HETA 87-371-1986
SEPTEMBER 1989
TECHNICAL ASSISTANCE TO THE
JAMAICAN MINISTRY OF HEALTH
KINGSTON, JAMAICA

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I. SUMMARY

On January 26, 1987, the Principal Medical Officer of the Epidemiology Unit, Jamaican Ministry of Health (MOH), Kingston, requested technical assistance from the National Institute for Occupational Safety and Health (NIOSH) in studying and preventing lead poisoning in Jamaica. NIOSH assisted the Jamaican MOH between October 20-23, 1987, in surveying occupational and environmental lead exposure at three lead-acid battery manufacturers in Kingston: (1) Tropical Battery, Ltd; (2) Apex Battery, Ltd.; and (3) Unistate Battery, Ltd. This survey was one of three NIOSH studies conducted consecutively with the Jamaican MOH between October 4 and 24, 1987. NIOSH, along with investigators from the Center for Environmental Health and Injury Control (CEHIC) of the United States (U.S.) Centers for Disease Control, assisted the Jamaican MOH in two other surveys of lead exposure. These evaluations are reported separately.

There are no formal Jamaican occupational health standards for workplace monitoring of lead in air or biological screening of employees with potential lead exposures. The U.S. Occupational Safety and Health Administration (OSHA) general industry standard for lead exposure was selected for the evaluation criteria. It should be emphasized that different criteria and exposure limits are applied in various countries regarding exposure to toxic substances in the working environment.

A. Tropical Battery Ltd.

Full-shift personal breathing-zone air samples for lead were collected on October 20-21, 1987. Concentrations ranged from 40 to 5,300 micrograms per cubic meter (ug/m^3), time-weighted average (TWA) over the period sampled. Operations with the highest lead exposures included the plate separator (5,300 ug/m^3); cell dropper (2,400 ug/m^3); and battery assembly (2,600 ug/m^3). These concentrations exceed the U.S. OSHA permissible exposure limit (PEL) for lead in air of 50 ug/m^3 calculated as an 8-hour TWA for daily exposure.

Blood samples from production employees showed that blood lead (PbB) levels among seven of 29 employees (24%) at Tropical Battery exceeded the U.S. medical removal level of 50 ug/dl, and that 17 of 29 employees (59%) had PbB levels of 40 ug/dl or greater, a level at which bimonthly PbB monitoring is required under existing U.S. standards. The highest blood lead levels occurred in the assembly/production area (mean 46 ug/dl, maximum 64 ug/dl), but blood lead levels above 40 ug/dl were found in all work areas.

B. Apex Battery Ltd.

Full-shift personal breathing-zone air samples for lead collected on October 22, 1987, ranged from 50 to 3,400 ug/m^3, TWA. The highest lead exposures occurred during the melting of battery posts and connectors (3,400 ug/m^3); battery plate filing (2,570 ug/m^3); and manual grid pasting (1,630 ug/m^3). Blood lead levels in 9 of 12 employees were 60 ug/dl or greater, a level requiring immediate medical removal under U.S. occupational health regulations. The geometric mean PbB level was 65 ug/dl.

C. Unistate Battery Ltd.

Lead concentrations measured by personal breathing-zone air samples collected on October 22, 1987, ranged from 30 to 190 ug/m^3, TWA. Lead concentrations in three general area air samples collected during the same period ranged from 10 to 100 ug/m^3. Blood samples from three of the four production employees tested exceeded 60 ug/dl. Each employee performed a variety of tasks throughout the work day and some work was performed outdoors.

Engineering controls and respiratory protection were judged to be inadequate at all three companies. Workers with PbB levels above 60 ug/dl tended to have higher prevalences of most symptoms of lead toxicity than did workers with lower PbB levels. The relationship between zinc protoporphyrin concentrations and increasing PbB concentrations was consistent with that described among workers in developed countries. The high risk of lead toxicity among Jamaican battery workers is consistent with studies of battery workers in other developing countries.

Based on the data collected during this evaluation, NIOSH investigators concluded that employees at battery manufacturers surveyed in Jamaica are exposed to lead concentrations in excess of occupational exposure limits used in various countries, including the U.S. and the United Kingdom. Furthermore, 28% of workers from the companies surveyed by NIOSH had PbB levels above 60 ug/dl. It is the opinion of NIOSH investigators that the high risk of lead toxicity among Jamaican battery workers results from deficiencies in engineering controls, respiratory protection, and safe work practices. Recommendations for providing general and local exhaust ventilation, altering work practices to reduce lead exposure, and implementing respiratory protection programs are included in Section VIII.

KEYWORDS: SIC 3691 (Storage Batteries), lead, blood lead, battery manufacturing, occupational diseases, developing countries, adults.

II. INTRODUCTION.

The third largest of the Greater Antilles, Jamaica is located 550 miles south of Florida. The island, settled by British farmers in 1655, became independent within the British Commonwealth in 1962 and a prime minister heads the government. Jamaica has approximately 2.3 million English speaking inhabitants and the capital city, Kingston, is its largest metropolitan area (665,000 people). Most Jamaicans are descendants of African slaves brought to the island between the 17th and 19th centuries, but Chinese, East Indians, Lebanese, Europeans, and North Americans comprise a portion of the population. Principal industries include bauxite (aluminum ore) mining, and tourism. Sugar, bananas, and coffee, while fluctuating in prominence, remain the chief export crops.

On January 26, 1987, the principal Medical Officer of the Epidemiology Unit in the Jamaican Ministry of Health (MOH) requested NIOSH assistance in studying and preventing lead poisoning in Jamaica. Two preliminary visits to Jamaica were made by NIOSH on May 4-8, and August 10-21, 1987. During these planning trips various Jamaican public health officials were contacted and results of blood lead testing by the Jamaica Government Chemist were examined.

Three battery manufacturers participated in this study: Tropical Battery, Ltd. (approximately 30 production workers); Apex Battery Ltd. (12 production workers); and Unistate Battery, Ltd. (5 production workers). As all three companies were conducting limited medical screening on their production workers, it is possible that they were more conscious of worker health and had lower lead exposure than at other Jamaican battery manufacturers. NIOSH investigators considered it unlikely that the companies surveyed had higher employee lead exposures than is typical at Jamaica battery makers.

Between October 20-23, 1987, NIOSH assisted the Jamaican MOH in surveying occupational and environmental lead exposures at these battery manufacturers. An interim report for each battery manufacturer surveyed was provided to the Jamaican MOH on May 25, 1988. These three reports contained environmental and medical results and interim recommendations for reducing employee exposures to lead. NIOSH and the Center for Environmental Health and Injury Control (CEHIC) also assisted the MOH in conducting two other studies of occupational and environmental lead exposure from the lead-acid battery industry between October 4 and 24, 1987. These are reported elsewhere.

This technical assistance evaluation was designed to assist the Jamaican MOH in achieving three objectives:

1. To assess the working environment at battery manufacturers and recommend appropriate measures to reduce lead exposure to workers.

2. To determine the factors influencing blood lead levels in exposed workers, such as air lead levels, cigarette smoking, use of personal protective equipment, and seniority.

3. To assess the relationship between symptoms and signs that may be related to lead toxicity and blood lead levels in the workforces studied.

III. BACKGROUND

A. Battery Manufacturers in Jamaica

The lead-acid battery industry in Jamaica is characterized by small factories, the largest of which employs approximately 30 production workers. Much smaller (1-3 workers) independent "backyard" shops that repair and/or rebuild car batteries are numerous in the greater Kingston area and were examined in a separate NIOSH evaluation. A review by NIOSH investigators of blood lead tests collected by the Jamaican Government Chemist between January 1986 and March 1987 revealed that lead-acid battery production, repair, and recycling was the most commonly identified source of elevated blood lead levels in both children and adults in Jamaica.[1]

While the risk of occupational lead exposure in the battery industry has been thoroughly studied and regulated in most developed countries, less is known about lead exposure among battery workers in developing countries. Because lead-acid battery manufacture can be carried out in small scale operations, using relatively simple technology, it is an attractive industry for some developing countries. There are no formal Jamaican occupational health standards for workplace monitoring of lead in air or biological screening of employees with potential lead exposures.

Routine monitoring for airborne lead was not performed by any of the companies surveyed. All of the workplaces studied performed biannual blood lead monitoring on production workers, and participation by workers was a condition of employment. Generally, workers with blood lead levels of 70 ug/dl or greater were removed from exposure for several weeks, then retested before returning to work. However, in some cases workers would return to work before the repeat test results were available. In other situations employees were transferred to "unexposed" jobs or laid off. In the former case employees may be transferred to another job with little, if any, corresponding reduction in lead exposure. In the latter case pay and benefits could be maintained, reduced, or terminated.

B. Lead-acid Battery Manufacturing

Lead-acid storage batteries, developed in the 1800's, have a wide variety of applications. Their ability to deliever high current at relatively constant voltage within a wide temperature range make them useful in numerous starting, lighting, and ignition applications. Twelve-volt automotive batteries are the principal product from the three Jamaican manufacturers involved in this project. The largest manufacturer, Tropical Battery, also produces larger batteries for industrial use. All three companies "wet-charge" their batteries, meaning that assembled batteries are filled with sulfuric acid and electrically charged. A battery maintainer (trickle charger) is used to maintain the charge until the battery is installed.

An average lead-acid battery contains over 20 pounds of lead coming from either primary (separating elemental lead from lead containing ores) or secondary lead smelting (extracting lead from recycled batteries and other salvage materials containing lead). In Jamaica, secondary smelting is the principal lead source for the battery companies. This reclaimed lead, containing trace amounts of antimony, arsenic, and other impurities, is used to cast parts like battery terminals, cell connectors, and battery grids where impurities are not critical to the desired performance.

