HETA 98-0320-2751
Mercury Waste Solutions, Inc.
Union Grove, Wisconsin

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PREFACE

The Hazard Evaluations and Technical Assistance Branch (HETAB) of the National Institute for Occupational Safety and Health (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.

HETAB also provides, upon request, technical and consultative assistance to Federal, State, and local agencies; labor; industry; and other groups or individuals to control occupational health hazards and to prevent related trauma and disease. Mention of company names or products does not constitute endorsement by NIOSH.

ACKNOWLEDGMENTS AND AVAILABILITY OF REPORT

This report was prepared by Joel McCullough, M.D., M.P.H., M.S., of the Hazard Evaluations and Technical Assistance Branch, Division of Surveillance, Hazard Evaluations and Field Studies (DSHEFS). Field assistance was provided by Robert Dick, Ph.D., of the Applied Psychology and Ergonomics Branch, Division of Biomedical and Behavioral Sciences, Jonathan Rutchik, M.D., of Occupational Health and Rehabilitation, Inc., and Angela Lovelace of Neurotron, Inc. Desktop publishing was performed by Patricia McGraw. Review and preparation for printing was performed by Penny Arthur.

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Investigation of Mercury Waste Solutions, Inc.

In September 1998, NIOSH representatives conducted a health hazard evaluation at Mercury Waste Solutions, Inc. We looked into concerns about exposure to mercury and health problems. This sheet summarizes our evaluation and findings.

What NIOSH Did

We had workers complete a questionnaire about mercury, their exposure, and health conditions.

Workers were examined by a neurologist.

We performed several tests to look at the function of the nervous system.

We reviewed test results related to past mercury exposures.

What NIOSH Found

Thirteen out of sixteen employees had average mercury levels that were above the recommended level.

Most of the tests of nerve function were normal in this group of workers as a whole.

The test that measured tremor (steadiness in the hand) showed that there was a small decrease in nerve function in workers with high mercury levels.

What Mercury Waste Solutions, Inc. Managers Can Do

The level of mercury exposure should be kept within acceptable limits.

Annual training should be done to inform workers of the health hazards associated with mercury exposure.

Workers who are exposed to mercury should have their urine checked for mercury regularly.

Workers with high urine mercury levels should be removed from exposure until the mercury level returns to an acceptable level.

What the Mercury Waste Solutions, Inc. Employees Can Do

Attend annual training on the hazards of working with mercury.

Report to your physician if you feel your health is being affected by mercury exposure.

CDC
CENTERS FOR DISEASE CONTROL AND PREVENTION

What To Do For More Information:
We encourage you to read the full report. If you would like a copy, either ask your health and safety representative to make you a copy or call 1-513/841-4252 and ask for
HETA Report # 98-0320-2751

NIOSH National Institute for Occupational Safety and Health

Health Hazard Evaluation Report 98-0320-2751

Mercury Waste Solutions, Inc.
Union Grove, Wisconsin
August 1999

Joel McCullough, M.D., M.P.H., M.S.
Robert Dick, Ph.D.

SUMMARY

On August 21, 1998, the National Institute for Occupational Safety and Health (NIOSH) received a request for a health hazard evaluation (HHE) from the State of Wisconsin, Department of Health and Social Services, Division of Environmental and Occupational Health. This request concerned potential health effects related to mercury (Hg) exposure among employees of Mercury Waste Solutions, Inc. (MWSI) in Union Grove, Wisconsin. The requestor sought a clinical evaluation of current and past workers to determine if signs of acute or chronic inorganic mercury poisoning existed among the workforce.

A medical evaluation was conducted on September 3-4, 1998. The medical evaluation consisted of a self-administered symptom questionnaire, a physical examination by a neurologist, a test of sensory nerve function (neurometer), and other tests of neurologic function, including a tremor test. NIOSH investigators also reviewed medical records of employees, which contained information about biological monitoring for Hg which included spot (random) and 24-hour urinary Hg levels, and for some employees blood Hg levels.

Sixteen of 17 current workers at MWSI participated in the NIOSH investigation. These included both production and office workers. The average spot urine mercury level was 167.7 microgram per gram of urinary creatinine (µg/g-Cr) (range: 24.9 - 939.7 µg/g-Cr), the average peak urine Hg level was 209.7 µg/g-Cr (range: 24.9 - 1212.9 µg/g-Cr), and the average 24-hour urine for Hg was 437.4 µg/g-Cr (range: 62.0 - 905.0 µg/g-Cr). Thirteen workers had an average spot urine Hg level above the American Conference of Governmental Industial Hygienists (ACGIH®) Biological Exposure Index (BEI®) of 35 µg/g-Cr.

Based on questionnaire responses, the most common symptom that began in the previous 6 months and may be associated with Hg toxicity was frequent headaches (6 workers). The report of other new onset symptoms was infrequent. Fourteen workers had a neurological examination; nine showed evidence of a mild upper extremity tremor. No other overt signs of Hg toxicity were noted. Of the other tests administered, the grooved peg board test, color vision test, and neurometer test, showed no significant differences between workers with elevated urine Hg levels compared to those with low Hg levels.

Among the tests administered, the tremor test showed differences between workers with elevated urinary Hg levels compared to workers whose levels were below the BEI for Hg. Participants whose Hg level was below 35 µg/g-Cr had more "A" test results (most parameters within human normal range), while those with Hg levels above 35 µg/g-Cr had more "B" and "C" test results (fewer parameters within normal range).

A statistical comparison was made of the mean tremor index, which is a measure of the characteristics of a tremor calculated by the hand-held tremor device, among participants whose average spot urinary Hg level was above the BEI versus those with an average Hg level below the BEI. The mean tremor index for participants whose urine Hg was below the BEI was 115.0, compared to 83.6 for participants whose urine Hg was above the BEI ($p = 0.042$; Wilcoxon Rank Sum Test) (a lower tremor index is in the direction of abnormality).

