HETA 95–0097–2661
Battery Conservation Technologies, Inc.
(Formerly Recovery & Reclamation, Inc.)
Pecos, Texas

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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.

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ACKNOWLEDGMENTS AND AVAILABILITY OF REPORT

This report was prepared by Christopher M. Reh, Daehee Kang, and Veronica Herrera–Moreno of the Hazard Evaluations and Technical Assistance Branch (HETAB), Division of Surveillance, Hazard Evaluations and Field Studies (DSHEFS). Field assistance was provided by Richard W. Hartle, M.S.P.H., C.I.H., Leo M. Blade, M.S.E.E., C.I.H., Calvin K. Cook, M.S., Michael E. Barsan, Dino A. Mattorano, Michael V. King, O.H.S.T., and Marian E. Coleman of the HETAB, DSHEFS; also, Pamela L. Drake of the NIOSH Spokane Research Laboratory. Analytical support was provided by DataChem Laboratories, Salt Lake City, Utah, and Pacific Toxicology Laboratories, Los Angeles, California. Desktop publishing was performed by Ellen Blythe.

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Health Hazard Evaluation Report 95–0097–2661
Battery Conservation Technologies, Inc. (BCTI)
(Formerly Recovery & Reclamation, Inc. [R&R])
Pecos, Texas
October 1997

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SUMMARY

On December 14, 1994, the National Institute for Occupational Safety and Health (NIOSH) received a request for a health hazard evaluation (HHE) from the Texas Department of Health (TDH). This request centered on TDH's concern that employees at Recovery & Reclamation, Inc. (R&R) in Pecos, Texas, were exposed to hazardous concentrations of mercury (Hg) during the recycling/reclamation of household–type alkaline batteries (*e.g.* battery sizes AAA, AA, C, D, and 9–volt). During the conduct of this HHE, the owner of R&R filed for bankruptcy and the facility was re–incorporated as Battery Conservation Technologies, Inc. (BCTI). The NIOSH investigators conducted an initial site visit and walk–through inspection on March 2–3, 1995, and conducted Hg exposure assessment studies during the May 16–17, 1995, and December 10–12, 1996, site visits.

The Hg exposure assessment studies consisted of concurrent industrial hygiene and medical studies. Two and three consecutive days of Hg exposure monitoring were conducted during the first (May 16–17, 1995) and second site visits (December 10–12, 1997), respectively. Workers' Hg exposure concentrations and area air concentrations were determined using NIOSH Method 6009. Bulk dust samples were also collected. The medical protocol consisted of the administration of a questionnaire and the collection of a "spot" urine sample. The questionnaire was designed to collect demographic, work, and health information from the workers. Each urine sample was analyzed for Hg and creatinine; in addition, the urine samples collected during the December 10–12, 1996, (BCTI) site visit were analyzed for N–acetyl–β–D–glucosaminidase (NAG), a non–specific indicator of proximal tubule damage.

During the May 16–17, 1995, site visit at R&R, the NIOSH investigators collected 67 full–shift air samples from the breathing zones of participating workers. The mean (average) Hg exposure concentration for all workers participating in this survey was 53.0 micrograms of Hg per cubic meter of air (μg/m^3), with a range from 0.9 to 612.7 μg/m^3. Thirty–nine percent were above the NIOSH recommended exposure limit (REL) of 50 μg/m^3, and 52% of the exposure measurements were above the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Value (TLV®) of 25 μg/m^3. Also, 7 of the 67 full–shift time–weighted average (TWA) Hg exposure measurements exceeded the Occupational Safety and Health Administration (OSHA) ceiling limit of 100 μg/m^3. A total of 58 workers from first and second shifts completed the questionnaire and provided pre–shift urine samples. The mean urine Hg concentration was 38.9 micrograms per gram creatinine (μg/g–Cr), and ranged from 1.6 to 172.0 μg/g–Cr. Forty and 31% of the workers had urine Hg concentrations above the ACGIH Biological Exposure Index (BEI®) of 35 μg/g–Cr, and the World Health Organization (WHO) study group's recommended limit of 50 μg/g–Cr, respectively. A statistically significant correlation was found between the personal breathing–zone Hg exposure concentrations and the urine Hg levels (r_p=0.32, p=0.04). In addition,

a statistically significant relationship was found between urine Hg levels (dichotomized using the ACGIH BEI) and the following central nervous system and respiratory symptoms as determined from the questionnaire: feeling tired, weak, depressed, and shortness of breath ($p<0.05$, Fisher's exact test).

A total of 51 full–shift TWA Hg exposure samples were collected during the December 10–12, 1996, site visit at BCTI. For the most part, each worker had a full–shift Hg exposure measurement for each day of the three–day period. Using these data, three–day Hg exposure means were calculated for each worker by averaging the worker's three daily exposure measurements for the three day period. The overall mean Hg exposure concentration for the 51 full–shift TWA Hg exposure measurements was 229.8 $\mu g/m^3$, and ranged from 2.9 to 2021.3 $\mu g/m^3$. Fifty–three percent (27 of 51) of the exposure measurements were above the OSHA ceiling limit. In addition, 76% (39 of 51) and 84% (43 of 51) of the exposure measurements were above the respective NIOSH REL and ACGIH TLV, respectively. The three–day means ranged from 5.6 to 1293.1 $\mu g/m^3$, with 53% and 79% of the Hg exposure means above OSHA ceiling limit and NIOSH REL, respectively. Also, 84% of the three–day Hg exposure means exceeded the ACGIH TLV. All 19 workers employed at BCTI provided a urine sample. The urine Hg levels averaged 136.5 µg/g–Cr, and ranged from 4 to 508 µg/g–Cr. Seventy–four percent of the workers at BCTI had urine Hg levels in excess of the WHO standard. In addition, 79% of the workers had urine Hg levels exceeding the ACGIH BEI. The average urine NAG level was 4.8 International Units per gram of creatinine (IU/g–Cr), and ranged from 1.2 to 19.4 IU/g–Cr. Only two workers had urine NAG levels above the reference values for adults; levels of 12.1 and 19.4 IU/g–Cr were observed in two male maintenance workers. Both of these workers had urine Hg levels above 200 µg/g–Cr. A statistically significant correlation was found between the three–day mean Hg exposure metric and the urine Hg levels ($r_p=0.45$, $p=0.03$). Also, a non–significant correlation was found between the urine Hg and urine NAG data ($r_p=0.28$, $p=0.12$). Of the 14 workers who had urine Hg levels over 50 µg/g-Cr, 8 (57%) reported symptoms suggestive of Hg overexposure, such as tiredness, headaches, weakness, or soreness of the gums. Two of these workers had elevated NAG excretion (12.1 and 19.4 IU/g-Cr). Of the five workers with urine Hg levels under 50 µg/g–Cr, three reported tiredness, one reported weakness, and one reported headache and soreness of the gums.

The NIOSH investigators conclude that a serious health hazard exists at R&R/BCTI from the recycling and reclamation of household–type alkaline batteries. A significant number of workers at this facility have full–shift Hg exposure levels in excess of the OSHA PEL, NIOSH REL, and ACGIH TLV; these exposures were associated with high urine Hg levels and the prevalences of symptoms reported in a questionnaire. Changes in the process related to the conversion from R&R to BCTI have produced an increase in the workers' Hg exposures and urine Hg levels, and the current respirator program is not protecting workers from inhalation exposures. There is also a possibility that workers' homes are being contaminated with Hg due to the wearing of work clothing home and not showering before leaving the workplace. Considering the results from this study, Hg should be considered a potential health hazard whenever recycling/reclaiming alkaline batteries. Recommendations are provided in this report to protect workers from Hg exposures.

Keywords: SIC 5093 (Scrap and Waste Materials), mercury, alkaline batteries, urine mercury, recycling operations, reclamation operations, N–acetyl–β–D–glucosaminidase, NAG, central nervous system, renal system, kidneys.

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INTRODUCTION

On December 14, 1994, the National Institute for Occupational Safety and Health (NIOSH) received a request for a health hazard evaluation (HHE) from the Environmental and Occupational Epidemiology Program of the Texas Department of Health (TDH). This request centered on TDH's concern that employees at Recovery & Reclamation, Inc. (R&R) in Pecos, Texas, were exposed to hazardous concentrations of mercury (Hg) during the recycling/reclamation of household–type alkaline batteries (*e.g.* battery sizes AAA, AA, C, D, and 9–volt). In response to this request, the NIOSH investigators conducted an initial site visit and walk–through inspection on March 2–3, 1995, and conducted Hg exposure assessment studies during the May 16 –17, 1995, and December 10–12, 1996, site visits.

During the March 1995 and the May 1995 NIOSH site visits, R&R recycled/reclaimed alkaline batteries, zinc/carbon–potassium hydroxide batteries (railroad batteries), and lithium batteries. Lead–acid batteries were collected at the facility but shipped to another company for reclamation. Between the May 1995 and December 1996, NIOSH site visits, the owner of R&R filed bankruptcy and the facility was closed. After a brief period, the facility was reopened by some former R&R management personnel under the name Battery Conservation Technologies, Inc (BCTI). As a result, the process was redesigned to recycle only alkaline batteries. For clarity in this report, data and descriptions related to R&R are from the May 1995 site visit, whereas data and descriptions related to BCTI are from the December 1996, site visit.

An interim report was issued to R&R, TDH, and the employee representatives on September 20, 1995. This report included the Hg exposure data and urine Hg data from the May 1995 site visit, and provided recommendations for protecting workers potentially exposed to Hg. In addition, draft copies of all the Hg exposure, urine Hg, and urine N–acetyl–β–D–glucosaminidase (NAG) data collected during the HHE were provided to R&R/BCTI management, TDH, and the employee representatives. Workers who provided a urine sample received their individual results (by letter) from the urine analyses performed during this study.

BACKGROUND

The R&R site contained several sheet metal structures built on concrete slabs. Each building contained a specific process and was typically identified by a letter–number combination. The workers at R&R were classified as sorters, laborers, or mechanical/electrical workers. Sorters would remove non–battery debris (scrap metal, medical wastes, paper, trash, *etc.*) from the batteries on conveyor belts, and hand–sort batteries by size and type into appropriate containers. Workers classified as laborers performed several tasks, including fork lift operation, machine operation, and housekeeping. Mechanical/electrical workers performed both routine maintenance and repair, and some construction–like tasks. The job title of "supervisory" was created by the NIOSH investigators to include all foremen, superintendents, and office workers surveyed during this site visit. In addition, the job title of "skilled laborer" includes truck drivers, forklift operators, welders, and janitors.

Large palletized containers of used batteries arrived at the facility via truck or railroad car and were usually received at the W–1 building. From here, the pallets were weighed and stacked on the ground in vacant areas surrounding the buildings. Forklift trucks transported the pallets to the S–1 (Sorting) building. The forklifts dumped the batteries into a large hopper, which deposited the batteries on a perforated shaker belt. The hopper was equipped with a local exhaust ventilation system that used a cyclone and bag collector to remove the dust from the hopper. Also, the shaker belt had an exhaust hood with a dust collector (55–gallon drum). The shaker belt transported the batteries into an enclosed room called the dungeon, which contained the shaker machine. The shaker sorted the batteries by size, and funneled batteries of a certain size to one of six conveyor belts. The belts were referred to by battery size, and included a AA/AAA–cell belt, C–cell belt, D–cell belt, button battery belt, and lantern battery belt. The sixth belt was not used by R&R. The conveyor belts transported the batteries out of the dungeon and dumped them into empty palletized containers. During the first NIOSH visit, only the lantern battery, AA/AA–cell, C–cell, and D–cell belts were being operated. Most of the workers in this area were either sorters or supervisory, and worked at the shaker belt or on the conveyor belts to remove debris and mis–sorted batteries from the sorted batteries. One sorter routinely entered the dungeon to maintain the shaker and to clean the dungeon area. This worker donned a negative–pressure, half–face, air–purifying respirator when entering the dungeon.