At Tropical and Apex the battery grids (the metallic lattice used to make battery plates) are manufactured using automatic casting machines equipped with thermostatically-controlled lead pots. These same two companies also purchase PbO (litharge) from the United States. Lead oxide, free of trace metal impurities which can reduce its electrical storage capacity, is mixed with sulfuric acid, water, and other additives in rotary mixers to make a thick paste. The paste is then applied manually (Apex) or automatically (Tropical) to the battery grids to produce the battery plates. Unistate Battery, because of its small size, purchased prepasted plates.

The battery plates pass through a drying oven (Tropical) or are stored on wooden pallets (Apex) to allow the paste to dry. The plates, which are cast, pasted, and dried in pairs, are broken apart (plate breaking) and excess metal and PbO is filed off. At both Tropical and Apex plate breaking and filing were manually performed.

The finished (filed and separated) battery plates are manually stacked with separators (insulators). These alternating stacks of plates and separators are then grouped together and lead connectors are gas-welded onto the terminals of the individual plates. This process, which forms the battery cell, is called group burning.

The assembled battery cells from the group burning process are placed in plastic battery cases (termed "cell dropping"), the remaining small lead parts (intercell connectors) are attached, and the battery case cover is installed. The batteries are filled with sulfuric acid and initially wet-charged by applying an electric current. The batteries are then emptied and fresh acid is supplied. A second formation charge or booster charge is applied and the battery is transferred to storage. A flow diagram of the entire manufacturing process is shown in Figure 1.

IV. EVALUATION DESIGN AND METHODS

A. Industrial Hygiene

1. Tropical Battery

Twenty-eight full-shift breathing-zone air samples were collected from October 20 to 21, 1987 at Tropical Battery, the largest of the companies studied by NIOSH in this evaluation. All phases of lead-acid battery manufacturing were evaluated at the plant at least once during the two day survey. The company had resumed full production only four weeks before this survey, following a period of minimal production lasting about three months.

Operations monitored included PbO mixing, lead melting, grid and small parts casting, automatic grid pasting, battery cell stacking, battery cell assembly (group burning), cell dropping (insertion of the completed cells into the battery case), battery assembly, and wet charging. General area air samples were collected in the employee lunch room and an office used during this evaluation for employee interviews and blood drawing. A plant diagram is shown in Figure 2.

2. Apex Battery

Ten personal breathing-zone air samples were collected on October 22, 1987. Operations monitored included lead melting, grid and small parts casting, PbO mixing, manual grid pasting, plate and spacer stacking and assembly, group burning, and battery assembly. A plant diagram is shown in Figure 3.

3. Unistate Battery

Six air samples (three personal breathing-zone, three general area) were collected on October 22, 1987, at Unistate Battery, the smallest company involved in this evaluation. Because of the company's small size, each employee performed multiple tasks during the work day, including lead melting, grid and small parts casting, plate and spacer stacking and assembly, group burning, and battery assembly. Some operations, such as lead melting and parts casting, were performed outdoors. No PbO was used at Unistate since battery grids were purchased pre-pasted. A plant diagram is shown in Figure 4.

4. Air Sampling Methodology

Air samples were collected on mixed cellulose-ester filters (37 millimeter diameter, 0.8 micron pore size) using a flowrate of 2.0 liters per minute. Personal breathing-zone and general area air samples were collected for a period as near as possible to an entire work shift. In the lab, the filters were digested using concentrated nitric and perchloric acids. The residues obtained were then dissolved in a dilute solution of the same acids and the resulting sample solutions analyzed for trace metals by inductively coupled plasma-atomic emission spectrometry. This analytical procedure follows the NIOSH analytical method No. 7300 for elements.[3] The limit of quantitation for the sample set was 1.0 microgram per filter.

B. Medical

Venous blood samples were drawn from 29 workers at Tropical Battery who were involved in battery production or whose supervisory responsibilities required them to spend significant time in production areas (one worker declined blood drawing). Venous blood samples were drawn from 12 workers at Apex (all workers participated) and from four workers at Unistate Battery who were involved in battery production. Blood samples were also drawn from the shop owner and secretary at Unistate Battery. Employees at all three battery manufacturers were similar in terms of age and years employed as battery workers (Table 1).

Blood samples were tested for zinc protoporphyrin (ZPP) using a portable hematoflourometer (Aviv

Biomedical*).[2] Lead in blood was analyzed by anodic stripping voltometry at a NIOSH contract lab which participated in a Centers for Disease Control (CDC) proficiency testing program.[4]

Informed verbal consent was obtained from all participants. Written consent was not used based on advice from the Jamaican MOH that it would be an impractical means of obtaining consent among Jamaicans, many of who have limited literacy and a cultural reluctance to sign any document. This waiver was approved by a NIOSH human subjects review board as not adversely affecting subject rights and welfare. Venipuncture was the only medical procedure performed in this study.

A standard questionnaire was administered to workers at all three plants to record basic demographic information, work practices, smoking, and symptoms of possible lead toxicity.

V. EVALUATION CRITERIA

Inhalation (breathing) of lead dust and fume is the major route of lead exposure in industry. A secondary source of exposure may be from ingestion (swallowing) of lead dust deposited on food, cigarettes, or other objects. Once absorbed, lead is excreted from the body very slowly. Absorbed lead can damage the kidneys, peripheral and central nervous systems, and the blood forming organs (bone marrow). These effects may be felt as weakness, tiredness, irritability, digestive disturbances, high blood pressure, kidney damage, mental deficiency, or slowed reaction times. Chronic lead exposure is associated with infertility and with fetal damage in pregnant women.[5,6]

Overt symptoms of lead poisoning in adults generally begin at blood lead levels between 60 and 120 ug/dl.[5] Lead-acid battery workers, who may be heavily exposed to lead, have been shown to be at higher risk of dying from cerebrovascular and renal disease.[5,6] Neurologic, hematologic, and reproductive effects, however, may be detectable at much lower levels, and the World Health Organization has recommended an upper limit of 40 ug/dl for adult males.[7] Recent studies suggest that exposure of the developing fetus to blood lead levels far below these occupational exposure limits is associated with subtle neurologic impairment in early life and that there may not be a safe threshold for this effect.[8,9]

The U.S. OSHA Permissible Exposure Limit (PEL) for lead in air is 50 ug/m^3 calculated as an 8-hour TWA for daily exposure.[10] This regulation also requires semi-annual blood lead monitoring of employees exposed to 30 ug/m^3 or greater of lead.[10] Employees whose blood lead level is 40 ug/dl or greater must be retested every two months, and be removed from a lead-exposed job if their average blood lead level is 50 ug/dl or more over a 6 month period. A blood lead level of 60 ug/dl or greater, confirmed by retesting within two weeks, is an indication for immediate medical removal. Workers on medical removal should not be returned to a lead-exposed job until their blood lead level is confirmed to be below 40 ug/dl.[10] Removed workers in the U.S. have protection for wage, benefits, and seniority for up to 18 months until their blood levels decline to below 40 ug/dl and they can return to lead exposure areas. This provides an incentive for employers to correct excessive exposures and avoids a disincentive for employee participation.
The blood lead levels used in the U.S. lead standard are a compromise between the established relationship between blood lead levels and adverse health effects and the feasibility of controlling lead exposure with current technology. Thus, the U.S. standard permits higher blood lead levels than would be allowed if only health considerations were used.

It should be emphasized that different criteria and exposure limits are applied in various countries regarding exposure to toxic substances in the working environment. For example, in 1980 a comprehensive Approved Code of Practice was issued in the United Kingdom (U.K.) regarding the control of lead at work. The U.K. occupational exposure limit for lead in air is 150 ug/m^3, 8-hour TWA (compared to the U.S. limit of 50 ug/m^3). In the U.K. workers with a confirmed PbB level in excess of 80 ug/dl are certified as unfit for work which exposes them to lead. For women of reproductive capacity the U.K. PbB level drops to 40 ug/dl.

VI. RESULTS

A. Industrial Hygiene

1. Tropical Battery

Employee exposures to airborne lead dust and fume from all manufacturing operations were monitored during this survey with the exception of the employee working in the battery charging department. All samples except one exceeded the U.S. OSHA PEL for workplace exposure to airborne lead dust and fume. Workplace lead concentrations at Tropical ranged from 40 to 5,300 ug/m^3, TWAs over the period sampled. These levels are up to 100 times greater than the U.S. lead standard.[10]

Operations with the highest lead exposures included battery plate separation (5,300 ug/m^3); cell dropping (2,400 ug/m^3); and battery assembly (2,600 ug/m^3). Lead concentrations in the lunch and interview rooms were less than 10 ug/m^3. All sample results collected from Tropical Battery are presented in Table 2.

2. Apex Battery

Employee exposures to airborne lead dust and fume ranged from 50 to 3,400 ug/m^3, TWA. The highest levels were as much as 70 times the U.S. OSHA lead standard.[10] Operations with the highest lead exposures were the melting of lead to produce battery posts and connectors (3,400 ug/m^3); battery plate filing (2,570 ug/m^3); and manual grid pasting (1,630 ug/m^3). All sample results from Apex are shown in Table 3.

3. Unistate Battery

Personal lead concentrations at Unistate ranged from 30 to 190 ug/m^3, TWA. Area air samples ranged from 10 to 100 ug/m^3. These sample results are shown in Table 4.

B. Medical

1. Tropical Battery

Table 5 summarizes the results of blood lead testing. Seventeen of 29 employees tested (59%) had blood lead levels 40 ug/dl or greater, and seven employees (24%) had blood lead levels of 50 ug/dl or more. NIOSH investigators were informed by management that full production had resumed only a few weeks before this survey, after little or no production for the previous few months. Blood lead levels can take several weeks to stabilize after a change in exposure levels. Therefore, it is likely that a higher prevalence of elevated blood lead levels would be found after a few months of normal operations. Although blood lead levels varied somewhat throughout the plant, elevated levels were found in all departments.

