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Case Studies

Mercury Exposures During the Recycling/Reclamation of Household-Type Alkaline Batteries

Dawn Tharr, Column Editor

Reported by Christopher Reh, Daehae Kang,
and Veronica Herrera-Moreno

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 a recovery facility 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). The facility in question initially recycled/reclaimed alkaline batteries, zinc/carbon-potassium hydroxide batteries (railroad batteries), and lithium batteries. Lead-acid batteries were also collected at the facility, but these were shipped to another company for reclamation. During this study, the process was redesigned to recycle only alkaline batteries.

Background

The 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 were classified as sorters, laborers, or mechanical/electrical workers. Sorters would remove non-battery debris (scrap metal, medical waste, paper, trash, etc.) from the batteries on conveyor belts, and hand sort batteries by size and type into appropriate containers. Laborers performed a variety of tasks including fork lift operation, machine operation, and housekeeping. Mechanical/electrical workers performed both rou-

tine maintenance and repair, and some construction-like tasks. The job classification "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 "skilled laborer" included 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 (Shipping & Receiving) 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 those of each 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. The conveyor belts carried the batteries out of the dungeon and dumped them into empty palletized containers. During the first NIOSH visit, only the lantern battery, AA/AAA-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 separate debris and missorted 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 being sorted, 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 conveyor belt to remove any remaining debris and odd-shaped batteries. The conveyor belt dumped the batteries into a screw auger, which placed 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, which sorted them into bags containing metals, inorganic material, and carbon.

Other buildings and processes at the facility were 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 opening conference, management representatives stated that 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); however, these batteries were no longer accepted by the facility. At the time of the first NIOSH site visit an additional storage building (designated W-3), an 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.

At the time of the second 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 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 were 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 was 80 feet in length, and extended beyond the walls of the A-2 building. The main function of the oven was to bake off the moisture and mercury in the alkaline batteries. After exiting the oven, the bullet was rotated 180° to dump the heated batteries onto a conveyor belt that transported the batteries to a dumpster. The bullet rotation device and conveyor belt were in a cylindrical structure, which was equipped with a gas-powered cooling unit that cooled the heated batteries and vapors. These vapors were collected using a scrubber and the liquid was stored in a chemical tank. In addition, the oven was 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 was filled with batteries, it was transported to A-1 and weighed. The dumpster was then carried by forklift to A-3 and dumped into a hopper that fed the hammer mill. The hammer mill roughly pulverized the batteries, which were then run through a granulator to be further pulverized. A

shaker separated the pulverized batteries into metal, carbon, and non-metal components, which were bagged and shipped to the customer. Using this operation, the facility was processing 20 to 30 tons of batteries per day. During the site visit, management indicated to the NIOSH investigators its intent to bring the sorting operation in S-1 online 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 percent 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 the proper use and care of the respirators. The respirators were NIOSH/MSHA-approved, and the mercury cartridges had end-of-service-life indicators. In addition, all personnel wore hard hats during the work shift.

Methods

The HHE included two NIOSH site visits where similar Hg exposure assessment protocols were implemented. 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 and second site visits, respectively. Workers' Hg exposure concentrations were determined by sampling the air from the workers' breathing zones; 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 (cm³/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. Also, bulk dust samples were collected and analyzed for Hg by modifying NIOSH Method 6009.

The limit of detection (LOD) and limit of quantification (LOQ) for NIOSH Method 6009 are 0.01 micrograms per sample ($\mu\text{g}/\text{sample}$) and 0.034 $\mu\text{g}/\text{sample}$, 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 cm³/min to calculate an air sample volume of 96 liters (0.096 cubic meters). This resulted in an MDC of 0.1 $\mu\text{g}/\text{m}^3$ and an MQC of 0.35 $\mu\text{g}/\text{m}^3$. 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 pre-shift, 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 second 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 ($\mu\text{g/g-Cr}$). Creatinine is a protein normally found in urine and 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 Pearson's 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

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 percent of the absorbed Hg dose, whereas dermal exposure and ingestion contribute only 2.6 percent and 0.1 percent to this dose, respectively.⁽²⁾ Eighty percent of inhaled Hg is retained in the lungs, while the remainder is exhaled. Due to its high degree of lipophilicity, 74 percent of inhaled Hg rapidly diffuses across the alveolar membranes into the blood.⁽³⁻⁵⁾ 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.^(2,6) 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.^(2,7) In fact, more than 50 percent 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.⁽⁸⁾