After sorting, the batteries were transported by forklift to either the A–1 or A–2 buildings. These contained identical processes for the recycling/reclamation of alkaline batteries. The batteries were dumped into a hopper, which deposited them onto a conveyor belt. Workers were stationed at the conveyer belt to remove any remaining debris and odd–shaped batteries. The conveyor belt dumped the batteries into a screw auger, which moved the batteries into a shredder for initial breaking of the casings. From the shredder, the batteries were moved into a drying oven, which removed the moisture and some of the Hg. Next, a screw auger transported the batteries to a second shredder, and the battery pieces were then conveyed to a shaker/separator. The shaker/separator sorted the battery pieces into bags containing metals, inorganic material, and carbon.

Other buildings and processes at the R&R facility are as follows: Z–1: empty drum storage; Z–2: also referred to as Tops/Bottoms Plant, recycled railroad batteries; Z–3: also referred to as Saw Plant, housed a large band saw for sawing railroad batteries in half; B–building: storage for incoming batteries; L–1: lithium batteries deactivation process; and L–2: recycled lithium batteries. During the March 1995 opening conference, R&R management representatives stated the facility had recycled/reclaimed approximately 100 Hg–containing railroad batteries during the start–up phase of operations (presumably using the processes located in the Z–2 and Z–3 buildings), but these batteries were no longer accepted by the facility. At the time of the May 1995 NIOSH site visit, an additional storage building (designated W–3), alkaline recycling/reclamation process building (designated A–3), and an employee locker room with showers were proposed, and ground had been broken in the construction of these new buildings.

As mentioned, the owner of R&R filed for bankruptcy, and the company was reorganized as BCTI. Along with the reorganization, the process was changed to recycle/reclaim only alkaline batteries. The following processes/buildings were no longer in operation at the time of the December 1996, site visit: Sorting (S–1), lithium deactivation and recycling/reclamation (L–1 and L–2), and railroad batteries recycling/reclamation (Z–2 and Z–3).

At the time of the last NIOSH site visit, buildings S–1 (Sorting), W–1 (Shipping & Receiving), and W–3 were used to store pallets of batteries waiting to be processed. In addition, a very large number of battery pallets were stored outside of the buildings on the facility's grounds. In general, the beginning of the process was A–1, where pallets of batteries where roughly sorted to remove debris and odd–sized batteries. The sorted batteries were placed in large metal containers (called bullets) and transported via forklift truck to a conveyor belt that fed the oven in A–2.

The A–2 oven is 80 feet in length, and extends beyond the walls of the A–2 building. The main function of the oven is to bake–off the moisture and mercury in the alkaline batteries. After exiting the oven, the bullet is rotated 180° to dump the heated batteries on a conveyor belt, which transports the batteries to a dumpster. The bullet rotation device and conveyor belt are in a cylinder structure, which is equipped with a gas–powered cooling unit which cools the heated batteries and vapors. These vapors are collected using a scrubber, and the liquid is stored in a chemical tank. In addition, the oven is equipped with two interlocked inner and outer doors to prevent fugitive emissions during the bullet loading and unloading operations.

When the dumpster at A–2 is filled with batteries, it is transported to A–1 and weighed. The dumpster is then carried by forklift to A–3 and dumped into a hopper that feeds the hammer mill. The hammer mill roughly pulverizes the batteries, which are then run through a granulator for further pulverization. A shaker separates the pulverized batteries into metal, carbon, and non–metal components, which are bagged and shipped to the customer. Using this operation, BCTI was processing 20 to 30 tons of batteries per day. During the site visit, BCTI management indicated to the NIOSH investigators their intent to bring the sorting operation in S–1 on–line in the near future.

The NIOSH investigators observed many workers wearing negative pressure air purifying respirators with mercury vapor cartridges. Most of the workers reported wearing the respirators at least 50% of the time, with the workers in the A–1, A–2, and A–3 buildings wearing the respirators during the entire work shift. The respirators were routinely cleaned and inspected, and the NIOSH investigators observed that the workers were trained in proper respirator usage and care techniques. The respirators were NIOSH/MSHA approved, and the mercury cartridges had end of service life indicators. In addition, all BCTI personnel wore hard hats during the work shift.

Prior to the March 2–3, 1995, NIOSH site visit, the Occupational Safety and Health Administration (OSHA) office in El Paso, Texas, had conducted an inspection of the R&R facility, and faxed the Hg exposure monitoring data to the NIOSH project officer. The information provided by the OSHA office showed that full–shift Hg exposure determinations were performed on two workers in A–1 and two workers in A–2. The Hg exposure concentrations measured during the OSHA inspection were 45 and 53 micrograms of Hg per cubic meter of air (μg/m^3) for the A–1 workers, and 12 and 13 μg/m^3 for the A–2 workers. In addition, an area air sample collected in the A–1 building had a Hg concentration of 19 μg/m^3. According to the OSHA inspector, the facility did not have a serious Hg exposure problem and no citations were issued.

On February 10, 1995, the TDH faxed the NIOSH project officer a letter containing the results from spot urine Hg testing performed on 11 current or former R&R employees. The urine Hg levels measured in these workers averaged 31.1 micrograms of Hg per gram of creatinine (μg/g–Cr), and ranged from 10.3 to 85.1 μg/g–Cr. With the permission of the TDH representative, the NIOSH project officer provided these data to R&R management, without the personal identifiers of the participating R&R employees.

METHODS

As previously mentioned, this HHE included two NIOSH site visits where similar Hg exposure assessment protocols were implemented. These site visits occurred on May 16–17, 1995, and December 10–12, 1996. During each site visit, concurrent industrial hygiene and medical studies were performed to evaluate workers' exposures to Hg. The specific methods employed in these studies are discussed below.

Industrial Hygiene Study

Two and three consecutive days of Hg exposure monitoring were conducted during the first (May 16–17, 1995) and second site visits (December 10–12, 1996), respectively. Workers' Hg exposure concentrations were determined by sampling the air from the workers' breathing zone; these were full shift samples used to determine the workers' time–weighted average (TWA) exposure concentrations. The air sampling and analysis method used to determine Hg exposures was NIOSH Method 6009.[1] In this method, air is drawn through a solid sorbent tube containing 200 milligrams (mg) of hopcalite at a nominal flow rate of 200 cubic centimeters per minute (cc/min). The samples were prepared by adding 2.5 milliliters (ml) of concentrated nitric and hydrochloric acids to a vial containing the hopcalite granules and glass wool plugs. After this preparation, the samples were diluted to volume and analyzed using a cold vapor atomic absorption spectrometer. In addition, area air samples were collected to determine Hg emission sources and ambient Hg concentrations related to the recycling and reclamation processes. The area air samples were also collected and analyzed according to NIOSH Method 6009.[1] Also, bulk dust samples were collected and analyzed for Hg by modifying NIOSH Method 6009.[1]

The limit of detection (LOD) and limit of quantification (LOQ) for NIOSH Method 6009 are 0.01 micrograms per sample (µg/sample) and 0.034 µg/sample, respectively. LODs and LOQs are values determined by the analytical procedure used to analyze the samples, and are not dependent on sample volume. Minimum detectable concentrations (MDCs) and minimum quantifiable concentrations (MQCs) are determined by dividing the LODs and LOQs by air sample volumes appropriate for the given set of samples. In determining the MDC and MQC for these data, the NIOSH industrial hygienist used a sampling period of 8 hours (480 minutes) and the above flow rate of 200 cc/min to calculate an air sample volume of 96 liters (0.096 cubic meters). This results in a MDC of 0.1 $\mu g/m^3$ and a MQC of 0.35 $\mu g/m^3$. The MDC and MQC reflect the sensitivity of the air sampling and analysis protocol, *i.e.*, the lowest Hg exposure concentration that could be detected and quantified by the procedures used in this HHE.

Medical Study

The medical protocol employed during both site visits consisted of the administration of a questionnaire, and the collection of a spot urine sample. The questionnaire was designed to collect demographic, work, and health information from the responding worker. The urine samples were collected preshift either on the last day of the Hg exposure monitoring or the following morning. Each urine sample was analyzed for Hg and creatinine. In addition, the urine samples collected during the December 1996, (BCTI) site visit were analyzed for N–acetyl–β–D–glucosaminidase (NAG).

The ideal method for determining urine Hg concentrations is to collect all of a worker's urine over a 24–hour period, with the results being expressed in micrograms (mass) of Hg per liter (volume) of urine. Since the collection of 24–hour urine samples is not feasible in many occupational studies, a single ("spot") urine sample is collected instead. This assumes that workers with chronic Hg exposure excrete Hg at a constant rate. Since urinary water output varies between urinations, a dilution correction is used to normalize the volume portion of the urine Hg concentration. The preferred method for dilution correction is to express the urine Hg concentrations in micrograms of Hg per gram of creatinine (µg/g–Cr). Creatinine is a protein normally found in urine and is excreted at a fairly constant rate independent of the urinary water output. A similar dilution correction was applied to the urine NAG measurements.

Statistical Analyses

All statistical analyses were performed using the software packages Epi Info 6, Version 6.02 (developed and distributed by the U.S. Centers for Disease Control and Prevention, Atlanta, GA) and WinSTAT Version 3.1 (produced by Kalmia Company, Inc., Cambridge, MA). The level of correlation between the Hg exposure measurements, urine Hg levels, and urine NAG levels, was determined using the Pearsons correlation coefficient. Differences between mean Hg exposures and mean urine Hg levels were tested using the Student's t–test.

The Pearson's correlation coefficient (r_p) is a parametric test that measures the strength of the linear relationship (or dependency) between two variables. The major assumption of this test is that the data follow the normal distribution (also referred to as the bell–shaped curve). If one variable x can be expressed exactly as a linear function of another variable y, then the correlation is 1 if the variables are directly related, or -1 if the variables are inversely related. If the variables are independent of each other, then the correlation will be 0. Statistical significance is expressed as a p–value, which is the probability of obtaining a given result or one more extreme by chance alone. Correlations and Student's t–tests with a p–value less than or equal to 0.05 are considered statistically significant.

EVALUATION CRITERIA

To assess the hazards posed by workplace exposures, NIOSH investigators use a variety of environmental evaluation criteria. These criteria suggest exposure levels to which most workers may be exposed for a working lifetime without experiencing adverse health effects. However, because of wide variation in individual susceptibility, some workers may experience occupational illness even if exposures are maintained below these limits. The evaluation criteria do not take into account individual hypersensitivity, pre–existing medical conditions, or possible interactions with other workplace agents, medications being taken by the worker, or environmental conditions.