Table 6 shows the mean blood lead and maximum blood lead level in work areas with two or more workers. The highest blood lead level (64 ug/dl) was observed in the assembly production area where the mean blood lead level was also relatively high (46 ug/dl). Blood lead levels above 40 ug/dl were found in all departments, except for supervisory/managerial personnel.

2. Apex Battery

Table 7 summarizes the results of blood lead testing. Eleven of 12 employees tested (92%) had blood lead levels 40 ug/dl or greater, and nine employees (75%) had blood lead levels of 60 ug/dl or more. The highest blood lead level (89 ug/dl) was found in a supervisory employee. Although blood lead levels varied throughout the plant, elevated levels were found in all departments. This is not surprising given the small size of the plant and the shared work responsibilities.

3. Unistate Battery

Table 8 summarizes the results of blood lead testing at Unistate Battery. All four production employees tested (100%) had blood lead levels 40 ug/dl or greater, and three (75%) had blood lead levels of 60 ug/dl or more. Since workers performed a variety of tasks in a small area, high PbB levels could not be attributed to particular processes.

The PbB levels in the two office workers (28 and 34 ug/dl) were lower than in the production workers. However, based on data from a separate survey, blood lead levels above 25 ug/dl are unusual in adult residents of Kingston who are not exposed to battery shops or other unusual sources of exposure.[11] Although no air samples were taken in the office, it is likely that the shop owner and secretary have significant lead exposure from either airborn lead or lead dust on environmental surfaces in the office, which adjoins the shop.

4. Combined Workplaces

a. Blood Lead Levels

Twenty-eight percent of workers at these battery manufacturers had blood lead levels above 60 ug/dl, a level requiring medical removal under U.S. occupational health regulations. Presumably because of the recent resumption of full production at Tropical Battery, PbB levels there tended to be lower than at the two remaining battery companies. Eight of the production workers at battery manufacturers were considered supervisory, but their duties required them to spend varying periods in production areas. Six of these workers had blood lead levels of 30 ug/dl or above (range 28 to 86 ug/dl).

b. Predicators of Blood Lead

In analyzing the relationship between work practices and blood lead, supervisory employees at battery manufacturers (most of whom did not consider themselves "exposed" to lead) were excluded. At battery manufacturers, the geometric mean PbB was significantly increased among current smokers, compared to non-smokers, and among those who reported not always washing their hands before meals, compared to those who always washed. These behavioral variables are presented in Table 9. For each hygienic practice, however, the geometric mean PbB was still above 40 ug/dl among those workers who reported following that practice.

Air lead levels from personal breathing-zone samples were available for 32 workers. For these employees there was no crude correlation between $\log_{10}$[PbB] and $\log_{10}$[air lead] ($r=0.002$, $p=0.99$). However, it was possible that any underlying relationship could have been obscured by differences in work practices, or the shorter duration of recent exposure among workers at Tropical Battery. A multivariate model of $\log_{10}$[PbB] was derived from the following variables: $\log_{10}$[air lead]; behavioral variables from Table 9; and a variable for workplace (Tropical vs. Apex and Unistate). After backwards elimination of the least significant variables, until only those significant at the $p<0.10$ level remained, the following model was derived:

$$\log_{10}[\text{PbB}] = 1.59 - 0.19*(\text{Tropical Battery}) + 0.07*(\text{smoking}) + 0.05*\log_{10}[\text{air lead}]$$

This model explained 63% of the variance in $\log_{10}$[PbB].

c. Lead Toxicity

To assess relationships between blood lead and symptoms of possible lead toxicity, the prevalence of selected symptoms among workers whose PbB was 60 ug/dl and above was compared to the prevalence among workers with lower blood lead levels (Table 10). The prevalences of all but one symptom were higher among workers in the high blood lead group. The differences were statistically significant for muscle weakness (prevalence ratio (PR) 2.5, 95%, Confidence Interval (CI) 1.3 to 4.9) and decreased appetite (PR 3.2, 95%, CI 1.0 to 10.0).

Among all workers, PbB explained 65% of the variance in $\log_{10}$[ZPP] ($p<0.0005$, Figure 5). The shorter duration of recent lead exposure employees at Tropical Battery affected the intercept of this relationship. The coefficient of the indicator variable for Tropical Battery vs. others was significantly ($p<0.05$) less than zero, indicating lower ZPP levels for a given PbB among Tropical Battery workers than among other workers. However, this term only explained an additional 2% of the variance in $\log_{10}$[ZPP].

C. Observations of Engineering Controls and Work Practices

1. Tropical Battery

a. Grid Casting

Workers were observed using compressed air to remove dust and debris from molds and work clothing.

b. Lead Oxide Paste Mixer

Two exhaust fans on the rotary mixer, a device used to mix the PbO paste, were operated intermittently on October 20, 1987. Twin, 5-inch diameter ducts were located above this mixer to provide the exhaust ventilation; however, one duct was broken. During the paste mixing cycle visible emissions (combination of PbO dust and steam) were observed escaping from a cloth shroud which had been draped around the mixer by the operator.

c. Plate Drying and Storage

At Tropical Battery, freshly pasted grids were allowed to cool after emerging from the curing (drying) oven prior to further handling. Although minimal exposure occurs during this time, employees were observed fanning the pasted grids to promote more rapid drying, a technique potentially creating more dust in the work area.

d. Plate Breaking and Filing

Battery grids were cast and pasted in pairs. Two employees, working at a 4 by 6 foot table, manually separated the cast, pasted grids and filed off excess Pb flashing and PbO. Dust was generated during the handling and filing of the plates and no local exhaust ventilation (LEV) was provided.

e. Assembler (Plate Stacking)

Two employees (one at each station) arrange stacks of pasted grids (plates) and separators to assemble the battery cell. No LEV is used, although visible dust is generated during the handling of the dry, dusty plates. Stacks of plates and spacers are stored on work tables awaiting sorting.

2. Apex Battery

a. Grid Casting

The two semi-automatic grid casters were thermostatically controlled and airborne lead levels, while still high by U.S. standards, were among the lowest concentrations measured on October 22 (50 and 100 ug/m^3 for each caster operator).

b. Grid Pasting

Grids are hand pasted on a table covered with newspapers. Although the paste is moist when first applied, it rapidly dries, accounting for the third highest airborne lead concentration measured at Apex Battery. Because of the company's smaller size, a automatic grid paster, while desirable, could probably not be economically justified.

c. Grid Breaking and Filing

As with Tropical Battery, grids are cast and pasted in pairs, then manually separated and filed. Handling of these dried grids creates significant amounts of lead-containing dust. No LEV is provided for the operation.

3. Unistate Battery

a. Grid Casting

Although not operated during this evaluation, a manual grid casting machine (not thermostatically controlled) was located outdoors. An area air sample collected over the grid caster during this evaluation measured a lead concentration of 10 ug/m^3. Because of its outdoor location, this operation does not appear to be a significant source of lead exposure to the workers.

b. Cell Assembly and Group Burning

Since Unistate Battery purchases only pre-pasted plates, PbO handling is minimized. Individual plates are stacked indoors without the benefit of LEV. Group burning (connecting lead parts to battery cells) was performed both inside and outside. Results from general area air samples collected near group burning operations indicate that significant lead exposures (up to 100 ug/m^3) may occur during this activity.

D. Respiratory Protection

1. Tropical Battery

Half-mask dust respirators were worn by some of the employees but several wore the devices incorrectly. For example, workers used only a single head strap to hold the respirator in place (both straps must be used to get a proper fit) and several employees supplemented the respirator by wearing a handkerchief or cloth under the mask (a practice which compromises the respirator facepiece seal). Other employees with respirators had full beards or other facial hair which interfered with a proper facial seal. At least two employees had been given half-mask respirators of the incorrect size, virtually eliminating any possibility of a good fit. No formal, written respiratory protection program existed at Tropical.

2. Apex Battery

A variety of half-mask dust respirators were in use but none were equipped with the necessary high efficiency filters. Some respirator models were not NIOSH-approved respiratory devices. As with workers at Tropical, several employees wore their respirators incorrectly and one employee had been given a half-mask respirator of the incorrect size. No formal, written respiratory protection program existed at Apex.

3. Unistate Battery

No approved half-mask dust respirators were used and no formal respiratory protection program existed.

VII. DISCUSSION AND CONCLUSIONS

This survey revealed a high prevalence of elevated blood lead levels among workers at battery manufacturers in Jamaica. The sample of workplaces was not random, but for reasons stated earlier NIOSH investigators do not believe the workplaces surveyed have higher lead exposure than at other Jamaican battery manufacturers. As these manufacturers were already conducting some medical screening of their production workers, it is possible that these companies were more conscious of workers health and may, in fact, have lower lead exposures than other Jamaican battery manufacturers who were not surveyed. Regardless, PbB levels at these manufacturers were higher than those found among workers at a large U.S. battery manufacturer where only 6% of blood leads exceeded 60 ug/dl.[12]

The Jamaican battery workers at the three plants studied had a risk of blood lead levels above 60 ug/dl that was similar to that found at a Korean battery manufacturer.[13] Based on data from a separate NIOSH survey of smaller "backyard" battery repair shops located primarily in residential areas of Kingston, blood lead levels above 25 ug/dl are unusual in adult Jamaicans who are not exposed to battery shops or other unusual sources of exposure.[14]

High air lead levels prevailed at all battery manufacturers. At these companies engineering controls were generally lacking or non-functional. A comparison of air lead concentrations in various departments at Tropical and Apex, and those reported in other published surveys, show the difficulty in generalizing about high- and low-risk processes in battery manufacturer.[13,15] Furthermore, in small work areas, workers in one department may be exposed to high lead levels generated from nearby processes.

