Applied Occupational and Environmental Hygiene

ISSN: 1047-322X (Print) 1521-0898 (Online) Journal homepage: https://www.tandfonline.com/loi/uaoh20

Case Studies

To cite this article: (1998) Case Studies, Applied Occupational and Environmental Hygiene, 13:12, 799-803, DOI: 10.1080/1047322X.1998.10389156

To link to this article: https://doi.org/10.1080/1047322X.1998.10389156

Published online: 25 Feb 2011.

Serious Mercury Contamination at a Glass Plant Following Extensive Cleanup

Introduction

On August 15, 1997, the National Institute for Occupational Safety and Health (NIOSH) received a request for a health hazard evaluation from the International Union of Electrical, Radio, and Machine Workers. The request centered on the concern that employees at a glass plant were exposed to hazardous concentrations of mercury during the manufacture of glass tubing and related maintenance activities.

Background

The glass plant under investigation operates three shifts a day, 7 days a week, 365 days a year. The plant employs approximately 200 workers. Last year the 11-acre plant produced 45 million pounds of glass and over 750 different glass products. Included in their operation was the recycling of material from fluorescent lamp manufacturing.

During the fluorescent lamp manufacturing process, mercury is inserted into glass tubes. The change in electron levels of the mercury generates an ultraviolet light that is absorbed by the white coating (phosphor) on the inside of the glass tube. The white coating inside the glass tube then re-emits the light as visible light. During production the tips of the glass tubes are removed after the mercury has been inserted. These tips (cullet) are then collected and sent to lead glass manufacturing plants for recycling. The cullet may be contaminated with trace amounts of mercury as a result of the manufacturing process.

The glass plant in this study recycled cullet from three fluorescent lamp assembly plants. The cullet was stored on a cement slab inside a storage building. A front end loader would remove the cullet from the storage building and transport it to a loading chute located outside of the cullet processing building. From the chute, the cullet was transported through the building by a system of conveyor belts to an enclosed elevator and then to storage bins. From the storage bins, the cullet was conveyed to a crusher and then a dryer (located downstairs inside the building). The cullet would then be transferred to another series of storage bins. At this point raw batch materials (i.e., sand, lead, and cadmium) were mixed into the cullet. The cullet was then melted in a furnace and formed into new glass tubes.

Past environmental sampling conducted at the plant did not detect elevated mercury levels. However, on June 11, 1997, contract workers discovered mercury in the ventilation system originating from the dryer. During the removal of duct work, located on the roof of the building, workers noticed a visible amount of mercury fall from the duct work to the roof below. The company contracted with an environmental consultant to clean this area, and the consultant responded on the day of the request. Although the company considered this to be an isolated event, contract workers at the site on June 17, 1997, reported feeling ill, and one worker reported that his gold necklace turned silver after working at the plant that day. These employees were interviewed by the company in an effort to determine whether the exposures had occurred. Work activities were suspended and medical appointments were scheduled at a local university medical center for the symptomatic employees. On June 18, 1997, the environmental consultant was again contacted and requested to identify all mercury-contaminated areas. Based on the consultant's evaluation, the plant notified employees of the mercury contamination and established control areas to isolate the mercury contamination. In addition, the company implemented personal protective equipment measures (i.e., respirators with mercury cartridges) to help protect employees who may be exposed to mercury.

On June 19, 1997, the company initiated various strategies and procedures to isolate and clean mercury contamination, including hand wiping, and vacuuming, pressure wash, acid wash, and barriers coating techniques on all exposed surfaces (floors, walls, and ceilings). Equipment cleaned in the cullet processing building included conveyor systems, elevators, storage bins, cement floors, crushers, dryer, and equipment used to handle cullet (i.e., carts and shovels). Company readings obtained with the Jerome® mercury analyzer indicated mercury concentrations as high as 900 μg of mercury per cubic meter of air in the dryer area. This area was isolated with plastic barriers and maintained under negative pressure (relative to areas outside the enclosure) with three negative air pressure-inducing machines equipped with high efficiency particulate air (HEPA) filters and charcoal filters. Once the mercury contamination problem was identified, the plant stopped receiving the mercury-contaminated cullet from the fluorescent lamp manufacturing plants. During the evaluation no cullet from fluorescent lamp manufacturing plants was stored or used at the facility. The company also reported that it would not accept this type of cullet in the future.