The primary sources of evaluation criteria for workplace inhalation exposures are: (1) NIOSH recommended exposure limits (RELs),[2] (2) the American Conference of Governmental Industrial Hygienists' (ACGIH) Threshold Limit Values (TLVs®),[3] and (3) the U.S. Department of Labor, OSHA permissible exposure limits (PELs).[4] Occupational health criteria are established based on the available scientific information provided by industrial experience, animal or human experimental data, or epidemiologic studies. Differences between the NIOSH RELs, OSHA PELs, and ACGIH TLVs may exist because of different philosophies and interpretations of technical information. It should be noted that RELs and TLVs are guidelines, whereas PELs are legally enforceable standards. OSHA PELs are required to take into account the technical and economical feasibility of controlling exposures in various industries where the agents are present. The NIOSH RELs are primarily based upon the prevention of occupational disease without assessing the economic feasibility of the affected industries and as such tend to be conservative. A U.S. Court of Appeals decision vacated the OSHA 1989 Air Contaminants Standard in *AFL–CIO v OSHA*, 965F.2d 962 (11th cir., 1992); and OSHA is now enforcing the previous 1971 standards (listed as Transitional Limits in 29 CFR 1910.1000, Table Z–1–A).[3] However, some states which have OSHA–approved State Plans continue to enforce the more protective 1989 limits. NIOSH encourages employers to use the 1989 limits or the RELs, whichever are lower.

Evaluation criteria for chemical substances are usually based on the average worker breathing zone exposure to a specific airborne substance over an entire 8– to 10–hour workday, expressed as a time–weighted average (TWA). Personal exposures are usually expressed in parts per million (ppm), milligrams per cubic meter (mg/m^3), or micrograms per cubic meter ($\mu g/m^3$). To supplement the 8–hr TWA where there are recognized adverse effects from short–term exposures, some substances have a short–term exposure limit (STEL) for 15–minute peak periods; or a ceiling limit, which is not to be exceeded at any time. Additionally, some chemicals have a "skin" notation to indicate that the substance may be absorbed through direct contact of the material with the skin and mucous membranes.

It is important to note that not all workers will be protected from adverse health effects if their exposures are maintained below these occupational health exposure criteria. A small percentage may experience adverse health effects because of individual susceptibility, a pre–existing medical condition, previous exposures, and/or a hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, or with medications or personal habits of the worker (such as smoking) to produce health effects even if the occupational exposures are controlled to the limit set by the evaluation criterion. These combined effects are often not considered by the chemical specific evaluation criteria. Furthermore, many substances are appreciably absorbed by direct contact with the skin and thus potentially increase the overall exposure and biologic response beyond that expected from inhalation alone. Finally, evaluation criteria may change over time as new information on the toxic effects of an agent become available. Because of these reasons, it is prudent for an employer to maintain worker exposures well below established occupational health criteria.

For some substances, a biological marker exists that can be used in workplace exposure investigations or studies. In order to measure these markers, a biologic specimen (*e.g.*, exhaled breath, blood, urine) must be obtained from the participating worker through informed consent. A biological marker can measure acute or chronic exposures, provide an estimation of the dose of a substance in the body or an organ, integrate exposures from more than one exposure route into a dose estimation, measure damage to a target cell and/or organ, or indicate the presence of a disease process. Two sources of reference values for biological markers are the ACGIH Biological Exposure Indices (BEIs®)[3] and the various guidelines developed by the World Health Organization (WHO). In addition, the clinical medicine literature contains reference values for tests used by practicing physicians.

Mercury Exposure–Related Health Effects and Exposure Criteria

Since metallic Hg is volatile at ambient temperatures, the majority of human exposure is by inhalation. In fact, inhalation exposure accounts for more than 95% of the absorbed Hg dose, whereas dermal exposure and ingestion contribute only 2.6% and 0.1% to this dose, respectively.[5] Eighty percent of inhaled Hg is retained in the lungs, while the remainder is exhaled. Due to its high degree of lipophilicity, 74% of inhaled Hg rapidly diffuses across the alveolar membranes into the blood.[6,7,8] Mercury's high level of lipophilicity aids in its distribution to the many tissues and organs throughout the body; it can readily cross the blood–brain and placental barriers, and has a high degree of affinity for red blood cells. Mercury absorbed into the blood and other tissues is quickly oxidized into divalent Hg via the hydrogen peroxide–catalase pathway, and accumulates in the renal cortex of the kidney.[5,9] After a substantial exposure, Hg reaches peak levels within the various tissue reservoirs within 24 hours, except in the brain where peak levels are not reached for 2–3 days.[5,10] In fact, more than 50% of the initially–absorbed dose is deposited in the kidneys, with the brain, liver, spleen, bone marrow, muscles, and skin being minor reservoirs for absorbed Hg.[11]

The feces and urine are the primary pathways for the elimination of Hg from the body, though it is unclear which is the dominant pathway.[5,7,8,9] Elimination through sweat, saliva, nails, hair, and bile also contribute a small portion to the excretion process. The elimination kinetics (measured in half–lives) for the major compartments involved with the uptake, distribution, and elimination of Hg are: lungs – 2 days; blood – 2 to 4 days; brain – 21 days; kidneys – 40 to 60 days; and whole body – 40 to 60 days.[5] Thus, blood Hg concentrations are considered markers of recent or acute Hg exposures; whereas urine Hg concentrations tend to integrate exposures over several weeks, *i.e.*, are markers of chronic exposure. Some evidence suggests that Hg elimination via urine occurs in two exponential phases. Under steady state conditions, a fast phase with a half–life of two days accounts for the elimination of 20 to 30% of the Hg body burden. The majority of the Hg body burden is eliminated through a slow phase with a half–life of 40 to 60 days. Because of this slow phase, urinary Hg excretion is slightly dependent on temporal variability in Hg airborne exposure.[12]

Acute or short–term exposure to high concentrations of elemental Hg causes erosive bronchitis, bronchiolitis, and diffuse interstitial pneumonia. Symptoms include tightness and pain in the chest, cough, and difficulty breathing.[13] Other acute effects include nausea, abdominal pain, vomiting, diarrhea, headache, and inflammation of the mouth and gums.[14]

Chronic or long–term exposure to Hg can result in symptoms of weakness, fatigue, loss of appetite, loss of weight, gingivitis, metallic taste, disturbance of gastrointestinal functions, and discoloration of the lens in the eye. The target organs for Hg toxicity are the central nervous system (CNS) and the kidneys. A wide variety of CNS–related symptoms, *e.g.*, cognitive, sensory, personality, and motor disturbances, have been reported in humans exposed to Hg. Early CNS effects include increased irritability, loss of memory, loss of self–confidence, weakness, reflex abnormalities, emotional instability with depressive moods, and insomnia. At higher exposure levels, fine tremor and coarse shaking can appear, as well as severe behavioral changes including delirium and hallucination. Tremor progresses in severity with duration of exposure. Although the symptoms in cases of slight poisoning regress and disappear when exposure has ceased, CNS effects may persist in cases of long–term exposure.[5,6,9,15]

A large proportion of the absorbed dose that accumulates in the renal cortex of the kidneys. Acute Hg exposure has produced proteinuria, hematuria, oliguria, necrosis of the proximal tubule, and acute renal failure.[5] Chronic exposure is characterized by proteinuria (*e.g.*, albumin, β–2–microglobulin, retinol–binding protein) and enzymuria (*e.g.*, β–galactosidase, NAG, β–glucuronidase).[16,17,18,19,20,21,22,23,24,25] In severe cases, a nephrotic syndrome has been observed, consisting mostly of hematuria, oliguria, urinary casts, edema, and the inability to concentrate urine.[5,16,24,26,27,28,29,30] In addition, chronic Hg exposure can lead to an increase in proximal tubular cell turnover and microdamage to specific segments of the proximal tubule's cell wall.[31,32,33,34,35,36] These manifestations can diminish the ability of proximal tubular segments to reabsorb water, proteins, and other glomerular filtrates, thus affecting the kidneys' ability to maintain volume and composition of body fluids within normal limits.

OSHA currently enforces a PEL for Hg of 100 μg/m^3, as a ceiling limit that should not be exceeded during a work shift.[4] The NIOSH REL for Hg exposure is 50 μg/m^3 as a TWA exposure for up to 10–hours per day, 40–hours per week; NIOSH does not have a urine Hg recommendation.[2] In 1980, a WHO study group recommended an 8–hour TWA exposure limit of 25 μg/m^3 and a urine Hg limit of 50 micrograms per gram creatinine (μg/g–Cr).[13] In 1994, the ACGIH lowered the TLV and BEI for Hg to 25 μg/m^3 (TWA exposure, 8–hours per day, 40–hours per week) and 35 μg/g–Cr, respectively.[3] The reason for lowering the TLV was a finding of pre–clinical signs of CNS and renal dysfunction at worker exposure levels above 25 μg/m^3. People without occupational exposure to Hg generally have urine Hg concentrations of 5 μg/g–Cr or less.[5,13]

Urine NAG and Reference Values

NAG is a large hydrolytic enzyme with a molecular weight of 130,000 to 140,000 Daltons, and is abundant in the lysosomes of proximal tubular cells of the kidneys.[19] An increase in urinary NAG levels is considered an indicator of nonspecific microdamage to proximal tubular cells, *e.g.* cell breakdown, necrosis, or increased cellular turnover.[33,34] Since Hg is eliminated from the kidney through active secretion, it can concentrate in the proximal tubule and produce microdamage to the cells composing this structure.[9,37,38] Urinary NAG excretion is clinically used as a biological marker of disease–related renal damage in cases of diabetes mellitus, hypertension, and rheumatoid arthritis.[39,40] NAG has also been used in cross–sectional studies as a non–specific indicator of cadmium– and Hg–related microdamage to the kidneys' proximal tubules.[19,21,22,24,25,41] Urine NAG levels are considered abnormal when they exceed 9.3 International Units per gram of creatinine (IU/g–Cr) in females, and 7.9 IU/g–Cr in males.[42]

RESULTS

May 16–17, 1995, Site Visit – R&R

The data from the May 1995 Hg exposure assessments at R&R are presented in Tables 1–3. Table 4 contains a data analyses by survey date and building, and Table 5 contains an analysis by job title. A total of 67 full shift air samples were collected from the breathing zones of participating workers during the two–day period. Forty–three workers were sampled on May 16, and 24 workers were sampled on May 17. The reason for the discrepancy in the number of participating workers during the two–day period is that the NIOSH investigators monitored every first shift employee on May 16, then concentrated the exposure monitoring on workers believed to be in high exposure jobs. The mean (average) 8–hour TWA Hg exposure concentration for all workers in this survey was 53.0 μg/m^3, with a range from 0.9 to 612.7 μg/m^3. Thirty–nine percent of the Hg exposure measurements were above the NIOSH REL, and 52% of the exposure measurements were above the ACGIH TLV. Mean Hg exposures on May 17 (68.5 μg/m^3) were higher than the mean exposures on May 16 (44.3 μg/m^3). This observation can be attributed to two reasons: (1) the workers were away from their jobs for a short period of time on the morning of May 16 to complete the questionnaire and provide a urine sample, (2) exposure monitoring on May 17 focused on workers in suspected high Hg exposure jobs.

