Public Safety

Peer-Reviewed

Mercury Contamination

Review of a Residential Response

By Marcella R. Thompson

IN BRIEF

- A residential elemental mercury contamination incident in Rhode Island resulted in the evacuation of an entire apartment complex.
- To develop recommendations for improved response, all response-related documents were examined; personnel involved in the response were interviewed; policies and procedures were reviewed; and environmental monitoring data were compiled from specific phases of the response for analysis of effect.
- A significant challenge of responding to residential elemental mercury contamination lies in communicating risk to residents affected by a HazMat spill. An ongoing, open and honest dialogue is emphasized where concerns of the public are heard and addressed, particularly when establishing and/or modifying policies and procedures for responding to residential elemental mercury contamination.

A **residential elemental mercury** contamination incident in Rhode Island resulted in the evacuation of an entire apartment complex, temporary relocation of 140 residents and subsequent investigation of 130 additional sites in 15 cities across two states. This study was undertaken to develop evidence-based recommendations for responding to future incidents, thereby increasing the efficiency and expediency of response and remediation processes; minimizing secondary contamination of evacuation sites; facilitating a more timely return of residents to their homes; and assuring residents that their homes are safe once again.

The first step involved a review of scientific literature (see "Hazards of Mercury" sidebar on p. 52). In addition, the author examined all response-related documents, interviewed key government and contract personnel involved in response, reviewed and evaluated national and state regulatory policies and procedures, and extracted and compiled large amounts of environmental monitoring data collected during specific phases of the response. Residents were not interviewed due to pending litigation. There were no records of any meetings with the residents.

The Contamination Site

The incident occurred at Lawn Terrace Apartments in Pawtucket, RI. The complex has five apartment buildings with a total of 56 apartments and one maintenance building (Burns & McDonnell Engineering, 2005). These units alternate between subsidized housing and open market, depending on the renter's economic status and eligibility. The complex is adjacent to an unoccupied and unsecured property owned by the region's gas company, Southern Union. On that property, the company stored mercury removed from residential gas regulators.

Summary of Events

On Oct. 22, 2004, local authorities notified the Rhode Island Department of Environmental Management (RIDEM) of an elemental mercury spill, the result of vandalism that occurred sometime within the prior 3 to 4 weeks. Initially, it was estimated that 25 lb of mercury were spilled inside the gas company's storage shed with an equal amount missing. A maintenance employee told authorities about beads of mercury in the adjacent apartment complex parking lot (Marcelo, 2008).

PHOTOS COURTESY RHODE ISLAND DEPARTMENT OF ENVIRONMENTAL MANAGEMENT

Marcella R. Thompson, Ph.D., M.S., R.N., CSP, COHN-S, FAAOHN, is a post-doctoral research associate and the environmental health state agency liaison for Brown University's Superfund Research Program. She holds a B.S. in Nursing from Salve Regina University, an M.S. in Occupational Health Nursing from Boston University, an M.S. in Occupational Health from Harvard School of Public Health and a Ph.D. in Nursing from the University of Rhode Island. In 2009, Thompson was awarded Fellow by the Academy for American Occupational Health Nurses (FAAOHN). In 2011, she was named by ASSE's Women in Safety Engineering common interest group as one of 100 Women Making a Difference in SH&E. Thompson is a professional member of ASSE's Greater Boston Chapter.

Referral

RIDEM notified EPA Region I, since the reportable quantity for elemental mercury is 1 lb. One pound of elemental mercury is equivalent to 2 tablespoons; 25 lb equals 1 quart. EPA emergency response guidelines for residential mercury contamination were employed (Singhvi, Mehra & McGuire, 2004; see "Six Rs of Emergency Response" sidebar on p. 54). RIDEM, EPA Region 1, Rhode Island Department of Health Office of Environmental Health (EHEALTH) assumed joint command for the response.

Reconnaissance

Initial environmental monitoring was conducted with the only Jerome Mercury Vapor Analyzer (MVA) available. An initial assessment and clearance screening level (ACSL) of 3,000 ng/m^3 was used (Tables 1, 2). These readings were taken in real-time. Three of the six buildings' common areas failed this criterion (Table 3).

Subsequent to this initial screening, a national call was issued for Lumex 915+ and Lumex RA-915 Light meters for reconnaissance, remediation and reoccupancy. Lack of real-time equipment availability was a major obstacle to efficiency. Contractors reported that the Lumex meters only had 3.5 hours of actual work time. Recharging took 8 hours, during which the unit had to be turned off. Additionally, 10% variability was found across units due to differences in sensitivity and drift (see "Direct Reading Instruments" sidebar on p. 57).

Hg^0 Air Monitoring

On Oct. 28, RIDEM, EPA Region 1 and EHEALTH agreed to an ACSL of 300 ng/m^3, the inhalation reference concentration (RfC) for elemental mercury (EPA, 1999). An RfC is an estimate of a continuous inhalation exposure concentration to people (including sensitive subgroups) that is likely to be without risk of deleterious effects during a lifetime (EPA, 2011).

