GUIDANCE ON THE CLEANUP, TEMPORARY OR INTERMEDIATE STORAGE, AND TRANSPORT OF MERCURY WASTE FROM HEALTHCARE FACILITIES

CONTENT

INTRODUCTION

The UNDP GEF project involves demonstrating best practices for the management of mercury waste and promoting mercury-free devices. As health facilities phase out mercury devices, proper methods of storage and transport are needed. This document is intended for project countries where national norms and guidelines for cleanup, storage, and transport of mercury waste do not exist at this time. These suggested guidelines should become part of a broader plan for sequestration and phase-out of mercury.

OBJECTIVE AND SCOPE OF THE GUIDANCE

Objective

The objective of this document is to provide guidance to health facilities on the cleanup and temporary on-site storage of mercury, the transport of mercury waste, and its intermediate storage at a centralized facility.

Scope

This guidance document deals with the following different forms of mercury waste from healthcare facilities:

- Elemental mercury collected from broken mercury devices
- Undamaged mercury thermometers and sphygmomanometers
- Devices and equipment containing elemental mercury (gastro-intestinal tubes such as Cantor tubes, esophageal dilators, bougie, and Miller-Abbott tubes; mercury switches, etc.)
- Broken glassware contaminated with elemental mercury (specifically, broken thermometers and sphygmomanometers)
- Fluorescent lamps (fluorescent tubes, compact fluorescent lights, UV germicidal lamps)
- Dental amalgam.

Not included in this document are other forms of mercury found in health facilities, namely, mercury-containing batteries, and mercury-containing chemicals such as Thimerosal used in some ophthalmic products, nasal sprays, and vaccines; Merbromin; diuretics containing mercury salts; mercury-based

preservatives, fixatives, and stains; cleaners and degreasers with mercury-contaminated caustic soda or bleach; and laboratory reagents that contain some mercury.[1]

This document provides guidance on the clean-up of mercury spills, especially spills resulting from the breakage of mercury thermometers and sphygmomanometers.

Two types of storage are considered in this document: (1) temporary storage on site (i.e., inside hospitals, clinics, and other health facilities) for the purpose of accumulation or sequestration of waste until such time as centralized storage or approved treatment and disposal facilities become available in the country; and (2) storage in a centralized facility for an intermediate period until such time as long-term storage (terminal storage), treatment or disposal facilities become available in the country. Intermediate storage should not exceed five years. This document also provides guidance on the transport of mercury waste from a health facility to an intermediate storage facility.

How to Use this Document

Different parts of this document can be used at the level of a healthcare facility as part of a mercury reduction and phase-out program. Other parts may be useful at provincial or national levels. The guidance can be used as a basis for developing facility-specific guidelines, staff training, local or national policies, and planning at all levels.

Healthcare facilities should first assess current guidelines and practices dealing with mercury, the availability of materials and resources, and levels of staff training on mercury. (The UNDP GEF Project's PowerPoint presentation "Mercury: Its Properties, Sources, and Health Effects" could be used as an awareness-raising tool and is available at www.gefmedwaste.org.) In low-income settings, it may not be possible to obtain mercury decontaminant solutions or adopt a comprehensive approach to clean-up and storage, but some effort is better than no effort at all. Facilities should implement a phased plan to upgrade mercury management that begins with awareness-raising and policies to prevent dumping of mercury from broken sphygmomanometers and thermometers in the domestic waste, followed by simplified procedures that recover as much spilled mercury as possible while minimizing exposure of health workers and patients, and temporary storage arrangements that take into consideration worker health and safety. Priority should be given to aspects of the plan that have the most impact.

This guidance may be useful to provincial or national governments in developing plans and infrastructure for the packaging, off-site transport, and intermediate storage of mercury at central facilities, even as regional and international efforts proceed towards finding long-term solutions to the global mercury problem. Although this guidance is focused on mercury from health care, many of the concepts may be applicable to other sources of mercury waste.

[1] "Instruments, Products, and Laboratory Chemicals Used in Hospitals That May Contain Mercury," Publication 2-03 in *Going Green: A Resource Kit for Pollution Prevention in Health Care*, Health Care Without Harm, November 5, 2002.

BASIC INFORMATION

Properties

Elemental mercury (Hg) is a heavy, silvery metal that melts at -38.9°C and boils at 357°C. It is the only metal that is liquid at room temperature. Drops of mercury have a high surface tension and appear round. The liquid droplet is very mobile and combines with other metals such as tin, copper, gold, and silver to form alloys (solid solutions called amalgams). An exception is iron which does not amalgamate with mercury. The density of mercury is 13.5 g/cm^3 at 25°C. Mercury has the highest volatility of any metal, forming a colorless, odorless gas.

When mercury is spilled, it can break into very small droplets resulting in a large total surface area. These tiny droplets can volatilize at a rate faster than room ventilation can safely dilute the mercury concentration. The vaporization rate of elemental mercury approximately doubles with every temperature increase of 10°C. Air that is saturated with mercury vapor at 25°C is a thousand times higher than the occupational exposure limit of 0.02 mg of mercury vapor per m^3 in air.[2] Small droplets of spilled mercury can lodge in cracks, adhere to carpet fabric, mix with dust, go down drains, stick to the soles of shoes, and dissolve to form alloys with the metals in watches and jewelry. Some materials are resistant to mercury.[3]

Toxicity

The toxic effects of mercury are well known.[4] Mercury vapor affects the central and peripheral nervous systems, lungs, kidneys, skin, and eyes. It also affects the immune system and is mutagenic. Acute exposure to high concentrations of mercury vapor causes severe respiratory damage, while chronic exposure to lower levels is primarily associated with central nervous system disorder, behavioral changes, and effects on the peripheral nervous system. Chronic mercury exposure can cause eyelid tremor and disturbances of vision.

