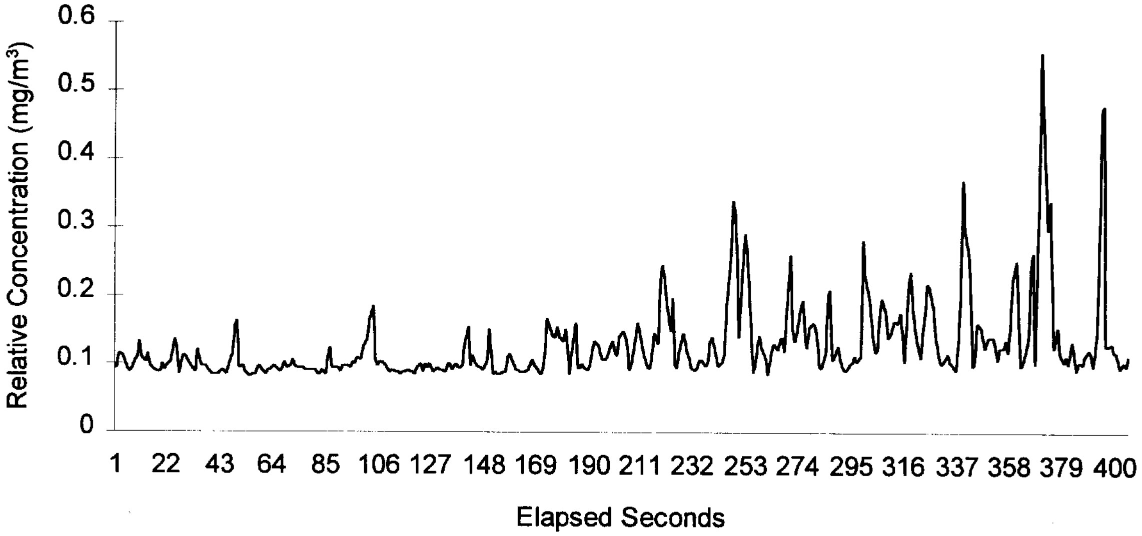


Figure 8. Plate Stacking Trend

First Assembly - TBS Machine Unloader

The TBS machine is a rotating assembly with four equally spaced stopping positions. Two workers operate the machine and each are required to engage a safety button before the machine will advance. Prior to this, in the assembly process, Worker A (See Figure 9) stacked sets of grid plates by alternately interleaving pouched and unpouched plates. This task was performed over a down-draft hood separated from the worker by a transparent shield. Worker B receives the mixed stacks from the stacker, places them into the TBS Machine, and prepares them for welding. At the next rotation point (90 degrees clockwise) the machine automatically applies flux to the welding tabs. At rotation point number 3, the automatic welder uses molten lead from a melting pot to weld the grid tabs together. This location was served by an overhead canopy hood, connected by flexible duct to the main exhaust system. Worker C, receives the welded plates from the automatic welder, loads them into battery cases, and places the cases on the roller conveyor for the next operation.

The sample results for personal and area samples collected in the First Assembly Area are in Table VII. Worker C was the only worker who agreed to allow personal sampling. During our real-time evaluation, worker C had a breathing zone lead exposure of 75.6 µg/m^3. Four area samples were collected. The height of these samples approximated the breathing zone height. The area sample locations and the sample results are identified in Figure 9.