Our evaluation found that some workers at MWSI had subclinical detriment of neurological function that seemed to be related to Hg exposure. The clinical significance of these changes is uncertain. Only the tremor test results showed evidence of decreased function.

Mercury contamination at the plant resulted in overexposure of the employees to Hg vapor and particulates. The majority of the workforce had elevated urinary Hg levels (above the BEI). Workers with elevated urine Hg levels had worse performance on the tremor test compared to workers with low Hg levels.

KEYWORDS: SIC 5093 (Scrap and Waste Materials), mercury, urine mercury, central nervous system, mercury recycling, tremor, neurobehavioral testing.

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INTRODUCTION

On August 21, 1998, the National Institute for Occupational Safety and Health (NIOSH) received a request for a health hazard evaluation (HHE) from the State of Wisconsin, Department of Health and Social Services, Division of Environmental and Occupational Health. This request concerned potential health effects related to mercury (Hg) exposure in the employees of Mercury Waste Solutions, Inc. (MWSI) in Union Grove, Wisconsin. The requestor sought a clinical evaluation of workers to determine if physical signs of acute or chronic inorganic Hg poisoning existed among the workforce. In response to this request, NIOSH investigators conducted a medical evaluation on September 3-4, 1998. The NIOSH medical evaluation consisted of a questionnaire, a physical examination by a neurologist, a neurometer test (a test of sensory nerve function), and a battery of neurobehavioral tests. Participants were notified of their medical test results by letter on November 19, 1998.

At the time of the NIOSH site visit, the Occupational Safety and Health Administration (OSHA) was in the process of investigating MWSI. NIOSH investigators reviewed the results of the OSHA industrial hygiene evaluation.

After completing its investigation, OSHA alleged 12 serious and 4 other-than-serious violations. Alleged violations related to Hg exposures included the following: MWSI was cited for failure to comply with the OSHA permissible exposure limit (PEL) for airborne Hg; on several occasions, the air monitoring results exceeded the PEL. The respiratory protection program was found to be deficient because of inadequate cartridge selection, insufficient fit testing, and improper storage. Engineering controls were insufficient to control Hg vapor release at specific points during recycling process. Workers were exposed to a sudden oven pressurization during the heating cycle which could have resulted in serious physical harm. MWSI was cited for having both inadequate hazardous waste training and emergency response plans. The company also allegedly failed to notify a commercial laundry of the hazards of Hg in contaminated uniforms and did not inform outside contractors of the hazards of Hg in their workplace. The company was cited for inadequate record keeping related to the restricted duty six workers received, but not recorded on the OHSA 200 log. MWSI was contesting the citations and proposed penalties at the time of this report.

BACKGROUND

The Union Grove facility was constructed by US Technologies in 1993 and was purchased by MWSI in 1995. MWSI in Union Grove currently operates 3 shifts a day, 5 days a week. MWSI collects and recycles about 16,000 pounds of products which contain Hg each year.

MWSI recycles Hg by a retorting process. Retorting involves heating the scrap with an external source in a closed still pot to vaporize the Hg; condensing the Hg vapor in condensers; and collecting the condensed Hg. The final purification process was proprietary.

The company had several unintentional releases of Hg which resulted in contamination of the plant. On July 31, 1998, an equipment malfunction occurred causing a larger than normal release of smoke from the plant's exhaust system. The malfunction was due to a partial airflow blockage in one of its Hg collection systems. The malfunction resulted in the release of Hg vapor within the plant. Also, on October 14, 1998, a sudden retort oven over pressurization caused a breach of the oven door. The oven over pressurization was caused by lithium batteries that were mistakenly placed in the oven. The incident necessitated extensive clean-up within the building. The company has since revised operating procedures to include expanded battery sorting protocols and additional notification of customers regarding acceptance and packaging materials.

Before July 1998, medical surveillance included monitoring for blood and urine Hg levels. The urine Hg levels were not corrected for creatinine or specific gravity, but generally were below toxic levels, as defined by the laboratory. MWSI began medical surveillance for Hg with a new occupational medicine provider in July 1998. At this time, urine Hg levels were elevated in several employees, including office workers. The high Hg levels in the employees of MWSI were reported to the Division of Environmental and Occupational Safety Health (DEOSH) of the Wisconsin State Department of Health and Social Services. After the discovery of the elevated Hg levels, OSHA began an investigation. In addition, DEOSH requested an

HHE to determine if current and past employees of MWSI exhibited signs of acute of acute or chronic effects of Hg toxicity.

METHODS

The primary objective of the HHE was to determine if current employees were experiencing health effects from exposure to Hg. The assessment of health effects possibly related to Hg was assessed by a self-administered questionnaire, a physical examination by a neurologist, a test of sensory nerve function (neurometer), a tremor test, a color vision test, and a test of fine psychomotor control (grooved pegboard test). Because chronic exposure to inorganic Hg results primarily in effects on the nervous system, the investigation focused on possible neurologic effects.[1] Other chronic health effects which may be related to Hg exposure were elicited from the questionnaire.

All workers were informed of the NIOSH investigation and were invited to participate on a voluntary basis. An explanation of the right to refuse participation and of the Privacy Act (including conditions under which confidential information could be released) was also given to each participant. Once employees agreed to participate, they read and signed an informed consent form, completed a questionnaire, and then took part in the described testing. A brief explanation of the testing follows. Details of the specific instruments and procedures can be found in Appendix A.

Questionnaire

The questionnaire contained detailed questions about the worker's symptoms, personal and family medical history, hobbies, diet, smoking history, caffeine and alcohol use, and work history. A NIOSH investigator was available to answer questions about the form.

Physical Examination

A limited physical examination focusing on the nervous system was performed by a neurologist. The neurologic exam focused on signs of tremor, incoordination, and cognitive deficits. A standardized data form was used to record the findings of this examination. Where neurologic abnormalities were found, the neurologist took a relevant history to determine the presence of non-occupational causal factors.