The symptoms of acute inhalation of high levels of mercury vapor include chills, nausea, malaise, chest pains, shortness of breath, coughing, gingivitis, salivation, and diarrhea. Symptoms of chronic exposure to mercury include weakness; weight loss; gastrointestinal disturbances; a tremor that begins with the fingers, eyelids, and lips and progresses to generalized trembling of the body and violent spasms of the extremities; and behavioral and personality changes including increased excitability, memory loss, insomnia, and depression. Additionally, there may be a painful scaling or peeling of the skin of the hands and feet.

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[2] Recommendation from the Scientific Committee on Occupational Exposure Limits for elemental mercury and inorganic divalent mercury compounds, SCOEL/SUM/84, European Commission, May 2007; the threshold limit value (daily exposure level above which it is believed a worker could suffer adverse health effects) or TLV assigned by the American Conference of Governmental Industrial Hygienists (ACGIH) is 0.025 mg per m^3 averaged over a normal 8-hour work day and a 40-hour work week; the National Institute for Occupational Safety and Health (NIOSH) has a recommended exposure limit (REL) for mercury vapor of 0.05 mg per m^3 as a time-weighted average (TWA) for up to a 10-hour work day and a 40-hour work week; the permissible exposure limit (PEL) for mercury vapor is a ceiling value of 0.1 mg per m^3 in air according to the U.S. Occupational Safety and Health Administration (OSHA).

[3] Examples of materials resistant to mercury at room temperature are: gray and ductile cast iron, carbon steel, 304 and 316 stainless steel, Hastalloy C, titanium; epoxy, high density polyethylene, crosslinked polyethylene, polypropylene, polyethylene terephthalate, polyvinyl chloride, polyvinylidene fluoride, polyetheretherketone; nitrile rubber (Buna-N), chloroprene rubber (neoprene), fluorine rubber, chlorosulfonated polyethylene; glass, and ceramics.

[4] Occupational Safety and Health Guideline for Mercury Vapor, U.S. Occupational Safety and Health Administration, Washington, DC; http://www.osha.gov/SLTC/healthguidelines/mercuryvapor/recognition.html

Persistence Mercury is not biodegradable and persists in the environment. When released into the air, it cycles between the air, land, and water, and undergoes a series of complex chemical and physical transformations resulting in other forms of mercury. Elemental mercury is the most common form of mercury in the air. In aquatic systems, mercury is transformed into organic forms, such as methyl mercury which is more toxic than inorganic forms and bioaccumulates in fish and other wildlife as it moves up the food chain.

Principles Procedures for handling and storing mercury waste must take into account its weight, mobility, high volatility, ability to form amalgams, severe inhalation hazard, ability to be absorbed through skin and cause skin irritation and burns, danger to the eyes, and the adverse health effects due to chronic exposure at low concentrations.

In general, controlling exposures to occupational hazards is based on a hierarchy of controls, which can be summarized as follows:

- Elimination
- Substitution
- Engineering controls
- Administrative controls
- Personal protective equipment.

Elimination of mercury and substitution with mercury-free alternatives are at the top of the hierarchy. A mercury phase-out plan involves, among others, conducting an inventory, decommissioning mercury devices, safe packaging and temporary storage of unbroken mercury devices, procurement of non-mercury devices that meet standards, training on the use of non-mercury devices, and a preventive maintenance program. Engineering controls are used to remove a hazard or place a barrier between the worker and the hazard. Well-designed engineering controls will typically be independent of worker interactions to provide a high level of protection. Administrative controls involve safe workplace procedures, training, awareness-raising, and warning signs. Personal protective equipment or PPE is equipment worn to protect workers from serious workplace injuries or illnesses due to exposure to the chemical.

CLEAN-UP OF SMALL MERCURY SPILLS IN A HEALTHCARE FACILITY

1.0 Planning

The objectives of safe management of mercury waste in a healthcare facility are to minimize exposure to patients, health workers, waste workers, and the community, and to prevent environmental pollution. In order to accomplish these objectives, a mercury waste management plan is essential. A plan should include:[5]

- *Education and training of staff and community* – awareness-raising, public education, periodic training on mercury management, simulation (response to mock spills) as part of training

[5] Adapted from "Managing Small Mercury Spills," Fact Sheet, Health Care Without Harm Europe (Praha, Czech Republic) and Health & Environmental Alliance (Brussels, Belgium), October 2006.
http://www.noharm.org/europe/issues/toxins/mercury/resources.php

- *Proper maintenance of mercury devices* – safe procedures for calibration and preventive maintenance
- *Appropriate labeling and collection* – segregation of mercury from infectious and regular wastes, use of appropriate containers, labeling
- *Mercury spill management* – spill kits, proper procedures, staff training
- *Mercury waste collection plan* – procedures for on-site storage and transport, a designated storage area
- *External management strategies* – take-back arrangements with vendors for used or obsolete mercury devices, arrangements with approved mercury recycling facilities (if available), phase-in of non-mercury devices
- *Proper disposal methods* – transport to approved treatment and disposal facilities (if available)

Mercury plans and policies should also consider such critical issues as:

- Ensuring that a competent staff person trained in mercury spill cleanup is always available
- Ensuring that personal protective equipment is always available for the cleanup staff
- Training for all staff on how to respond to a mercury spill, how to secure an area in the event of a mercury spill, and who to report a spill to.
- Guidelines that specify the circumstances when the patient(s), visitors, and staff should be evacuated from the area before cleanup
- Guidelines that specify what to do with mercury spills that occur during a medical or surgical procedure
- Guidelines that specify when a room is "clean enough" to re-occupy
- Preparation of incident reports that describe the spills, the cleanup methods used, unusual circumstances, and follow-up
- Documentation of training of general staff and staff specializing in mercury cleanup; documentation of each spill incident; use of documentation to evaluate causes of incidents, effectiveness of responses, medical monitoring of individuals exposed to mercury, and preventive measures; and regular reporting of results to the administration.

The healthcare facility should be prepared for a spill in any area of the hospital where mercury-containing devices are used.