Over 3 days, contractors conducted a detailed environmental assessment using MVAs. They measured every room with 10-second average samples at each sample point at a minimum of 1 to 3 in. and 3 ft above the floor. Additional samples were taken of upholstered furniture, beds, closets, sink and tub/shower drains, and vacuum cleaners. In one building, four apartments had readings above 28,000 ng/m^3, requiring response personnel to wear level C PPE (air-purifying respirators with mercury vapor cartridges). Seven apartment units had levels within ±20% instrumentation error (240 to 300 ng/m^3) (Table 4, p. 53).

Locations of Highest & Lowest Hg0 Readings.

In 62% of the apartments, the highest reading was found in the apartment's entryway. In 65% of apartments, the lowest reading was in the bedroom. Sixty-eight percent of the highest readings were found at floor level (Table 5, p. 53).

Relocation

All 140 residents were sent to local hotels with the assistance of the Red Cross or stayed with relatives or friends. Residents were not told how long they would be relocated. Most assumed it would be a few days. Limited documentation was available regarding screening of individuals for mercury contamination prior to relocation. Some residents left without being screened.

Some personal belongings underwent screening. Because too few analyzers were available, the screening process was time-consuming; this angered residents so some left the premises without being screened. Those belongings that failed screening were held on site. Nothing in the available documents indicated that responders intended to decontaminate the residents, their pets or their belongings prior to relocation.

Table 1

U.S. EPA Action Levels

Level	Mercury (concentration measured in air)	Response
1	≥ 10,000 ng/m^3 (real-time)	Relocate residents immediately
2	> 1,000 ng/m^3 to < 10,000 ng/m^3	Schedule relocation as soon as possible
3	≤ 1,000 ng/m^3 (8-hr TWA)	No action necessary

Note. *From* Mercury Response Guidebook, *by U.S. EPA Region 5, 2001, Washington, DC: Author, pp. 3-13.*

Table 2

U.S. EPA Action Levels for Mercury Concentrations Measured in Soil

Land use	Mercury action levels (concentration measured in soil)
Residential	16 mg/kg
Commercial	250 mg/kg

Note. *From* Mercury Response Guidebook, *by U.S. EPA Region 5, 2001, Washington, DC: Author, pp. 5-11.*

Table 3

Units Failing Initial ACSL

Building	% Units failed ACSL (> 3,000 ng/m^3)
1	50%
2	100%
3	92%
4	67%
5	83%
6	100%

Since no perimeter security was established initially, property and building access continued sporadically for 8 days, with many residents subsequently removing unscreened items from the property. It was generally assumed that if some of a resident's belongings were found to be not contaminated, all of that resident's belongings were not contaminated. This contributed significantly to secondary contamination of other sites.

Removal

RIDEM abdicated oversight responsibility to Southern Union since the gas company had accepted liability and agreed to pay all remediation costs. Southern Union then hired contractors to perform removal and replacement. These contractors met EPA registration guidelines for hazardous waste/mercury handler/transporter, minimum insurance requirements for environmental spills,

Hazards of Mercury

Mercury can exist in three forms: elemental (Hg^0), inorganic (IHg or Hg^{+1}, Hg^{+2}) and organic [e.g., ethyl-, phenyl- and methyl-mercury (MeHg)]. Humans have daily contact with both naturally occurring and anthropogenic sources of elemental mercury (U.S. Geological Survey, 2000). Mercury has been measured at or above detectable levels in air, water and food; in places where people live, work, play and learn; and in products purchased and equipment used (EPA, Great Lakes Region, 1998). Outdoor urban air has approximately 10 to 20 nanograms per cubic meter (ng/m^3) mercury concentration (Singhvi, Mehra & McGuire, 2004). In 1998, EPA established an air reference concentration (RfC) for elemental mercury at 300 ng/m^3 (EPA, 1999). A reference concentration is an estimate of continuous inhalation exposure in a human population (including vulnerable subpopulations) that is likely to be without appreciable risk of deleterious effects during a lifetime (EPA, 1998).

Residential elemental mercury sources include thermometers, thermostats, heating oil, coal, regulators for gas delivery systems, switches, fluorescent light bulbs, automobiles and cell batteries (U.S. Geological Survey, 2000). Additionally, mercury has been incorporated into certain sociocultural behaviors and ritual practices that can occur within a residence (EPA, 2002). Little data are available regarding background levels of mercury in residences. One environmental survey of 12 New York residences suggested that indoor sites may have higher concentrations than those outdoors (Carpi & Chen, 2001). However, the study suggested that short-term monitoring was not sufficient to adequately characterize the degree of background residential contamination due to large seasonal changes.

Mercury persists both in the environment and in the human body. Elemental mercury vaporizes at room temperatures. As a result, exposure to elemental mercury occurs primarily through inhalation and to a lesser extent through skin absorption or (secondary) ingestion. Eighty percent of inhaled Hg^0 enters the bloodstream then travels to the brain and kidneys where it accumulates (Cherian, Hursh, Clarkson, et al., 1978). Exposure to high levels of Hg^0 vapor can cause symptoms such as irritation to the lining of the mouth, lungs and airways, increased blood pressure and heart rate, and/or nausea, vomiting and diarrhea. Even a small amount of Hg^0 remaining in a room after a spill can continue to vaporize slowly over time resulting in sustained elevated air concentrations of mercury and chronic exposure. Early symptoms of chronic mercury exposure include loss of sensation in the extremities and constriction of the visual field. More severe symptoms include emotional lability (irritability, shyness, nervousness), tremors, muscle incoordination, memory loss, deafness and eventually, total incapacitation and death (Agocs & Clarkson, 1995). Depending on the dose and the individual, the latency period between exposure and the appearance of symptoms may span weeks. Because Hg^0 is slowly excreted from the body, it accumulates in the kidneys, which are particularly sensitive to damage. Little to no information is available regarding health effects associated with low-level long-term mercury exposures (ATSDR, 1999).