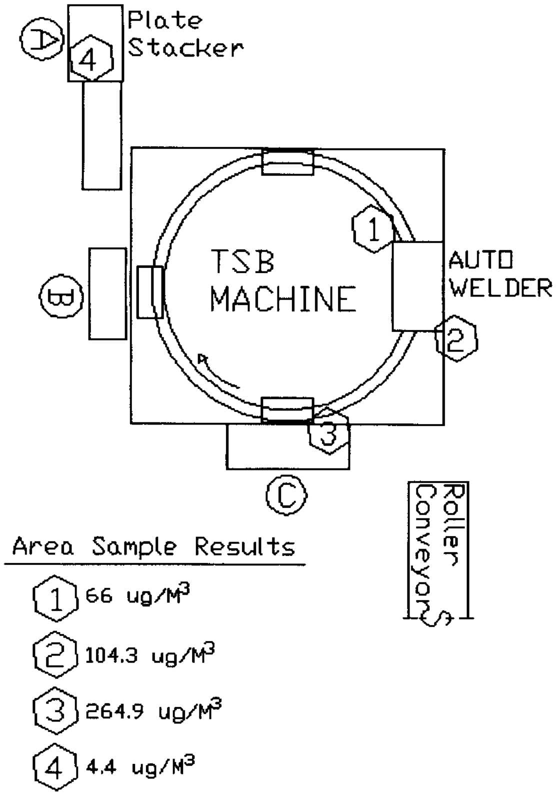


Figure 9. First Assembly

Worker C agreed to be evaluated using VEM techniques. During this evaluation period, air was pulled through the HAM's sensing chamber and onto a filter cassette at 2.0 lpm. Subsequent laboratory analysis of the filter cassette revealed a lead concentration of 21.8 µg/m³. Earlier in the evaluation, a filter sample collected at the same work station but not mounted on a worker resulted in an airborne lead concentration of 45 µg/m³. For the task-analysis, we divided the stacking activities into three categories. These are identified with the summary statistics shown in Table VII.

Table VII
Summary Statistics for TBS Machine Unloader

Code	Work Description	Count	Average	Sum
1	Push Rotation Button	187	0.06896	12.8958
2	Unload TBS/load battery	460	0.12530	57.6364
3	Put case onto conveyor	82	0.09397	7.7058
Total		729	0.10732	78.2380

Where:
Code = Category designation used for analysis
Work Description = Task description
Count = Number of seconds elapsed for this category
Average = Average relative response from the HAM (units are mg/m^3)
Sum = Represents the integrated relative exposure (Count x Average)

The worker's exposure encountered during task item #2, unloading the freshly welded plates and placing them into the battery case, constituted 74% of the HAM's reported exposure. The physical requirements of this task appeared to contribute little to this exposure. The timing of the task, occurred simultaneously with the automatic welding at the previous rotation position. This welding process produced visible emissions which escaped from the canopy hood and drifted into Worker C's breathing zone. This source is very evident in both the Video Exposure Monitoring video footage and in the graph shown in Figure 10.

A work practice of interest occurred when a worker tilted the canopy hood back to perform some minor maintenance on the automatic welder. After completing this task, the hood was not returned. Figure 10 shows where this maintenance and hood position resulted in HAM particulate concentrations which were off the scale of the instrument. Once the omission was noted, the worker was asked to return the hood to the original position.

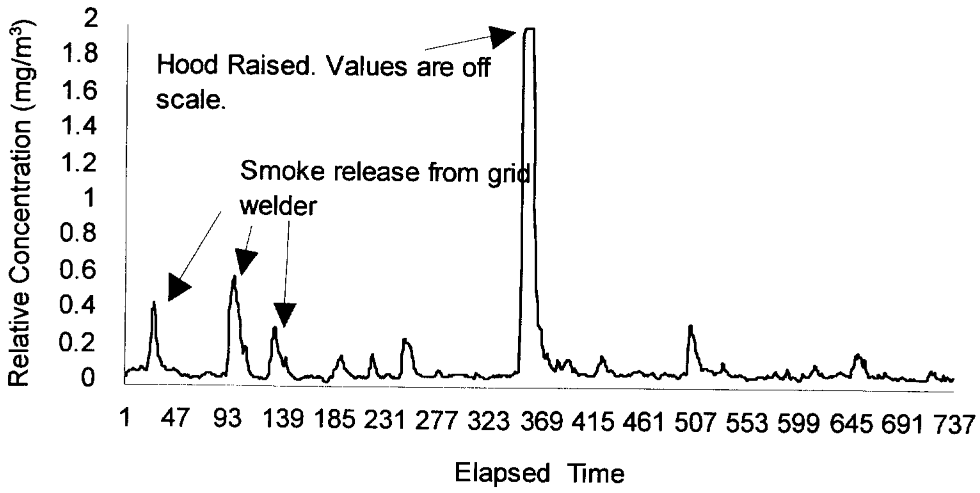


Figure 10. First Assembly-TBS Machine

CONCLUSIONS AND RECOMMENDATIONS

Flexible duct is used in engineering controls throughout the facility. The use of flexible duct can cause high static pressure losses and reduce the overall efficiency of the ventilation system. During the survey it was noted that lead can accumulate in the flexible ducts and potentially restrict air flow. All flexible duct should be replaced with metal round ducts where possible. Round ducts are preferred for industrial exhaust systems because of a more uniform air velocity to resist settling of material and an ability to withstand higher static pressure.(4) The metal thickness of the duct should be selected in accordance with the recommendations provided in the Industrial Ventilation Manual, Table 8-1.(4) If the use of flexible duct in an area is unavoidable, than the use of a non-collapsible type should be used and the length should not be any longer than necessary. Minimum duct velocities of 4000 fpm should be maintained in order to provide sufficient transport velocities that would minimize settling and plugging of lead dust in the duct.(4)