2.0 Spill Kit for a Small Mercury Spill in a Healthcare Facility

Although mercury spill kits are commercially available, a spill kit can be made by putting together the following items and storing them in a marked box or portable container:[6]

- □ Step-by-step instructions
- □ Personal protective equipment (PPE):
  - Several pairs of rubber or nitrile gloves

[6] Adapted from "Managing Small Mercury Spills," Fact Sheet, HCWH Europe and HEAL (ibid.); U.S. Environmental Protection Agency's website "Mercury Releases and Spills: Cleanups and Proper Disposal," updated December 2, 2009 (http://www.epa.gov/hg/spills/); "Mercury Spill Information and Cleanup Guidance," Indiana Department of Environmental Management, May 2007; "Personal Protective Equipment Information for Mercury," Canadian Centre for Occupational Health and Safety, updated December 21, 1998; and comparisons of various commercial spill kit contents.

- Safety goggles or protective eyewear
- Respiratory protection:
  - Fit-tested full- or half-facepiece air-purifying respirator with mercury vapor cartridges, or
  - Face mask with sulfur or iodide impregnated activated carbon, or face mask made of sandwiched activated charcoal-impregnated cloth (Note that face masks that do not seal tightly around the face could allow contaminated air to enter through the edges), or
  - Other specialty mask or respirator designed particularly for mercury, or
  - *If no specialty masks are available*: a face mask with a 0.3 micron HEPA filter to capture amalgam particles and mercury-laden dust (unfortunately, regular masks will NOT protect against mercury vapor)
- Coveralls, apron, and other protective clothing
- Disposable shoe covers

□ Containers:
- Air-tight, sealable plastic bags (small and large sizes, thickness: 2 to 6 mils, or 50 to 150 microns)
- Small, air-tight, rigid plastic container with some water or vapor suppression agent for collecting elemental mercury (see recommendation below)
- Air-tight, puncture-resistant, rigid plastic or steel jar or container with a wide opening for collecting mercury-contaminated broken glass
- Plastic tray
- Regular plastic waste bags (thickness: 2 to 6 mils, or 50 to 150 microns)

□ Tools for removing mercury
- Flashlight (electric torch) to locate shiny mercury beads
- Plastic-coated playing cards or thin pieces of plastic to push mercury beads into a plastic scoop or pan; if these are not available, use index cards, pieces of cardboard, or stiff paper
- Small plastic scoop or plastic dust pan to catch the mercury beads
- Tweezers to remove small broken glass pieces
- Eyedropper or syringe (without the needle) to draw up large mercury beads
- Duct tape or sticky tape to pick up tiny mercury droplets
- Vapor suppression agents:
  - Sulfur powder (available from pharmacies) to absorb mercury by forming mercuric sulfide
  - Zinc or copper flakes (available from hardware stores) to absorb mercury by forming amalgams
  - Commercial absorbent pads or vapor suppressants[7]
  - Brush to remove powder or flakes
- Utility knife blade

□ Materials for decontamination
- Vinegar, hydrogen peroxide, and cotton swabs for final cleaning when using sulfur powder
- Decontaminant solution or commercial decontaminant[8]

[7] An example of a dry vapor suppressant is the Mercon™Tainer (Ross Healthcare) which contains a foam pad saturated with a suspension containing small amounts of sodium thiosulfate, copper sulfate, calcium chloride, and potassium iodide. Small quantities of x-ray fixer (which contains thiosulfate) or a propylene glycol solution of sodium thiosulfate and copper sulfate have also been used as vapor suppression agents.

[8] Decontamination solutions can be made of sodium thiosulfate solution (photographic fixer); or a mixture of sodium thiosulfate and EDTA. Examples of commercially available decontaminant solutions are Spilfyter® Decon Solutions, HgX® Mercury Decontaminant Solution (Acton Technology), and Mercon™ Wipes (Ross Healthcare). Mercon™ uses a mixture of about 0.01% by weight iodine, 0.13% copper sulfate, 0.15% ferric chloride, 1.3% ammonium chloride, and 15% isopropanol and varying amounts of propylene glycol.

- Piece of soap and paper towels

□ "Danger: Mercury Waste" labels to put on waste containers

Whenever a spill kit is used, the most senior staff involved in the cleanup should take responsibility for ensuring that the contents are replenished as soon as possible. All spill kits should have a sheet attached indicating when they were used and verifying that the expended supplies have been replaced. The sheet should be signed and dated by the responsible staff.

Recommendation: Healthcare facilities that deal with frequent spills should use a large, air-tight, rigid plastic container or steel flask with some water or vapor suppression agent for accumulating elemental mercury, as well as a large, air-tight, puncture-resistant, rigid plastic or steel container with a wide opening and with water or vapor suppression agent for accumulating mercury-contaminated broken glass. When using water, the water should fully cover the mercury or contaminated glass. Each of these primary containers should be labeled and placed in a secondary container (thick, re-sealable plastic bags) and kept with or near the spill kit. When a spill kit contains accumulation jars or containers, the storage location of the spill kit should be locked, secure, and readily accessible to authorized personnel. Ideally, the storage location should have an exhaust vent to the outside of the facility away from crowded areas.

3.0 Cleanup Procedure for Mercury Spills

This detailed mercury spill cleanup procedure was adapted from many sources[9] and is intended as a guide to help develop facility-specific procedures. Each healthcare facility should develop its own procedures according to what is practical and available while maximizing protection for their patients and health workers.

Recommendation: After these procedures have been reviewed and modified to meet the needs of a health facility, the procedures should be translated into the local language or dialect as needed. In addition, drawings or graphical illustrations could be used both for training and as a step-by-step reminder during an actual spill.

- **Step 1 – Quickly determine the extent of the spill:** Determine on what surfaces the mercury spilled and how far the mercury beads traveled.

- **Step 2 – Immediately block off foot traffic:** Do not allow anyone to walk across the contaminated site or to go near areas where the mercury traveled. If the extent of a small spill is not immediately obvious, block off traffic for a radius of about 2 meters around the center of the spill.