At companies in Jamaica where "informal" (not written) blood lead monitoring policies have been established, a blood lead level of 70 ug/dl has been used as a threshold for medical removal from exposure, and documentation of an acceptable fall in blood lead is not required before return to work. Although such a threshold may protect most workers from overt, symptomatic lead poisoning, it is too high to protect workers from chronic health effects of lead. Furthermore, workers returning to exposure after a few weeks of medical removal, but before repeat testing is completed, may still have unsafe blood lead levels.

Respirators in use at the three workplaces surveyed were not adequate for the lead concentrations that prevailed, and none of the companies had programs to ensure proper respirator use and maintenance. Therefore, even if a higher proportion of workers wore respirators regularly, it is probable that blood lead levels would remain unacceptably high.

Inhaled airborne lead is the most important route of lead exposure in occupational settings and control of airborne lead should reduce lead absorption by other routes as well.[5] Although this small, cross-sectional study was not designed to assess the relationship between airborne and blood lead, a positive association was detected when adjusting for other factors. That a stronger relationship was not found is not surprising since several factors could not be accounted for, including: (1) the effect of size of airborne lead particulate; (2) job tenure; or (3) lead ingestion from contamination of the hands and face.[6,11] Even in a much larger battery factory survey, only 9% of the variance in blood lead was explained by air lead levels alone.[12]

Symptoms are a relatively crude measure of lead toxicity, and this study included a relatively small number of workers. Still the data is consistent with some symptoms of lead toxicity occurring in workers with blood lead levels above 60 ug/dl.[5] Zinc protoporphyrin elevation is a more sensitive index of lead toxicity and the relationship between ZPP and blood lead among Jamaican workers was similar to that described for lead-exposed males in developed countries by Wildt et al [1987][16] who reported a regression equation for Swedish lead workers of:

$$\log[ZPP(ug/dl)] = 1.21 + 0.0148*PbB.$$

The AVIV hematoflourometer measures ZPP in micrograms per gram of hemoglobin. Because hemoglobin was not measured in this evaluation, a constant, equal to the log of the average hemoglobin concentration, should be added to the y intercept from the data for comparison with Swedish workers. Assuming the subjects in this study, who were all black males, had an average hemoglobin value of 14.5 grams per deciliter [National Center for Health Statistics, 1983][17], the adjusted regression equations for the Jamaican workers were:

$\log_{10}$[ZPP(ug/dl)] = 1.06 + 0.0168*PbB (Tropical Battery workers)

$\log_{10}$[ZPP(ug/dl)] = 1.25 + 0.0168*PbB (Other workers)

VIII. RECOMMENDATIONS

Because of the absence of occupational health regulations in Jamaica, several recommendations reference the U.S. OSHA lead standard, 29 Code of Federal Regulations Part 1910.1025. The guidelines for air lead levels, respirator use, and blood lead monitoring in this standard are based on a considerable body of scientific data and should be useful guidelines for protection of Jamaican workers. However, the adoption of any specific occupational health regulations is a policy issue for the MOH and the Jamaican government, and beyond the scope of this report.

A. Ventilation Recommendations

1. Downdraft ventilation work tables are recommended to reduce the dust levels generated at the grid breaking and filing operations at Tropical and Apex. Existing work tables could be modified to accommodate such a local exhaust ventilation system. This design would also be applicable for the cell assembly stations at Tropical Battery. Figure 6 provides an example of a design which may be adaptable to the existing tables at both companies.

2. Slotted, back-draft ventilated work benches are recommended to control the dust generated at several operations performed at Tropical and Apex. The plate stacking operation at Tropical Battery, based on personal breathing-zone air samples, generated the highest lead exposures in the plant (up to 5,300 ug/m^3). At Apex Battery the highest airborne lead concentrations (up to 3,400 ug/m^3) occurred at the lead melting and assembly operations. Figure 7 shows an example of a slotted back-draft bench which could be installed at these operations to exhaust the lead dust away from the employees. A similar design could be adopted for the workers at the "cell dropper" operation (inserting the battery cell into the battery case prior to final assembly). It is recommended that a smaller version of a slotted, back-draft work bench could be used to control the lead dust and fume generated from melting lead posts and connectors at Unistate Battery. The exhaust bench should be installed to exhaust the lead fume away from the employees. This ventilation system would also help control lead dust emissions from the plate stacking operation.

3. It is recommended that exhaust fans be installed in the walls of the main work areas at all three companies. Although not as beneficial as local exhaust ventilation, these fans should be expeditious to install and would introduce fresh outside air into the work areas. Such a system would especially be applicable at Unistate Battery since many of its operations are intermittent. The cost of these fans, and their installation, should be minimal.

4. At Tropical Battery, the damaged and missing duct work on the rotary PbO paste mixer should be repaired and the exhaust fans operated continuously during paste mixing operations. The cloth shroud draped over the mixer to control dust emissions should be replaced with flexible, transparent plastic curtains which would surround the mixer during operation.

B. Respiratory Protection

Respirators are designed to protect only against certain specific types of substances and in certain concentration ranges, depending on the type of equipment used. Consequently, other factors, such as engineering or administrative controls, should be considered first in an effort to reduce air lead exposures to the employees. Nevertheless, there may be situations where respirators can and should be used, especially while engineering controls are being implemented.

1. It is recommended that employees wear appropriate respiratory protection while working because of the high lead concentrations measured in all the surveyed plants. The one exception would be the battery charging area at Tropical Battery. To assure that the workers are adequately protected, it is recommended that the respirator program be consistent with the requirements of the U.S. Occupational Safety and Health Administration's General Industry Standards [29 CFR 1910.1025 (appendix A) and 29 CFR 1910.134 (appendix B)].

2. Standard operating procedures should be developed concerning respirator use and maintenance, and employees should be trained in the hazards associated with the manufacture of lead-acid batteries. In this situation, special emphasis on the toxicity of lead, and the need to wear respiratory protection, should be made. All employees who will be required to wear a respirator should be medically evaluated to determine if they are physically able to wear a respirator.

3. Selection of the appropriate respirator is largely influenced by the concentration of contaminants (in this case lead) in the work place. A half-mask, air purifying respirator equipped with high efficiency filters is recommended for employees not exposed to lead in excess of 500 ug/m^3. For those workers whose exposures exceed 500 (but less than 2,500) ug/m^3, a full-face piece respirator with high efficiency filters is required. For exposures up to 50,000 ug/m^3, a powered air-purifying respirator with high-efficiency filters, or a half-mask supplied-air respirator operated in a positive-pressure mode, is required. Tables 11, 12, and 13 list the appropriate level of respiratory protection for specific operations at Tropical, Apex, and Unistate battery companies, respectively. Respirators specified for high concentrations may be used at lower concentrations of lead.

4. Respirators should be stocked in varying sizes to accommodate differing facial features. All major respirator manufacturers produce respirators in small and large facepiece sizes. Some also manufacture medium and extra large sizes. Once respirators are selected, employees must be properly trained in their use and routine maintenance. Facial hair, which prevents a proper facepiece to face seal, can not be permitted. When not in use, the respirators must be properly stored in an area free from contamination (such as a locker, cabinet, plastic storage bag, or other designated storage area). Prior to storage, the respirator must be cleaned and sanitized following the manufacturer's recommendations.

5. All respirators issued to employees should exhibit minimum facepiece leakage. The company should perform qualitative face fit tests on their workers to determine the correct facepiece size. Methods for conducting qualitative respirator fit-tests, as well as quidelines for operating a respirator and lead monitoring program, are discussed in the OSHA occupational lead standard.

C. Work Practices

1. Dry sweeping should be eliminated. Regular wet sweeping and cleaning should be performed to minimize dust generation.

2. Compressed air should not be used to blow dust from machinery, parts, or worker's clothing.

3. Signs should be posted at all entrances to the battery manufacturing area warning employees of the hazards associated with lead dust and fume, the necessity of wearing a respirator, and prohibiting eating, drinking, and smoking in the work area.

4. Employees should not be permitted to eat, drink, or smoke in the work area since ingestion of lead can be a significant route of exposure.

5. Cylinders of compressed gases should be properly chained and capped to reduce the chance of an accident. Oxygen and acetylene cylinders should not be stored together. During this evaluation unchained oxygen and acetylene cylinders were stored together at Tropical Battery near an entrance where lift trucks were moving pallets of materials.

6. Written policies for implementing and monitoring compliance with recommended work practices, safety procedures, respirator use, and hygiene at all three companies should be developed.

7. Work clothing and laundering facilities should be provided for the workers at Apex and Unistate. Shower facilities should also be available to the employees at Unistate Battery so they may clean up prior to leaving work. The changing of work clothing and showering by employees of both companies should not be done in the residential buildings located on the work premises near each plant.

8. A permanent emergency eye wash and shower station should be installed in the battery charging area at all companies.

9. Chemical splash goggles should be provided and worn whenever acid is handled. Employees at both Apex and Unistate were observed pouring concentrated sulfuric acid into containers and batteries without splash protection.

10. A formal, written blood lead monitoring policy should be developed which specifies time intervals for testing, blood lead thresholds for medical removal from, and resumption of, exposure, and pay and benefits for workers removed from work because of high blood leads. It is recommended that blood lead thresholds specified in U.S.-OSHA regulations be used.

11. Residents in apartments located on the premises of both Apex and Unistate should undergo blood lead screening as they were not tested during these workplace surveys.