As mercury bioaccumulates in the body, there is the potential for transfer to progeny. Mercury crosses the placenta easily. Fetal exposure results in more severe disease manifestation than adult exposure. Effects can range from subtle decrements in development or intelligence to acute and chronic developmental disabilities such as cerebral palsy, kidney, immune and/or reproductive system disorders and an increase in the likelihood of heart disease. Fetal damage has been reported in cases where their mothers did not exhibit overt symptoms (Clarkson, Magos & Greenwood, 1972.)

Among infants and toddlers, postnatal exposures occur through lactation and general hand-to-mouth contact. Additionally, children are closer to the floor or ground where mercury vapor concentrations tend to be higher. Acrodynia is seen in children often. It is an idiosyncratic hypersensitivity hallmarked by bright pink or red hands and feet with peeling skin (Weinstein, & Bernstein, 2003).

Mercury can be detected in blood, urine, feces, exhaled breath and hair. Laboratory analysis of blood and urine mercury can be speciated (organic vs. non-organic) (Langworth, Elinder, Gothe, et al., 1991). According to 2004 data collected on the U.S. population by the National Health and Nutritional Examination Survey, the geometric mean for total blood mercury was 0.797 µg/L, 95% CI [0.703, 0.903] with the 95th percentile equal to 4.90 µg/L, 95% CI [4.30, 5.50] and the geometric mean for total urinary mercury was 0.447 µg/L, 95% CI [0.406, 0.492] with the 95th percentile equal to 3.19 µg/L, 95% CI [2.76, 3.55] (CDC, 2011). Epidemiological studies have demonstrated health effects with blood concentrations less than 10 µg/L (Axelrad, Bellinger, Ryan, et al., 2007).

workers' compensation and other liabilities, and verifiable business history.

Each contractor created and implemented a safety and health plan (EPA, 1991). While RIDEM met with contractors regularly, it made no attempt to coordinate their efforts. In addition, no third-party safety and health professional was on site to ensure that each contractor followed EPA remediation and sampling guidelines. There were inconsistencies with documentation, monitoring and remediation procedures among and within on-site contractors.

Decontamination Process

In 3 weeks, contractors documented the contents of each apartment and identified mercury-impacted items. A scribe was paired with each worker to assist with this process. Subsequently, mercury-impacted items were cleaned using a decontaminating agent (HgX Acton Technologies, 2008) and/or a special vacuum with a high-efficiency (HEPA) filter (Mini-Merc Nilfisk, 2008).

After each round of cleaning, the apartment was resampled for mercury vapors. Concurrently, remediation began in the least and most contaminated buildings. Unfortunately, some remediated apartments were recontaminated during remediation of more heavily contaminated apartments, thus requiring additional rounds of decontamination.

Heating/Ventilation Cycles

Heating cycles of 8 hours at 80 to 85 °F or higher then reducing the heat to 70 °F, and venting to the air for at least 2 hours were employed. At first, existing baseboard heating systems and open windows were used.

However, these existing systems were unable to consistently maintain the required temperature for decontamination. For the most contaminated building, portable heaters and negative air scrubbers with activated carbon filters accelerated vapor removal. This process was extremely efficient and effective. Monitoring of the scrubber outlets ensured that exhaust mercury vapor concentrations did not exceed 300 ng/m^3.

Household & Personal Items

Some items were taken off site for additional decontamination. This off-site process involved bagging the personal items, heating them (90 to 140 °F for 24 hours), then ventilating them adequately before retesting. Items that could not be adequately decontaminated to less than 1,000 ng/m^3 were disposed of as household waste. These items included refrigerators, sink/tub/shower drains, vacuums, mattresses and carpets. Personal items not able to be decontaminated included leather shoes, plastic toys and doormats/floormats.

All frozen and refrigerated food, and sink/tub/shower drains were discarded automatically. Items such as carpet, tile flooring, garbage disposals, furnace filters, vacuum cleaners, mattresses, leather shoes, sneakers, clothes and plastic toys were disposed of as hazardous waste when readings exceeded 10,000 ng/m^3.

In general in this complex, porous materials were difficult if not impossible to decontaminate. One car was impounded and disposed of as hazardous waste. All other mercury sources present in the home (e.g., thermometers and thermostats) were removed and replaced with electronic versions.

Overall, the highest readings were found in apartment entryways and the lowest in the bedrooms. Highest readings were generally found at floor level.