[9] "Cleaning Up Small Mercury Spills," Environment Canada, updated April 26, 2010 http://www.ec.gc.ca/mercure-mercury/default.asp?lang=En&n=D2B2AD47-1&printerversion=true; "Mercury Releases and Spills," U.S. Environmental Protection Agency, updated December 2, 2009 http://www.epa.gov/hg/spills/; "Mercury Spill Cleanup Instructions," Fact Sheet, Oklahoma Department of Environmental Quality, September 2009; "Mercury Spill Information and Cleanup Guidance," Mercury Awareness Program, Indiana Department of Environmental Management, May 2007; "Managing Small Mercury Spills," Fact Sheet, Health Care Without Harm Europe (Praha, Czech Republic) and Health & Environmental Alliance (Brussels, Belgium), October 2006 http://www.noharm.org/europe/issues/toxins/mercury/resources.php; "Mercury Spill Response & Clean-up Guidance Document," Ohio Spill Planning, Prevention and Emergency Response Association, Columbus, Ohio, 2002; "Cleaning Up Small Mercury Spills," Michigan Department of Environmental Quality, 2002 http://www.p2pays.org/ref/15/14605.htm;

- **Step 3 – Contain the spill:** If necessary, prevent the mercury beads from traveling further by blocking their path with rags or impervious material. Take steps to keep mercury from falling into drains or cracks. Check to see if anyone's skin, shoes or clothing was splashed with mercury. If shoes or parts of clothing were contaminated, they should be removed and left around the spill area before allowing the person to leave. Skin that was in contact with mercury should be washed with an alkaline soap.

- **Step 4 – Evacuate the area:** Ask everyone to leave the room or the general area, giving priority to pregnant women and children. Seek assistance to provide first-aid to anyone requiring immediate medical attention. (See Appendix A.)

- **Step 5 – Minimize the spread of vapors to interior areas:** Close all interior doors that lead to other indoor areas. Turn off central ventilation, heating or air conditioning systems that circulate air from the spill site to other inside areas of the building.

- **Step 6 – Reduce vapor concentrations in the spill area if possible:** After making sure that windows and exterior doors open to outside areas that are free of people, open the windows and exterior doors to dilute the vapor concentrations in the room. Prevent access to the area by putting up signs and, if necessary, seeking help from other staff persons, and then leave the area to prepare for cleanup.

- **Step 7 – Prepare for cleanup:** Remove jewelry, watch, mobile phones, and other metal-containing items. Get the mercury spill kit.

- **Step 8 – Put on personal protective equipment (PPE):** Change to old clothes if possible. Put on the apron or coveralls, disposable shoe covers, rubber or nitrile gloves, goggles, and face mask before re-entering the spill site. Make sure metal items such as eyeglass frames are covered by PPE.

- **Step 9 – Remove visible mercury beads and broken glass:** Place the jar and container on the plastic tray. Starting from the outside of the spill site and moving towards the center, carefully remove visible mercury beads and broken glass. Use tweezers to remove broken glass pieces and place them in the jar or wide-mouthed container over the tray. Using a playing card or piece of plastic, slide the mercury beads onto the plastic dustpan or scoop, and away from any carpet or porous surface. Use a slow, short, sweeping motion to prevent spreading mercury droplets. Carefully place the mercury beads into the plastic container partially filled with water or vapor suppression agent. Do this over the tray to catch any spillage. You can also use an eyedropper or syringe for small beads. Hold the eyedropper or syringe almost parallel to the floor to draw in the beads and keep the eyedropper or syringe horizontal when transferring the beads to the plastic container so as to prevent the mercury from falling out.

- **Step 10 – Search for and remove tiny mercury droplets and glass:** Search for any remaining droplets and glass pieces by shining the flashlight at different low angles to the floor and looking for reflections from the shiny droplets and glass. For very tiny droplets, it may be easier to pick them up using sticky tape but be careful since they may not always stick. Place the sticky tape in the sealable plastic bag.

- **Step 11 – Clean up cracks and hard surfaces:** Sprinkle sulfur powder on cracks and crevices, and on hard surfaces (tile, linoleum, wood, etc.) that had come in contact with mercury; a color change in the powder from yellow to reddish brown indicates that mercury is still present and more cleanup is needed. If so, sprinkle zinc flakes or copper flakes to amalgamate any residual mercury. Use the brush or small broom to remove the

powder and/or the metal flakes and place them in the sealable plastic bag. An alternative way to clean hard surfaces after adding sulfur powder is to wipe them with vinegar-soaked cotton swabs, followed by peroxide-soaked swabs. Place the swabs in a sealable plastic bag.

- **Step 12 – Remove contaminated soft materials:** Carpets, carpet padding, upholstery, curtains, rugs, bedding, and other soft materials cannot be cleaned easily. Use the utility knife to cut out pieces of carpet, padding, and other soft materials that are contaminated with mercury. Place the contaminated materials in a sealable plastic bag.

- **Step 13 – Clean out contaminated drains:** If mercury was spilled over a drain, sink or wash basin, work with the facility engineer to remove and replace the "J", "U" or "S" trap. Put a sheet of plastic or plastic tray under the work area to catch any mercury that might spill out. Hold the old trap over a tray while transferring the mercury to the air-tight container. Dispose of the old trap as hazardous waste.

- **Step 14 – Dispose of or decontaminate cleanup material:** Place all contaminated materials used during the cleanup (including cards, plastic pieces, cardboard, paper, rags, cotton swabs, paper towels, sticky tape, piece of soap, brush, or broom) into a leak-proof, sealable plastic bag. Other items (tweezers, plastic scoop, tray, eyedropper, utility knife, etc.) should either be disposed with the contaminated items in the sealable plastic bag or cleaned thoroughly with the decontaminant solution.

- **Step 15 – Label and seal all contaminated material:** Ensure that the air-tight jar and container are filled with enough water to cover the elemental mercury and broken glassware, close the jar and container tightly, label, and place each in a re-sealable plastic bag. The jar and container should be stored safely for future use. Place all sealed plastic bags with mercury-contaminated waste inside a second plastic bag, seal the outer bag using duct tape, and affix a label ("Mercury: Hazardous waste" or as directed by local authorities) and include a brief description of the contents. The mercury waste can be stored temporarily on site (see next section).