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.^(2,4-6) Elimination through sweat, saliva, nails, hair, and bile also contributes 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 as follows: lungs—2 days; blood—2 to 4 days; brain—21 days; kidneys—40 to 60 days; and whole body—40 to 60 days.⁽²⁾ 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 2 days accounts for the elimination of 20 to 30 percent 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.⁽⁹⁾

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.⁽¹⁰⁾ Other acute effects include nausea, abdominal pain, vomiting, diarrhea, headache, and inflammation of the mouth and gums.⁽¹¹⁾

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.^(2,3,6,12)

A large proportion of the absorbed dose 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.⁽²⁾ Chronic exposure is characterized by proteinuria (e.g., albumin, β -2-microglobulin, retinol-binding protein) and enzymuria (e.g., β -galactosidase, NAG, β -glucuronidase).⁽¹³⁻²²⁾ In severe cases, a nephrotic syndrome has been observed, consisting mostly of hematuria, oliguria, urinary casts, edema, and the inability to concentrate urine.^(2,13,21-27) 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.⁽²⁸⁻³³⁾ 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 bodily fluids within normal limits.

The Occupational Safety and Health Administration (OSHA) currently enforces a permissible exposure limit (PEL) for Hg of $100 \mu\text{g}/\text{m}^3$ as a ceiling limit that should not be exceeded during a work shift.⁽³⁴⁾ The NIOSH REL for Hg exposure is $50 \mu\text{g}/\text{m}^3$ as a TWA exposure for up to 10 hours per day, 40 hours per week; NIOSH does not have a urine Hg recommendation.⁽³⁵⁾ In 1980, a World Health Organization (WHO) study group recommended an 8-hour TWA exposure limit of $25 \mu\text{g}/\text{m}^3$ and a urine Hg limit of $50 \mu\text{g}/\text{g-Cr}$.⁽¹⁰⁾ In 1994, the American Conference of Governmental Industrial Hygienists (ACGIH[®]) lowered the Threshold Limit Value (TLV[®]) and Biological Exposure Index (BEI[®]) for Hg to $25 \mu\text{g}/\text{m}^3$ (TWA exposure, 8 hours per

day, 40 hours per week) and $35 \mu\text{g}/\text{g-Cr}$, respectively.⁽³⁶⁾ The reason for lowering the TLV was a finding of preclinical signs of CNS and renal dysfunction at worker exposure levels above $25 \mu\text{g}/\text{m}^3$. People without occupational exposure to Hg generally have urine Hg concentrations of $5 \mu\text{g}/\text{g-Cr}$ or less.^(2,10)

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.⁽¹⁶⁾ 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.^(30,31) 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.^(6,37,38) 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 nonspecific indicator of cadmium- and Hg-related microdamage to the kidneys' proximal tubules.^(16,18,19,21,22,41) 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

Initial Site Visit

The data from the initial Hg exposure assessments are presented in Tables I and II. Table I contains a data analysis by survey day and building, and Table II 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.

TABLE I
Summary statistics for the Hg exposure data: Analysis by date and building

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—day 1	43	44.3	253.4	1.9	14/43 (33%)	21/43 (49%)
Hg exposure data—day 2	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%)

¹The letter "n" denotes the number of participating workers in the given data set.

²Mean (average) of "n" worker exposure measurement for the data set; the mean is in units of micrograms of Hg per cubic meter of air ($\mu\text{g}/\text{m}^3$).

³Max—maximum value of the data set in $\mu\text{g}/\text{m}^3$; Min—minimum value of the data set in $\mu\text{g}/\text{m}^3$.

⁴Number of exposure measurements greater than the NIOSH REL for Hg of $50 \mu\text{g}/\text{m}^3$.

⁵Number of exposure measurements greater than the ACGIH TLV[®] for Hg of $25 \mu\text{g}/\text{m}^3$.

TABLE II

Summary statistics for the mercury (Hg) exposure data: Analysis by job title

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%)

¹The letter "n" denotes the number of participating workers in the given job title.

²Mean (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 ($\mu\text{g}/\text{m}^3$).