Casting and Drossing Operations

In the grid casting area, the worker removed dross from the casting machines and place it in an unventilated drum. During this operation, high relative HAM responses were seen identifying this process as a major exposure source. The drum needs to be enclosed in a ventilation system. In order to reduce exposures the ventilation system should be designed so that the dross can be removed from the casting machine and placed in the drum under the ventilated enclosure. Any open face area should be designed to achieve 150 cfm/ft^2 (ACGIH Ventilation Manual barrel filling operations, Chapter 10, Figure VS-15-01).(4) The ventilation system should be designed with a duct velocity of 4000 fpm in order to minimize dust settling in the duct.(4) The worker also received high HAM responses when pushing scrap material into the casting machine melting pot. The worker's breathing zone was in the capture zone of the exhaust hood contributing to potential exposures. A small shovel or a push rod should be used to push the material into the melting pot instead of pushing the material by hand. This would eliminate the possibility of the employee's breathing zone entering the capture zone of the ventilation system.

Another exposure source in the casting and drossing area was dry sweeping operations. Large pieces of scrap material should be picked off the floor by hand and a vacuum cleaner, equipped with HEPA filters for removing smaller scrap and particulate from the floor should be used.

Pouching Machine Operations

The employee in the pouch machine area that was responsible for stacking the pouched plates was found to have high relative PBZ concentrations of lead during clean-up and setup procedures. When a pouch was defective, the workers would remove it from the pasted lead plate and throw it into a cardboard box. The cardboard box would then be taken to a larger box where the contents would be dumped. This process was determined to generate high HAM responses during our survey. The following recommendations are intended to reduce exposures at the source:

1) Employees should examine pouched plates while holding them over the downdraft ventilation hood located at the conveyor near the pouch machine.

2) Workers should tape a plastic trash bag to the side of the downdraft hood and throw any bad pouches into the trash bag.

3) When the bag is approximately half full the workers should seal the bag, over the downdraft ventilation hood, and then remove the bag to the trash area. This will eliminate the need to dump any bad pouches out of a cardboard box into another trash receptacle which can cause employee exposure.

The employee at the pouching machine also received high relative PBZ concentrations of lead when replacing the pouch reel on the pouching machine. During this procedure, we speculate that the source of exposures were from dust on the new reel or from dust falling off the worker's clothing. The worker placed the reel on the holder and hit it with his shoulder in order to get the reel into place. During this process lead particles from the worker's coveralls or from the pouch reel could potentially become airborne and create worker exposures. To prevent this exposure, new pouch reels should be stored in a different building until needed. This will reduce the possibility of lead particles settling on the pouch reels before they are used. It is also recommended that the worker clean his coveralls off with the vacuum (connected to the ventilation exhaust) in the pouch machine area before placing the pouch reel on the holder.

A canopy hood is located over the pouch machine in the pouch area. Canopy hoods are mainly used over heated process and are not recommended where material is toxic and the worker must bend over the process.(4) The canopy hood located over the pouch machine should be replaced with a slot hood similar to the slot hood at the pouch stacking location. A slot hood should be more effective in reducing worker exposures in front of the pouch machine. The slot hood should be enclosed as much as possible and have a capture velocity of 200 fpm near the worker's position in front of the pouch machine.

Area samples taken during our real-time monitoring evaluation indicated that the highest air lead concentrations in the pouching area were located at the exit of the pouch machine (near the belt conveyor used to transfer pouched plates to the pouch stacking area). In an effort to reduce air lead concentrations in this area, the slot hood, located next to the conveyor between the pouch machine and pouch stacking slot hood, should be modified to extend the length of the conveyor and be enclosed as much as possible. Plexiglass® material could be used to help enclose the hood and maintain the worker's ability to view the operation. This hood should also be designed with a capture velocity of 200 fpm near the worker's position in the front of the conveyor.

Paste Machine Area

Several work practices were identified in the paste machine area which contributed to higher air lead concentrations in the worker's breathing zone. The following recommendations are designed to reduce exposures related to these activities and ultimately reduce the worker's overall lead exposure.

1) Tool and Parts Retrieval: Increased aerosol concentrations were indicated by the HAM during these activities. Regular cleaning of tool boxes and parts storage lockers should reduce these exposures.