Grooved Pegboard Test

The grooved pegboard test was used to test for fine psychomotor control and evaluate visual, tactile, and kinesthetic motor systems. Participants were asked to place pegs in the holes of the board as fast as they could. Age and gender norms are available.[2]

Color Vision Tests

The purpose of this test was to reveal color blindness and to differentiate among the participants that have imperfect color vision. The color vision tests could differentiate participants with acquired color vision loss from those with congenital color vision loss. This test was administered because several studies report that Hg exposure may result in acquired color blindness.[3,4]

Color vision was evaluated using the Lanthony 15 Hue desaturation panel and Farnsworth D-15 panel test, which are tests based on the ability to recombine a set of 15 colored caps according to a definite chromatic sequence.[5] The results of the test were expressed as color confusion index (CCI)[6]; an index of 1 means the test was completed correctly, and each error in recombining the sequence increases the value of the CCI.

Tremor Test

The tremor test was performed to determine tremor characteristics of the upper extremities. This device measures the number of tremor parameters that are within normal limits, but does not characterize the tremors as they relate to clinical significance. The tremor is a classic sign of Hg toxicity, and different tremor devices have been used to characterize these tremors in other studies. For this investigation, hand tremor was measured by the TREMOR 3.0™ (developed by Danish Product Development).[7]

The parameters measured by TREMOR 3.0 are the tremor intensity, center frequency, standard deviation (SD) of center frequency, harmonic index, and the tremor index. The tremor intensity is the amplitude of the tremor. The center frequency is the average frequency of accelerations. The harmonic index compares the tremor frequency pattern to a single oscillation. The tremor index is calculated from the parameters above. An additional tremor characteristic, the Quality Indicator, tells how many of the measured parameters are within the normal range; an "A" score indicates nine to ten parameter are within the mean ± SD; a "B" score indicates four to eight parameters are within the mean ± SD; and a "C" score indicates three or fewer parameters are within the mean ± SD. A more detailed explanation of the tremor test is given in Appendix A.

Neurometer

Current Perception Threshold (CPT) was tested using a transcutaneous nerve stimulator (Neurometer™ manufactured by Neurotron Inc).[8] CPT is the minimum amount of painless neuroselective transcutaneous electrical stimulus required to evoke a sensation. This experimental test was used to determine if Hg had adversely effected sensory nerve function. Sensory peripheral neuropathy with distal paresthesias have been reported after Hg exposure.[9]

Urine Mercury

NIOSH investigators reviewed the biological monitoring results (July 1998–August 1998). Having biological monitoring results over several months allowed the assessment of the chronic nature of this exposure. The occupational medicine provider ordered additional testing on employees with elevated spot urine Hg levels (> 100 micrograms per gram of creatinine [µg/g-Cr]). This included monthly spot urine Hg, blood Hg, 24-hour urine Hg, urine beta-2-microglobulin, and a medical evaluation. These records and results were also reviewed. Also, medical records and laboratory tests, which related to Hg exposure, of current and former employees were reviewed.

EVALUATION CRITERIA

As a guide to the evaluation of the hazards posed by workplace exposures, NIOSH field staff employ environmental evaluation criteria for the assessment of a number of chemical and physical agents. These criteria are intended to suggest levels of exposure to which most workers may be exposed up to 10 hours per day, 40 hours per week for a working lifetime without experiencing adverse health effects. It is, however, important to note that not all workers will be protected from adverse health effects even though their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a pre-existing medical condition, and/or a hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by the criterion. These combined effects are often not considered in the evaluation criteria. Also, some substances are absorbed by direct contact with the skin and mucous membranes, and thus potentially increase the overall exposure. Finally, evaluation criteria may change over the years as new information on the toxic effects of an agent become available.

The primary sources of environmental evaluation criteria for the workplace are: (1) NIOSH Recommended Exposure Limits (RELs),[10] (2) the American Conference of Governmental Industrial Hygienists' (ACGIH®) Threshold Limit Values (TLVs®),[11] and (3) the U.S. Department of Labor, OSHA PELs.[12] NIOSH encourages employers to follow the OSHA limits, the NIOSH RELs, the ACGIH TLVs, or whichever are the more protective criterion. The OSHA PELs reflect the feasibility of controlling exposures in various industries where the agents are used, whereas NIOSH RELs are based primarily on concerns relating to the prevention of occupational disease. It should be noted when reviewing this report that employers are legally required to meet those levels specified by an OSHA standard.

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

Mercury

Mercury, also known as quicksilver, is one of the oldest industrial hazards. Hg vaporizes at room temperature, and the Hg vapor-holding capacity of air is increased by increased temperature. The amount of Hg vapor in the air is also affected by pressure, rate of air exchange, and the amount of Hg surface exposed.[13]

Due to its affinity to be absorbed in fat, 74% of inhaled Hg rapidly diffuses across the alveolar membrane into the blood.[14] Hg'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 barrier and has a high affinity for red blood cells. Hg 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.[15] After a substantial exposure, Hg reaches peak levels in the various tissues within 24 hours, except in the brain, where peak levels are not reached for 2-3 days.[16]

Occupational exposure usually occurs to inorganic forms of mercury, either by inhalation of elemental Hg vapor or by exposure to aerosols of readily reducible mercuric salts. Elemental Hg also can enter the body through the skin, although the rate of penetration is slow and has been estimated to be about 2.2% of the lung uptake rate.[17] The molecular structure, stability, and routes of biotransformation and excretion all influence the toxicologic properties of Hg compounds; therefore, the dose-effect and dose-response relationships are unique for each Hg compound.[18]