Table 4

Highest Mercury Vapor Readings From Initial Site Assessment by Unit & Building

Hg^0 (ng/m^3)	Bldg 1	2	3	4	5	6
Building entry	**297**[a]	4,438	88	1,570	159	1,626
Boiler room	114	627	1,020	1,522	NA	NA
Unit 1	372	2,357	1,648	793	74	2,760
2	**295**[a]	5,478	797	392	7,420	
3	224	504	4,973	**286**[a]	1,373	
4	200	1,820	**276**[a]	**294**[a]	525	
5	543	13,090	2,939	230	342	
6	303	**28,830**[b]	1,649	446	671	
7	1,557	2,454	626	**299**[1]		
8	354	**28,000**[b]	323	487		
9	253	5,783	729	864		
10	**295**[a]	**28,337**[b]	810	399		
11	**256**[a]	**28,830**[b]	2,748	1,790		
12	2,540	3,770	620	2,081		

Note. *Direct reading instrument: Lumex 915+ meter with level of detection 2 ng/m^3. [a]Air levels 240 ng/m^3 to 320 ng/m^3 within ±20% instrument error. [b]Air levels > 28,000 ng/m^3 require Level C PPE.*

Table 5

Highest & Lowest Readings of Mercury Vapor by Specific Location & Sampling Level Within Each Apartment

	Specific location						Sampling level		
Hg^0 Readings	Entry	Kitchen	Living	Master	Bedroom	Bath	Floor	Waist	Breathing
Highest	31	3	7	0	4	5	34	9	7
Lowest	3	7	5	19	15	3	-	-	-

Note. *Instrument used: Lumex 915+ meter with level of detection 2 ng/m^3.*

Structural Items & Surrounding Property

For the most contaminated building, disposed items included base moldings, plywood subfloors, baseboard heater covers, plumbing to the main drain stack, building entryway and concrete stairs. On the surrounding property, all plantings, grass, top soil and pavement were removed and replaced.

Reoccupancy

Within each building, post-heat measurements had to satisfy the screening protocol before clearance sampling was conducted; that is, 90% of readings had to be less than 300 ng/m^3 and 100% less than 360 ng/m^3. This was to account for the direct-reading mercury vapor analyzer's ±20% instrumentation error. Figure 1 illustrates the average mercury levels taken after a second round of cleaning and after each round of heating/ventilation. While initial readings (post-clean no. 2) were below 300 ng/m^3, the readings after the first heat-vent cycle clearly shows the release of additional mercury vapor. In 43% of the units, mercury vapor levels increased post-heating over post-cleaning. Readings taken after the second heat-vent cycle were less than or equal to 100 ng/m^3 with one exception.

EHEALTH established the residential occupancy level (ROL) at 1,000 ng/m^3. Using a modified NIOSH (2004) method 6009, 8-hour time-weighted average (TWA) hopcalite air samples tested below 500 ng/m^3. Fifty-two percent were below the level of detection (200 ng/m^3) (Table 6). It was concluded that no further remediation was required. EHEALTH issued a clearance letter for site reconstruction. Reoccupancy was completed Dec. 18.

Prior to residential reoccupation, all personal belongings, vehicles and frequented locations were screened for mercury vapors. Several personal items exceeded the ACSL and were disposed of with the owners' permission. EHEALTH tested 130 sites in 15 cities and towns across RI and MA, including 96 private residences, 23 institutions and 11 commercial properties, and found extensive secondary contamination in two schools and four residences. School contamination was isolated from occupied areas while residences were evacuated until remediation and reconstruction were completed. By Dec. 27, all residents had returned to their apartments.

Six Rs of Emergency Response to Mercury Contamination

Referral. The roles, responsibilities and authorities of local, state and federal agencies are delineated. This section addresses consent for entry and access to property.

Reconnaissance. Procedures are detailed for initial assessment of the extent and degree of contamination present in the residences. The Agency for Toxic Substances and Disease Registry (ATSDR) action level for cleanup is 1,000 ng/m^3 (Singhvi, Mehra & McGuire, 2004, p. 9). Level C PPE (air-purifying respirator) is required for air levels greater than or equal to 25,000 ng/m^3 (Singhvi, Mehra & McGuire, p. B-v).

Relocation. Residents should be temporarily relocated if assessment and clearance screening level (ACSL) is > 10,000 ng/m^3 real-time or > 1,000 ng/m^3 8-hour time-weighted average (Table 1, p. 51). A step-by-step process is outlined for screening residents' clothing prior to relocation.

Removal. The lengthy process of documenting and decontaminating residences, their contents and surrounding property is provided. Action levels for soil remediation are referenced (Table 2, p. 51). Disposal characterization is detailed (e.g., waste manifests).

Replacement. Residential restoration should return each residence to its prior condition and repair damage secondary to decontamination procedures. EPA has the legal authority to recover costs under Superfund although it is reluctant to do so when it involves a residence. In this case, the gas company assumed full financial responsibility. Replacement is not discussed further in this article.

Reoccupation. Again, the roles, responsibilities and authorities of local, state and federal agencies are delineated. It addresses by whose authority residential reoccupation is allowed. Typically, representatives from all of these agencies meet with residents prior to and following reoccupation. The residential occupancy level is 1,000 ng/m^3 as an 8-hour time-weighted average. When postdecontamination levels by direct reading instrumentation are within acceptable limits, 8-hour time-weighted samples are taken. If these samples are less than 1,000 ng/m^3, then reoccupation can occur.