2) Roller Maintenance During Machine Setup: This activity required close manipulation of machinery parts while simultaneously prying or tapping on the machine to correctly position the rollers. A pre-setup spraying of this equipment could reduce the potential for dust generation during this activity. Extra precautions to prevent electrical and slip hazards should be instituted for all wet method procedures.

3) Plywood Supports in Grid Pallets: Unpasted grids are delivered to the pasting area on metal pallets. In the pallet, plywood supports are used to separate and protect the different grid layers. As the paste machine operator advances through the grids, he removes the plywood supports, lifting them over his head, and tossing them on top of the pallet side walls for removal by another worker. During the lifting and tossing process, lead dust from the plywood support was dispersed into the air creating the highest observed breathing zone lead concentrations of the paste machine operation segment. Alternatives such as substituting an open-grate spacer, vacuuming the plywood with a ventilation attachment or a HEPA vacuum, or using wet methods to suppress lead dust prior to the plywood removal, could help to eliminate exposures related to this activity.

4) Paste Roller Repair: This process involved the removal of an outer layer of open weave cloth from a replacement roller prior to its installation on the grid cast machine. The material was impregnated with caked lead oxide which was dispensed intop the air as the material was removed. Wetting of this material, prior to its removal, should eliminate most of this exposure.

Pasted Plate Stacking Area

There were three work practice activities identified in this area which contributed to increased worker exposures. A brief description and a recommended remediation of each activity is addressed below.

Gathering Plates: As the worker collected plates from the conveyor, he used a flipping action with his wrist to upright the plates on their bottom edge. The more vigorous he made this movement, the higher the aerosol concentration detected by the HAM. This exposure could be reduced by educating the worker to perform this motion as smoothly as possible. Another alternative which relies less on worker habits is to install an upward slope at the end of the conveyor which automatically begins to upright the grids as they progress to the end of the conveyor.

Gathering Plates (Ventilation Controls): The plate gathering process is the first disturbance of the pasted plates after they exit the paste machine and drier. As such, increased exposure potential is still likely, even if the previously mentioned flipping action is remediated. The ideal protective solution is a local exhaust ventilation system, designed to capture the dust as it is generated at the grid plate. Such an ideal system would require an undisturbed capture velocity approximating 150-200 feet per minute (fpm). In the interim, it is possible that a slight modification to the unmanned workstation on the opposite side of the conveyor could approximate this protective design. Figure 11a shows a sketch of the grid stacker's work station. The observed worker occupied working position A and the vacant working position is position B. A ventilation modification, which could assist in the control of lead dust, is shown in Figure 11b. This hood uses a magnetic perimeter to hold it in place. Positioned over the vacant working position's down draft hood, the magnetic hood uses the down draft hood as its exhaust source. This design will only be feasible if a sufficient volume of air (and available negative static pressure) is exhausted through the down draft hood to allow a minimum capture velocity of 100 fpm at the grid plates.