was conducted to familiarize NIOSH personnel with the process, specifically the flow of the mercury-contaminated cullet through the facility. After the walk-through inspection, full-shift area samples for mercury were collected in eight separate locations. Seven of these area samples were located inside the building where the cullet is processed, and one was located in the building where the cullet was stored before processing. Area samples were collected in the cullet processing building as indicated in Table 1. Outdoor and indoor back-

TABLE 1. Mercury Area Sample Locations and Results in the Cullet Processing Building

Area	Sample Time (min)	Sample Volume (L)	Mercury Concentration ($\mu g/m^3$)
Above 001 crusher	431	86	6.4
At top of stairwell leading down to dryer area	424	85	3.3
Directly outside dryer containment	427	85	46
General area outside dryer containment	422	84	27
Next to conveyor in the 772 mix area	415	83	20
Inside dryer containment next to dryer outlet	388	78	206
Inside dryer containment next to dryer inlet	355	71	775

ground samples were collected in the parking lot (hanging on the visitor parking sign) and in the office area, respectively.

NIOSH Method 6009 was used for airborne solid sorbent samples of mercury.[1] Air was drawn through a solid sorbent tube containing 200 mg of hopcalite at a nominal flow rate of 200 cc/min. The samples were prepared by adding 2.5 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 Leeman Labs PS200 mercury analyzer.

A Jerome model 431-mercury vapor analyzer (Arizona Instrument Corp., Phoenix, Arizona) was used to collect real-time measurements of mercury. Measurements were collected in the containment area around the dryer, throughout the cullet processing building, and in the cullet storage building. The dryer was not in production during the survey; however, it was operated briefly (for a few minutes) to determine the potential for vaporization of any latent mercury contamination.

Bulk samples of cullet, dirt, and dust were collected and analyzed for mercury from the following locations: (1) dust on the conveyor in the dryer containment area; (2) dust at the exit of the dryer; (3) dust at the entrance of the dryer; (4) dirt and cullet outside the cullet processing building near the cullet chute; (5) cullet in a hopper that had been processed through the elevator; (6) clean cullet outside on the storage pad (front left of cullet storage pile); and (7) clean cullet outside on the storage pad (middle of cullet storage pile). The cullet on the storage pads was not from fluorescent lamp manufacturing plants and thus was considered to be clean (not contaminated). Bulk dust samples were analyzed for mercury according to the Environmental Protection Agency SW-846 Method 7471, modified for matrix.

Medical

Upon realizing that employees had been exposed to mercury, the company offered mercury testing to all employees, regardless of work area. While they had no medical surveillance program for mercury in place at the time, the medical department obtained an appropriate protocol from another plant. Based on that protocol, employees with urine mercury levels of ≥ 50 $\mu g/g$ creatinine were referred for medical evaluation. Initially employees were referred to the University of Pittsburgh; however, employees felt these evaluations were biased since the company doctor arranged them. These employees were subsequently referred to West Virginia University. Finally, a local occupational medicine physician was selected to do all the evaluations. Employees were referred for evaluation for levels of ≥ 50 $\mu g/g$ creatinine or for symptoms regardless of the level.

Urine mercury samples were collected by the company on 192 of the 200 employees at the plant. Eight employees either declined testing or were out on long-term leave. All results were reviewed. The NIOSH physician reviewed medical records for six employees who had been evaluated for mercury poisoning at the University of Pittsburgh and at West Virginia University. In addition, six employees were interviewed. The purpose of the interviews was to determine if there were symptoms that could be related to mercury exposure, as well as to determine if and how work practices may have contributed to exposures. Of those interviewed, two had undetectable urine mercury levels and were asymptomatic. They were selected by the NIOSH physician from a list of employees. One had a level below 35 $\mu g/g$ creatinine but reported numerous symptoms (i.e., rash, headache, confusion, and fatigue). This individual asked to be interviewed. Another was selected because of an elevated urine mercury level. Another employee was selected for having the highest urine mercury level measured in the plant. This individual was responsible for loading cullet with a front end loader in the storage building and transporting it to the cullet processing building. The last person interviewed was a former employee who had previously been responsible for loading cullet in the storage area and transporting it to the cullet processing building for more than 10 years.