Note. *From* Mercury Response Guidebook, *by U.S. EPA Region 5, 2001, Washington, DC: Author.*

Biological Monitoring

Biological monitoring was not initiated at the time of evacuation. Initially, EHEALTH did not obtain residents' contact information. Sixty-four percent of residents voluntarily submitted blood samples within 30 days of first exposure. Ninety-one nonresidents at secondary mercury-impacted locations were voluntarily tested for total blood mercury. A month later, only 7% of these individuals voluntarily submitted random urine samples.

All individuals with blood mercury levels ≥ 10 µg/dL were advised by EHEALTH to followup with their healthcare providers. Specific test results cannot be disclosed here due to medical confidentiality. Blood samples were not speciated for organic and inorganic mercury, and urine mercury levels were not creatinine corrected.

Risk Communication

Regularly scheduled meetings were held between residents and representatives from RIDEM, EHEALTH and Southern Union to address residents' concerns. However, inconsistencies in the information provided by each agency confused residents. One-way, carefully orchestrated messages from Southern Union served to erode public trust in the gas company and, by association, the regulatory governmental agencies involved. Residents' anger, fears and frustration were clearly voiced at these meetings. During these meetings, residents' concerns centered around three questions:

1) Is it safe? According to the protocols established for this incident by state agencies and EPA, within each building, post-heat measurements had to satisfy the screening protocol before clearance sampling was conducted (i.e., 90% of readings had to be less than 300 ng/m³ and 100% less than 360 ng/m³ to account for the direct-reading mercury vapor analyzer's ±20% error margin). Subsequent to this screening, an 8-hour TWA hopcalite air sample was taken. If that sample was below 300 ng/m³, then the residents could return home safely. Once the site met these standards, the residence was considered safe for reoccupancy.

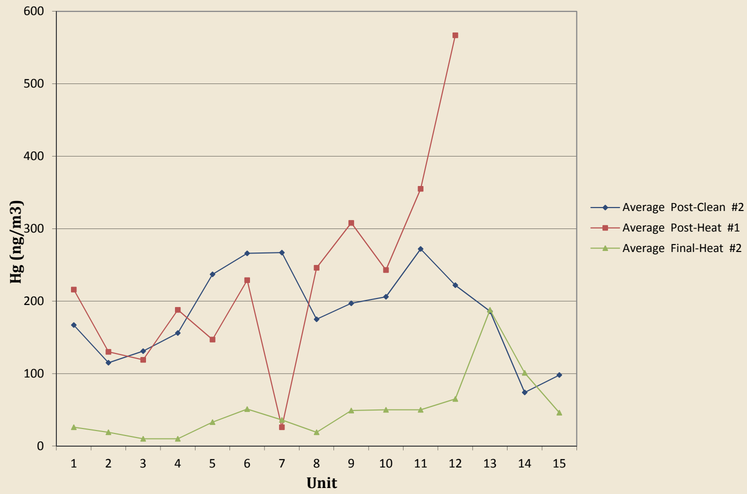
2) Is it safe enough? Residents asked, "Why isn't the level zero?" By modifying both air sampling and analytical methods, the level of detection was able to be lowered to 200 ng/m³. According to these protocols, it was safe enough. It is important to explain that the lowest detection level is the amount of airborne mercury that can be measured reliably.

3) Is it right? "If mercury is so hazardous, why are you saying it is safe to return when there is still mercury in our apartments?" As noted, according to these protocols, it was both safe and safe enough. Once the department of health issued a clearance letter for site reconstruction and reoccupancy to commence, there was no further state agency involvement. Once the property is reoccupied, there was no assurance that the apartments were not newly contaminated. The most prudent practice would be to apply the as low as reasonably achievable (ALARA) principle.

The concept of contamination is not an easy concept for the public to understand, particularly when there is an absence of sensory input. Although beads of mercury may have been visible on the pavement at the complex, no fire, no train wreck or chemical plant was emitting foul-smelling smoke. The initial vandalism incident had happened 3 weeks previously, and residents felt fine. In particular, extended latency periods with long-term health implications are very difficult to comprehend.

Figure 1

Mercury Vapor Readings Post-Clean & Post-Heat Cycles



Recommendations

Analysis of this response suggests that modifications to assessment and decontamination procedures would increase the efficiency and expediency of future responses to elemental mercury-related incidents. These recommendations were made:

Assessment & Decontamination Procedures

1) Establish immediately and continue to enforce strict perimeter security.

2) Set up designated walking paths to avoid walking in contaminated areas.

3) Conduct and document monitoring identically to facilitate comparison of subsequent measurements and to minimize transcription errors, especially when multiple contractors are involved.

4) When external contamination is being brought into the residence (as opposed to the residence being the primary source of contamination), initially sample only the residential entry. If the entry is greater than or equal to ACSL, the residence fails. If the entry is less than ACSL, sample each room.

5) Take only floor-level readings during the initial assessment and remediation process to ascertain degree of contamination. In addition, take air samples in the breathing zone to ensure adequate worker protection.

Table 6

Distribution of Hopcalite Clearance Sampling Results (8-Hour TWA) in Building Entries & Units

Hg^0 (ng/m³)	< 200	200-499	500
Entries	4	1	0
Units	28	14	12

Each contractor created and implemented a safety and health plan. RIDEM met with contractors regularly but did not coordinate their efforts. In addition, no third-party safety and health professional was on site to ensure that each contractor followed EPA remediation and sampling guidelines.