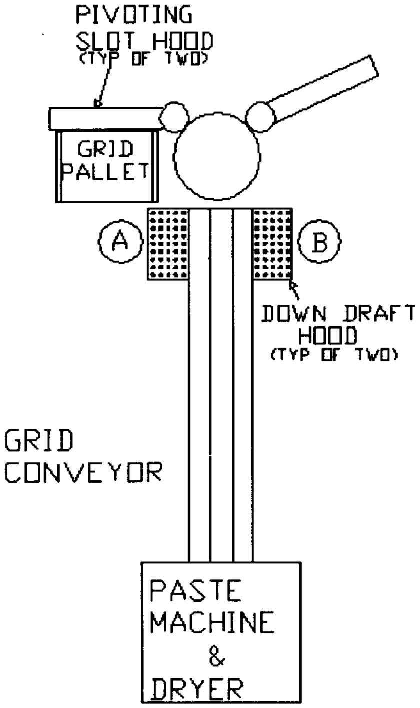


Figure 11b. MAGNETIC HOOD

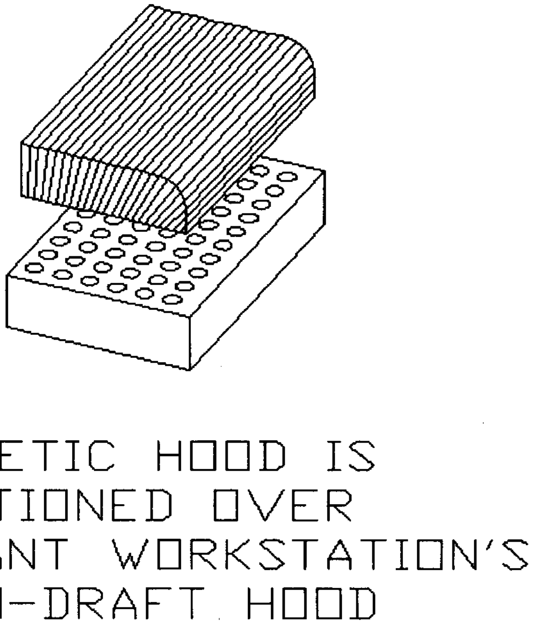


Figure 11a. PLATE STACKING

The actual exhaust volume for the down draft hood was not recorded during the survey. A second alternative is to design a portable hood which ties into the same exhaust duct as the pivoting slot hood. Since the slot hood will not be needed on the unoccupied side of the conveyor, the portable hood could use this exhaust source to exhaust air from the grid conveyor area.

Pallet Stacking: pasted grids are removed from the conveyor and placed onto an adjacent pallet. Initially, the worker builds up several rows at the rear of the pallet and works forward. Since the local exhaust ventilation is at the rear of the pallet, airflow becomes progressively obstructed as the pallet is filled. An improved stacking method is for the worker to begin each layer of plates along one side of the pallet and progressively work his way across to the opposite side. He should not start a new layer until the current one is complete. By stacking from side to side, rather than from rear to front, the worker would minimize his breathing zone excursions into an area where the exhaust ventilation has been blocked.

TBS Machine - First Assembly

Automatic Welder - Moveable Hood: During the evaluation of the TBS machine, a worker performed some brief maintenance on the automatic welder. Access to the welder was facilitated by hinges which allow the entire canopy hood to tilt away from the machine. Excess flex-duct, connecting the hood to the main exhaust, allows the hood to tilt without disconnecting the duct work. After completing his task, the employee apparently forgot to replace the hood to its proper position. Subsequent HAM response exceeds the scale of the instrument during the VEM evaluation. Hopefully, this is an infrequent mistake, persistent instruction of employees and supervisors on the importance of properly operating engineering controls could dramatically reduce this exposure potential. For those instances when maintenance must occur, the conceptual hood design discussed in the following paragraphs will allow machinery access without requiring excessive amounts of flexible duct and without removing the hood from the contaminant capture position.

Automatic Welder - Hood Design: The canopy hood serving the TBS machine's automatic welder was not completely effective in its current design. This was evidenced by the cyclical escape of smoke and fume when the automatic welder performed the welding process.

Hot temperature processes are unique in their requirements for exhaust ventilation. The exhaust volume for aerosol removal must exceed the quantity of convection air currents generated from the high temperature process. The raising plume of contaminant increases in both volume and cross-sectional area as adjacent air molecules are entrained in the raising air stream. Air contaminants can potentially reach employees' breathing zones when: 1) capture velocities are insufficient to overcome the raising air currents; 2) mechanical exhaust volumes are smaller than the enlarged exhaust requirement; 3) the canopy hood's face-opening is too small to contain an expanding exhaust plume.

In the case of the TBS machine, we were unable to collect flow measurements due to the elevated temperatures at the welder, so discrepancies between recommended and design flow conditions are not known. However, the canopy hood's face area approximated the same dimensions as the hot contaminant-generating surface area. An aerosol was clearly visible and detected by the HAM as it escaped from the current canopy hood. Subsequent analysis of area samples collected adjacent to the canopy hood confirmed the presence of lead in this escaping aerosol.

Design recommendations for hot process canopy hoods can be found in the ACGIH, Industrial Ventilation Manual.(4) A "Conceptual Design" for a new canopy hood is located in Appendix B. Prior to installing a new canopy hood, the final designer should re-evaluate the TBS machine and acquire detailed information concerning dimensions and operating temperatures. Exhaust volume and static pressure requirements should be identified and the present exhaust system should be evaluated to verify sufficient capacities exist to install an improved hood.