- **Step 16 – Remove and dispose or decontaminate PPE:** Remove PPE beginning with the shoe covers which should be placed in another sealable bag. Then remove the gloves by grasping one glove with the other, peeling off the first glove, sliding the fingers under the remaining glove at the wrist, peeling off the second glove, and discarding both gloves in the sealable plastic bag. Next, remove the goggles by the head band or ear pieces. Remove the apron or coverall without touching the front and turn inside out. Finally, remove the face mask or respirator without touching the front. Dispose of the gloves, shoe covers, apron (and regular face mask if used in lieu of a specialty mask) in the sealable plastic bag, which should be stored along with the mercury waste. Decontaminate goggles and respirators or specialty face mask using the decontaminant solution.

- **Step 17 – Wash hands and all exposed skin:** Use soap and water to scrub all exposed skin and rinse thoroughly.

- **Step 18 – Ventilate the spill area:** Place a fan next to the spill area to volatilize mercury and a second fan in a window or doorway to move air to the outside air for 48 hours or more. If this is not possible due to central heating or air conditioning, increase the air exchange rate for the building for several days to reduce any mercury vapor concentrations. (See Appendix B to estimate the number of air changes per hour.) NOTE: If more than the amount in one thermometer was spilled on a wood floor or other porous material, use heaters to heat the room to about 30^{o}C while blowing the air to the outside

using a fan or blower for at least 48 hours. Treating the porous flooring with a sealant is an added safety option.

- **Step 19 – Medical monitoring:** If the spill resulted in acute exposure to a patient or health worker, conduct blood and urine tests, provide support for respiratory and cardiovascular function and, if necessary, initiate chelation therapy if the person is symptomatic of acute mercury poisoning.

- **Step 20 – Write a report on the spill incident:** Document the incident in keeping with the procedures of the health facility. The report can be used to improve safety in the facility.

The following should NOT be done in the event of a spill:

- Do not use a regular vacuum cleaner to pick up the mercury and mercury-contaminated items. The mercury will become airborne by way of the vacuum's exhaust and spread the contamination. Moreover, the vacuum cleaner will become contaminated and would have to be disposed as hazardous waste.

- Do not wash mercury-contaminated clothing, rugs or other fabrics in a washing machine. The washing machine and wastewater may become contaminated.

- Do not use a broom to sweep up the mercury. It can break the mercury into smaller beads, spreading them.

- Do not pour mercury down the drain. You may contaminate your plumbing, septic system, or your local sewage treatment plant.

- Do not spread mercury that has gotten onto your shoes. If possible, clean the shoes with the decontaminant solution (see Section 2.0, page 5). If the shoes cannot be decontaminated, wrap them in a plastic bag and dispose of them properly.

TEMPORARY ON-SITE STORAGE AT A HEALTHCARE FACILITY

1.0 General Guidelines for Temporary On-Site Storage[10]

The following general points should guide the design of on-site storage of mercury devices, mercury-contaminated waste, and elemental mercury:

SITING AND PREPARATION:

[10] Based on various sources including: "Technical Guidelines for the Environmentally Sound Management of Waste consisting of Elemental Mercury and Wastes Containing or Contaminated with Mercury," 5th Draft, Secretariat of the Basel Convention, Geneva, May 14, 2010; "Municipal Collections of Mercury," J. Alphin, South Central Recycling Association of Massachusetts; Chemical Control Order for Mercury and Mercury Compounds DENR No. 97-38, Philippine Department of Environment and Natural Resources, December 23, 1997.

- The storage space should be located in a secure, restricted-access area. If the storage space is in a multi-purpose building, it should be a locked room or locked partitioned space.

- The storage space should be readily accessible to personnel who are authorized to collect, store, and transport the waste.

- The exhaust vent from the storage space should not direct air towards crowded areas and should be far from any air intake vents.

- An estimate should be made of the anticipated volume of mercury and mercury waste to be stored and this value should be used to determine the minimum size of the storage space, and the types and sizes of containers. (See Appendix C.)

- Mercury waste should be kept segregated from regular waste, infectious waste, and other types of waste.

STORAGE SPACE DESIGN REQUIREMENTS:

- The storage space should have:
  - A roof and walls that protect from the weather, insects, and other animals; a sloping roof to drain water away from the site is preferred
  - Floor made of a material that is smooth and impervious to mercury[11]
  - If there is a drain in the storage space, it should have an easily accessible and replaceable drain trap to capture mercury in the event of a spill.

- The storage space should be locked to prevent theft.

- The storage space should have ventilation that can eject air from the space directly to the outside and ventilation controls that can stop air circulation from the storage space to the inside of the facility.

- The storage space should have bunding or barriers on the floor or a spill containment tray directly below the waste containers to prevent spills from spreading. The containment volume inside the bund wall or the containment volume of the tray should be at least 125% of the total volume of liquid mercury stored.

- Personnel protection equipment, a spill kit, and wash areas should be located near (but not in) the storage space for easy access by authorized personnel.

- The storage space should be kept cool and dry (ideally below 25°C to minimize volatilization and below 40% relative humidity to minimize corrosion if steel containers and shelves are used).

LABELING AND SIGNAGE:

- The entrance and exit doors of the storage space should be marked with warning signs, such as “Danger: Hazardous Mercury Waste” and the skull-and-crossbones symbol for toxic or poisonous waste.

[11] The floor should be non-porous and seamless. Examples include epoxy-coated cement, polyurethane coated floors, seamless rubber floors, polyester flooring, etc.; see also section on Properties (page 3) for examples of mercury-resistant materials.

- The waste containers should be labeled "Hazardous Mercury Waste" along with a description of the contents and the initial date of storage.