From the building data analysis in Table 4, the highest mean Hg exposures were among workers from Sorting (76.1 μg/m^3), and the second highest were among workers from the Z–buildings (67.2 μg/m^3). The lowest mean exposures were found in the maintenance/mechanical workers (18.1 μg/m^3). Some workers in all buildings experienced overexposure to Hg based on both the NIOSH REL and the ACGIH TLV. In fact, 50% of the workers' exposures in the Z–buildings, 46% of workers' exposures in Sorting, 36% of the workers' exposures in the A–buildings, and 19% of the maintenance/mechanical workers had Hg exposures above the NIOSH REL.

From Table 5, workers classified as sorters had the highest mean Hg exposures (97.5 μg/m^3), followed by laborers with a mean Hg exposure of 49.8 μg/m^3, supervisory personnel with a mean Hg exposure of 34.9 μg/m^3, and mechanical/electrical workers with a mean Hg exposure of 25.0 μg/m^3. Seventy percent of the sorters, 38% of the laborers, 25% of the supervisory workers, and 23% of the mechanical/electrical workers experienced Hg exposures above the NIOSH REL.

Tables 6 and 7 contain the area air sampling data for May 16 and 17, respectively. Note that the data within each table are grouped by building name. During the two–day period, 12 area air samples were collected in Sorting, 11 in A–2, five in A–1, 3 in the Saw Plant, and 4 in Bottoms. One area air sample collected in the Sorting dungeon on May 17 was considered invalid by the NIOSH investigators, and is not included in this analysis. The reason this sample was invalidated is the sampling device became dislodged and fell to the floor, where it remained for an unknown period of time. The mean Hg concentrations by process building, in descending order, were as follows: Sorting – 188.2 μg/m^3, A–1 building – 125.4 μg/m^3, Bottoms – 60.8 μg/m^3, Saw Plant – 29.6 μg/m^3, and A–2 building – 8.3 μg/m^3. The high mean Hg concentration for the Sorting building was influenced by two area samples of 571.4 and 861.7 μg/m^3, which were collected inside the dungeon. This is an area that was infrequently visited by one worker who donned an air–purifying respirator with Hg vapor cartridges. Nonetheless, removing these two area air samples from the mean Hg concentration calculation still yields a high mean of 82.5 μg/m^3. This mean concentration is more indicative of Hg concentrations in the Sorting work areas.

Six bulk dust samples were collected from the Sorting, Bottoms, Saw, and A–2 buildings. The data from the analysis of these samples are presented in Table 8. The highest Hg concentration in dust was 3100 micrograms of Hg per gram of dust (μg/g), and was found in the dungeon of the Sorting building. Dust collected from the C line and the shaker ventilation collector (drum) had Hg concentrations of 1700 and 2400 μg/g, respectively. Hg concentrations were also found in the settled or floor dust found in Bottoms (1200 μg/g), Saw (210 μg/g), and A–2 (620 μg/g). These data indicate that any dust associated with this process should be considered contaminated with Hg.

The urine Hg data are presented in Tables 9 and 10. A total of 58 workers from first and second shifts provided preshift urine samples. None of the workers at the facility refused to provide the NIOSH investigators with a urine sample. Their mean urine Hg concentration was 38.9 μg/g–Cr, and 40% and 31% of the workers had urine Hg concentrations above the ACGIH BEI and WHO limit, respectively. There was a statistically significant correlation between personal breathing–zone TWA Hg exposures and the urine Hg levels ($r_p = 0.32$, p=0.04).

Table 11 presents the urine Hg data grouped by building. The mean urine Hg concentrations found among workers in the A–buildings, Z–buildings, and Sorting building were similar, 49.3 μg/g–Cr, 45.5 μg/g–Cr, and 42.9 μg/g–Cr, respectively. Conversely, the mean urine Hg concentration measured among the maintenance workers was 28.6 μg/g–Cr. Fifty percent of the workers in the A–buildings, 47% in Sorting, 44% in the Z–buildings, and 28% in Maintenance had urine Hg concentrations above the ACGIH BEI.

The job title analysis of the urine Hg data (Table 12) revealed that sorters had the highest mean urine Hg concentration (50.6 μg/g–Cr), followed by supervisory (41.3 μg/g–Cr), laborer (34.3 μg/g–Cr), and mechanical/electrical (22.8 μg/g–Cr). The percentage of workers in these job titles with urine Hg levels above the ACGIH BEI are: sorters–44%; supervisory–50%; laborers–33%; mechanical/electrical–18%. In addition, workers in these job titles also had urine Hg concentrations above the WHO standard.

A total of 58 workers completed the symptom questionnaire. The mean age of the workers was 34.4 years (range 19 to 58 years old), they were predominantly male (81%), and the majority were of Hispanic origin (62%). The average duration of employment at this company was 3.2 months, with a range of 1 to 15 months. The questionnaire revealed the following prevalences of symptoms among the workers: felt tired during the past month (78%), headache (52%), difficulty sleeping (48%), cough (43%), weakness (40%), memory problems (40%), and shortness of breath (35%). A statistically significant relationship was found between urine Hg levels (dichotomized using the ACGIH BEI) and each of the following CNS and respiratory symptoms: feeling tired, weak, depressed, and shortness of breath ($p<0.05$, by Fisher's exact test).

December 10–13, 1996, Site Visit – BCTI

The data from the ambient (environmental) area air sampling conducted on the premises of BCTI are shown in Table 13. These samples were collected to determine the background Hg concentration in the vicinity of the facility. The mean (average) Hg concentration was 0.6 μg/m^3, ranging from trace levels to 1.9 μg/m^3. Three of the six ambient air samples detected Hg concentrations below the MQC; these are considered trace levels.

Table 14 contains the data from the three days of Hg exposure monitoring on all workers at BCTI. A total of 51 full–shift, TWA exposure samples were collected during this time period. Of the 51 exposure samples collected during the three day period, 18 were collected on December 10, 15 on December 11, and 18 on December 12. A worker hired on December 12 did not participate in the December 10 and 11 survey dates. Three workers were absent on December 11 and one worker was absent on December 12. The mean Hg exposure concentration for the 51 exposure samples collected over the three day period was 229.8 μg/m^3, and ranged from 2.9 to 2021.3 μg/m^3. When segregated by date of collection, the mean Hg exposure concentrations were 134.8 μg/m^3 (range of 4.5 to 704.2 μg/m^3), 333.2 μg/m^3 (range of 9.4 to 2021.3 μg/m^3), and 238.7 μg/m^3 (range of 2.9 to 1153.8 μg/m^3) for December 10, 11, and 12 respectively.

A comparison of the Hg exposure data to the OSHA, NIOSH, and ACGIH exposure criteria reveals most workers were over–exposed during the three–day survey period. Fifty–three percent (27 of 51) of the exposure measurements were above the OSHA ceiling limit of 100 µg/m^3. In addition, 76% (39 of 51) and 84% (43 of 51) of the exposure measurements were above the respective NIOSH REL and ACGIH TLV for Hg.

Using the data in Table 14, three–day Hg exposure means were calculated by averaging each worker's three daily exposure measurements for the study period. Thus, Table 15 contains the three–day means, along with the urine Hg and urine NAG levels. The three–day means ranged from 5.6 to 1293.1 µg/m^3, with 53% (10 of 19) and 79% (15 of 19) of the Hg exposure means above OSHA PEL and NIOSH REL, respectively. Also, 84% (16 of 19) of the three–day Hg exposure means exceeded the ACGIH TLV. It should be noted that five of the three–day means are calculated using less than three Hg exposure measurements. As previously mentioned, the workers with less than three Hg exposure measurements were either absent on the days of the NIOSH survey or hired after the start of the survey.

The urine Hg levels averaged 136.5 µg/g–Cr, and ranged from 4 to 508 µg/g–Cr. Seventy–four percent (14 of 19) of the workers at BCTI had urine Hg levels in excess of the WHO standard. In addition, 79% (15 of 19) of the workers had urine Hg levels exceeding the ACGIH BEI. The average urine NAG level was 4.8 IU/g–Cr, ranging from 1.2 to 19.4 IU/g–Cr. Only two workers had urine NAG levels above the reference values for adults; levels of 12.1 and 19.4 IU/g–Cr were observed in two male maintenance workers. Both of these workers had urine Hg levels above 200 µg/g–Cr.

A comparison of the three–day Hg exposure means to the urine Hg data revealed a statistically significant correlation between these variables (r_p=0.38, p=0.05). In addition, correlation was also found between the highest Hg exposure measurement per worker and the urine Hg levels (r_p=0.49, p=0.02), and the lowest Hg exposure measurement per worker and the urine Hg levels (r_p=0.45, p=0.03). Finally, a correlation between the urine Hg data and the urine NAG data was found, though not statistically significant (r_p=0.28, p=0.12).

The data from the three days of area air sampling are presented in Tables 16, 17, and 18. Area air sampling was conducted in the active process buildings (A–1, A–2, and A–3) and the battery storage buildings (W–1/S–1 and W–3). The highest Hg concentrations were found in buildings A–2 and A–3, which had overall building mean Hg concentrations of 165.7 µg/m^3 and 155.8 µg/m^3, respectively. High Hg concentrations were also found in A–1, with a building mean of 59.1 µg/m^3. Finally, the Hg concentrations in W–1/S–1 and W–3 were 3.2 µg/m^3 and 2.6 µg/m^3, respectively.

All 19 workers in the plant consented to be interviewed. They included 17 men and 2 women, and their ages ranged from 19 to 56 years with an average age of 36 years. Seniority ranged from 1 day to 6 years, with an average of 1½ years.

According to the questionnaire data, the most frequently used personal protection device was gloves (95%), followed by disposable filter respirators (90%), half–mask cartridge respirators (79%), and aprons (48%). The workers reported they did not eat or smoke at the workplace, which is consistent with plant policy. Nine workers (47%) are current smokers, with an average of nine cigarettes per day (range: 5 to 20 cigarettes).

Only 18 workers answered the portion of the questionnaire related to symptoms. The exception was a recently hired worker who had only worked one day. The prevalences of symptoms were: tiredness: 10 (56%), headaches: 6 (33%), weakness: 5 (28%), soreness of gums: 3 (17%), shaking: 2 (11%), increased salivation: 2 (11%), irritability: 2 (11%), weight loss: 2 (11%), tremors: 1 (6%), excitability, 1 (6%), mood swings: 1 (6%), and tremors in eyelids, lips or tongue: 1 (6%).

Of the 14 workers who had urine Hg levels over 50 µg/g–Cr, 8 (57%) reported symptoms suggestive of Hg overexposure, such as tiredness, headaches, weakness, or soreness of the gums. Two of these workers had elevated NAG excretion (12.1 and 19.4 IU/g–Cr). Of the five workers with urine Hg levels under 50 µg/g–Cr, three reported tiredness, one reported weakness, and one reported headache and soreness of the gums. It must be noted that the workers attributed their "tiredness" to the fact they had been working shifts greater than 8–hours.

DISCUSSION

The data from both site visits demonstrate that all workers at R&R and BCTI were exposed to Hg, and many workers were over–exposed on a daily basis. The data from the R&R site visit show that 39% of the workers' Hg exposure measurements were above the NIOSH REL, and 52% were above the ACGIH TLV and WHO recommended limit. The highest exposures were found among workers in the Sorting, A–1, and Bottoms buildings, where the average exposure exceeded the NIOSH REL and ACGIH TLV. Also, workers classified as sorters and laborers had the highest Hg exposures, with the average for workers in these job titles exceeding the ACGIH TLV. Hg over–exposures were documented in every production–related building and in every job title included in this survey. Similarly, 40% and 31% of the workers had urine Hg levels above the respective ACGIH BEI and WHO recommended limit. Four employees had urine Hg levels more than three times the ACGIH BEI.