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Table II
Appendix A
HETA 94-0268
Standard Industries
San Antonio, Texas
March 27-31, 1995

	Sample	Sample	Sample	Location Information/Work Activity	Time	Flow	Volume	Pb	Pb	Ln
Date	Number	TYPE	Location		(min)	(Lpm)	(L)	(ug)	(ug/m3)	Pb
3/28/95	201	P	Pasting	Running paste machine (on HAM)	88	2	176	120	682	6.52
3/28/95	202	P	Pasting	Running paste machine (on collar)	88	2.2	194	34	176	5.17
3/28/95	203	A	Pasting	Left of Paste machine PBZ level	84	2	168	28	167	5.12
3/28/95	204	A	Pasting	Near Paste Machine PBZ level from I beam	83	2	166	27	163	5.09
3/28/95	207	A	Pasting	Near Pasting Machine on I beam, PBZ level	84	2.2	185	28	152	5.02
3/28/95	205	P	Pasting	Near Pasting Machine	40	2.3	92	2800	30435	10.32
3/28/95	213	A	Pasting	Hanging over ventilation at stacking area	146	2	292	2.5	9	2.15
3/28/95	212	A	Pasting	Hanging over plate bin	137	2	274	18	66	4.18
3/28/95	209	P	Pasting	Stacking pasted grids (on HAM)	145	2	290	30	103	4.64
3/28/95	208	P	Pasting	Stacking pasted grids (on collar)	145	2.2	319	25	78	4.36
3/28/95	214	A	Pasting	Near Pasting Machine on I beam, PBZ level	70	2	140	26	186	5.22
3/29/95	218	P	Pouching	Loading Pouching Machine (on HAM)	44	2.4	103	2.7	26	3.26
3/29/95	224	P	Pouching	Loading Pouching Machine (on Collar)	44	2.1	92	11	119	4.78
3/29/95	219	A	Pouching	Near slot hood at pouching machine exit	508	2.2	1092	140	128	4.85
3/29/95	206	A	Pouching	Near plate breaking downdraft hood	510	2.1	1046	60	57	4.05
3/29/95	215	A	Pouching	Near 2nd poucher above exit conveyor	480	2.1	984	100	102	4.62
3/29/95	211	A	Pouching	Near 2nd poucher near loaders breathing zone	480	2	960	17	18	2.87
3/29/95	230	P	Pouching	Pouch stacker (on HAM)	62	2	124	4.9	40	3.68
3/29/95	236	P	Pouching	Pouch stacker (on collar)	62	2	124	15	121	4.8
3/29/95	235	A	Pouching	Above plate pallet (near stacks, pouched plates)	252	2	504	13	26	3.25
3/30/95	231	P	Grid Casting	Loading, drossing, sweeping at casting machines (on HAM)	45	2	90	3.3	37	3.6
3/30/95	225	P	Grid Casting	Loading, drossing, sweeping at casting machines (on collar)	45	2	90	6.2	69	4.23
3/30/95	246	A	Grid Casting	Behind grid casting melting pots	535	2	1070	12	11	2.42
3/30/95	232	A	Grid Casting	Near machine exit, grid caster	531	2	1062	10	9	2.24
3/30/95	240	A	Grid Casting	Feeding into grid casting lead pot	525	2	1050	72	69	4.23

Table II
Appendix A
HETA 94-0268
Standard Industries
San Antonio, Texas
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Date	Sample Number	Sample TYPE	Sample Location	Location Information/Work Activity	Time (min)	Flow (Lpm)	Volume (L)	Pb (ug)	Pb (ug/m3)	Ln Pb
3/30/95	242	A	1st Assembly	Area, hanging near caster on TBS Machine	441	2	882	92	104	4.65
3/30/95	247	A	1st Assembly	Area, hanging to left of TBS Machine	440	2.1	924	61	66	4.19
3/30/95	237	A	1st Assembly	Area, near hood, over TBS welder	453	2	906	240	265	5.58
3/30/95	243	A	1st Assembly	Area, hanging near PBZ of plate loader	188	2	376	9	24	3.18
3/30/95	241	A	1st Assembly	Area, hanging near PBZ of plate loader	188	2	376	5.9	16	2.75
3/30/95	222	A	1st Assembly	Area, near PBZ-plate stacker	429	2.1	901	4	4	1.49
3/30/95	249	P	1st Assembly	Personal, battery plate loader (on HAM)	39	2	78	1.7	22	3.08
3/30/95	244	P	1st Assembly	Personal, battery plate loader (on collar)	39	2	78	5.9	76	4.33
3/30/95	238	A	1st Assembly	Area, HAM positioned above TBS unloader	189	2	378	17	45	3.81

P= Personal
A = Area
Ln = natural log

APPENDIX B

Canopy Hood Concept Design
TBS Machine Welding Operations
HETA 94–0268
Standard Industries
San Antonio, Texas

At the time of the March 1995 evaluation, the TBS machine was in full production. Elevated operating temperatures impeded precise dimensional measurements. A detailed evaluation of the TBS machine and the welding operation should be conducted prior to the design and installation of a replacement engineering control for this operation. This design follows recommendations in the Industrial Ventilation Manual(4) combined with the approximate measurements and assumptions gathered during the March 1995 engineering controls evaluation.