Mercury Exposure-Related Health Effects and Exposure Criteria

Since metallic mercury 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 mercury dose, whereas dermal exposure and ingestion contribute only 2.6 percent and 0.1 percent to this dose, respectively.[2] Eighty percent of inhaled mercury is retained in the lungs, while the remainder is exhaled. Due to its high degree of lipophilicity, 75 percent of inhaled mercury 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 mercury via the hydrogen peroxide–catalase pathway and accumulates in the renal cortex of the kidney.[2,6] After a substantial exposure, mercury reaches peak levels within the various tissue reservoirs within 24 hours, except in the brain, where peak levels are not reached for 2 to 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 mercury.[8]

The major pathways for elimination of mercury from the body are via the feces and the urine. The half-life is 40 to 60 days for the whole body, while the half-life is 2 days for the lungs, 2 to 4 days for the blood, 21 days for the brain, and 40 to 60 days for the kidney.[2] Thus, urine mercury concentrations reflect chronic exposure, while blood mercury concentrations reflect only recent exposure. Urinary mercury levels in the general population generally are less than 5 μg/g creatinine[9,10] or 10 mg/L[11,12] to 20 μg/L.[13] Symptoms are generally not present until levels of 200[11] to 300 μg/L are reached.[9,10,12] The World Health Organization (WHO) recommends a threshold level of 50 μg/g creatinine, and the American Conference of Governmental Industrial Hygienists (ACGIH®) has set a Biological Exposure Index (BEI®) of 35 μg/g creatinine.[14] These numbers reflect dose, not necessarily health effects. Background mercury levels in the blood are less than 1[10] to 1.5 μg/dl.[13]

The lungs is the target organ with acute, high level exposure to mercury vapor. Effects include cough, shortness of breath, chest pain, interstitial pneumonitis, bronchiolitis, and pulmonary edema. Nausea, vomiting, fever, stomatitis, and gingivitis can also occur.

The nervous system is the target organ in chronic exposure to mercury vapor. Effects include emotional lability, shyness, insomnia, irritability, and memory loss. The symptom complex is called erethism. Tremor and peripheral neuropathy can also occur, as can stomatitis and gingivitis. Other symptoms include fatigue, weakness, loss of appetite, and headache. These symptoms are usually reversible with cessation of exposure.[9–11] Mercury accumulates in the kidneys but rarely produces significant renal injury.[9,10]

The Occupational Safety and Health Administration (OSHA) currently enforces a permissible exposure limit for mercury of 100 μg/m^3 as a ceiling limit that should not be exceeded during a work shift.[15] The NIOSH recommended exposure limit for mercury exposure is 50 μg/m^3 as a time-weighted average (TWA) exposure for up to 10 hours per day, 40 hours per week; NIOSH does not have a urine mercury recommendation.[16] In 1980 a WHO study group recommended an 8-hour TWA exposure limit of 25 μg/m^3.[17] In 1994 ACGIH lowered the Threshold Limit Value (TLV®) for mercury to 25 μg/m^3 (TWA exposure, 8 hours per day, 40 hours per week).[14] The reason for lowering the TLV was a finding of preclinical signs of central nervous system and renal dysfunction at worker exposure levels above 25 μg/m^3.[18]

Results

Industrial Hygiene

The results for the mercury area samples in the cullet processing building ranged between 3.3 and 775 μg/m^3 (Table 1). Samples taken inside the containment area near the dryer indicated the highest mercury concentrations of 206 and 775 μg/m^3. A sample collected in the storage building had a mercury concentration of 2 μg/m^3. The indoor and outdoor background samples of mercury were both below the minimum detectable concentration (MDC). The analytical limit of detection (LOD) is 0.05 μg/sample, which equates to an MDC of 0.59 μg/m^3, based on an air sampling volume of 85 L.

In the storage building a measurement using the Jerome mercury vapor analyzer showed a mercury concentration of 3 μg/m^3. Measurements collected in the cullet processing building, outside the dryer containment area (when the dryer was not in operation), ranged between 6 and 19 μg/m^3. A measurement collected directly outside the dryer containment revealed a concentration of 49 μg/m^3 when the dryer was not operating. Measurements were collected at various locations inside the containment area around the dryer when the dryer was not in operation. These values ranged from 50 to 330 μg/m^3 with an average concentration of 170 μg/m^3. These results indicate that the area inside the containment is still contaminated, even after cleanup procedures. During the time of our evaluation no one worked inside the dryer containment area.