STORAGE OF ELEMENTAL MERCURY:

- When elemental mercury is stored for the purpose of accumulation, the primary container should have the following characteristics:
  - Easy to open and re-seal
  - Leak-proof, air-tight
  - Made of a material that does not react or amalgamate with mercury (see footnote in the Properties section on page 3)
  - Made of a material that is not brittle
  - Made of a material that resists corrosion
  - Small enough such that the weight of mercury is not too heavy to lift (a typical ergonomic weight limit is 23.5 kg)
  - Small enough such that the weight of mercury does not exceed the strength of the container (see Appendix C).

- When elemental mercury is stored for the purpose of accumulation, a vapor suppression agent or water should be added to the primary container to protect workers when adding more mercury. Workers should use PPE including respiratory protection.

- The primary container should be marked with the type of mercury waste and the date mercury was first placed in the container.

- When elemental mercury is stored, storage should include a secondary container that further prevents the release of mercury vapor as a redundant safety measure. If the secondary container is not transparent or the label on the primary container cannot be seen, a label should also be placed outside the secondary container.

- The mercury waste containers that are used for accumulation should be on top of a plastic pan or spill-control tray to catch any spills during filling. The containment volume of the pan or tray should exceed the total volume of liquid mercury stored in the container.

STORAGE OF MERCURY DEVICE:

- Since unbroken mercury devices (e.g., thermometers and sphygmomanometers) are fragile, they should be stored in a manner that reduces the chance of breakage.

- Since mercury devices may break during storage or transport, the primary container must be puncture-resistant and air-tight unless they are placed in their original portable cases or individual boxes used during shipment.

- The primary container should be marked with the type of mercury device, the quantities inside the container, the initial date of storage, and any additional description if necessary.

- As a redundant safety measure, the primary container should be placed in a secondary container that prevents release of mercury vapor in case the mercury devices break. If the secondary container is not transparent or the label on the primary container cannot be seen, a label should also be placed outside the secondary container.

STORAGE OF MERCURY-CONTAMINATED WASTE:

- Mercury-contaminated wastes that include broken glass or other items with sharp edges or points (e.g., broken thermometers) should be placed in a primary container that is puncture-resistant and air-tight. As a redundant safety measure, the primary container should be placed in a secondary container that further prevents the release of mercury vapor.

- Mercury-contaminated wastes that do not contain sharp edges or points or that do not result in sharp edges or points when dropped or smashed (e.g., contaminated rags, paper towels, or pieces of carpet) should be placed in an air-tight primary container. As a redundant safety measure, the primary container should be placed in a secondary container that further prevents the release of mercury vapor.

- The primary container should be marked with the type of mercury waste, the estimated amount, the date the material was placed in the container, and additional description if necessary. If the secondary container is not transparent or the label on the primary container cannot be seen, a label should also be placed outside the secondary container.

STORAGE OF DENTAL AMALGAM:

- When dental amalgam is stored for the purpose of accumulation, storage should include:
  - A primary container that is easy to open, re-sealable, leak-proof and air-tight
  - A vapor suppression agent or water in the primary container
  - A label with the type of mercury waste and the date mercury was first placed in the container.
  - A secondary container that further prevents the release of mercury vapor as a redundant safety measure. If the secondary container is not transparent or the label on the primary container cannot be seen, a label should also be placed outside the secondary container.

STORAGE OF FLUORESCENT LAMPS:

- When unbroken fluorescent lamps are stored, storage should include:
  - A primary container that prevents breakage, preferably the original box in which the lamps were shipped. (If available, a box with a well-sealed vapor-resistant liner, such as a plastic-foil liner, is recommended. Otherwise a long box or other box that fits the shape of the lamp can be used.)
  - A secondary container, such as a taped plastic sheet, that prevents the release of mercury vapor as a redundant safety measure. If the secondary container is not transparent or the label on the primary container cannot be seen, a label should also be placed outside the secondary container.
  - If the fluorescent lamps are stored in their original shipping cases, in a UN-approved fluorescent lamp drum or container, or in a box with a vapor-resistant liner, a secondary container is not required.
- Broken fluorescent lamps should be stored as mercury-containing waste.

GENERAL PROCEDURES:

- All personnel involved in collection, storage, transport, and supervision of mercury waste should receive special training on mercury waste management including spill cleanup.

- Material Safety Data Sheets and International Chemical Safety Cards on mercury (see Appendix D) should be available to the employees and discussed during training sessions.

- The storage space should be inspected every month to check for leaks, corroded or broken containers, improper methods of storage, ventilation, the condition of the PPE and wash area, spill kit contents, and updated records. Special attention should be given to waste that has the potential to generate the highest vapor concentrations (e.g., elemental mercury, sphygmomanometers, etc.).

- There should be no smoking or eating in and around the storage space.

- Inventory records should be kept of the types of mercury waste, descriptions, quantities in storage, and initial dates of storage.

2.0 Examples of On-Site Storage

The following are examples of acceptable storage options based on the guidelines above:

EXAMPLE 1 Hospital A

- Hospital A decides that the basement is a good place to site the storage space since it is off limits to patients and visitors but is readily accessible to the personnel involved in mercury storage.

- Hospital A estimates that they need to store 1000 unbroken fever thermometers, 20 unbroken sphygmomanometers, 500 broken thermometers, 350 liters of cleanup waste, 40 ml of elemental mercury that is being accumulated, 1.5 liters of amalgam waste being accumulated by the dentistry department, and 1260 linear T8 (1200 mm long) fluorescent lamps.

- Based on calculations using the above quantities, the storage plan is as follows:

    - The 1000 thermometers are carefully wrapped in a plastic bag and taped together to form a compact volume of about 2 liters; the thermometers—along with crumpled paper, plastic bubble wrap, or packing foam to prevent breakage—are then placed in a 3 liter stainless steel can with a tight-fitting lid (primary container). The outside of the can is marked with the quantity, description, and date. The can is placed inside a 4 liter, 2 or 3 mil (50 or 75 micron) thick, transparent, sealable plastic bag (secondary container).

    - The 20 unbroken sphygmomanometers are placed back in their original 2-liter cases which have labels that identify the contents (primary container). The cases are taped together in groups of 4 and placed in 2 to 4 mil (50 to 100 micron) thick garbage bags which are taped close with duct tape or strong adhesive tape (secondary container). A label is placed on the outside of the garbage bag.