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Acknowledgements:

The authors are grateful to the management and workers at Tropical Battery, Apex Battery, and Unistate Battery for their cooperation with our survey. NIOSH is also grateful for the assistance of Dr. Eunice Forrest of Medical and Industrial Laboratories, Ltd., Jamaica; Norbert Campbell of the Environmental Control Division, Ministry of Health, Jamaica; Patience Dennis, Sonja Roche, and other staff of the Government Chemist, Jamaica; Elaine Gunter of the Center for Environmental Health and Injury Control, CDC; and to the Pan American Health Organization for funding travel expenses associated with this investigation.

XI. DISTRIBUTION AND AVAILABILITY OF REPORT

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

1. Dr. Peter Figuoroa, Epidemiology Unit, Jamaican Ministry of Health, 10 Caledonia Avenue, Kingston, Jamaica

2. U.S. Department of Labor, OSHA - Region III

3. Dr. Norma Andrews, Pan American Health Organization/World Health Organization Representative, 60 Knutsford Boulevard, Kingston 5, Jamaica.

4. Caribbean Epidemiology Centre, 16-18 Jamaica Boulevard, Federation Park, Port of Spain, Trinidad.

5. Dr. Homero Silva, Environmental Control Division, Life of Jamaica Building, 61 Halfway Tree Road, Kingston, Jamaica.

Table 1

Age And Years Of Battery Work Among Battery Workers Surveyed* In Jamaica, By Work Place
HETA 87-371
Technical Assistance to the Jamaican Ministry of Health

		Battery Manufacturer		
		A	B	C
Number of production employees surveyed		29	12	5
Age (years)	mean	31	31	29
	(range)	(20-50)	(20-51)	(19-51)
Years employed as battery worker	mean	8	8	5
	(range)	(0-22)	(0-25)	(0-13)

* All workers were black males.

Company A: Tropical Battery Company, Ltd.
Company B: Apex Battery Company, Ltd.
Company C: Unistate Battery Company, Ltd.

Table 2

Personal and Area Air Samples for Lead
Tropical Battery, Ltd.
HETA 87-371
Technical Assistance to the Jamaican Ministry of Health

Operation	Sample Volume[a]	Concentration of Lead, TWA[b]
Assembly	808	180
Paste Mixer	908	210
Plate Stack	902	200
Dump	894	230
Assembly	884	2,600
Group Burning	864	420
Parts Molder	920	100
Plate Breaker	924	400
Plate Breaker	922	390
Recasting	924	90
Cell Dropper	906	2,400
Plate separator	807	5,300
Group Burning	846	310
Battery Tech.	874	340
Stump Burning	882	210
Plate Breaking	842	690
Group Burning	840	440
Recasting	876	110
Plate Stacker	864	180
Recasting	788	170
Paste Mixer	862	960
Grid Paster	864	240
Battery Charging	852	40
Battery Tech.	826*	260*
Grid Casting	864	110
Plate Breaker	852	380
Area Samples:		
Lunch Room	760	10
Interview Room	836	4
Evaluation Criteria:		
U.S. OSHA Permissible Exposure Limit for airborne lead		50

*Sample volume estimated due to pump failure.
a Sample volume, in liters.
b All lead concentrations are TWAs over the period sampled and are expressed in ug/m^3 of air.

Table 3

Personal and Area Air Samples for Lead
Apex Battery, Ltd.
HETA 87-371
Technical Assistance to the Jamaican Ministry of Health

Operation	Sample Volume[a]	Concentration of Lead, TWA[b]
Parts Casting	840	3400
Plate Filing	646	2570
Grid Pasting	834	620
Grid Pasting	872	1630
Grid Casting	850	50
Grid Casting	806	100
Assembly & Burn	788	50
Assembly & Burn	604	70
Battery Repair	800	60
Charging	756	50

Evaluation Criteria:	
U.S. OSHA Permissible Exposure Limit for airborne lead	50

a Sample volume, in liters.
b All lead concentrations are time-weighted averages over the period sampled and are expressed in micrograms of lead per cubic meter of air.

Table 4

Personal and Area Air Samples for Lead
Unistate Battery, Ltd.
HETA 87-371
Technical Assistance to the Jamaican Ministry of Health

Operation	Sample Volume[a]	Concentration of Lead, TWA[b]
Production	846	30
Production	814	80
Production	820	190
Area Sample[c]	800	10
Area Sample[d]	786	60
Area Sample[e]	776	100

Evaluation Criteria:
U.S. OSHA Permissible Exposure Limit for airborne lead 50

a Sample volume, in liters.
b All lead concentrations are time-weighted averages over the period sampled and are expressed in micrograms of lead per cubic meter of air.
c Area air sample collected at the manual grid caster, outside location.
d Area air sample collected adjacent to plate assembly operation, inside.
e Area air sample collected over the group burning operation, inside.

Table 5

Blood Lead Levels
Tropical Battery, Ltd.
HETA 87-371
Technical Assistance to the Jamaican Ministry of Health

Blood Lead Level (ug/dl)	Number of Workers	Percent of Workers
Less than 40	12	41%
40 to 49	10	34%
50 to 59	6	21%
60 and above	1	3%

Table 6

Blood Lead Levels by Department for
Departments with Two or More Workers
Tropical Battery, Ltd.
HETA 87-371
Technical Assistance to the Jamaican Ministry of Health

Department or Work area	Number Tested	Average Blood Lead (ug/dl)	Maximum Blood Lead
Pasting	4	44	51
Grid casting	3	46	52
Industrial	4	33	43
Charging	2	47	55
Assembly/production	10	46	64
Supervisors/managers	4	31	34

Table 7

Blood Lead Levels
Apex Battery
HETA 87-371
Technical Assistance to the Jamaican Ministry of Health

Blood Lead Level (ug/dl)[a]	Number of Workers	Percent of Workers
Less than 40	1	8%
40 to 49	1	8%
50 to 59	1	8%
60 and above	9	75%

a Micrograms of lead per deciliter of blood.

Table 8

Blood Lead Levels
Unistate Battery
HETA 87-371
Technical Assistance to the Jamaican Ministry of Health

Blood Lead Level[a]	Number of Workers	Percent of Workers
25 to 40	2	33%
40 to 49	1	17%
50 to 59	0	0%
60 and above	3	50%

a Micrograms per deciliter of blood.

TABLE 9

Geometric Mean Blood Lead Levels By Smoking And
Work Practices Among Battery Workers[a] Surveyed In Jamaica
HETA 87-371
Technical Assistance to the Jamaican Ministry of Health

Behavior present?>		YES	NO
Behavior			
Current smoker	GM (N)	57 (15)	46* (23)
Always washes hands before eating	GM (N)	48 (34)	71* (4)
Always showers before leaving work	GM (N)	48 (29)	59 (9)
Always changes clothes before leaving work	GM (N)	b	b
Always wears respirator while working	GM (N)	45 (14)	54 (24)

a excludes supervisory employees
b all workers always changed clothes
* $p<0.05$, t-test for difference in geometric means
GM = geometric mean blood lead in ug/dl.
(N) = number of workers

TABLE 10

Symptoms by Blood Lead Level

Among Battery Manufacturing Workers Surveyed in Jamaica
HETA 87-371
Technical Assistance to the Jamaican Minstry of Health

	Percent with symptom			
Symptoms	PbB < 60 (N=33)[a]	PbB $\geq$ 60 (N=13)[b]	Prevalence Ratio[c]	95% C.I.
Severe headaches	18	33	1.8	(0.6 - 5.4)
Trouble concentrating	18	31	1.7	(0.6 - 5.0)
Trouble remembering	27	38	1.4	(0.6 - 3.4)
Trouble sleeping	19	8	0.4	d
Muscle weakness	27	69	2.5	(1.3 - 4.9)
Joint pain	30	53	1.8	(0.9 - 3.7)
Decreased libido or potency	24	31	1.3	(0.5 - 3.5)
Decreased appetite	12	38	3.2	(1.0 - 10.0)
Nausea	9	31	3.4	(0.9 - 13.1)
Abdominal pain	12	31	2.5	(0.7 - 8.7)

Comments:

a Missing data (no answer given) for trouble sleeping (2 workers).
b Missing data for headaches (1 worker).
c Prevalence of symptoms in workers with PbB > 60 ug/dl divided by the prevalence of symptoms in workers with PbB < 60 ug/dl.
d Fishers exact test: p=0.65.

C.I. = Taylor-series confidence interval.
PbB = blood lead level in ug/dl.

Table 11
Respiratory Requirements
Tropical Battery, Ltd.
HETA 87-371
Technical Assistance to the Jamaican Ministry of Health

Concentration of Lead[a]	Operation	Recommended Respiratory Protection (NIOSH Approved)
40	Battery Charging	For airborne concentrations not in excess of 500 ug/m^3, any half-mask, air-purifying respirator equipped with high efficiency filters.[b] Single-use (disposable) respirators are not recommended. Any of the following respirators are also acceptable at this level.
90	Recasting	
100	Parts Molder	
110	Grid Casting	
110	Recasting	
170	Recasting	
180	Assembly	
180	Plate Stacker	
210	Paste Mixer	
200	Plate Stacker	
210	Stump Burning	
230	Dump	
240	Grid Paster	
260	Battery Tech.	
310	Group Burning	
340	Battery Tech.	
380	Plate Breaker	
390	Plate Breaker	
400	Plate Breaker	
420	Group Burning	
440	Group Burning	
690	Plate Breaker	
960	Paste Mixer	
2,400	Cell Dropper	For airborne concentrations not in excess of 2,500 ug/m^3, a full facepiece, air-purifying respirator equipped with high efficiency filters.
2,600	Assembly	
5,300	Separator	For airborne concentrations not in excess of 50,000 ug/m^3, a powered air-purifying respirator with high efficiency filters or a half-mask, supplied-air respirator operated in a positive pressure mode.

a Lead concentration expressed in micrograms per cubic meter (ug/m^3), TWA.
b A high efficiency particulate filter means 99.97% efficiency against 0.3 micron sized particles.