³Max—maximum value of the data set in $\mu\text{g}/\text{m}^3$; Min—minimum value of the data set in $\mu\text{g}/\text{m}^3$.

⁴Number of exposure measurements greater than the NIOSH REL for Hg of 50 $\mu\text{g}/\text{m}^3$.

⁵Number of exposure measurements greater than the ACGIH TLV[®] for Hg of 25 $\mu\text{g}/\text{m}^3$.

Forty-three workers were sampled on day 1, and 24 workers were sampled on day 2. 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 day 1, and then focused the exposure monitoring of day 2 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 $\mu\text{g}/\text{m}^3$, with a range from 0.9 to 612.7 $\mu\text{g}/\text{m}^3$. Thirty-nine percent of the Hg exposure measurements were above the NIOSH REL, and 52 percent of the exposure measurements were above the ACGIH TLV. Mean Hg exposures on day 2 (68.5 $\mu\text{g}/\text{m}^3$) were higher than the mean exposures on day 1 (44.3 $\mu\text{g}/\text{m}^3$). This observation can be attributed to two factors: (1) The workers were away from their jobs for a short period of time on the morning of day 1 to complete the questionnaire and provide a urine sample, and (2) exposure monitoring on day 2 focused on workers in suspected high-Hg-exposure jobs.

From the building data analysis in Table I, the highest mean Hg exposures were among workers from Sorting (76.1 $\mu\text{g}/\text{m}^3$) and the second highest were among workers from the Z-buildings (67.2 $\mu\text{g}/\text{m}^3$). The lowest mean exposures were found in the maintenance/mechanical workers (18.1 $\mu\text{g}/\text{m}^3$). Some workers in all buildings

experienced overexposure to Hg, based on both the NIOSH REL and the ACGIH TLV. In fact, 50 percent of the workers' exposures in the Z-buildings, 46 percent of workers' exposures in Sorting, 36 percent of the workers' exposures in the A-buildings, and 19 percent of the maintenance/mechanical workers had Hg exposures above the NIOSH REL.

From Table II it is evident that workers classified as sorters had the highest mean Hg exposures (97.5 $\mu\text{g}/\text{m}^3$), followed by laborers with a mean Hg exposure of 49.8 $\mu\text{g}/\text{m}^3$, supervisory personnel with a mean Hg exposure of 34.9 $\mu\text{g}/\text{m}^3$, and mechanical/electrical workers with a mean Hg exposure of 25.0 $\mu\text{g}/\text{m}^3$. Seventy percent of the sorters, 38 percent of the laborers, 25 percent of the supervisory workers, and 23 percent of the mechanical/electrical workers experienced Hg exposures above the NIOSH REL.

Area air sampling data were collected during the two-day period; 12 area air samples were collected in Sorting, 11 in A-2, 5 in A-1, 3 in the Saw Plant, and 4 in Bottoms. The mean Hg concentrations by process building, in descending order, were as follows: Sorting—188.2 $\mu\text{g}/\text{m}^3$; A-1 building—125.4 $\mu\text{g}/\text{m}^3$; Bottoms—60.8 $\mu\text{g}/\text{m}^3$; Saw Plant—29.6 $\mu\text{g}/\text{m}^3$; and A-2 building—8.3 $\mu\text{g}/\text{m}^3$. The high mean Hg concentration for the Sorting building was influenced by two area samples of 571.4 and 861.7 $\mu\text{g}/\text{m}^3$ that were collected inside the dungeon.

This is an area that was frequently 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 $\mu\text{g}/\text{m}^3$. 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 highest Hg concentration in dust was 3,100 micrograms of Hg per gram of dust ($\mu\text{g}/\text{g}$) 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 1,700 and 2,400 $\mu\text{g}/\text{g}$, respectively. Hg concentrations were also found in the settled or floor dust found in Bottoms (1,200 $\mu\text{g}/\text{g}$), Saw Plant (210 $\mu\text{g}/\text{g}$), and A-2 (620 $\mu\text{g}/\text{g}$). These data indicate that any dust associated with this process should be considered contaminated with Hg.