Acute Effects

Inhalation of high concentrations of mercury vapor or dust is the most likely occupational exposure that produces acute effects. The emergence of signs and symptoms may be delayed up to 4 hours after exposure. Initial signs and symptoms include coughing, fever, chills, difficulty breathing, dryness of mouth, muscle ache, and headache followed by gastrointestinal and urinary effects, including nausea, vomiting, abdominal pain, a metallic taste in the mouth, and sometimes protein in the urine (albuminuria). Inhalation of Hg vapor may result in acute lung diseases, including interstitial pneumonitis, bronchitis, and bronchiolitis. Ingestion of mercury salts results in gastrointestinal complaints of nausea, vomiting, abdominal pain, and diarrhea.[1]

Chronic Effects

The most important route of absorption is the respiratory tract, where there is approximately 80% deposition and retention.[19] Hg has a cumulative effect and has a tendency to deposit in certain organs, most notably the brain, liver, and kidneys, although it can be found in nearly all tissues. There is a markedly nonuniform distribution of inorganic Hg after absorption; the highest concentrations are found in the kidneys.[20] The main source of excretion is via the urine, although some Hg is excreted in feces, sweat, tears, milk, and saliva. The human whole-body half life is approximately 50 to 70 days. The excretion of Hg in the urine bears a relation to Hg exposure but varies widely in individual cases because of many variable factors. Biological markers of exposure to Hg are more informative for comparing groups than for assessing an individual exposure. Urinary Hg level often have shown poor correlation with signs and symptoms of Hg poisoning. Although neither blood nor urine appear to correlate with the effects seen in an individual, the urine Hg level of large groups appears to show a biological threshold for preclinical changes at 50 µg/g-Cr.[21]

Personality changes are the most common findings in chronic mercurial poisoning. There is evidence that impaired neurobehavioral performance, caused by long-term occupational exposure to Hg vapor, improves significantly after exposure ends.[22] Some studies show that residual effects can persist longer than 10 years after exposure ends. The psychopathologic effects are called erethism and can include the following symptoms: irritability, excitability, fearfulness, restlessness, inability to concentrate, shyness, fatigue, weakness, and drowsiness. The person may appear indecisive, have a memory defect, and sometimes complain of insomnia and depression. Headache and digestive disturbances often are present.[23] Exposure to elemental Hg has been associated with both sensory and motor nerve conduction abnormalities in asymptomatic workers.[24]

Tremor is a classic sign of mercurialism. It usually comes on slowly and first affects the muscles of the eyelids, tongue, and fingers. As it becomes worse, it affects to the arms and legs. It is a typical intention tremor which means it increases with the effort to control it and subsides when at rest. The trembling may cause a change in handwriting; an effect on handwriting has been a frequent observation.[25]

Hg concentrates primarily in the renal tubules of the kidneys. The kidneys can eliminate low levels of Hg for a long period without damage. However, when overexposure occurs, the first signs of excessive exposure from inhalation of elemental Hg may be mild proteinuria. Mild proteinuria has been observed in workers exposed up to 0.1 mg/m^3. Tubular damage may manifest as hematuria or tubular casts (fragments of sloughed renal tubular cells). With high cumulative doses, glomerular damage, including decreased glomerular filtration rate (decreased kidney function) and albuminuria (loss of protein in the urine), can occur. At early stages, these toxic effects are reversible with cessation of exposure.[26]

Exposure Limits

OSHA currently enforces a PEL for Hg of 100 micrograms per cubic meter (µg/m^3) as a ceiling limit that should not be exceeded during a workshift.[27] 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. In 1980, a World Health Organization (WHO) study group recommended an 8-hour TWA exposure limit of 25 µg/m^3. WHO also recommended a threshold level of 50 µg/g-Cr for urine.[28] In 1994, the ACGIH lowered the TLV for Hg to 25 µg/m^3. Also, ACGIH has set a Biologic Exposure Index (BEI) of 35 µg/g-Cr. The reason for lowering the TLV was a finding of pre-clinical signs of central nervous system (CNS) and renal dysfunction at worker exposure levels above 25 µg/m^3.[11]

RESULTS

Sixteen of 17 workers one worker was not present on the days of the NIOSH investigation) at MWSI participated in the NIOSH investigation; 13 were male. The average age of the participants was 32.5 years, with a range of 18 to 47 years, and the average time of employment at MWSI was 10.1 months, with a range of 0.5 to 38 months.

The average spot urine Hg level was 167.7 µg/g-Cr (range: 24.9 - 939.7 µg/g-Cr), the average peak urine Hg level was 209.7 µg/g-Cr (range: 24.9 - 1212.9 µg/g-Cr), and the average 24-hour urine for Hg was 437.4 µg/g-Cr (range: 62.0 - 905.0 µg/g-Cr). Thirteen workers (81.2 %) had an average spot urinary Hg level above the BEI of 35 µg/g-Cr; elevated Hg levels were present in both office and production workers. Eight workers had an average Hg level above 100 µg/g-Cr, and 4 workers had an average Hg level above 200 µg/g-Cr. Seven workers had urine β-2 microglobulin tests and all were within the normal range. Eight workers had blood Hg levels, and the average level was 7.62 micrograms per deciliter (mcg/dL), with a range of <2 to 17 mcg/dL (normal laboratory range: 0– 5 mcg/dL).

Questionnaire

All 16 employees completed a questionnaire. The workers were asked if they had any of the 28 listed symptoms beginning in the last 6 months. The average number of new onset symptoms per participant was 2.25 (range: 0- 9). The most frequent symptom was headache (6 participants), followed by chest pain (2), depression (2), irritability (2), and nervousness (2). There was no difference in the number of symptoms reported by participants with urine Hg above the BEI compared to those below. There was a significant difference between the number of symptoms reported by workers that had a average spot urinary Hg level greater than 200 µg/g-Cr (average number of symptoms: 4.2) and those with lower Hg (1.5) ($p= 0.045$; Wilcoxon Rank Sum Test).

Physical examination

Fourteen workers had a neurologic examination. Ten workers were found to have at least one abnormal neurologic finding. Nine showed evidence of an upper extremity tremor. All tremors were rated as mild by the neurologist. Five workers had other neurological findings, such as brisk reflexes and anxiety, but it was not clear if these findings were related to Hg exposure. No other overt signs of Hg toxicity were noted.