Two of the highest Hg exposure concentrations measured during the R&R survey were found on the same sorting worker (195.7 and 612.7 µg/m^3). This worker frequently entered the dungeon to monitor the shaker and sweep the area. This worker donned a negative pressure air–purifying respirator when entering the dungeon, so the air samples may not reflect the internal dose received by the worker's body.

The NIOSH investigators were perplexed by the high Hg exposure concentrations and urine Hg concentrations observed among workers in the Z–buildings. The processes in these buildings are devoted to the recycling of railroad batteries, which do not contain Hg. In fact, observations made during the survey indicate that no alkaline batteries were being recycled in these buildings. Thus, a question exists as to the source(s) of the mercury exposures for these workers. It is possible these workers are secondarily exposed by visiting buildings with known Hg exposures, or that the Z–buildings are contaminated with Hg. As previously mentioned, these buildings and the processes are not used by BCTI.

The symptoms most commonly reported by workers at R&R were tiredness, headache, difficulty sleeping, cough, weakness, and memory problems. A statistical analysis found correlation between the urine Hg levels and the presence of these symptoms. The symptoms surveyed using the questionnaire are not specific for Hg toxicity and may be transient in nature, and are not necessarily related solely to Hg exposure. Nonetheless, considering the number of Hg over–exposures and high urine Hg levels measured during the NIOSH site visit, and the correlation between the urine Hg levels and the symptoms, it is reasonable to conclude that Hg exposure plays a role in producing these symptoms.

The data from three days of worker exposure monitoring at BCTI demonstrated that 76% of the Hg exposure measurements exceeded the NIOSH REL, and 84% exceeded the more conservative ACGIH TLV and WHO standard. Also, 79% of the three–day worker exposure means exceeded the NIOSH REL, and 84% exceeded the ACGIH TLV and WHO limit. These data indicate workers are currently over–exposed to Hg.

The BCTI worker over–exposures to Hg were confirmed by the urine Hg data. Seventy–four percent of the workers' urine Hg samples were above the WHO recommended limit, whereas 79% of the workers sampled had urine Hg levels exceeding the more conservative ACGIH TLV. A significant degree of correlation was found between the three different Hg exposure metrics (three–day mean, highest Hg exposure during the three–day exposure monitoring period, and lowest Hg exposure during the three–day exposure monitoring period) and the urine Hg levels. This relationship demonstrates that workers are receiving a potentially hazardous dose of Hg through their workplace inhalation exposures.

The combined Hg exposure data and urine Hg data indicate that the current BCTI respiratory protection program is not adequately protective. The correlation between the Hg exposure and urine Hg measurements indicates that the air–purifying respirators are not effectively removing Hg from the workers' inhaled air. Other routes of exposure, *i.e.* dermal and ingestion, do not contribute significantly to the workers' dose, as Hg is poorly absorbed through the skin and gastrointestinal tract. The NIOSH investigators believe there is either a significant amount of leakage between the face–to–facepiece seal, and/or the workers are not wearing the respirators during all exposure periods. One reason that workers frequently remove negative pressure air–purifying respirators is a lack of comfort in warm work environments. Use of positive–pressure air–purifying respirators would provide the worker with a higher degree of protection and are more comfortable in warm environments.

It is difficult to interpret the relationship found between the urine Hg and urine NAG data, since the correlation was not statistically significant. For the most part, the large number of urine NAG levels below the guideline probably indicates this increase has not yet reached a hazardous level. But the high NAG levels observed in two workers suggests that a continuation of the high Hg exposures may lead to more workers exhibiting abnormal NAG excretion. Whether elevated NAG excretion is a risk factor in chronic renal disease or a health hazard is unknown.

A comparison of the mean Hg exposure concentrations measured during the R&R site visit (53.0 $\mu g/m^3$) and that measured during the BCTI site visit (229.8 $\mu g/m^3$) indicates the Hg exposures are significantly higher at BCTI (Student's $t=4.24$, $p<0.0001$). A similar analysis of the two sets of urine Hg data found the urine Hg levels were higher at BCTI when compared to R&R (Student's $t=3.19$, $p=0.005$). This indicates that the changes in the process made by BCTI have increased the workers' Hg exposures.

The NIOSH data indicate at least 7 of 67 (10%) Hg exposure measurements collected at R&R, and 27 of 51 (53%) Hg exposure measurements collected at BCTI exceeded the OSHA PEL–ceiling limit of 100 $\mu g/m^3$. In addition, 10 of the three–day means exceed the OSHA PEL–ceiling limit. In reality, the number of workers with exposures exceeding the OSHA ceiling limit is probably greater than the observed 7 and 27, as this analysis compares a full–shift TWA Hg exposure measurement to a ceiling limit that should not be exceeded during a given work shift. A TWA measurement dampens the effect of temporal and spatial variability on the exposure measurement. Thus, normal variability in exposure would dictate that some of the Hg TWA exposure measurements below the OSHA ceiling limit had short term Hg exposure excursions that exceeded the OSHA PEL.

Experience has shown that workers can inadvertently transport hazardous materials form the workplace to their home via skin, hair, clothes, tools, or by contaminating their vehicles. As a result, family members can be exposed and may develop various health effects. This is particularly disconcerting, since children may be involved and are a sensitive population. A recent NIOSH health hazard evaluation of workers exposed to Hg in a thermometer plant found the home environment had become contaminated with Hg.[25,43] During the study, NIOSH found that 21 workers were exposed to an average Hg concentration of 50.1 $\mu g/m^3$ (exposures ranging from 2.8 to 270.6 $\mu g/m^3$), and the workers' urine Hg levels ranged from 1 to 345 µg/g–Cr. Company records revealed Hg vapor levels in the facility ranging from 24 to 308 $\mu g/m^3$. A survey of some of the workers' homes revealed Hg concentrations ranging from 0.02 to 10 $\mu g/m^3$. Twenty–three children within the homes had a mean urine Hg level of 25 micrograms per liter (µg/L); which is five times higher than the mean urine Hg level found in controls (children whose parents did not work in the facility). There was a significant correlation between the urine Hg levels in the children and the urine Hg levels in the parents. Considering the extent of Hg over–exposure measured during this NIOSH HHE, it is reasonable to conclude there is a strong potential that workers are contaminating their homes with Hg. This form of cross–contamination can be controlled by providing workers with work clothing that is not worn home, by having the workers shower before leaving the facility, and by providing the workers with uncontaminated lockers to store their street clothes during the work shift.

CONCLUSIONS

The NIOSH investigators have documented a serious Hg exposure health hazard associated with the battery reclamation/recycling processes at both R&R and BCTI. These exposures have produced high urine Hg levels and CNS and respiratory symptoms that may be Hg–related. Changes in the process related to the conversion from R&R to BCTI have produced a significant increase in the workers' Hg exposures and urine Hg levels, and the current respirator program is not protecting workers from inhalation exposures. There is also a possibility that workers' homes are being contaminated with Hg because workers wear their work clothing home, and do not shower before leaving the workplace.

RECOMMENDATIONS

1. Considering the number of workers with high Hg exposures and high urine Hg levels, and the relationship between the Hg exposure data and urine Hg data, it is reasonable to assume the workers are not protected from hazardous exposures when using the negative pressure air–purifying respirators. The NIOSH investigators recommend that BCTI provide all workers with powered air–purifying respirators equipped with mercury cartridges with end-of-service-life indicators. This program should be consistent with the NIOSH recommendations and the enforceable requirements set forth in the OSHA Safety and Health Standards.[44,45] The NIOSH investigators recommend that all workers receive annual fit testing with a quantitative testing device.

2. Workers should not be allowed to wear work clothing home at the end of the work shift. BCTI should provide employees with work clothing that the workers change into and out of at the beginning and end of the work shift. Work and street clothing should not be stored in the same locker. Before removal, work clothing should be vacuumed with a dedicated mercury vacuum, and stored in vapor–proof containers pending laundering. All work clothing should be laundered onsite, or sent to a laundering service with the capability to clean potentially contaminated work clothing. If a laundering service is used, the operators of the service should be informed that the clothes are contaminated with Hg.

3. Adequate shower facilities with hot and cold water should be available for use by the workers before they change into their street clothes. Workers should be required to shower before changing into street clothes and leaving the facility.

4. Dry–sweeping of work areas should be prohibited, as the Hg contamination in the dust may increase workers' Hg exposures. Only wet clean–up methods or vacuuming with a mercury vacuum should be allowed during clean–up activities.

5. The worker exposure and area airborne Hg concentrations suggests that the A–2 oven area is a major source of mercury exposure and contamination. This process should be completely enclosed in a room under negative air pressure to prevent fugitive Hg emissions.

6. Considering the airborne Hg concentration measured at the exit end of the oven and in A–3, it is apparent that the oven process is not effectively removing the mercury from the batteries. The NIOSH investigators recommend that BCTI investigate the possibility of raising the temperature of the oven, and increasing the bullet transit time in the oven in order to drive–off the Hg in the batteries. All emissions from the oven (and the above

recommended oven enclosure) and any other Hg–generating process should be collected in a mercury trap. Considering the high concentrations of mercury measured in the NIOSH surveys, a considerable amount of airborne mercury is generated at BCTI.

7. BCTI should implement a medical surveillance program, which includes biological monitoring for mercury and an appropriate medical evaluation. The biological monitoring program should consist of quarterly urine monitoring on all workers potentially exposed to Hg. These samples should be spot samples collected at the beginning of the work shift, and the concentrations should be expressed in terms of "micrograms of Hg per gram of creatinine" (*i.e.*, creatinine corrected). If a worker has a urine Hg level above the ACGIH BEI of 35 µg/g–Cr, then the worker should be assigned to work areas without Hg exposure and have his/her urine Hg level tested on a monthly basis. The worker should work in the no Hg exposure job until two consecutive monthly urine tests demonstrate a reduction in urine Hg level below the ACGIH BEI. A pre–employment urine Hg measurement should be obtained from all newly–hired workers. The above medical evaluation should include detailed occupational and medical histories, and a physical examination focusing on the known symptoms and effects of Hg toxicity. The medical surveillance program should strive for regular communication and coordinated interactions between safety and medical personnel, which will facilitate timely follow–up evaluations of specific work areas/processes when health problems are discovered. All workers participating in this program should be informed of their results, and BCTI should maintain all medical records for a period of 30 years.

8. BCTI should implement an exposure monitoring program for all workers potentially exposed to Hg as well as any other hazardous substances that may be used in the workplace. This program should consist of full–shift air sampling from the worker's breathing zone to measure the worker's TWA exposures to specific chemicals or substances. The purpose of this exposure monitoring is to determine whether exposures may exceed the applicable exposure limits. Whenever a worker over–exposure is measured, a survey should be conducted to determine the reason behind the hazardous workplace exposure. Engineering and/or administrative controls should be implemented to effectively control this exposure, and to protect the workers in similar jobs and processes. Exposure monitoring surveys should be performed on a semi–annual basis, or whenever changes in work processes or conditions are likely to lead to a change in exposures. Though not all workers have to be monitored, sufficient samples should be collected to characterize the workers' exposures. Variations in work habits and production schedules, worker locations, and job functions should be considered when developing exposure monitoring protocols. A given workroom or area is considered an Hg exposure hazard area whenever the industrial hygiene studies find that environmental Hg concentrations and worker exposure concentrations exceed 40% of the NIOSH REL (20 $\mu g/m^3$). All workers participating in the monitoring should be informed of the results, and the employer should maintain these records for a period of 30 years.