A total of 58 workers from first and second shifts provided pre-shift 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 $\mu\text{g}/\text{g-Cr}$, and 40 percent and 31 percent of the workers had urine Hg concentrations above the ACGIH BEI and WHO limits, 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 III 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 $\mu\text{g}/\text{g-Cr}$, 45.5 $\mu\text{g}/\text{g-Cr}$, and 42.9 $\mu\text{g}/\text{g-Cr}$, respectively. Conversely, the mean urine Hg concentration measured among the maintenance workers was 28.6 $\mu\text{g}/\text{g-Cr}$. Fifty percent of the workers in the A-buildings, 47 percent in Sorting, 44 percent in the Z-buildings, and 28 percent in maintenance had urine Hg concentrations above the ACGIH BEI.

TABLE III
Summary statistics for the urine mercury (Hg) data: Analysis by building

Urine Hg data set	n ¹	Mean urine			>ACGIH BEI ⁴	>WHO ⁵
		[Hg] ²	Max ³	Min ³		
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%)

¹The letter “n” denotes the number of participating workers in the given data set.

²Mean (average) of “n” urine mercury measurements for the data set; the mean is in units of micrograms of Hg per gram of creatinine ($\mu\text{g/g-Cr}$).

³Max—maximum value of the data set in $\mu\text{g/g-Cr}$; Min—minimum value of the data set in $\mu\text{g/g-Cr}$.

⁴Number of urine Hg measurements greater than the ACGIH BEI of 35 $\mu\text{g/g-Cr}$.

⁵Number of urine Hg measurements greater than the WHO standard of 50 $\mu\text{g/g-Cr}$.

The job title analysis of the urine Hg data (Table IV) revealed that sorters had the highest mean urine Hg concentration (50.6 $\mu\text{g/g-Cr}$), followed by supervisory (41.3 $\mu\text{g/g-Cr}$), laborer (34.3 $\mu\text{g/g-Cr}$), and mechanical/electrical (22.8 $\mu\text{g/g-Cr}$). The percentage of workers in these job titles with urine Hg levels above the ACGIH BEI are as follows: sorters—44 percent; supervisory—50 percent; laborers—33 percent; mechanical/electrical—18 percent. 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 descent (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).

Second Site Visit (18 Months Later)

Table V contains the data from the three days of Hg exposure monitoring on all workers during the second site visit. A total of 51 full-shift, TWA exposure samples were collected during this time period. Of the samples collected, 18 were collected on day 1, 15 on day 2, and 18 on day 3. The mean Hg exposure concentration for the 51 exposure samples collected over the three-day period was 229.8 $\mu\text{g/m}^3$ and ranged from 2.9 to 2,021.3 $\mu\text{g/m}^3$. When segregated by date of collection, the mean Hg exposure concentrations were 134.8 $\mu\text{g/m}^3$ (range of 4.5 to 704.2 $\mu\text{g/m}^3$), 333.2 $\mu\text{g/m}^3$ (range of 9.4 to 2021.3 $\mu\text{g/m}^3$), and 238.7 $\mu\text{g/m}^3$ (range of 2.9 to 1153.8 $\mu\text{g/m}^3$) for day 1, 2, and 3, respectively.

A comparison of the Hg exposure data to the OSHA, NIOSH, and ACGIH exposure criteria reveals that most workers were overexposed during the three-day

TABLE IV

Summary statistics for the urine mercury (Hg) data: Analysis by job title

Job titles	n ¹	Mean urine			>ACGIH	
		[Hg] ²	Max ³	Min ³	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%)

¹The letter “n” denotes the number of participating workers in the given job title.

²Mean (average) of “n” urine mercury measurements for the given job title; the mean is in units of micrograms of Hg per gram of creatinine ($\mu\text{g/g-Cr}$).

³Max—maximum value of the data set in $\mu\text{g/g-Cr}$; Min—minimum value of the data set in $\mu\text{g/g-Cr}$.

⁴Number of urine Hg measurements in the data set that are greater than the ACGIH BEI of 35 $\mu\text{g/g-Cr}$.

⁵Number of urine Hg measurements in the data set that are greater than the WHO standard of 50 $\mu\text{g/g-Cr}$.

TABLE V
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}
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
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			

¹This is the start and stop time (in military time) for the sampling device.

²Sample volumes are expressed in liters of air.

³Mercury concentrations are expressed in micrograms of mercury per cubic meter of air ($\mu\text{g}/\text{m}^3$).