Groove Pegboard Test

Sixteen participants completed the grooved pegboard test. Four participants had at least one abnormal result (placed the pegs in the board outside the time range for their age and gender norm); four had abnormal results for their dominant hand, and two had abnormal results for the non-dominant hand. There was no association between abnormality of grooved pegboard tests and having an elevated urinary Hg level. The average number of abnormal tests for participants with urine Hg below the BEI was 0.67, compared to 0.15 for those above ($p= 0.073$; Wilcoxon Rank Sum Test).

Color Vision Test

Sixteen participants completed the color vision tests. Four cases of congenital color blindness were discovered, and no cases of acquired color blindness were detected. The mean CCI for the desaturation test in workers below the BEI was 1.233, compared to 1.381 for those above the BEI. The mean CCI for the standard test in workers below the BEI was 1.017, compared to 1.269 for those above the BEI.

Neurometer Test

Thirteen participants completed the neurometer test. Only four workers had more than one test that showed a dulled sensitivity to touch (hypoesthesia) (nine tests performed per individual). Only two workers had more than one hypoesthetic result from a single nerve root. There was no association between either the number of abnormal neurometer test results or having more than one abnormal result along a single nerve root and an elevated urinary Hg level. The average number of hypoesthetic results for participants with urine Hg below the BEI was 1.3, compared to 1.3 for those above the BEI.

Tremor Test

Sixteen participants completed the tremor test. Of the tremor test parameters evaluated, the quality indicator score, tremor index, and tremor intensity best described the tremors of the participants.

There was a non-significant trend of increasing urinary Hg levels with worsening of the quality indicator score, but the mean urine Hg levels by quality indicator showed at least 2 groups differed significantly from each other (Table 1). There was little agreement between the quality indicator scores and the presence or absence of tremor by neurology exam.

An analysis was conducted of the tremor index among participants whose average spot urinary Hg was above the BEI versus those with urine Hg was below the BEI. A lower tremor index indicates a worse performance. The mean tremor index for participants whose urine Hg was below the BEI was 115.0 (SD: 23.2), compared to 83.6 (SD: 12.3) for participants whose urine Hg was above the BEI ($p = 0.043$; Wilcoxon Rank Sum Test). Also, there was no correlation between presence of tremor found by neurology exam and tremor index outside the normal range (less than 80). In addition, there was no correlation between average urinary Hg level and mean tremor index (Table 2).

We also compared the tremor intensity among participants whose average spot urinary Hg was above the BEI compared to those with urinary Hg below the BEI. The mean tremor intensity of employees with Hg levels above the BEI was 0.16 meters per second-squared (m/s^2), compared to 0.13 m/s^2 for those below the BEI ($p = 0.500$; Wilcoxon Rank Sum Test). There was not a linear increase in tremor intensity with increasing urine Hg levels; for participants whose urine Hg was above 100 µg/g-Cr, the tremor intensity was 0.17 m/s^2; and for participants whose urine Hg was above 200 µg/g-Cr, the tremor intensity was 0.14 m/s^2. There was no correlation between the average urinary Hg level and tremor intensity. Furthermore, there was no differences among groups of participants with high and low urinary Hg levels and measures of harmonic index, center frequency, or standard deviation of center frequency (Table 3). Employees with elevated Hg levels did not differ by age, smoking, status, alcohol consumption, or caffeine consumption from those with lower levels.

DISCUSSION

The objective of this evaluation was to determine if neurologic signs associated with Hg toxicity could be detected in current workers of MWSI. Multiple testing procedures were used to address this issue. Because all workers were exposed to Hg in the workplace, there was no unexposed comparison group. Also, there were few workers in this workplace, which makes finding statistically significant associations between health endpoints and exposure difficult.

The prevalence of symptoms commonly associated with Hg toxicity was higher among workers with elevated urinary Hg levels. New onset of headache, which has been associated with acute and chronic Hg exposure, was the most common symptom of workers with elevated Hg levels. Reporting bias was possible because the workers were aware of their exposures and biological monitoring results. However, most workers reported having few symptoms associated with Hg poisoning, so reporting bias probably did not significantly influence the questionnaire results.

Neurological examination revealed the presence of mild tremors in nine of 16 workers. However, tremor was not associated with high Hg levels. It is possible that the clinical examination was not sensitive enough to differentiate mild postural tremors (worse when at rest and working against gravity) compared to mild intention tremors (accentuated when precise motor movement is required), which are associated with Hg toxicity.[25]

No other significant neurological signs associated with Hg toxicity were found by examination.

Only the tremor test revealed a difference between workers with elevated Hg levels and those with lower levels. Previous studies that have measured tremor in Hg-exposed workers contain results that are often contradictory.[29,30,31,32] The studies differed in the instruments used to measure the tremors, the anatomical location of the recordings, tasks executed by the participants, and the nature of the Hg exposure. The diversity of methods contributes to the discrepancies in results and limits our understanding of the effect of chronic Hg exposure on the neuromotor system. The literature suggests that the tremor amplitude generally increases in participants chronically exposed to Hg.[33] The increase in tremor intensity in this investigation in the high exposure group of workers was not statistically significant, but this may be due to the small number of participants. One previous study examined tremor associated with Hg toxicity using the same tremor test device. This study found lower tremor index and higher tremor intensity in Hg-exposed workers, although the differences were not statistically significant.[34]

The grooved pegboard test, the neurometer test, and the color vision test were unable to discriminate between workers who had elevated urinary Hg levels and those with relatively low levels. Of these tests, only the color vision test previously had been evaluated in the context of Hg exposure. Previous studies have shown that Hg exposure could result in a subclinical decrease in color vision.[3,4] The color vision test in this investigation was consistent with the other studies in that the CCI was worse in workers with elevated Hg levels compared to those with low Hg levels. However, the differences in CCI in our investigation were not statistically significant.