9. No eating and drinking should be allowed in the work areas and/or process buildings. These activities should be restricted to designated areas away from contaminants. Workers should wash their hands before eating, drinking, or smoking.

10. BCTI should provide workers with annual training and education on the health hazards associated with workplace exposure the Hg and other hazardous substance present in their workplace. At a minimum, this training should conform to the regulations set forth in OSHA's Hazard Communication Standard.[46]

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Table 1
Personal Breathing Zone Exposure Data for Workers in the Sorting and A–Buildings Potentially Exposed to Mercury (Hg) — May 16, 1995

Recovery & Reclamation, Inc.
HETA 95–0097
May 16–17, 1995

JOB TITLE	BUILDING	SAMPLE TIME[1]	SAMPLE VOLUME[2]	[Hg][3]	>NIOSH REL[4]	>ACGIH TLV®[5]
Skilled Laborer	Sorting	0727–1610	105	1.9		
Sorter	Sorting	0716–1529	99	48.7		X
Skilled Laborer	Sorting	0710–1531	100	16.0		
Sorter	Sorting	0714–1528	99	64.8	X	X
Sorter	Sorting	0724–1529	97	195.9	X	X
Sorter	Sorting	0713–1524	98	37.7		X
Sorter	Sorting	0653–1559	109	77.8	X	X
Supervisory	Sorting	0709–1526	99	46.3		X
Sorter	Sorting	0722–1525	97	48.7		X
Sorter	Sorting	0711–1528	99	39.2		X
Sorter	Sorting	0720–1527	97	34.9		X
Sorter	Sorting	0717–1345	78	70.9	X	X
Supervisory	Sorting	0722–1525	97	2.3		
Supervisory	A–1 + A–2	0707–1515	98	56.4	X	X
Sorter	A–1	0713–1540	101	10.9		
Supervisory	A–1 + A–2	0728–1523	95	21.1		
Sorter	A–2	0714–1516	96	69.5	X	X
Laborer	A–2	0712–1541	102	14.7		
Supervisory	A–2	0703–1541	104	7.2		

1 This is the start and stop time (in military time) for the sampling device; all samples were full–shift samples.
2 Sample volumes are expressed in liters of air.
3 This column contains the worker Hg exposure concentrations (as time–weighted averages) in micrograms of Hg per cubic meter of air (μg/m^3).
4 An "X" indicates the worker Hg exposure concentration exceeded the NIOSH REL of 50 μg/m^3.
5 An "X" indicates the worker Hg exposure concentration exceeded the ACGIH TLV® of 25 μg/m^3.

Table 2
Personal Breathing Zone Exposure Data for the Mechanical Workers and the Z–Buildings' Workers Potentially Exposed to Mercury (Hg) – May 16, 1995

Recovery & Reclamation, Inc.
HETA 95–0097
May 16–17, 1995

JOB TITLE	BUILDING[1]	SAMPLE TIME[2]	SAMPLE VOLUME[3]	[Hg][4]	>NIOSH REL[5]	>ACGIH TLV®[6]
Mechanic	All	0725–1535	98	4.5		
Electrical	All	0715–1539	101	4.7		
Laborer	All	0654–1535	104	3.8		
Skilled Laborer	All	0711–1515	97	2.7		
Janitor	All	0649–1519	102	6.6		
Supervisory	All	0706–1517	98	9.1		
Skilled Laborer	All	0710–1514	97	3.9		
Supervisory	All	0704–1502	96	6.0		
Electrical	All	0708–1532	101	5.6		
Mechanic	All	0643–1534	106	4.7		
Mechanic	All (A–1)	0706–1541	103	67.0	X	X
Mechanic	All (A–1)	0701–1520	100	68.1	X	X
Supervisory	All (A–1)	0705–1517	98	93.5	X	X
Mechanic	All (A–3)	0647–1513	101	5.0		
Electrical	All (Office)	0709–1531	100	2.7		
Mechanic	All (Office)	0644–1524	104	1.9		
Supervisory	Bottoms	0702–1520	97	180.7	X	X
Electrical	Bottoms	0717–1528	98	112.0	X	X
Laborer	Saw	0658–1525	103	67.0	X	X
Laborer	Saw	0656–1529	103	253.4	X	X
Laborer	Saw	0659–1530	102	18.6		
Laborer	Saw	0651–1531	102	83.3	X	X
Supervisory	Saw	0651–1531	104	10.6		
Laborer	Saw	0642–1526	105	26.7		X

1 "All" refers to the fact that the mechanical workers may work in any of the buildings on–site. A specific building denoted in parenthesis after "All" indicates the building that worker was in during the work shift.
2 This is the start and stop time (in military time) for the sampling device; all samples were full–shift samples.
3 Sample volumes are expressed in liters of air.
4 This column contains the worker Hg exposure concentrations (as time–weighted averages) in micrograms of Hg per cubic meter of air ($\mu g/m^3$).
5 An "X" indicates the worker Hg exposure concentration exceeded the NIOSH REL of 50 $\mu g/m^3$.
6 An "X" indicates the worker Hg exposure concentration exceeded the ACGIH TLV® of 25 $\mu g/m^3$.

Table 3
Personal Breathing Zone Exposure Data for Workers Potentially Exposed to Mercury (Hg) — May 17, 1995

Recovery & Reclamation, Inc.
HETA 95–0097
May 16–17, 1995

JOB TITLE	BUILDING	SAMPLE TIME[1]	SAMPLE VOLUME[2]	[Hg][3]	>NIOSH REL[4]	>ACGIH TLV®[5]
Supervisory	A–1 + A–2	0701–0719 1247–1522	35	7.2		
Sorter	A–2	0652–1528	103	88.2	X	X
Sorter	A–2	0647–1535	106	73.9	X	X
Laborer	A–2	0654–1522	102	4.8		
Supervisory	A–2	0656–1523	101	5.6		
Supervisory	Bottoms	0700–1555	109	100.9	X	X
Laborer	Bottoms	0655–1556	108	74.9	X	X
Electrical	Bottoms	0654–1551	107	41.9		X
Laborer	Saw	0658–1552	107	6.2		
Laborer	Saw	0657–1550	107	17.8		
Laborer	Saw	0659–1550	106	68.7	X	X
Supervisory	Saw	0656–1523	101	5.6		
Laborer	Saw	0649–0858 1413–1550	45	7.3		
Supervisory	Sorting	0707–1520	99	5.3		
Skilled Laborer	Sorting	0657–1544	105	5.1		
Sorter	Sorting	0650–1532	104	77.6	X	X
Skilled Laborer	Sorting	0703–1539	103	40.7		X
Sorter	Sorting	0655–1521	101	612.7	X	X
Sorter	Sorting	0658–1531	102	74.2	X	X
Sorter	Sorting	0718–1527	98	52.2	X	X
Sorter	Sorting	0700–1525	101	64.4	X	X
Sorter	Sorting	0659–1534	103	68.9	X	X
Sorter	Sorting	0702–1524	100	139.4	X	X
Supervisory	Sorting	0704–1521	99	0.9		

1 This is the start and stop time (in military time) for the sampling device; all samples were full–shift samples.
2 Sample volumes are expressed in liters of air.
3 This column contains the worker Hg exposure concentrations (as time–weighted averages) in micrograms of Hg per cubic meter of air ($\mu g/m^3$).
4 An "X" indicates the worker Hg exposure concentration exceeded the NIOSH REL of 50 $\mu g/m^3$.
5 An "X" indicates the worker Hg exposure concentration exceeded the ACGIH TLV® of 25 $\mu g/m^3$.

Table 4
Summary Statistics for the Hg Exposure Data with Analysis by Date and Building

Recovery & Reclamation, Inc.
HETA 95–0097
May 16–17, 1995

Hg EXPOSURE DATA SET	n[1]	MEAN [Hg] [2]	MAX[3]	MIN[3]	>NIOSH REL[4]	>ACGIH TLV®[5]
All Hg Exposure Data	67	53.0	612.7	0.9	26/67 (39%)	35/67 (52%)
Hg Exposure Data – 05/16/95	43	44.3	253.4	1.9	14/43 (33%)	21/43 (49%)
Hg Exposure Data – 05/17/95	24	68.5	612.7	0.9	12/24 (50%)	14/24 (58%)
Hg Exposure Data – Sorting	24	76.1	612.7	0.9	11/24 (46%)	18/24 (75%)
Hg Exposure Data – A Buildings	11	32.7	88.2	4.8	4/11 (36%)	4/11 (36%)
Hg Exposure Data – Z Buildings	16	67.2	253.4	5.6	8/16 (50%)	10/16 (63%)
Hg Exposure Data – Maintenance	16	18.1	93.5	1.9	3/16 (19%)	3/16 (19%)

1 The letter "n" denotes the number of participating workers in the given data set.
2 Mean (average) of "n" worker exposure measurements for the data set; the mean is in units of micrograms of Hg per cubic meter of air ($\mu g/m^3$).
3 MAX – maximum value of the data set in $\mu g/m^3$.
MIN – minimum value of the data set in $\mu g/m^3$.
4 Number of exposure measurements greater than the NIOSH REL for Hg of 50 $\mu g/m^3$.
5 Number of exposure measurements greater than the ACGIH TLV® for Hg of 25 $\mu g/m^3$.

Table 5
Summary Statistics for the Mercury (Hg) Exposure Data: Analysis By Job Title

Recovery & Reclamation, Inc.
HETA 95–0097
May 16–17, 1995

JOB TITLES	n[1]	MEAN [Hg] [2]	MAX[3]	MIN[3]	>NIOSH REL[4]	>ACGIH TLV®[5]
Sorter	20	97.5	612.7	10.9	14/20 (70%)	19/20 (95%)
Laborer	13	49.8	253.4	3.8	5/13 (38%)	6/13 (46%)
Supervisory	16	34.9	180.7	0.9	4/16 (25%)	5/16 (31%)
Mechanical/Electrical	13	25.0	112.0	1.9	3/13 (23%)	4/13 (31%)

1 The letter "n" denotes the number of participating workers in the given job title.
2 Mean (average) of "n" worker exposure measurements for the given job title; the mean is in units of micrograms of Hg per cubic meter of air ($\mu g/m^3$).
3 MAX – maximum value of the data set in $\mu g/m^3$.
MIN – minimum value of the data set in $\mu g/m^3$.
4 Number of exposure measurements greater than the NIOSH REL for Hg of 50 $\mu g/m^3$.
5 Number of exposure measurements greater than the ACGIH TLV® for Hg of 25 $\mu g/m^3$.