Physical data from March 1995 Evaluation:

Hood Face Dimensions	13" x 33"
Hot Surface Area Dimensions	13" x 33"
Distance from hood to hot surface	16"
Room air temperature	75 degrees Fahrenheit (deg F)
Hot Surface Temperature	891 deg F (per digital indicator)

Design Equations

CHECK: Minimum distance from hood to surface (16") is greater than smallest hood face dimension (13") so LOW CANOPY HOOD design criteria is not applicable. Must use regular canopy hood design criteria.

$D_C = 0.5X_C^{0.88}$ (Eqn 1)

Where: D_C = Column dimension at hood face
$X_C = y + z$ = distance from the hypothetical point source to the hood face, ft
y = distance from process surface to hood face, ft
z = distance from process surface to hypothetical point source, ft
"z" can be calculated from: $z=(2D_S)^{1.138}$ (Eqn 2)

Where: D_S = dimension of hot source, ft

$V_F = 8(A_S)^{0.33}\,[(\Delta t)^{0.42}] \div [X_C^{0.25}]$ (Eqn 3)

Where: V_F = velocity of hot column at hood face, fpm
A_S = area of the hot source, ft^2
Δt = temperature difference between hot source & ambient, °F

The hood dimension must be larger than the dimension of the rising column to assure complete capture. The hood dimension is calculated from:

$D_F = D_C + 0.8y$ (Eqn 4) Where: D_F = dimension of hood face, ft

Total hood airflow rate is

$Q_T = V_F A_C + V_R(A_F - A_C)$ (Eqn 5)

Where: Q_T = total volume entering hood, cfm
V_F = velocity of hot air column at the hood face, fpm
A_C = area of hot column at the hood face, ft^2
V_R = required air velocity through remaining hood area, fpm
(We selected 100 fpm for this design)
A_F = total area of hood face, ft^2

Equations 1,2,&4 must be repeated for both dimensions (l x w) of a rectangular canopy hood.

DESIGN RESULTS:

1. Calculate using $D_S = W = 13'' = 1.08$ ft
   $z=(2D_S)^{1.138}=(2(1.08))^{1.138}= 2.40$ ft
2. $y = 16'' = 1.33$ ft
3. $X_C = y + z = 1.33 + 2.40 = 3.73$ ft
4. $D_C = 0.5X_C^{0.88} = 0.5(3.73)^{0.88} = 1.59$ ft = width of column at hood face
5. Using $A_S = (13 \times 16) \div 144 = 1.44$ ft^2
   $\Delta t = 891-75 = 816$ °F

$V_F = 8(A_S)^{0.33}\,[(\Delta t)^{0.42}] \div [X_C^{0.25}]$
$= 8(1.44)^{0.33}\,[(816)^{0.42}] \div [(3.73)^{0.25}]$
$= 108.48$ fpm

6. $D_F = D_C + 0.8y = 1.59 + 0.8(1.33) = 2.65$ ft = width of hood face

Now repeat the same calculations using $D_S = L = 33'' = 2.75$ ft

7. Calculate using $D_S = 2.75$ ft
   $z=(2D_S)^{1.138}=(2(2.75))^{1.138}= 6.96$ ft
8. $y = 16'' = 1.33$ ft
9. $X_C = y + z = 1.33 + 6.96 = 8.29$ ft
10. $D_C = 0.5X_C^{0.88} = 0.5(8.29)^{0.88} = 3.22$ ft = Length of column at hood face
11. Using $A_S = (13 \times 16) \div 144 = 1.44$ ft^2
    $\Delta t = 891-75 = 816$ °F

$V_F = 8(A_S)^{0.33}\,[(\Delta t)^{0.42}] \div [X_C^{0.25}]$
$= 8(1.44)^{0.33}\,[(816)^{0.42}] \div [(8.29)^{0.25}]$
$= 88.84$ fpm