    - The 500 broken thermometers are placed in a 3-liter, marked, stainless steel can (primary container). The can is placed inside a 4 liter, 2 or 3 mil (50 or 75 micron) thick, transparent, sealable plastic bag (secondary container).

    - The 350 liters of cleanup waste (contaminated rags, fabric and other materials that do not have sharp edges or points) are placed in multiple, 2 or 3 mil (50 or 75 micron) thick, sealable plastic bags (primary containers). The plastic bags are labeled and placed in two steel or plastic drums (secondary container), each with a capacity of 220 liters (55-gallons or 44 imperial gallons) and a gasketed, manual latching lid to prevent vapor release. The outside of the drums are labeled.

- The 40 ml of elemental mercury are stored in a marked, 100 ml, wide mouth, polyethylene terephthalate or PET bottle (primary container) that is at least 0.3 mm thick with a tight-fitting lid. [Note: Carbonated soda drink bottles are generally made of 0.3 mm thick PET plastic.] A small amount of water is added as a vapor suppressant. The bottle is placed inside a 6 mil (150 micron) thick, transparent, re-sealable plastic bag (secondary container), which in turn is placed on a plastic tray with raised edges.

- The 1.5 liters of dental amalgam are placed in a marked, 2-liter PET bottle (primary container) along with a dry vapor suppressant. The bottle is placed inside a 3 mil (75 micron) transparent, re-sealable plastic bag (secondary container), which in turn is placed on the plastic tray with raised edges.

- The 1260 T8 lamps are either placed in their original 42 cases which form a 1 m x 1 m x 1.25 m stack. Alternatively, they can be placed in 7 UN approved fluorescent lamp drums, each measuring 58.5 cm diameter x 123 cm high. The outside of the cases or drums are labeled.

- Hospital A determines that a 2 meter x 3 meter storage room in the basement is large enough to hold the mercury waste. The door to the room is marked "Danger: Mercury Waste". A hole is cut in the wall or ceiling to install an exhaust vent fan, which is connected to the existing electrical wiring. When turned on, the fan blows the air from the room out to an empty yard. The heating, ventilation and air-conditioning vents in the room are fitted with a mechanical damper plate or a pre-cut plastic sheet that can be taped to the vent to prevent air circulation to other parts of the hospital during a spill. A flexible plastic bunding strip, affixed to the floor by an adhesive, goes around the area where the mercury waste is stored to prevent any spill from spreading. Outside the door of the basement is a cabinet with a spill kit, PPE, MSDSs, a copy of the inventory, and other records.

- The healthcare waste management coordinator supervises mercury storage and uses a checklist to inspect the storage room every month. The coordinator and the other personnel involved in mercury waste receive special training on mercury waste management including spill cleanup.

EXAMPLE 2 Small Clinic B

- Clinic B determines that the laboratory is a good place to site the storage space since it is off limits to patients and visitors but is readily accessible to the personnel involved in mercury storage.

- Clinic B estimates that they need to store 20 unbroken fever thermometers, 2 unbroken sphygmomanometers, 10 ml of elemental mercury, and 300 ml of amalgam waste. No further accumulation of elemental mercury or amalgam is expected since the clinic has phased out mercury use.

- Based on calculations using the above quantities, the storage plan is as follows:

  - The 20 thermometers are carefully taped together and placed in a 500 cc, tall, wide-mouth, HDPE plastic bottle and cushioned with pieces of polystyrene foam--e.g., Thermocol or Styrofoam broken off from disposable coffee cups or from "peanuts" used for packing—to prevent breakage (primary container). The cap is sealed with tape and the bottle is marked with the quantity, description, and date. The bottle is placed inside a 150mm x 200mm, 50 micron thick, transparent, sealable plastic bag (secondary container).

- The 2 unbroken sphygmomanometers are wrapped in packing foam, taped up, and placed in a marked, rectangular, polypropylene container—such as a plastic food container—with a re-closable lid (primary container). The container is marked and placed in 50 micron thick, transparent garbage bags which is taped shut with adhesive tape (secondary container)

- The 10 ml of elemental mercury are kept dry in a small, 100 ml, stainless steel container with a tight-fitting lid (primary container). The container is clearly marked and the edges of the lid are sealed with tape. The container is placed inside a 50 micron thick, transparent, sealable plastic bag (secondary container).

- The 300 milliliters of dental amalgam are placed dry in a marked, 500 ml PET bottle (primary container) and the cap is sealed with tape. The bottle is placed inside a 50 micron thick, colored garbage bag which is sealed with adhesive tape (secondary container). The outside of the garbage bag is marked.

- Clinic B decides that the bottom shelf of a locked, steel, safety cabinet can serve as its storage space. The waste containers are placed in a plastic tray with raised edges to prevent spread of mercury in the event of breakage. The door to the cabinet is marked "Danger: Mercury Waste". The cabinet is next to the laboratory fume hood which discharges air directly to a hood exhaust stack that extends 2 meters above the roof line. A spill kit, PPE, MSDSs, a copy of the inventory, and other records are found in another part of the laboratory.

- The laboratory manager supervises mercury storage and inspects the storage cabinet every month. The manager and other personnel receive special training on mercury waste management including spill cleanup.