Table 12

Respiratory Requirements
Apex Battery, Ltd.
HETA 87-371
Technical Assistance to the Jamaican Ministry of Health

Concentration of Lead[a]	Operation	Recommended Respiratory Protection (NIOSH Approved)
50	Battery Charging	For airborne concentrations not in excess of 500 ug/m^3, any half-mask, air-purifying respirator equipped with high efficiency filters.[b] Single-use (disposable) respirators are not recommended. Any of the following respirators are also acceptable at this level.
50	Grid Casting	
60	Battery Repair	
62	Grid Pasting	
70	Assembly & Burn	
170	Recasting	
180	Assembly	
180	Plate Stacker	
1,630	Grid Pasting	For airborne concentrations not in excess of 2,500 ug/m^3, a full facepiece, air-purifying respirator equipped with high efficiency filters.
2,570	Plate Filing	For airborne concentrations not in excess of 50,000 ug/m^3, a powered air-purifying respirator with high efficiency filters or a half-mask, supplied-air respirator operated in a positive pressure mode.
3,400	Parts Casting	

a Lead concentration expressed in micrograms per cubic meter (ug/m^3), TWA.
b A high efficiency particulate filter means 99.97% efficiency against 0.3 micron sized particles.

Table 13

Respiratory Requirements
Unistate Battery, Ltd.
HETA 87-371
Technical Assistance to the Jamaican Ministry of Health

Concentration of Lead[a]	Operation	Recommended Respiratory Protection (NIOSH Approved)
30 80 190 10 60 100	Production Production Production Area Sample[c] Area Sample[d] Area Sample[e]	For airborne concentrations not in excess of 500 ug/m^3, then any half-mask, air-purifying respirator equipped with high efficiency filters.[b] Single-use (disposable) respirators are not recommended. Any of the following respirators are also acceptable at this level.
	No exposures measured at this level in the evaluation.	For airborne concentrations not in excess of 2,500 ug/m^3, a full facepiece, air-purifying respirator equipped with high efficiency filters.
	No exposures measured at this level in the evaluation.	For airborne concentrations not in excess of 50,000 ug/m^3, a powered air-purifying respirator with high efficiency filters or a half-mask, supplied-air respirator operated in a positive pressure mode.

a Lead concentration expressed in micrograms per cubic meter (ug/m^3), TWA.
b A high efficiency particulate filter means 99.97% efficiency against 0.3 micron sized particles.
c Outside area air sample collected over the manual grid caster, outside.
d Interior area air sample collected adjacent to plate assembly operation.
e Interior area air sample collected over the plate assembly operation.

FIGURE 1

BATTERY MANUFACTURE
FLOW DIAGRAM
(INTRODUCTION OF PARTS AND MATERIALS)

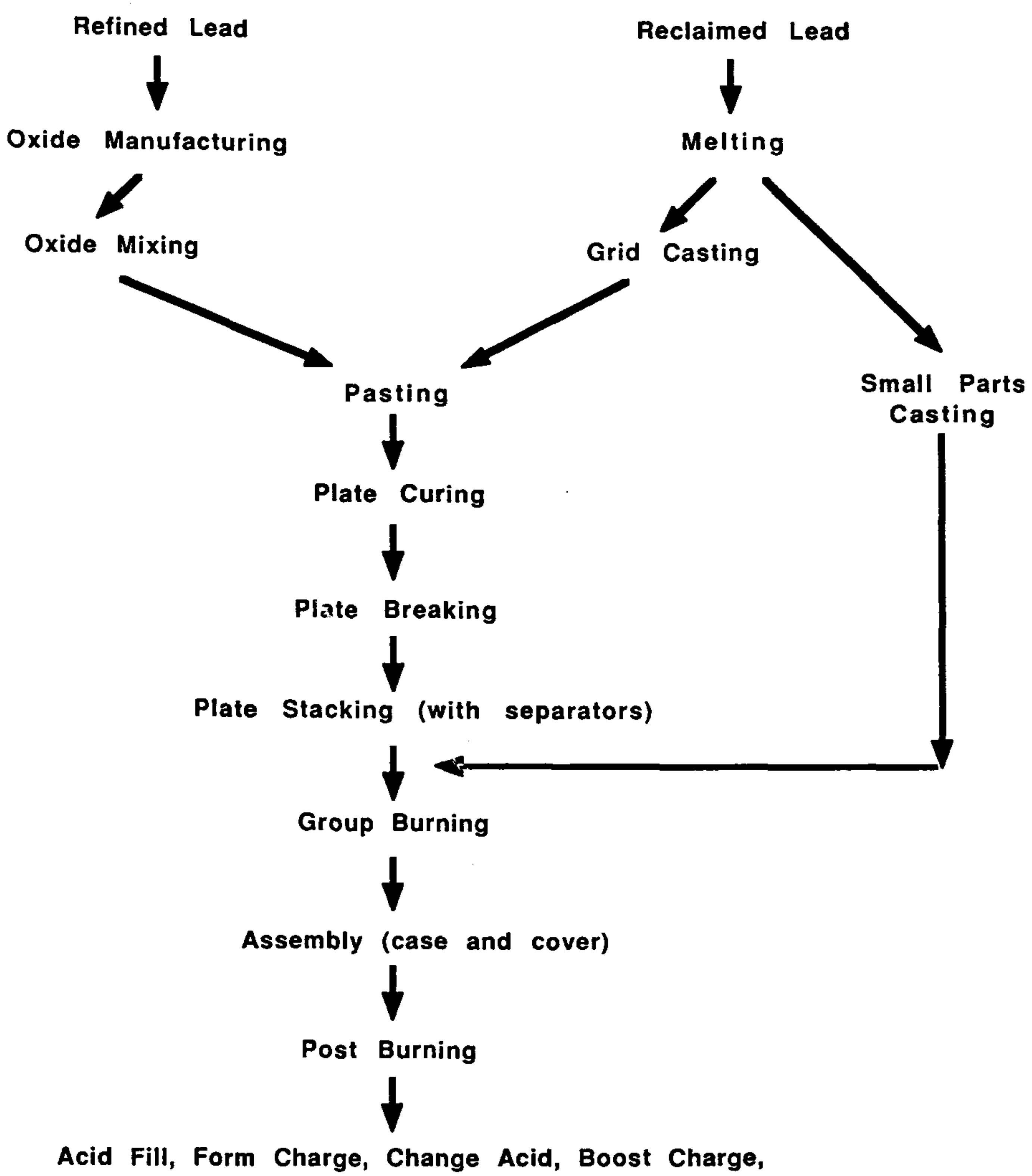
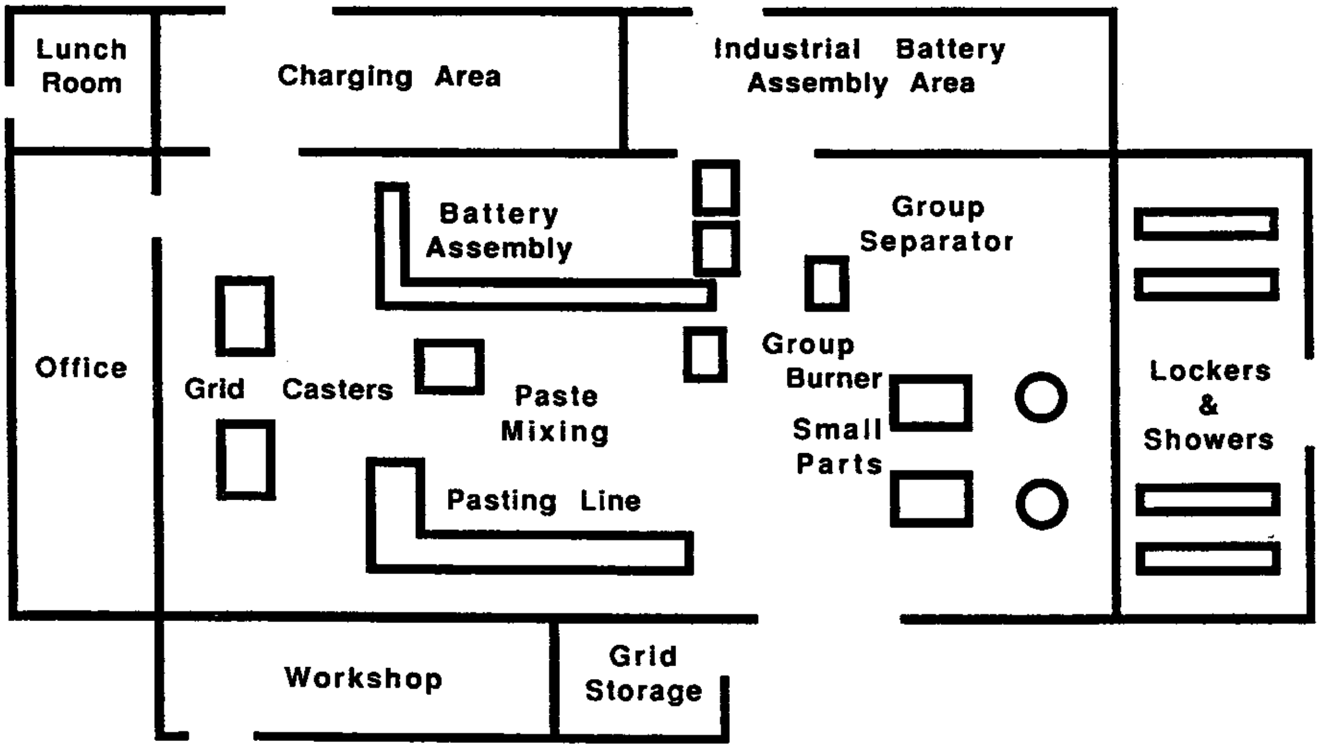


FIGURE 2

Tropical Battery Ltd.
HETA 87-371



COMMENTS:
NO LOCAL EXHAUST VENTILATION IN BUILDING
HIGHEST LEAD CONCENTRATIONS MEASURED AT GROUP SEPARATORS AND BATTERY CELL ASSEMBLY OPERATIONS.