Measurements were also collected with the Jerome mercury vapor analyzer inside the dryer containment area when the dryer was operating (without cullet being processed) for 15 minutes. These values ranged between 40 and 300 μg/m^3 with an average of 150 μg/m^3. When the dryer was in operation (without cullet being processed), the average mercury concentration inside the containment was less than the average mercury concentration in the containment when the dryer was not in operation. Additional measurements were collected for approximately 10 minutes when the dryer was running and clean cullet was processed. Measurements collected inside the containment during this period ranged from 400 to 900 μg/m^3. The operation was stopped following these measurements. Measurements with an additional Jerome mercury vapor analyzer were collected upstairs (near the elevator when clean cullet was processed through the system), revealing concentrations of mercury ranging from 300 to 900 μg/m^3. These values indicate that the cullet processing system (i.e., conveyors, elevators, storage bins, crushers, and dryer) remains contaminated with mercury despite cleaning.

Bulk samples of dust collected in the dryer containment area had mercury concentrations of 49 μg/g near the dryer exit (where cullet exists the dryer), 4300 μg/g from the conveyor in the containment area, and 51,000 μg/g near the dryer entrance (where the cullet enters the dryer). Bulk samples of cullet were collected in the clean cullet storage area, around the outside cullet chute (where clean cullet is dumped into the cullet processing system), and in a hopper on the first floor of the cullet processing building (this cullet had been processed through the storage bin and elevator). Two cullet bulk samples from the clean storage area had mercury concentrations of 0.034 and 0.017 μg/g. The bulk cullet and dirt sample collected at the cullet chute had a mercury concentration of 1800 μg/g and the cullet bank sample from the hopper had a mercury concentration of 29 μg/g. These results confirm mercury contamination of the cullet processing system.

Medical

Six employees were interviewed. The purpose of the interviews was to determine if there were symptoms that could be related to mercury exposure, as well as to determine if and how work practices may have contributed to exposure. Of those interviewed, two had undetectable urine mercury levels and were asymptomatic. One had levels below 35 μg/g creatinine, but reported numerous symptoms including rash, headache, confusion, and fatigue. Another employee was selected because of an elevated urine mercury level. The employee reported fatigue, insomnia, rash, and irritability that had improved as the urine mercury levels declined. Another employee was selected because of having the highest level measured in the plant. This person was responsible for loading cullet in the storage building (with a front end loader) and transporting it to the cullet processing building. The employee reported a wide variety of chronic symptoms including mood swings, frequent blinking, hypersomnia, inappropriate behavior, back pain, hand numbness, and breath that smelled like metal to others. The symptoms had mainly resolved, with the exception of night sweats. The employee had very meticulous work habits and would often clean around the dryer. The last was a former employee who had previously been responsible for loading cullet in the storage area (with a front end loader) and transporting it to the cullet processing building for more than 10 years. The employee reported no symptoms consistent with mercury exposure while working and noted not much overtime as compared with other employees; showers were taken daily before going home.

Testing of urine mercury levels was done by the company on 192 of the 200 employees at the plant. Eight employees either declined testing or were out on long-term leave. All urine mercury results were reviewed. Sixty-five employees (33.8%) had urine mercury levels below the LOD. The range of urine mercury levels among these employees with detectable levels was 1.4 to 345.4 μg/g creatinine. WHO recommends a threshold level of 50 μg/g creatinine, and ACGIH has set a BEI of 35 μg/g creatinine. Twenty-nine employees (15.1%) had levels >35 μg/g creatinine, and 20 (10.4%) had levels >50 μg/g creatinine. A local occupational medicine physician was selected to do medical evaluations on employees with levels ≥ 50 μg/g creatinine or for symptoms regardless of the level. The evaluations consisted of a thorough history and physical exam and appropriate laboratory and other diagnostic procedures as indicated. Employees with elevated urine mercury levels continued to be monitored.

Discussion

Exposure to elevated levels of mercury in the cullet processing areas of the plant resulted in elevated urinary mercury levels in 29 employees. Three of the interviewed employees reported symptoms such as fatigue, headache, irritability, and mood swings, which could be attributable to mercury exposure. However, one had levels of mercury in his urine that were low and not usually associated with symptoms. The employee's symptoms persisted while the other two interviewed employees had symptoms that declined as their mercury urine levels declined. Lead is another exposure hazard present in the plant, and it can cause nonspecific symptoms such as fatigue, headache, irritability, and mood swings. Nonspecific symptoms are also common in the general population. None of the employees reported gingivitis or stomatitis.