⁴An “X” indicates the worker Hg exposure concentration exceeded the OSHA PEL of $100 \mu\text{g}/\text{m}^3$.

⁵An “X” indicates the worker Hg exposure concentration exceeded the NIOSH REL of $50 \mu\text{g}/\text{m}^3$.

⁶An “X” indicates the worker Hg exposure concentration exceeded the ACGIH TLV[®] of $25 \mu\text{g}/\text{m}^3$.

survey period. Fifty-three percent (27 of 51) of the exposure measurements were above the OSHA ceiling limit of 100 $\mu\text{g}/\text{m}^3$. In addition, 76 percent (39 of 51) and 84 percent (43 of 51) of the exposure measurements were above the respective NIOSH REL and ACGIH TLV for Hg.

Using the data in Table V, three-day Hg exposure means were calculated by averaging each worker's three daily exposure measurements for the study period. Thus, Table VI contains the three-day means, along with the urine Hg and urine NAG levels. The three-day means ranged from 5.6 to 1,293.1 $\mu\text{g}/\text{m}^3$, with 53 percent (10 of 19) and 79 percent

(15 of 19) of the Hg exposure means above OSHA PEL and NIOSH REL, respectively. Also, 84 percent (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. 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 $\mu\text{g}/\text{g}$ Cr and ranged from 4 to 508 $\mu\text{g}/\text{g}$ -Cr. Seventy-four percent (14 of 19) of the workers had urine Hg levels in excess of

the WHO standard. In addition, 79 percent (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 $\mu\text{g}/\text{g}$ -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 ($r_p = 0.28$, $p = 0.12$).

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 $\mu\text{g}/\text{m}^3$ and 155.8 $\mu\text{g}/\text{m}^3$, respectively. High Hg concentrations were also found in A-1, with a building mean of 59.1 $\mu\text{g}/\text{m}^3$. Finally, the Hg concentrations in W-1/S-1 and W-3 were 3.2 $\mu\text{g}/\text{m}^3$ and 2.6 $\mu\text{g}/\text{m}^3$, 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 1 $\frac{1}{2}$ 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 that they did not eat or smoke at the workplace, which is consistent with plant policy. Nine workers (47%)

TABLE VI

Three-day mercury (Hg) exposure means, urine mercury, and urine NAG data

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

¹Mean exposure concentrations expressed in micrograms of Hg per cubic meter of air ($\mu\text{g}/\text{m}^3$). Means marked with an asterisk (*) are based on less than three exposure measurements.

²Urine mercury concentrations expressed in micrograms of Hg per gram of creatinine ($\mu\text{g}/\text{g}$ -Cr).

³Urine NAG concentrations expressed in International Units of NAG per gram creatinine.

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 as follows: 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 $\mu\text{g/g-Cr}$, 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 5 workers with urine Hg levels under 50 $\mu\text{g/g-Cr}$, 3 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 that they had been working shifts greater than eight hours.

Discussion

The data from both site visits demonstrate that all workers at this facility were exposed to Hg, and many workers were overexposed on a daily basis. The data from the first site visit show that 39 percent of the workers' Hg exposure measurements were above the NIOSH REL, and 52 percent were above the ACGIH TLV and WHO recommended limits. 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 overexposures were documented in every production-related building and in every job title included in this survey. Similarly, 40 percent and

31 percent of the workers had urine Hg levels above the respective ACGIH BEI and WHO recommended limits. Four employees had urine Hg levels more than three times the ACGIH BEI.

Two of the highest Hg exposure concentrations measured during the survey were found on the same sorting worker (195.7 and 612.7 $\mu\text{g/m}^3$). 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 exposure for these workers. It is possible that 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 were not in use during the second site visit.

The symptoms most commonly reported by workers 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, may be transient in nature, and are not necessarily related solely to Hg exposure. Nonetheless, considering the number of Hg overexposures 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 during the second site visit demonstrated that 76 percent of the Hg exposure measurements exceeded the NIOSH REL, and 84 percent exceeded the more conservative ACGIH TLV and WHO standards. Also, 79 percent of the three-day worker exposure means exceeded the NIOSH REL, and 84 percent exceeded the ACGIH TLV and WHO limits. These data indicate that workers are currently overexposed to Hg.