FIGURE 3
APEX BATTERY COMPANY
HETA 87-371

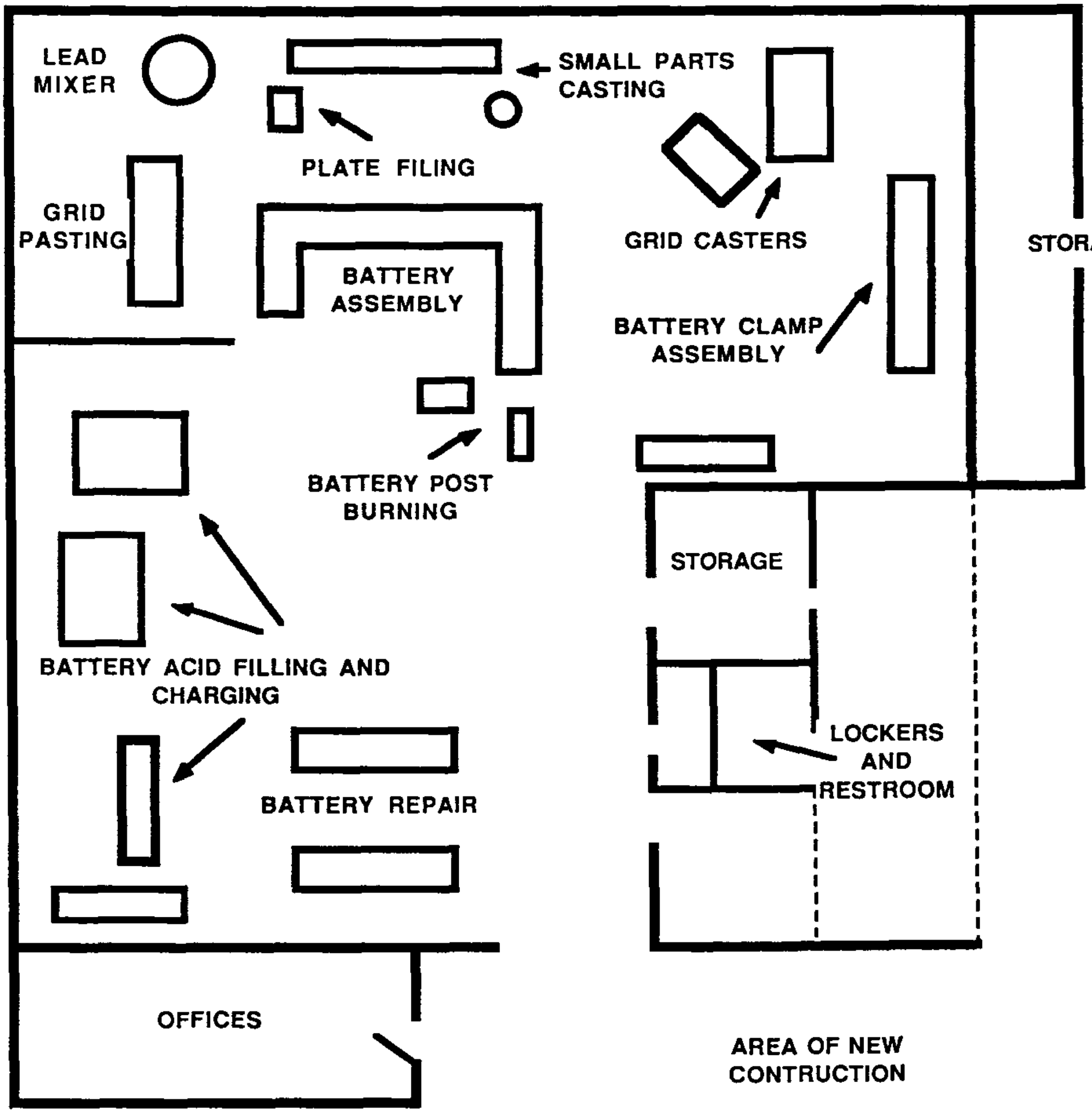
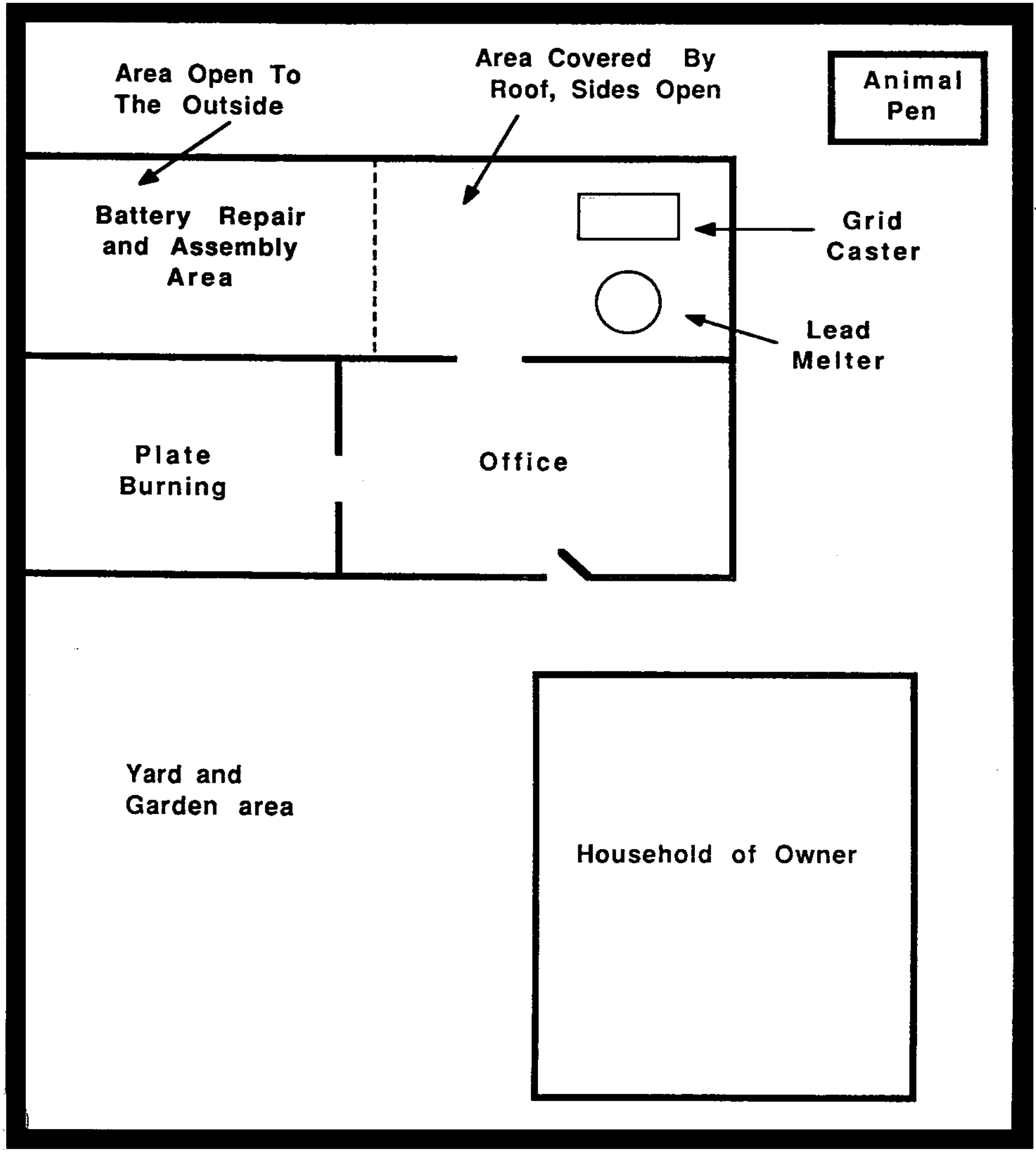


FIGURE 4
UNISTATE BATTERY COMPANY
HETA 87-371



COMMENTS:
GRID CASTER AND LEAD MELTER NOT IN OPERATION ON
OCTOBER 22, 1987

FIGURE 5

Zinc protoporphyrin (ZPP) levels vs.
Blood lead (PbB) levels, battery workers, Jamaica, 10/87
HETA 87-371, Technical Assistance to the Jamaican Ministry of Health