CONCLUSIONS

Exposure to Hg in the plant resulted in urinary Hg levels above the BEI in 13 employees (81 %). Overexposure to Hg occurred in areas of the plant where the Hg hazard was known to exit and in the office areas (which was physically separated from the industrial parts of the plant), where exposure to Hg was unexpected. Overexposure in the industrial areas occurred by several means: mercury levels in several of the industrial areas were above the OSHA PEL, there was inadequate personal protective equipment, and there were inadequate administrative and engineering controls to prevent contamination of non-hazardous areas. Elevated Hg levels in the workforce indicated previous ongoing exposures. Administrative controls, such as requiring showers after work shifts for workers with potential for elevated Hg exposure in the plant and requiring disposable booties be disposed of prior to entering the office was put into place should prevent further contamination of the office area. Engineering controls to reduce Hg exposure in the potentially contaminated areas of the plant, such as improving the ventilation systems, are on-going.

There appears to be a difference in tremor test results between workers with urinary Hg levels above the BEI of 35 µg/g-Cr and those below the BEI. Workers with urinary Hg levels above the BEI had a lower tremor index and had more parameters of the tremor test (quality indicators) outside of human normal range (more "B" and "C" scores). These results indicate that there were subclinical changes in the neurological function in the group of workers with elevated Hg levels. In addition, workers with elevated Hg levels reported more frequent symptoms associated with Hg toxicity than those with lower levels. These results indicate that there were neurological changes among the workforce with elevated Hg levels. The clinical significance of these changes are unclear.

RECOMMENDATIONS

1. Management should improve the quality of work conditions such that Hg exposure will continue to decrease in all employees of MWSI. The potential for overexposure to Hg continues to occur for those who work in potentially contaminated areas of the plant. A given work area is considered a Hg exposure hazard whenever the industrial hygiene studies find that Hg concentrations exceed 40% of the NIOSH REL (20 $\mu g/m^3$).[35]

2. Effective process controls may substantially decrease Hg contamination in the plant. Inadequate procedures to separate reactive or unstable materials placed in the retort oven has resulted in explosion hazards. Procedures and protocols have been put into place to ensure sufficient separation of materials. Workers should be thoroughly trained in the procedures and protocols for separation of materials with potential explosion hazards.

3. Employees who work in areas identified as potentially contaminated with Hg should enter through the clean area of the locker room where they

are supplied clean work clothes and a respirator for the shift. After the work shift, employees should enter the dirty side of the locker room, where they remove the dirty work clothes, then the respirator. Showers should be taken by each employee before entering the clean side of the locker room. A laundering service is currently used to clean potentially contaminated work clothing.

Before removal, work clothing should be vacuumed with a dedicated Hg vacuum and stored in a vapor-proof container pending laundering. The operators of the laundry service should be informed that the clothes may be contaminated with Hg. To prevent cross contamination, work and street clothes should not be stored in the same locker, and workers in contaminated areas of the plant should not wear work clothing in clean areas of the plant (offices). Workers should wear protective clothing continuously when working in potentially contaminated areas of the plant.

4. MWSI should provide workers with annual training and education concerning the health hazards associated with workplace exposure to Hg. At a minimum, this training should conform to the regulations set forth in OSHA's Hazard Communication Standard.[36] All workers participating in monitoring should be informed of the results, and the employer should maintain these records for a period of 30 years.

5. Engineering controls should be implemented to effectively control employee exposure to Hg. Local exhaust ventilation should be installed to capture airborne Hg released from processes to reduce the Hg contamination in the plant.

6. Hg contaminated areas in the plant should be cleaned by appropriate methods to decrease Hg exposures. Dry-sweeping of work areas should be prohibited, as the hazardous material contamination in the dust may increase workers' exposures. Only wet clean-up methods or vacuuming with an approved vacuum for Hg dust should be allowed during clean-up activities. Wet clean-up methods should not be used in any area where a potential explosion hazard exists. Detailed clean-up procedures for Hg are given in the Mine Safety and Health Administration (MSHA) document, "Controlling Mercury Hazards in Gold Mining: A Best Practice Toolbox."[37]

No eating, drinking, or smoking should be allowed in the work areas and / or process buildings. These activities should be restricted to designated areas away from contaminants. Smoking should either be prohibited at this work site or restricted to a separately-ventilated room not used for other purposes.[38] Workers should change out of contaminated clothing and wash their hands before eating, drinking, or smoking.

7. Respiratory protection programs must be consistent with the Occupational Safety and Health Administration's Respiratory Protection Standard.[39] For respirators to be effective and protect workers from harmful exposures, they must be selected, inspected, and maintained properly. When not in use, respirators must be stored in a clean environment located away from any source of contamination.

8. NIOSH does not have an official recommendation regarding biological monitoring for Hg; therefore more stringent guidelines should be continued if already in place to better protect workers. The following recommendations proposed by the authors of this report are based on existing scientific information and recommendations of other organizations regarding inorganic Hg.

A. Management has the primary responsibility for setting up Hg hazard controls and for maintaining a proper medical program. Management is also responsible for all costs of biological monitoring and surveillance programs.

B. A program of biological monitoring and medical surveillance should be made available to all employees exposed to inorganic Hg at or above the action level of 20 $\mu g/m^3$ (40% of the NIOSH REL[35])for more than 30 days each year.

C. The pre-placement exam should include a medical evaluation for signs and symptoms associated with Hg toxicity, a spot urine Hg, and urinalysis with microscopic exam.[1] The pre-placement evaluation should also include a history of previous Hg exposure, central nervous system disorders, or renal disease.[40]

D. In addition to the pre-placement examination, the urine Hg level of all employees who are exposed to Hg above the action level should be determined at least every 6 months. The frequency of urine monitoring should be increased to at least every 2 months for employees whose last urine Hg level was between 35 and 50 µg/g creatinine.