Table 6
Area Air Sampling Data for Mercury (Hg) – May 16, 1995

Recovery & Reclamation, Inc.
HETA 95–0097
May 16–17, 1995

BUILDING/LOCATION	SAMPLE TIME[1]	SAMPLE VOLUME[2]	[Hg][3]
A–1/Near Shredder	0852–1229*	43	95.3
A–1/Recovery Unit for Inorganics	0858–1500	72	101.4
A–1/Near Hopper	0853–1500	73	150.7
A–1/Recovery Unit for Metals	0858–1500	71	126.8
A–1/Recovery Unit for Carbon	0856–1500	72	152.8
Sorting/D–cell Line	0829–1500	78	46.2
Sorting/Dust Barrel Before Dungeon	0830–1458	77	90.9
Sorting/ AAA, AA–cell Line	0834–1500	76	34.2
Sorting/Shaker (in Dungeon)	0835–1501	77	571.4
Sorting/Button Batteries Line	0836–1501	77	120.8
Sorting/Lantern Batteries Line	0840–1459	76	65.8
Sorting/C–cell Line	0843–1502	75	49.3
Sorting/Above Battery Crate to be Processed	0844–1221*	43	139.5
A–2/Near Hopper	0908–1504	70	17.1
A–2/Near Shredder	0905–1504	71	7.0
A–2/Recovery Unit for Inorganics	0908–1505	71	9.4
A–2/Recovery Unit for Metals	0909–1342*	55	8.6
A–2/Recovery Unit for Carbon	0909–1505	70	8.6

1 This is the start and stop time (in military time) for the sampling device. An asterisk (*) next to a stop time indicates that the sampling pump failed, and the stop time and sample volume (for that sample) are estimated using the time counter on the sampling pump.
2 Sample volumes are expressed in liters of air.
3 Mercury concentrations are expressed in micrograms of mercury per cubic meter of air ($\mu g/m^3$).

Table 7
Area Air Sampling Data for Mercury (Hg) — May 17, 1995

Recovery & Reclamation, Inc.
HETA 95–0097
May 16–17, 1995

BUILDING/LOCATION	SAMPLE TIME[1]	SAMPLE VOLUME[2]	[Hg][3]
Saw Plant/Start of Line – Loader	0724–1509	93	8.0
Saw Plant/Near the Saw	0722–1509	93	32.3
Saw Plant/End of Line	0721–1508	91	48.4
Bottoms/Auger near Second Hammer Mill	0730–1512	92	31.5
Bottoms/Near Bins for KOH & Plastic	0731–1510	92	ND
Bottoms/Auger Near End of Third Belt	0735–1513	92	173.9
Bottoms/Start of Line, First Hammer Mill	0736–1512	91	37.4
A–2/Near Hopper	0710–1502	94	8.4
A–2/Near Dryer Entrance	0710–1505	95	5.2
A–2/Near Exit of Dryer	0716–1505	93	7.0
A–2/Recovery Unit for Inorganics	0712–1503	93	6.0
A–2/Recovery Unit for Metals	0713–1502	94	5.6
A–2/Recovery Unit for Carbon	0713–1504	94	8.1
Sorting/Dust Barrel Before Dungeon	0712–1507	95	73.7
Sorting/C–cell Line	0714–1507	93	78.5
Sorting/Button Batteries Line	0714–1507	95	126.3
Sorting/Belt Line to Shaker (in Dungeon)	0719–1507	94	861.7

1 This is the start and stop time (in military time) for the sampling device.
2 Sample volumes are expressed in liters of air.
3 Mercury concentrations are expressed in micrograms of mercury per cubic meter of air ($\mu g/m^3$). A concentration of "ND" indicates that the mercury concentration was not detectable; *i.e.* below the minimum detectable concentration (0.1 $\mu g/m^3$).

Table 8
Analysis of Bulk Samples of Dust for Mercury (Hg)

Recovery & Reclamation, Inc.
HETA 95–0097
May 16–17, 1995

BUILDING	DESCRIPTION OF THE BULK SAMPLES	[Hg][1]
Sorting	Settled dust on the shaker, in the dungeon	3100
Sorting	Floor dust near the "C" line	1700
Sorting	Dust in drum, collected from ventilation hood for shaker	2400
Bottoms	Settled dust near bins on west wall	1200
Saw	Dust from floor sweepings of the general area	210
A–2	Dust on floor below the shredder	620

[1] Data in this column are the concentrations of mercury in the bulk samples/dust. Units are in micrograms of mercury per gram of bulk sample; may also be referred to as parts per million of mercury in the bulk sample.

Table 9
The Urine Mercury (Hg) Data for Workers in the Sorting and A–Buildings

Recovery & Reclamation, Inc.
HETA 95–0097
May 16–17, 1995

JOB TITLE	BUILDING	URINE [Hg][1]	>ACGIH BEI[2]	>WHO[3]
Supervisory	A–1 + A–2	57.0	X	X
Laborer	A–1	18.7		
Sorter	A–1	163.7	X	X
Supervisory	A–1	46.6	X	
Supervisory	A–1	25.7		
Supervisory	A–1 + A–2	10.0		
Sorter	A–2	20.0		
Supervisory	A–2	40.0	X	
Laborer	A–2	76.6	X	X
Supervisory	A–2	34.3		
Sorter	Sorting	26.9		
Sorter	Sorting	10.4		
Skilled Laborer	Sorting	1.9		
Sorter	Sorting	2.5		
Skilled Laborer	Sorting	42.6	X	
Sorter	Sorting	77.6	X	X
Sorter	Sorting	55.1	X	X
Sorter	Sorting	20.0		
Sorter	Sorting	15.2		
Sorter	Sorting	172.0	X	X
Sorter	Sorting	3.7		
Supervisory	Sorting	81.9	X	X
Sorter	Sorting	92.4	X	X
Sorter	Sorting	54.0	X	X
Supervisory	Sorting	60.4	X	X
Sorter	Sorting	88.5	X	X
Sorter	Sorting	1.8		
Sorter	Sorting	5.5		
Supervisory	Sorting	3.0		

1 Units are expressed in micrograms of Hg per gram of creatinine (µg/g–Cr) in a workers urine sample.
2 An "X" indicates the concentration of Hg in the urine exceeded the ACGIH BEI of 35 µg/g–Cr.
3 An "X" indicates the concentration of Hg in the urine exceeded the WHO standard of 50 µg/g–Cr.

Table 10
The Urine Mercury (Hg) Data for the Mechanical Workers and the Workers in the Offices and Z–Buildings

Recovery & Reclamation, Inc.
HETA 95–0097
May 16–17, 1995

JOB TITLE	BUILDING[1]	URINE [Hg][2]	>ACGIH BEI[3]	>WHO[4]
Mechanic	All	4.8		
Electrical	All	2.6		
Laborer	All	10.2		
Supervisory	All	40.7	X	
Skilled Laborer	All	15.0		
Laborer	All	5.9		
Supervisory	All	29.0		
Skilled Laborer	All	84.0	X	X
Mechanic	All	127.2	X	X
Supervisory	All	10.3		
Electrical	All	39.0	X	
Mechanic	All	16.1		
Mechanic	All	26.5		
Mechanic	All	7.1		
Supervisory	All	71.0	X	X
Mechanic	All	15.2		
Electrical	All	2.1		
Mechanic	All	8.5		
Supervisory	Offices	8.3		
Supervisory	Offices	14.7		
Supervisory	Z–Bottoms	126.0	X	X
Laborer	Z–Bottoms	29.0		
Electrical	Z–Bottoms	1.6		
Laborer	Z–Saw	12.5		
Laborer	Z–Saw	69.8	X	X
Laborer	Z–Saw	79.8	X	X
Supervisory	Z–Saw	72.0	X	X
Laborer	Z–Saw	5.8		
Supervisory	Z Buildings	13.2		

1 "All" refers to the fact that the mechanical workers may work in any of the buildings on–site.
2 Units are expressed in micrograms of Hg per gram of creatinine (µg/g–Cr) in a workers urine sample.
3 An "X" indicates the concentration of Hg in the urine exceeded the ACGIH BEI of 35 µg/g–Cr.
4 An "X" indicates the concentration of Hg in the urine exceeded the WHO standard of 50 µg/g–Cr .

Table 11
Summary Statistics for the Urine Mercury (Hg) Data with Analysis by Building

Recovery & Reclamation, Inc.
HETA 95–0097
May 16–17, 1995

URINE Hg DATA SET	n[1]	MEAN URINE [Hg] [2]	MAX[3]	MIN[3]	>ACGIH BEI[4]	>WHO[5]
All Urine Hg Data	58	38.9	172.0	1.6	23/58 (40%)	18/58 (31%)
Urine Hg Data – Sorting	19	42.9	172.0	1.8	9/19 (47%)	8/19 (42%)
Urine Hg Data – A Buildings	10	49.3	163.7	10.0	5/10 (50%)	3/10 (30%)
Urine Hg Data – Z Buildings	9	45.5	126.0	1.6	4/9 (44%)	4/9 (44%)
Urine Hg Data – Maintenance	18	28.6	127.2	2.1	5/18 (28%)	3/18 (17%)

1 The letter "n" denotes the number of participating workers in the given data set.
2 Mean (average) of "n" urine mercury measurements for the data set; the mean is in units of micrograms of Hg per gram of creatinine (µg/g–Cr).
3 MAX = maximum value of the data set in µg/g–Cr.
MIN = minimum value of the data set in µg/g–Cr.
4 Number of urine Hg measurements greater than the ACGIH BEI of 35 µg/g–Cr.
5 Number of urine Hg measurements greater than the WHO standard of 50 µg/g–Cr.

Table 12
Summary Statistics for the Urine Mercury (Hg) Data: Analysis By Job Title

Recovery & Reclamation, Inc.
HETA 95–0097
May 16–17, 1995

JOB TITLES	n[1]	MEAN URINE [Hg][2]	MAX[3]	MIN[3]	>ACGIH BEI[4]	>WHO[5]
Sorter	16	50.6	172.0	1.8	7/16 (44%)	7/16 (44%)
Supervisory	18	41.3	126.0	3.0	9/18 (50%)	6/18 (33%)
Laborer	8	34.3	79.8	5.8	3/9 (33%)	3/9 (33%)
Mechanical /Electrical	11	22.8	127.2	1.6	2/11 (18%)	1/11 (9%)

1 The letter "n" denotes the number of participating workers in the given job title.
2 Mean (average) of "n" urine mercury measurements for the given job title; the mean is in units of micrograms of Hg per gram of creatinine (µg/g–Cr).
3 MAX = maximum value of the data set in µg Hg/g Cr.
MIN = minimum value of the data set in µg Hg/g Cr.
4 Number of urine Hg measurements in the data set that are greater than the ACGIH BEI of 35 µg/g–Cr.
5 Number of urine Hg measurements in the data set that are greater than the WHO standard of 50 µg/g–Cr.

Table 13
Ambient Air Sampling Data for Mercury (Hg)

Battery Conservation Technologies, Inc.
HETA 95–0097
December 10–12, 1996

LOCATION – DATE	SAMPLE TIME[1]	SAMPLE VOLUME[2]	[Hg][3]
Parking Lot, Personnel Building – 12/10/96	0828–1621	95	0.4
Parking Lot, Administration Building – 12/10/96	0833–1620	93	(0.3)
Parking Lot, Personnel Building – 12/11/96	1241–2013	90	0.6
Parking Lot, Administration Building – 12/11/96	1242–2013	90	(0.3)
On Fence, North of A–3 Building – 12/12/96	0730–1558	102	1.9
On Fence, South of W–2 Building – 12/12/96	0725–1544	100	(0.3)

[1] This is the start and stop time (in military time) for the sampling device.
[2] Sample volumes are expressed in liters of air.
[3] Mercury concentrations are expressed in micrograms of mercury per cubic meter of air (µg/m^3). Mercury concentrations in parentheses are between the minimum quantifiable concentration (0.4 µg/m^3) and the minimum detectable concentration (0.1 µg/m^3) for the sampling and analytical method.