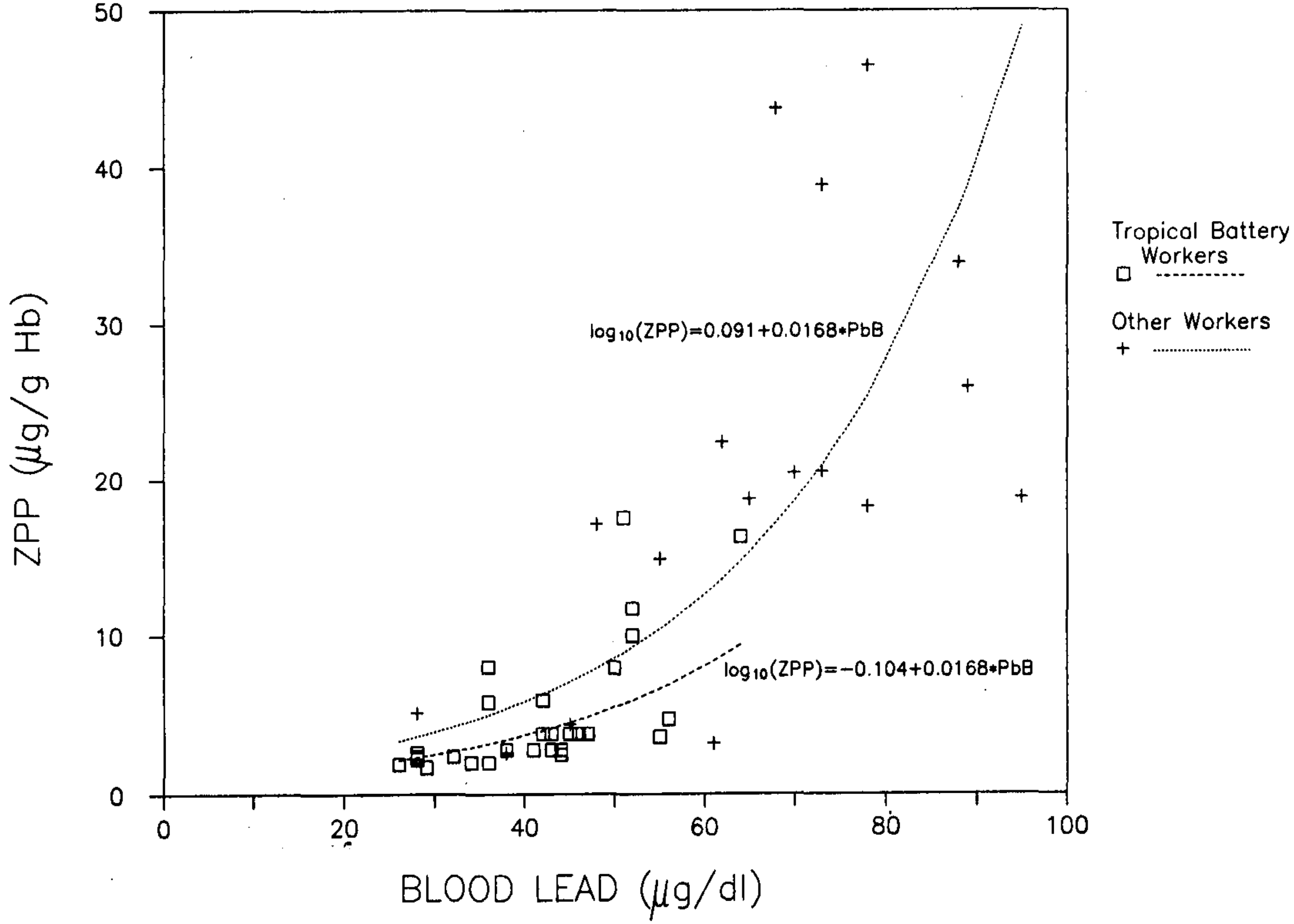


FIGURE 6

Example of a Downdraft Worktable
HETA 87-371
Technical Assistance to the Jamaican Ministry of Health

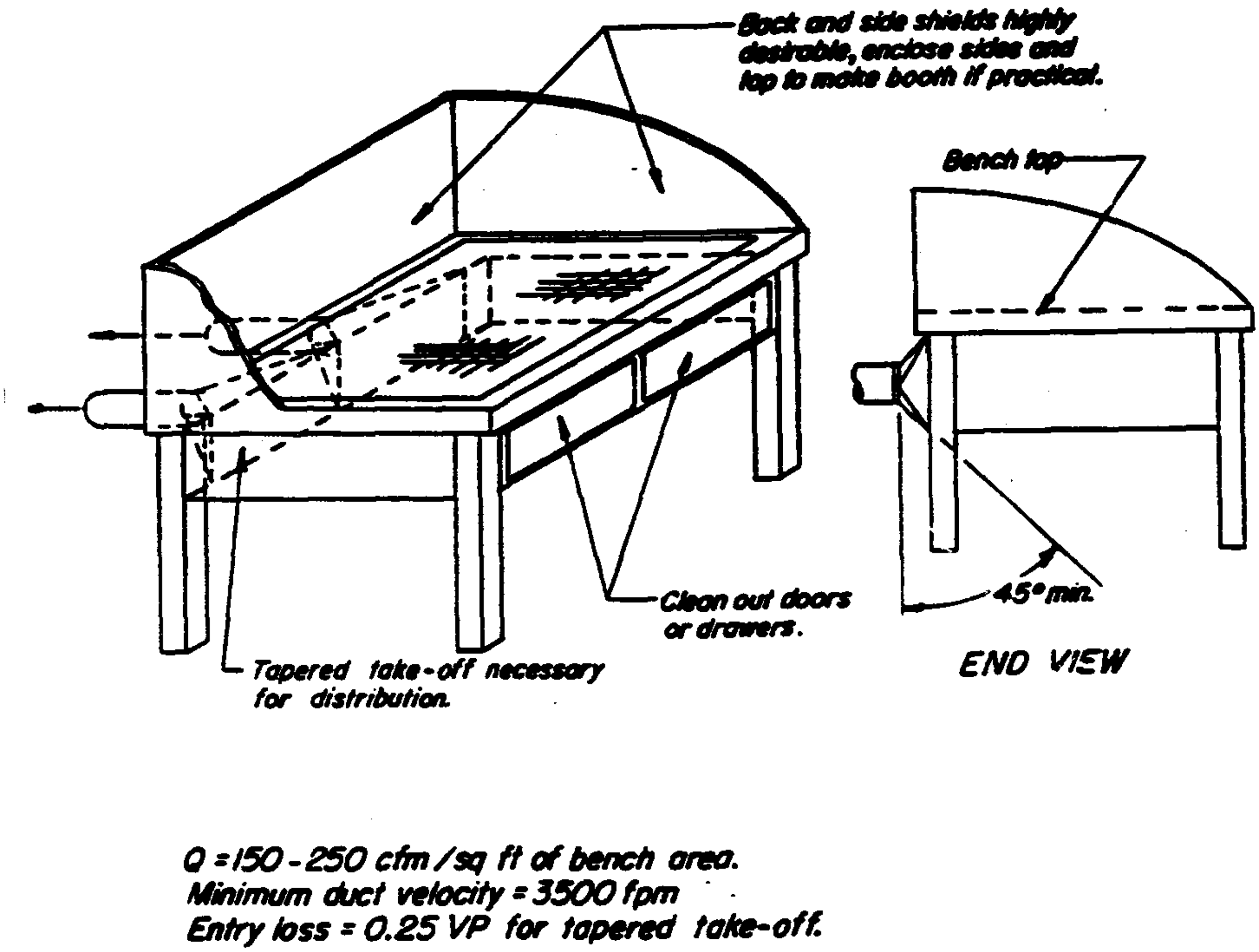


Figure courtesy of:
The American Conference of Governmental Industrial Hygienists
Industrial Ventilation - A Manual of Recommended Practice, 1986.

Figure 7

Example of a Slotted, Back-draft Work Bench
HETA 87-371
Technical Assistance to the Jamaican Ministry of Health

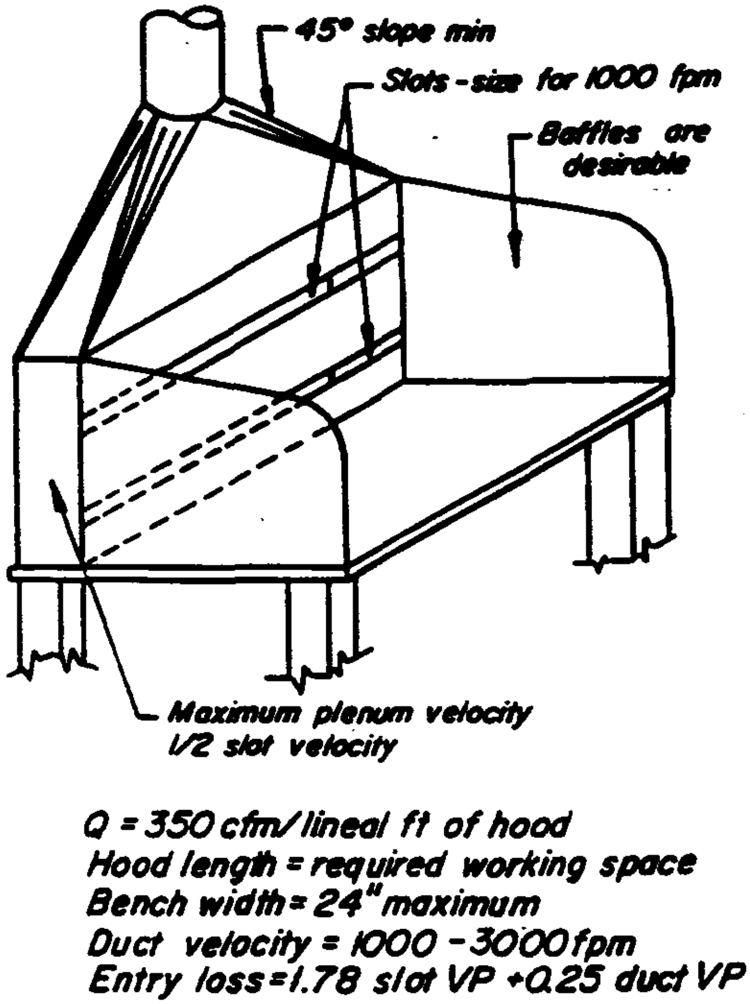


Figure courtesy of:
American Conference of Governmental Industrial Hygienists
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