The company had devoted significant resources to cleaning areas where mercury contamination was detected. The areas cleaned included the storage building and the cullet processing building. In the cullet processing building the conveyors, hoppers (that hold cullet), crushers, elevators, and storage bins were all cleaned inside and out by pressurized wash and acid wash techniques. The dryer area was also cleaned with these techniques. After the areas had been cleaned, an epoxy barrier coating was applied to all exposed surfaces in an effort to reduce any mercury vaporizing off the equipment, floors, walls, or ceilings. In addition, the plant stopped accepting mercury-contaminated cullet from fluorescent lamp manufacturing plants after recognizing the potential for mercury contamination.

During this evaluation most of the contaminated areas had mercury vapor concentrations below NIOSH and OSHA exposure criteria. However, mercury concentrations (as shown with the Jerome mercury vapor analyzer and solid sorbent samples) at the dryer area were elevated. This area was isolated from the rest of the plant and maintained under negative pressure relative to occupied areas of the building. The negative pressure was maintained by using blowers equipped with HEPA filters and charcoal filters to exhaust air from the dryer containment. The filtered exhausted air from the containment area was directed outside, away from occupied areas and air intakes. The dryer was currently not used, and no employees perform daily work activities inside the containment area. Workers entering the containment area to check and change filters in the blowers or to collect mercury samples were required to wear personal protective equipment that consisted of a respirator (equipped with HEPA filters and mercury vapor cartridges), disposable coveralls (with a hood and booties), gloves (nitrile of polyvinylchloride), and safety glasses.

When the dryer was turned on (and no cullet was processed), there was no noticeable increase in mercury concentrations inside the dryer containment area compared with mercury concentrations inside the containment when the dryer was not operating. However, when clean cullet was processed through the system (i.e., conveyors, elevators, storage bin, etc.) and the dryer was operating, mercury concentrations were elevated inside the dryer containment and near the elevator and storage bin areas. These data suggest that the cullet processing system and the dryer area remain contaminated with mercury despite having been cleaned. Bulk samples of dust and cullet confirm mercury contamination in the cullet processing system.

Conclusions

Exposure to mercury in the plant resulted in elevated urinary mercury levels in 29 employees (15.1%). NIOSH investigators have documented that there was still serious mercury contamination at the plant even after extensive cleanup procedures. Dust and cullet bulk samples confirm mercury contamination in the cullet processing building. During the evaluation the highest concentrations of mercury (in both air and bulk samples) were obtained in the dryer containment area. There were no production work activities inside the dryer containment.

Recommendations

NIOSH recommended that all equipment used to process the mercury-contaminated cullet be replaced. In addition, the mercury-contaminated areas of the plant needed to be cleaned with appropriate methods to help eliminate mercury exposures. The following cleanup procedures are outlined in the draft Mine Safety and Health Administration document, "Controlling Mercury Hazards in

Gold Mining: A Best Practice Toolbox,"[19] and were suggested to the plant as appropriate cleanup procedures.

1. Vacuum all surfaces to remove droplets of elemental mercury and mercury–contaminated debris.
2. Remove porous materials that cannot be completely cleaned or sealed with an epoxy paint and dispose of the debris properly.
3. Seal porous materials such as cinder block or concrete with an epoxy paint.
4. Clean cracks and crevices that contain elemental mercury with a zinc scrubbing pad.
5. Wash all nonporous surfaces with fresh water to remove dirt, wash with a sodium thiosulfate solution, and rinse with fresh water to remove the thiosulfate.
6. Spread mercury complexing agent or similar material on cracks and hard-to-reach places to adsorb microdroplets of mercury and leave overnight; then remove the material using a mercury vacuum cleaner.
7. Seal all waste material in a plastic bag and place the bag in a disposal drum.
8. Use chemical indicators, scrape samples, and air monitoring to evaluate decontamination effectiveness.
9. Reclean areas that are still sources of mercury vapor, as indicated by the above steps.

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EDITORIAL NOTE: Ronald M. Hall and Elena Page, MD, are with the Hazard Evaluation and Technical Assistance Branch of NIOSH. More detailed information on this investigation is contained in Health Hazard Evaluation Report No. 97-0292-2678, available through NIOSH, Hazard Evaluation and Technical Assistance Branch, 4676 Columbia Parkway, Cincinnati, Ohio 45226; telephone: (800) 35-NIOSH.