Table 14
Personal Breathing Zone Exposure Data for Workers Potentially Exposed to Mercury (Hg)

Battery Conservation Technologies, Inc.
HETA 95–0097
December 10–13, 1996
(Page 1 of 2)

JOB TITLE	DATE	SAMPLE TIME[1]	SAMPLE VOLUME[2]	[Hg][3]	>OSHA PEL[4]	>NIOSH REL[5]	>ACGIH TLV®[6]
Forklift Operator	12/10/96	0635–1610	115	32.2			X
	12/11/96	0634–1536	108	120.4	X	X	X
	12/12/96	0641–1530	106	103.8	X	X	X
Foreman	12/10/96	0648–1617	114	69.3		X	X
	12/11/96	0634–1527	107	168.2	X	X	X
	12/12/96	0652–1524	102	186.3	X	X	X
Operator	12/10/96	0637–1620	117	69.5		X	X
	12/11/96	0631–1535	107	55.1		X	X
	12/12/96	0648–1527	104	134.6	X	X	X
Operator	12/10/96	0633–1608	115	269.6	X	X	X
	12/11/96	0633–1540	109	1192.7	X	X	X
	12/12/96	0645–1524	104	250.0	X	X	X
Forklift Operator	12/10/96	0640–1556	111	13.5			
	12/11/96	0631–1545	111	13.5			
	12/12/96	0637–1523	105	12.4			
Maintenance/ Mechanic	12/10/96	0642–1557	110	53.8		X	X
	12/11/96	0636–1510	88	125.0	X	X	X
	12/12/96	0638–1523	105	190.5	X	X	X
Maintenance/ Mechanic	12/10/96	0643–1611	114	704.2	X	X	X
	12/11/96	0643–1535	94	2021.3	X	X	X
	12/12/96	0647–1526	104	1153.8	X	X	X
Foreman	12/10/96	0650–1625	115	121.7	X	X	X
	12/12/96	0722–1517	95	105.3	X	X	X

Table 14 (continued)
Personal Breathing Zone Exposure Data for Workers Potentially Exposed to Mercury (Hg)

JOB TITLE	DATE	SAMPLE TIME[1]	SAMPLE VOLUME[2]	[Hg][3]	>OSHA PEL[4]	>NIOSH REL[5]	>ACGIH TLV®[6]
Foreman	12/10/96	0646–1557	110	27.3			X
	12/11/96	0652–1526	103	10.7			
	12/12/96	0655–1515	100	22.0			
Forklift Operator	12/10/96	0636–1614	116	34.5			X
	12/11/96	0634–1537	109	89.0		X	X
	12/12/96	0644–1527	105	95.2		X	X
Foreman	12/10/96	1917–0127	74	60.0		X	X
	12/12/96	1505–2200	83	204.8	X	X	X
Foreman	12/10/96	0647–1331	81	56.8		X	X
	12/11/96	0635–1535	108	185.2	X	X	X
	12/12/96	0646–1526	104	442.3	X	X	X
Welder	12/10/96	0638–1615	115	139.1	X	X	X
	12/11/96	0630–1532	108	129.6	X	X	X
	12/12/96	0641–1526	105	476.2	X	X	X
Operator	12/12/96	0705–1523	100	39.0			X
Electrician	12/10/96	0643–1622	116	94.8		X	X
	12/11/96	0635–1526	106	55.7		X	X
	12/12/96	0640–1500	100	220.0	X	X	X
Maintenance	12/10/96	1913–0127	75	70.7		X	X
	12/12/96	1507–2200	83	156.6	X	X	X
Foreman	12/10/96	0645–1600	111	4.5			
	12/11/96	0638–1526	106	9.4			
	12/12/96	0650–1522	104	2.9			

[1] This is the start and stop time (in military time) for the sampling device.
[2] Sample volumes are expressed in liters of air.
[3] Mercury concentrations are expressed in micrograms of mercury per cubic meter of air ($\mu g/m^3$).
[4] An "X" indicates the worker Hg exposure concentration exceeded the OSHA PEL of 100 $\mu g/m^3$.
[5] An "X" indicates the worker Hg exposure concentration exceeded the NIOSH REL of 50 $\mu g/m^3$.
[6] An "X" indicates the worker Hg exposure concentration exceeded the ACGIH TLV® of 25 $\mu g/m^3$.

Table 15
Three–day Mercury (Hg) Exposure Means, Urine Mercury and Urine NAG Data

Battery Conservation Technologies, Inc.
HETA 95–0097
December 10–13, 1996

JOB TITLE	MEAN [Hg][1]	URINE Hg[2]	URINE NAG[3]
Forklift Operator	85.5	77	8.4
Foreman	141.3	150	6.6
Operator	86.4	119	4.6
Operator	570.8	508	1.8
Forklift Operator	13.1	172	3.6
Maintenance/Mechanic	123.1	316	3.7
Maintenance/Mechanic	1293.1	217	4.2
Foreman	113.5*	21	2.4
Foreman	20.0	19	1.9
Forklift Operator	72.9	54	1.9
Foreman	559.5*	39	3.8
Operator	269.8	59	2.9
Foreman	132.4*	71	3.1
Foreman	228.1	198	4.2
Maintenance	248.3	260	12.1
Operator	39.0*	4	1.8
Maintenance	123.5	232	19.4
Maintenance	113.7*	69	3.1
Foreman	5.6	9	1.2
OSHA PEL	100		
NIOSH REL	50		
ACGIH TLV®/BEI	25	35	
WHO Standard	25	50	
NAG Guideline			Males – 7.9, Females – 9.3

[1] Mean exposure concentrations expressed in micrograms of Hg per cubic meter of air (µg/m^3). Means marked with an asterisk (*) are based on less than three exposure measurements.
[2] Urine mercury concentrations expressed in micrograms of Hg per gram of creatinine (µg/g–Cr).
[3] Urine NAG concentrations expressed in International Units of NAG per gram creatinine.

Table 16
Area/Process Air Sampling Data for Mercury (Hg) – December 10, 1996

Battery Conservation Technologies, Inc.
HETA 95–0097
December 10–13, 1996

BUILDING/LOCATION	SAMPLE TIME[1]	SAMPLE VOLUME[2]	[Hg][3]
W–1/Northwest corner, on lunch table	0718–1553	102	2.1
W–1/Southeast corner near overhead door	0720–1554	102	2.0
S–1/Southeast corner on fire extinguisher	0723–1555	101	1.1
S–1/West corner on fire extinguisher	0724–1555	103	2.0
W–3/Northwest corner, on wall	0728–1548	99	3.6
W–3/Northeast corner, on wall	0730–1550	100	1.4
A–1/Center of room on hopper	0740–1536	94	37.1
A–1/East wall near end of conveyor	0741–1537	95	20.1
A–1/Northeast corner, on wall	0744–1538	94	29.8
A–1/Southwest corner, on wall	0746–1537	93	37.5
A–2/Center of Building, on control panel	0751–1540	93	68.1
A–2/East end of oven where bullets exit	0755–1541	92	173.2
A–2/West end of oven, entry point for bullets	0757–1538	92	31.6
A–2/East end where oven exits the building	0753–1540	93	214.1
A–3/Center of building, on control panel	0802–1618	98	73.2
A–3/West end of building on low platform	0809–1618	97	60.7
A–3/Southwest side of building on high platform	0810–1620	98	59.5

1 This is the start and stop time (in military time) for the sampling device.
2 Sample volumes are expressed in liters of air.
3 Mercury concentrations are expressed in micrograms of mercury per cubic meter of air ($\mu g/m^3$).

Table 17
Area/Process Air Sampling Data fir Mercury (Hg) – December 11, 1996

Battery Conservation Technologies, Inc.
HETA 95–0097
December 10–13, 1996

BUILDING/LOCATION	SAMPLE TIME[1]	SAMPLE VOLUME[2]	[Hg][3]
W–1/Northwest corner, on lunch table	0757–1542	93	0.8
S–1/Middle of room	0756–1540	93	2.6
W–3/Northwest corner, on lunch table	0754–1544	94	4.0
W–3/Attached to pallets in middle of building	0737–1538	97	1.8
W–3/Attached to pallets in south end of building	0739–1536	95	1.9
A–1/Center of room on hopper	0740–1556	99	121.0
A–1/East wall near end of conveyor	0742–1555	99	34.3
A–1/Northeast corner, on wall	0743–1555	99	77.8
A–1/Southwest corner, on wall	0744–1559	99	39.4
A–2/Center of Building, on control panel	0750–1601	98	59.1
A–2/East end of oven where bullets exit	0755–1603	97	471.3
A–2/West end of oven, entry point for bullets	0747–1600	99	19.3
A–2/East end where oven exits the building	0753–1602	98	132.9
A–3/East end on product chute	0809–1606	95	125.8
A–3/Center of building, on control panel	0802–1607	97	113.4
A–3/West end of building on low platform	0805–1608	97	38.3
A–3/Southwest side of building on high platform	0810–1609	96	69.9

1 This is the start and stop time (in military time) for the sampling device.
2 Sample volumes are expressed in liters of air.
3 Mercury concentrations are expressed in micrograms of mercury per cubic meter of air ($\mu g/m^3$).

Table 18
Area/Process Air Sampling Data for Mercury (Hg) – December 12, 1996

Battery Conservation Technologies, Inc.
HETA 95–0097
December 10–13, 1996

BUILDING/LOCATION	SAMPLE TIME[1]	SAMPLE VOLUME[2]	[Hg][3]
W–1/Northwest corner, on lunch table	0712–1527	99	9.6
S–1/Middle of room	0715–1524	98	3.4
S–1/East wall	0717–1525	98	5.5
W–3/Attached to pallets in middle of building	0722–1541	100	3.3
W–3/Attached to pallets in south end of building	0719–1542	101	2.4
A–1/Center of room on hopper	0741–1607	101	82.8
A–1/East wall near end of conveyor	0740–1608	102	61.0
A–1/Northeast corner, on wall	0739–1608	102	69.6
A–1/Southwest corner, on wall	0742–1608	101	98.8
A–2/Center of Building, on control panel	0745–1550	97	195.9
A–2/East end of oven where bullets exit	0746–1553	97	381.3
A–2/West end of oven, entry point for bullets	0744–1549	97	87.8
A–2/East end where oven exits the building	0746–1552	97	154.0
A–3/East end on product chute	0750–1555	97	453.6
A–3/Center of building, on control panel	0751–1556	97	205.6
A–3/West end of building on low platform	0754–1612	100	190.8
A–3/Southwest side of building on high platform	0755–1611	99	322.6

[1] This is the start and stop time (in military time) for the sampling device.
[2] Sample volumes are expressed in liters of air.
[3] Mercury concentrations are expressed in micrograms of mercury per cubic meter of air ($\mu g/m^3$).

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