E. If the urine Hg level is above 50 µg/g creatinine, the following measures should be taken:

i) the worker should be removed from exposure until the urine Hg level is below 35 µg/g creatinine.

ii) the urine Hg levels should be measured monthly until the level is below 35 µg/g creatinine.

iii) an industrial hygiene assessment should be made and measures should be taken to reduce exposure.

iv) medical testing should include 24-hour urinary Hg levels, serum creatinine, urinalysis with microscopic exam.

F. A medical examination should be done annually on any worker with a urine Hg level above 35 µg/g creatinine during the preceding year.

G. Workers with symptoms suggestive of Hg toxicity or a urine Hg level above 35 µg/g creatinine should be offered a medical examination.

H. Recent acute exposure to Hg should be assessed by blood Hg levels.[41] This test can be used to assess the worker's short-term exposure after an unplanned or infrequent event, i.e. spill or maintenance procedure. The ACGIH BEI for blood is 15 µg/L.[11]

I. If workers are assigned different job duties because of an elevated urine Hg level or other occupational reasons, they should retain their wages, seniority, and benefits to which they would have been entitled had they not been reassigned. Also, when medically eligible to return to their former jobs, the workers should be entitled to the position, wages, and benefits they would have had had they not been removed.

J. All employee health information must be kept confidential and in a secure location. This information should be released only when required by law or overriding public health considerations; when needed by other health professionals for pertinent reasons; and when provided to designated individuals at the request of the employee.[42]

K. Physicians qualified in the practice of occupational medicine should provide the expertise for developing a medical surveillance program. The conduct of the medical aspects of such a program may be provided by other physicians or other health care professionals.[43]

L. The data generated under the occupational medical surveillance system should recorded in a systematic manner. The data should be analyzed periodically in an epidemiologically meaningful manner, such as by job title or work area. The data should be made available for use by OSHA and NIOSH.[44]

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Table 1
Average urinary Hg level by Quality Indicator Score[1]
HETA 98-0320-2751
Mercury Waste Solutions, Inc.
Union Grove, Wisconsin

Test Score (Quality Indicator)	Mean Urinary Hg Level (μg/g-Cr)	p-value[2]
A	80.7	0.03
B	148.9	
C	234.5	

[1]A "Quality Indicator," scored from A to C, tells how many of the measured parameters from which the tremor index is calculated, are inside dispersion range of a human normal group. With an"A" score, nine to ten parameter are within the mean ± SD; with a "B" score, four to eight parameters are within the mean ± SD; with a "C" score, three or fewer parameters are within the mean ± SD.

[2]Kruskal-Wallis one-way ANOVA. P-value was not adjusted for multiple comparisons.

Table 2
Mean of tremor test results by urinary Hg level
HETA 98-0320-2751
Mercury Waste Solutions, Inc.
Union Grove, Wisconsin

Tremor Test Parameter	< BEI[1]	> BEI	p-value
Tremor Index[2]	115.0	83.6	0.04
Tremor Intensity[3] (m/s^2)	0.13	0.16	0.38
Harmonic Index[4]	0.90	0.88	0.44
Center Frequency[5] (Hz)[6]	6.88	7.11	0.80
Standard Deviation of Center Frequency (Hz)	3.52	3.35	0.59

[1]BEI= Biological Exposure Index. For mercury the BEI is 35 µg/g-Cr.
[2]The Tremor Index is a parameter that is calculated from five parameters center frequency, harmonic index, tremor intensity, standard deviation of center frequency, and standard deviation of the harmonic index.
[3]The Tremor Intensity is established as a Root-Mean-Square of accelerations recorded in 0.9 Hz to 15.0 Hertz (Hz) band during the 8 second test period. The unit of measure is meters per second squared (m/s^2). This parameter is often called "amplitude."
[4]Harmonic Index compares the tremor frequency pattern with the pattern of a single oscillation, which has a HI = 1.00. A tremor composed of few dominating frequencies will have a high HI, whereas the normal dyscoordinated tremor will have a relatively low HI.
[5]Center frequency is the average frequency of accelerations in the 0.9 to 15 Hz band during the 8 second test period: 50% of the energy that drives the tremor is produced at frequencies above the center frequency, and 50% is produced below.
[6]Hz = Hertz.

APPENDIX A

Grooved Pegboard Test

The test consists of a small board containing a 5 by 5 set of slotted holes angled in different directions. Each peg has a ridge along one side, so that the peg had to be rotated in position for correct insertion. Subjects were seated in front of the pegboard and instructed to insert 25 pegs into the 25 holes as fast as they could, starting with their dominant hand first. The time in seconds to complete the 25 insertions was recorded. After a short break, the non-dominant hand was tested.[1]

Color Vision Test

The color vision tests were carried out under strict lighting conditions (lighting type C of at least 500 lux). NIOSH investigators administered two types of color vision test: Farnsworth D-15 Panel Test [2] and the Lanthony's Desaturated 15 Hue Test.[3] Farnsworth was used to determine if a participant had congenital color vision deficiency. Lanthony is specifically suited for an early evaluation of mild to moderate acquired color vision impairment. Each test was performed identically, except that the hues of the caps were different. As acquired color vision loss may be monocular or asymmetrical, each eye was tested separately; the reported values represent the means of both eyes.

Lanthony's Desaturated 15 Hue Test and the Farnsworth Panel D-15 Test include a slender case with 16 color caps. The caps were placed randomly on a neutral-colored cloth on a tabletop. The caps were placed color side up and test-number side down. A sixteenth color cap, fixed at the left end of the case, was used as a reference. Participants were asked to place the cap that was nearest in color next to the reference cap in the case, then the one closest in color to the previous cap and so on. There is no time limit for this test. Participants wore eye patches to test each eye individually. Individual test results were plotted and score quantitatively using the Bowman scoring method.[2]

Tremor Test

Hand tremor was measured by the TREMOR 3.0™ (developed by Danish Product Development).[4] Tremor was recorded with a two-axis micro-accelerometer embedded in the tip of the 12 cm X 0.8 cm pencil. The TREMOR PEN™ was sensitive in a plane perpendicular to the tube axis. During a test, which lasts 10 seconds (2 seconds for stabilization after the beep and 8 seconds data harvest), the TREMOR PEN was held exactly like an ordinary pencil. The hand vibrations were recorded and displayed real-time in a time-axis plot on the computer screen.