The workers' overexposures 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 percent 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 indicated that the respiratory protection program was not adequately protective. The correlation between the Hg exposure and urine Hg measurements indicated that the air-purifying respirators were 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' doses, as Hg is poorly absorbed through the skin and gastrointestinal tract. The NIOSH investigators believed there was either a significant amount of leakage between the face-to-facepiece seal, and/or the workers were 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 they are more comfortable in warm environments.

It was 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 indicated this increase had not yet reached a hazardous level. However, the high NAG levels observed in two workers suggest 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 first site visit ($53.0 \mu\text{g}/\text{m}^3$) and those measured during the second site visit ($229.8 \mu\text{g}/\text{m}^3$) indicates that the Hg exposures were significantly higher during the second visit (Student's $t = 4.24$, $p < 0.0001$). A similar analysis of the two sets of urine Hg data found that the urine Hg levels were higher during the second site visit when compared with those of the first (Student's $t = 3.19$, $p = 0.005$). This indicates that the changes made in the process have increased the workers' Hg exposures.

The NIOSH data indicate that at least 7 of 67 (10%) Hg exposure measurements collected at the time of the first site visit and 27 of 51 (53%) Hg exposure measurements collected at the second site visit exceeded the OSHA PEL ceiling limit of $100 \mu\text{g}/\text{m}^3$. In addition, 10 of the three-day means exceeded 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 from 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 that the home environment had become contaminated with Hg.^(22,43) During the study, NIOSH found that 21 workers were exposed to an average Hg concentration of $50.1 \mu\text{g}/\text{m}^3$ (exposures ranging from 2.8 to $270.6 \mu\text{g}/\text{m}^3$), and the workers' urine Hg levels ranged from 1 to $345 \mu\text{g}/\text{g-Cr}$. Company records revealed Hg vapor levels in the facility ranging from 24 to $308 \mu\text{g}/\text{m}^3$. A survey of some of the workers' homes revealed Hg concentrations ranging from 0.02 to $10 \mu\text{g}/\text{m}^3$. Twenty-three children within the homes had a mean urine Hg level of 25 micrograms per liter ($\mu\text{g}/\text{L}$), 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 overexposure measured during this NIOSH HHE, it is reasonable to conclude that there is a strong possibility 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 in which to store their street clothes during the work shift.

Conclusions

The NIOSH investigators have documented a serious Hg exposure health hazard associated with battery reclamation/recycling processes. These expo-

surements produced high urine Hg levels and CNS and respiratory symptoms that may be Hg-related. Changes in the process produced a significant increase in the workers' Hg exposures and urine Hg levels, and the respirator program was 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 that the workers are not protected from hazardous exposures when using the negative-pressure air-purifying respirators. The NIOSH investigators recommended that the company 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 recommended 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. The company should provide employees with work clothing that the workers change in to 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 on-site 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 cleanup methods or vacuuming with a mercury vacuum should be allowed during cleanup activities.
 5. The worker exposure and area airborne Hg concentrations suggest that the A-2 oven area was 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 also in A-3, it was apparent that the oven process was not effectively removing the mercury from the batteries. The NIOSH investigators recommended that the company 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 was generated at the facility.
 7. The company 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 $\mu\text{g/g-Cr}$, then the worker should be assigned to work areas without Hg exposure, and have his or 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 management should maintain all medical records for a period of 30 years.
 8. The company should implement an exposure monitoring program for all workers potentially exposed to Hg or 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's overexposure 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 semiannual 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 percent of the NIOSH REL (20 $\mu\text{g/m}^3$). 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 or 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. The company should provide workers with annual training and education on the health hazards associated with workplace exposure to Hg and other hazardous substances 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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EDITORIAL NOTE: Christopher Reh, Daehee Kang, and Veronica Herrera-Moreno were all formerly with the Division of Surveillance, Hazard Evaluations, and Field Studies of NIOSH. More detailed information on this evaluation is contained in Health Hazard Evaluation Report No. 95-0097-2661, available through NIOSH, Hazard Evaluation and Technical Assistance Branch, 4676 Columbia Parkway, Cincinnati, Ohio 45226; telephone: (800) 35-NIOSH; fax: (513) 533-8573.