12. $D_F = D_C + 0.8y = 3.22 + 0.8(1.33) = 4.28$ ft = Length of hood face
13. $Q_T = V_F A_C + V_R(A_F - A_C)$:
    Since V_F(width) > V_F(length), Then $V_F = V_F$(width) = 108.48 fpm
    $A_F = D_F$(width) x D_F(length) = 2.65 x 4.28 = 11.34 ft^2
    $A_C = D_C$(width) x D_C(length) = 1.59 x 3.22 = 5.12 ft^2
    $V_R = 100$ fpm

$Q_T = 108.48(5.12) + 100(11.34 - 5.12) = 1177.42$ cfm
USE: $Q_T = 1200$ cfm

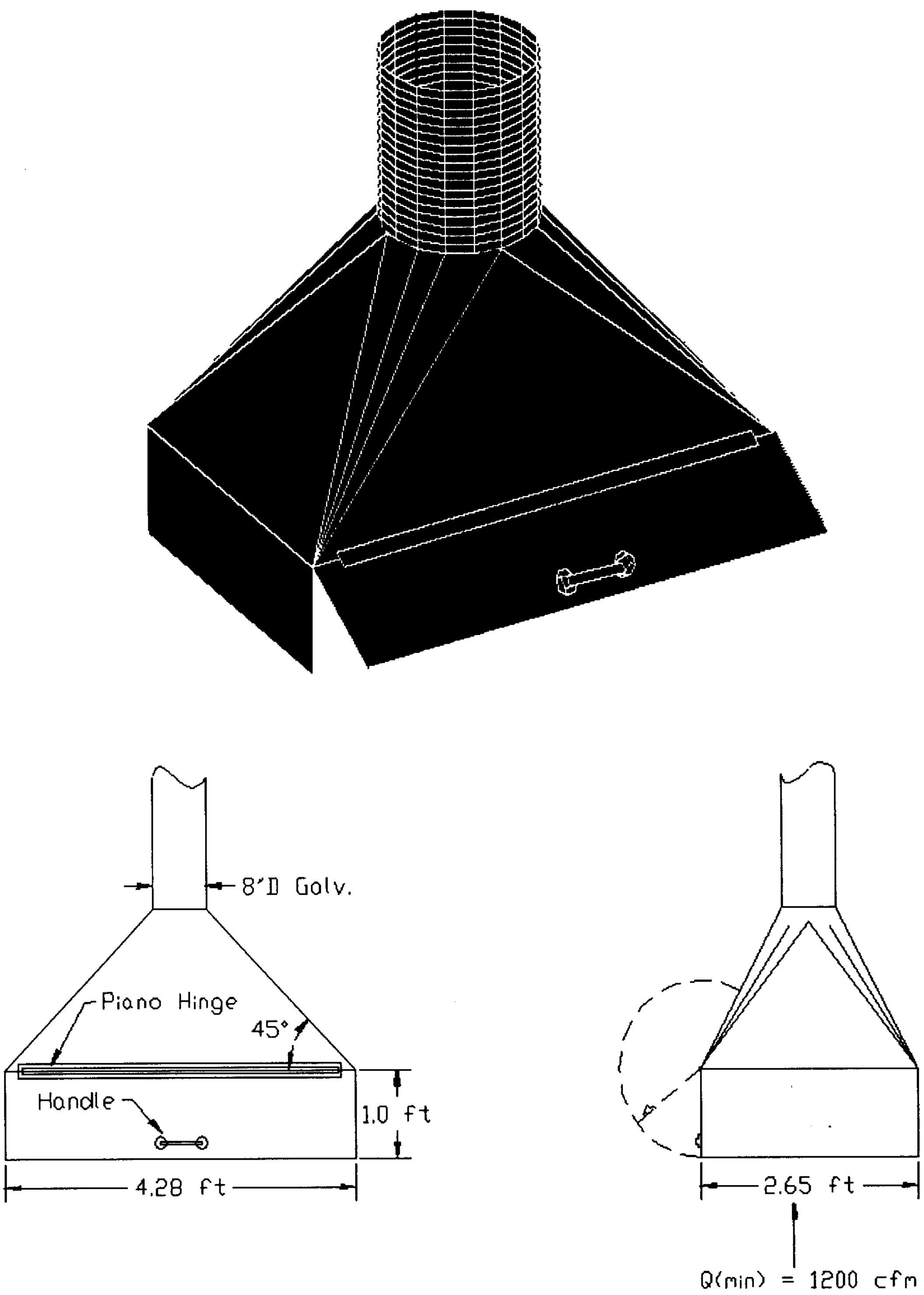

FIGURE 1. CONCEPT DESIGN: TBS CANOPY HOOD

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