The test was performed with participants sitting erect and off the back rest. They held the pen horizontally and at the level of the navel, bent their elbow at approximately 90 degrees, and let their arm hang loosely. Testing was done with dominant and non-dominant hands, to yield Test 1. The procedure was then repeated, to yield Test 2.

The accelerations were analyzed by methods drawn from vibration measurements. A Fourier analysis determines the power distribution in the frequency band 0.8 Hertz (Hz) to 15.0 Hz. The Fourier Power Spectrum presents the

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[1] Grooved Pegboard Test. Instruction/Owner's Manual, Lafayette Instrument, Lafayette, IN, pp. 1-8. 1989.

[2] Bowman KJ, [1982]. A method for quantitative scoring of the Farnsworth Panel D-15. Acta Ophthalmol 60: 907-16.

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[4] Danish Product Development Ltd. Tremor 3.0 User's Manual. Snekkersten, Denmark, 1994.

normalized power distribution (the relative harmonic contents) of the 8 second recording period in a frequency domain. It is composed of 116 bands, each approximately 0.12 Hz wide. The relative power contribution of each small band is plotted in the spectrum. The Fourier Power Spectrum reacts strongly to deviant tremor patterns, which have a tendency to concentrate power dissipation around a dominant frequency.

The parameters measured by TREMOR 3.0 are the Tremor Intensity (I), Center Frequency (F50), Standard Deviation of Center Frequency (SF50), Harmonic Index (HI), and Tremor Index (TI).

The **Tremor Intensity** (I) is established as a Root-Mean-Square of accelerations recorded in 0.9 Hz to 15.0 Hertz (Hz) band during the 8 second test period. The unit of measure is meters per second squared (m/s^2). This parameter is often called "amplitude." Results are displayed in graphics and figures on the screen.

Center Frequency (F50) is the average frequency of accelerations in the 0.9 to 15 Hz band during the 8 second test period: 50% of the energy that drives the tremor is produced at frequencies above the center frequency, and 50% is produced below. The unit of measure is Hz.

Standard Deviation of Center Frequency (SF50) indicates the degree of irregularity of the tremor. Sixty-eight percent of the area under the spectrum lies within 1 standard deviation of the center frequency. A very rhythmic tremor has a small SF50, indicating that most of the energy is produced within a narrow frequency band. The unit of measure is Hz.

Harmonic Index (HI) compares the tremor frequency pattern with the pattern of a single oscillation, which has a HI of approximately 1.00. A tremor composed of few dominating frequencies will have a high HI, whereas the normal dyscoordinated tremor will have a relatively low HI.

The **Tremor Index** (TI) is calculated as the mean value of the Tremor Index of each hand. The Tremor Index for each hand is calculated from five parameters: I, F50, SF50, HI, and standard deviation (SD) of the Harmonic Index (SHI).

$TI_{hand} = F * [1/3\ P_I + 1/3((P_{F50} + P_{SF50})/2) + 1/3((P_{HI} + P_{SHI})/2)]$

F is a scaling factor that adjusts the normal Tremor Index to equal 100. Each sub-index P_s is calculated from the following formula, which relates the measured parameters to mean values of a human normal group.

$$P_s = 1 / e\left|(K - K_m) / sK_m\right|$$

K is the individual parameter. (I, F50, SF50, HI, SHI)
K_m is the normal human value of that parameter.
sK_m is the standard deviation of the same parameter.

Normality is TI =100. Dispersion of normality is s(TI) = 20.

A "Quality Indicator," scored from A to C and reported after the Tremor Index, tells how many of the measured parameters from which the tremor index is calculated, are inside the dispersion range of a human normal group. With an"A" score, nine to ten parameter are within the mean ± SD; with a "B" score, four to eight parameters are within the mean ± SD; with a "C" score, three or fewer parameters are within the mean ± SD. The manual gives no instruction about the interpretation of the quality indicator score in the context of the tremor index or the other parameters.

Neurometer

The CPT evaluation procedure generates quantitative CPT measures of sensory nerve functional integrity.[5] The device emits a graded sinusoidal alternating stimulus at 5, 250, and 2000 Hz at intensities from 0.01 to 9.99 milliamperes maintained at a constant current by feedback circuits, irrespective of applied impedance. The current was delivered to the skin via a pair of 1 cm diameter standard carbon electrodes coated with conductive gel.

Three test stimulation sites were selected: the dorsal surface of the distal phalanx of left second digit (index finger), the dorsal surface of the distal phalanx of the left great toe, and the left ear lobe. Each participant was seated in a quiet area and asked to concentrate on the testing procedure. The device was switched on and a sinusoidal electrical stimulus was slowly increased until the subject felt the sensation. The stimulus was then turned off, the intensity level lowered and then turned back up. This sequence continued until a range of intensities was determined where the higher intensity stimulus was always perceived while the lower were not. Next, the employee was presented with 7-10 cycles of randomly selected stimuli, above and below the threshold, until the exact CPT value was within the range determined. At each frequency, the current was progressively increased until the subject first perceived the sensation. The current was then rapidly decreased and increased until the same threshold measured measure was obtained on at least five consecutive trials to establish a threshold.

[5][1999]. Technology review: the Neurometer Current Perception Threshold (CPT). AAEM Equipment and Computer Committee. American Association of Electrodiagnostic Medicine. Muscle Nerve 22(4):523-31.

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