6) Investigate use and efficacy of existing over-the-counter products containing selenium sulfide to decontaminate people and pets where elemental mercury contamination is suspected.

7) Initiate and maintain a registry that contains the contact information for all residents.

8) Remove the following items before heating/venting cycles: wall-to-wall carpet, J/P traps, garbage disposals, vacuum cleaners, shoes, plastic toys, and frozen and refrigerated food.

9) Remediate the most contaminated residences/rooms and all common areas first to minimize cross-contamination.

10) Employ two to three heating/venting cycles first, then identify remaining hot spots for decontamination/disposal. Use supplementary heaters with exhaust scrubbers.

State & Federal Response Guidelines

1) Require an on-site CSP or CIH to oversee the safety/health aspects of remediation. Minimally, this individual should meet OSHA's definition of qualified person per 29 CFR 1910.120 and job specifications as to be determined by EPA and/or the state agency responsible for environmental management.

2) Establish a level of 300 ng/m^3 for the ACSL (real-time) and the ROL (8-hour TWA) for residences in order to provide a greater margin of safety. These lower levels are both measurable and reasonably achievable. However, the lower ROL would require modifying and validating NIOSH air sampling method 6009.

3) To conservatively account for the ±20% error margin in direct reading instrumentation, require 90% of ACSL readings to be less than or equal to 240 ng/m^3 and 100% to be less than or equal to 300 ng/m^3.

4) EHEALTH (or similar state agency) should determine the need for clinical assessment and biological testing at the time of initial response. Collect blood and urine samples simultaneously; analyze the blood for speciated mercury with urinary mercury creatinine corrected.

5) More U.S.-population-based data are needed for mercury levels in blood and urine. Currently, mercury levels are tested only in women of child-bearing age and children age 6 and younger. It has been speculated that Rhode Islanders consume more fish than the U.S. population and, thus, would have higher blood levels. There is a need for state-specific biological and environmental background levels to confirm or disprove this perception.

Table 7

Risk-Related Characteristics That Contribute to Public Outrage

Less outrage (more safe)	More outrage (less safe)
Voluntary	Involuntary or coerced
Natural	Industrial or anthropogenic
Familiar	Unfamiliar/exotic
Not memorable	Memorable
Not dreaded	Dreaded
Chronic	Catastrophic
Knowable (detectable)	Unknowable (not detectable)
Controlled by the individual	Controlled by others
Fair	Unfair
Morally irrelevant	Morally relevant
Trustworthy sources	Untrustworthy sources
Responsive process	Unresponsive process

Note. *Adapted from* Responding to Community Outrage: Strategies for Effective Risk Communication, *by P.M. Sandman, 1993, Fairfax, VA: AIHA.*

Risk Communication

1) Consider the importance of participatory discourse when establishing and/or modifying response policies and procedures.

2) Clearly identify and separate issues before implementing specific communication strategies to resolve them (Klinke & Renn, 2002).

3) Present a balanced form of communication for issues of complexity, uncertainty and ambiguity. Since the social amplification of the consequences of risk is defined by the cultural, social and individual structures and processes that shape the overall societal experience of risk, meaning is as important as the numbers themselves. Sometimes science alone is just not enough (Table 7).

Final Outcome

This incident displaced 140 residents for 3 months and cost

Southern Union an estimated $6.6 million. The youths allegedly responsible for contaminating the apartment complex were arrested and processed through the juvenile courts. As a result, information regarding their adjudication was not released to the public.

On Oct. 15, 2008, Southern Union was convicted by jury of knowingly storing liquid mercury without obtaining the proper permits in violation of federal law (U.S. Department of Justice, 2008). On Oct. 2, 2009, a federal judge fined Southern Union $18 million with 2 years' probation during which time the company had to prove it had an environmental compliance program and performed an environmental audit (Mulvaney, 2009).

One year later, the First U.S. Circuit Court of Appeals in Boston upheld this conviction and fine (Neronha, 2010). A civil suit brought by residents against the company was settled out of court. The company paid an undisclosed sum of money to the residents (Bramson, 2009).

Direct Reading Instruments

At the time of the incident, several direct reading real-time instruments were market-available for detecting elemental mercury vapor (Rader Environmental Services, 2008). However, only three were used in this incident: the Jerome MVA, Lumex 915+ and Lumex RA-915 Light.

The Jerome Mercury Vapor Analyzer (Jerome MVA) was accurate only when mercury vapor concentrations were greater than 1,000 ng/m^3. Interferences to its accuracy included smoke, nitrogen and sulfide compounds. The Jerome MVA could not be used to sample ambient air at levels 300 ng/m^3 or less.

The Lumex 915+ conducted real-time monitoring (one per second), data collection and data logging in real-time with storage capability to save separate files. It featured an on-board display with a set point level alarm. Its standard multipath mode had levels of detection 2 to 20,000 ng/m^3. For higher concentrations, the single path mode was employed with levels of detection 500 to 200,000 ng/m^3.

The Lumex 915+ instrument is not to be confused with Lumex RA-915 Light which had levels of detection 100 to 100,000 ng/m^3. Both the Lumex 915+ and RA-915 Light had ±20% instrumentation error. High humidity (greater than 95% at 35 °C or 95 °F) gave false positive readings (Ohio Lumex, 2001). Periodic readings with on/off cycling were performed with and without the glass filter to check for mercury contamination of the sampling tube itself. The glass filter was replaced if the difference between these two readings was greater than 10%. Filter checks were performed initially and after every 4 hours. The instruments' major limitation was the 4-hour rechargeable battery that could not be removed from unit for charging.

Conclusion

This study's recommendations were based on the ALARA principle. Recommendations were matched to key findings. Data showed that lower action levels were achievable with currently available remediation methods. Modification to NIOSH method 6009 needs validation. Further research is recommended to assess the procedural efficacy and long-term outcomes of these recommendations. Efforts to modify EPA regulations and guidelines should be initiated as well. **PS**

References

Acton Technologies. (2008). HgX© decontaminant powder. Pittston, PA. Author. Retrieved June 9, 2011, from **www.actontech.com/hgx1.htm**.

Agency for Toxic Substances and Disease Registry (ATSDR). (1999). Toxicological profile for mercury. Washington, DC: U.S. Department of Health and Human Services (DHHS), CDC, Author. Retrieved June 9, 2011, from **www.atsdr.cdc.gov/toxprofiles/tp.asp?id=115&tid=24**.

Agocs, M. & Clarkson, T. (1995). ASTDR case studies in environmental medicine: Mercury toxicity. In A.M. Pope & D.P. Rall (Eds.), *Environmental medicine: Integrating a missing element into medical education* (pp. 450-472). Washington, DC: National Academy Press.

Axelrad, D.A., Bellinger, D.C., Ryan, L.M., et al. (2007). Dose-response relationship of prenatal mercury exposure and IQ: An integrative analysis of epidemiologic data. *Environmental Health Perspectives, 115*, 609-615.

Belson, M.G., Schier, J.G. & Patel, M.M. (2005, Jan. 14). Case definitions for chemical poisoning: Case definitions for potential terrorism agents: toxins and toxicants. *Mortality and Morbidity Weekly Report, 54(RR-1)*, 1-5, 11-13.

Bramson, K. (2009, July 17). Settlement reached in Pawtucket mercury spill case. *Providence Journal.*

Burns & McDonnell Engineering. (2005). Elemental mercury contamination of Lawn Terrace Apartments. Available from Pawtucket, RI, Public Library.

Carpi, A. & Chen, Y-F. (2001). Gaseous elemental mercury as an indoor air pollutant. *Environmental Science & Technology, 35*(21), 4170-4173.

CDC. (2006, Feb. 22). Case definition: Mercury (elemental). Washington, DC: DHHS, Author. Retrieved June 9, 2011, from **http://emergency.cdc.gov/agent/mercury/mercelementalcasedef.asp**.

CDC. (2009, Jan. 13). National health and nutrition examination survey 2001-2002. Washington, DC: DHHS, Author. Retrieved June 9, 2011, from **www.cdc.gov/nchs/about/major/nhanes/nhanes01-02.htm**.

CDC. (2011). Fourth national report on human exposure to environmental chemicals. Washington, DC: DHHS, Author. Retrieved June 9, 2011, from **www.cdc.gov/exposurereport/pdf/Updated_Tables.pdf**.

Cherian, M.G., Hursh, J.B., Clarkson, T.W., et al. (1978, May-June). Radioactive mercury distribution in biological fluids and excretion in human subjects after inhalation of mercury vapor. *Archives of Environmental Health, 33*(3), 109-114.

Clarkson, T.W., Magos, L. & Greenwood, M.R. (1972). The transport of elemental mercury into fetal tissue. *Biology of the Neonate, 21*, 239-244.

Davidson, P.W., Myers, G.J. & Weiss, B. (2004, April). Mercury exposure and child development outcomes. *Pediatrics, 113*(4), 1023-1029.

Douglas, M. & Wildavsky, A. (1982). *Risk and culture.* Berkeley, CA: University of California Press.

EPA. (1991). Health and safety roles and responsibilities at remedial sites. Washington, DC: Author. Retrieved Aug. 20, 2011, from **www.epa.gov/superfund/cleanup/pdfs/rdra/health.pdf**.

EPA. (1998). Glossary of terms. Washington, DC: Author. Retrieved June 9, 2011, from **www.epa.gov/nata2002/gloss.htm**.

EPA. (1998). Mercury in your community and the environment. Washington, DC: Author, Great Lakes Region. Retrieved June 9, 2011, from **www.epa.gov/glnpo/bnsdocs/merccomm**.

EPA. (1999). EPA's reference concentrations (RfCs). Washington, DC: Author.

EPA. (2001). *Mercury response guidebook.* Washington, DC: Author, Region 5. Retrieved June 9, 2011, from **www.epa.gov/mercury/spills**.

EPA. (2002, Dec.). Task force on ritualistic uses of Mercury. Washington, DC: U.S. EPA Office of Emergency and Remedial Response (540-R-01-005).

EPA. (2004). Mercury, elemental. Washington, DC: Author. Retrieved June 9, 2011, from **www.epa.gov/iris/subst/0370.htm**.

EPA. (2009, Feb. 3). Spills, disposal and site cleanup of mercury. Washington, DC: Author. Retrieved June 9, 2011, from **www.epa.gov/mercury/spills/index.htm**.

EPA. (2011, March 11). Mercury, elemental. Washington, DC: Author. Retrieved Aug. 19, 2011, from **www.epa.gov/iris/subst/0370.htm**.

Grandjean, P., Budtz-Jorgensen, E., Kieding, N., et al. (2004). Underestimation of risk due to exposure misclassification. *International Journal of Occupational Medicine and Environmental Health, 17*(1), 131-136.

International Risk Governance Council. (2005, July). Basic concepts of risk characterization and risk governance. Geneva, Switzerland: Author.

Kasperson, R.E. (1992). The social amplification of risk. In S. Krimsky & D. Golding (Eds.), *Social theories of risk* (pp. 153-178). Westport, CT: Praeger Publishers.

Klinke, A. & Renn, O. (2002, Dec.). A new approach to risk evaluation and management: Risk-based, precaution-based and discourse-based strategies. *Risk Analysis, 22*(6), 1071-1094.

Acknowledgments

This study was funded by a grant from Rhode Island Department of Health, Office of Environmental Risk Assessment through Salve Regina University of Newport, RI. The author thanks the following individuals for their expert assistance and editorial review of this manuscript: Thomas E. Hamilton, CIH, president of OccuHealth Inc., Mansfield, MA; Robert Vanderslice, Ph.D., toxicologist and team leader, Healthy Homes and Environment at the Rhode Island Department of Health; and Phil Brown, Ph.D., professor of sociology, and Kim Boekelheide, M.D., Ph.D., professor of pathology and laboratory medicine, at Brown University.

Langworth, S., Elinder, C., Gothe, C., et al. (1991). Biological monitoring of environmental and occupational exposure to mercury. *International Archives of Occupational and Environmental Health, 63*, 161-167.

Marcelo, P. (2008, Sept. 28). Trial over Pawtucket mercury spill opens. *The Providence Journal.*

Mulvaney, K. (2009, Oct. 3). Utility fined $18 million over Pawtucket mercury spill. *The Providence Journal.*

Neronha, P. (2010, Dec. 23). Southern Union Company conviction, $18 million fine for illegally storing mercury in Pawtucket Upheld. Washington: DC: U.S. Department of Justice, Rhode Island District. Retrieved June 9, 2011, from **www.epa.gov/compliance/resources/cases/criminal/highlights/2011/southern-union-appeal-12-23-10.pdf**.

Nilfisk. (2009). Nilfisk Mini-Merc. Morgantown, PA: Author. Retrieved June 9, 2011, from **www.nilfiskcfm.com**.

NIOSH. (2004). NIOSH analytical method 6009: Mercury. Washington, DC: DHHS, CDC, Author. Retrieved Jan. 9, 2012, from **www.cdc.gov/niosh/docs/2003-154/pdfs/6009.pdf**.

OhioLumex. (2001). Lumex 915+ ©Mercury Vapor Analyzer. Twinsburg, OH: Author. Retrieved June 9, 2011, from **www.ohiolumex.com/download/manual_RA_915.pdf**.

Rader Environmental Services. (2008). Field screening instruments for mercury vapors. Findlay, OH: Author. Retrieved June 9, 2011, from **www.raderenvironmental.com**.

Rayner, S. (1992). Cultural theory and risk analysis. In S. Krimsky & D. Golding (Eds.), *Social theories of risk* (pp. 83-115). Westport, CT: Praeger Publishers.

Renn, O. (1992). Concepts of risk: A classification. In S. Krimsky & D. Golding (Eds.), *Social theories of risk* (pp. 53-79). Westport, CT: Praeger Publishers.

Rhode Island Department of Environmental Management (RIDEM). (2005). Office of Emergency Response performance statistics (2000-2004). Providence, RI: Author. Retrieved June 9, 2011, from **www.dem.ri.gov/programs/director/emerresp/pdf/stats.pdf**.

Northeast Waste Management Officials' Association (NEWMOA). (2001, Oct. 1). Reported mercury spills in the northeast states: Executive summary. Boston: Author. Retrieved June 9, 2011, from **www.newmoa.org/prevention/mercury/SpillReport.pdf**.

Sandman, P.M. (1993). *Responding to community outrage: Strategies for effective risk communication.* Fairfax, VA: AIHA.

Schmidt, C.W. (2006, Dec.). Signs of the times: Biomarkers in perspective. *Environmental Health Perspectives A, 114*(12), 701-705.

Singhvi, R., Mehra, Y. & McGuire, N. (2004). *Metallic mercury spill response guide.* Edison, NJ: U.S. EPA Environmental Response Team Center.

U.S. Department of Justice. (2008). Company convicted for illegally storing hazardous waste in Rhode Island. Washington, DC: Author. Retrieved June 9, 2011, from **www.justice.gov/opa/pr/2008/October/08-enrd-922.htm**.

U.S. Geological Survey. (2000, Oct.). Mercury in the environment. Washington, DC: Author. Retrieved June 9, 2011, from **www.usgs.gov/themes/factsheet/146-00/#sources**.

Weiss, J., Trip, L. & Mahaffey, K.R. (1999, Sept./Oct.). Human exposures to inorganic mercury. *Public Health Reports, 114*, 400-401.

Weinstein, M. & Bernstein, S. (2003, Jan. 21). Pink ladies: Mercury poisoning in twin girls (clinical report). *Canadian Medical Association Journal, 168*(2), 201.