PACKAGING, LABELING, AND OFF-SITE TRANSPORT

The guidelines in this section are based on various sources.[12]

1.0 General Guidelines for Packaging and Labeling

Packaging:

- In preparation for transport, mercury waste should be placed in a transport container that is closed, structurally sound, compatible with the contents, and designed to prevent release of mercury. If the original transport case or box in

[12] "Storing, Transporting and Disposing of Mercury," U.S. Environmental Protection Agency, updated June 3, 2010 http://www.epa.gov/hg/spills/; "Technical Guidelines for the Environmentally Sound Management of Waste consisting of Elemental Mercury and Wastes Containing or Contaminated with Mercury," 5th Draft, Secretariat of the Basel Convention, Geneva, May 14, 2010; "Dangerous Goods Emergency Action Code List 2009," National Chemical Emergency Centre, AEA Technology, UK, 2009; "UN Recommendations on the Transport of Dangerous Goods - Model Regulations," Fifteenth revised edition, United Nations, 2007; "Management of Mercury Containing Equipment," Publication WA 1004-2006, Wisconsin Department of Natural Resources, 2006; "Municipal Collections of Mercury," J. Alphin, South Central Recycling Association of Massachusetts; "Mercury-Containing Lamp Waste Management: A Management Guidebook," Innogy Solutions, prepared for UNDP GEF, Philippine Efficient Lighting Market Transformation Project and Environmental Management Bureau; Chemical Control Order for Mercury and Mercury Compounds DENR No. 97-38, Philippine Department of Environment and Natural Resources, December 23, 1997.

which devices were shipped is still in good condition, it can be used for shipment of unbroken devices.

- The mercury waste should be packed carefully with packing material such as plastic bubble wrap or plastic packing foam to prevent breakage inside the container. Other packing options include bentonite clay (sold as commercial cat litter and found in Fuller's earth), kaolinite (sold for medicinal use, paper production, and farming), and vermiculite (used by gardeners as a soil conditioner, in packaging, and as insulation; note that some old vermiculite products sold before 1990 were contaminated with asbestos). These clay minerals can absorb mercury and act as a barrier to prevent spreading.[13] Commercial mercury absorbent products can also be used.

- The transport container should be tightly sealed to prevent escape of mercury if breakage occurs.

- NOTE on fluorescent lamps: The way fluorescent lamps are transported can be a health hazard. A study by the University of Minnesota School of Public Health that found that the way in which fluorescent lamps are packaged and sealed during transport makes a difference in terms of occupational and environmental health.[14] If only 5% of 30,000 lamps in a transport truck break, the transport workers will be exposed to 160 times the European Commission's recommended exposure limits. The researchers recommend placing the fluorescent lamps in a well-sealed vapor-resistant liner (such as a plastic-foil liner) inside an inner box which in turn is placed in an outer box that is structurally sound and adequate to prevent breakage.

Labeling:

- The outside of the container used for transport should have a clear label "Hazardous Mercury Waste."

- The label should also include content (chemical composition or description of the waste), warnings, special handling procedures if necessary, emergency contact numbers, and the name and contact information of the generator.

2.0 General Guidelines for Off-Site Transportation

Preparation:

- For transport of large amounts of mercury waste, the regulatory authority may issue special permits or licenses to the transporter and a special registration for the vehicle. The licensed transporter may be given a unique identification number or code. To obtain a license to transport mercury waste, the transporter may be required to undergo training specific to mercury waste, submit proof of liability insurance or guarantee bond, and provide copies of an emergency preparedness and emergency response plan. The training could include legal obligations,

[13] "Efficiency of industrial minerals on the removal of mercury species from liquid effluents," R. Melamed and A.B. da Luz, *Science of The Total Environment* 368 (1), 403-406, September 2006; "Mercury adsorption by montmorillonite and vermiculite: a combined XRD, TG-MS, and EXAFS study," M.F. Brigatti *et al., Applied Clay Science* 28 (1-4),1-8, January 2005; "Feasibility of compacted bentonite barriers in geological disposal of mercury-containing waste," R. Sjöbloma *et al*., *Applied Clay Science* 23 (1-4), 187-193, August 2003.

[14] "Preventing Mercury Vapor Release from Broken Fluorescent Lamps during Shipping," Tracy T. Glenz, Lisa M. Brosseau, and Richard W. Hoffbeck, *Journal of the Air & Waste Management Association* (Vol. 59, No. 3), March 2009.

planning, routing, handling, visual inspection, packaging, labeling, loading/unloading, securing, placarding, manifest or consignment forms, occupational safety, hazard recognition, hazard mitigation (including ways to minimize the possibility and the consequences of accidents), use of PPE, spill response planning, use of spill kits, emergency procedures, and accident reporting. The vehicle may be inspected and certified prior to obtaining a special vehicle registration.

- The regulatory authority may specify the maximum amounts above which a registered transporter is required. For example, the regulatory authority may allow a generator (hospital, clinic or other health facility) transporting less than 100 kilograms of mercury-containing waste,[15] less than 300 fluorescent lamps,[16] and less than 0.45 kilogram of elemental mercury[17] to transport the mercury waste by ground transportation to the storage facility in the generator's own vehicle; waste quantities above this limit would require a licensed transporter and a registered vehicle.

- A specially registered vehicle used to transport mercury care waste should fulfill some basic design criteria. Examples of the design criteria are as follows:[18]
  - The registered vehicle should be a closed vehicle.
  - The body of the vehicle should be of a suitable size commensurate with the design of the vehicle and the load to be transported.
  - There should be a bulkhead between the driver's cabin and the vehicle body, which is designed to retain the load if the vehicle is involved in a collision.
  - There should be a suitable system for securing the load during transport.
  - Empty air-tight containers, plastic bags, PPE, spill kits, cleaning equipment, and decontaminating agents should be carried in a separate compartment in the vehicle.
  - The registered vehicle should be marked with the name and address of the waste carrier.

- The licensed transporter should have appropriate warning signs and placards displayed on the registered vehicle in accordance to national or international regulations. Mercury compounds are generally categorized under Class 6.1 (toxic substances) and elemental mercury (UN number 2809) under Class 8 (corrosive substances). In countries that require Emergency Action Codes, elemental mercury is a 2X (fine water spray, liquid tight chemical protective clothing). Examples of placards are shown below:

[15] Based on the monthly hazardous waste generation limit for Conditionally Exempt Small Quantity Generators under U.S. EPA regulations 40 CFR 261.5.
[16] Based on the small quantity generator in "Mercury-Containing Lamp Waste Management: A Management Guidebook," Innogy Solutions, prepared for UNDP GEF, Philippine Efficient Lighting Market Transformation Project and Environmental Management Bureau.
[17] Based on the Reportable Quantity of the U.S. Department of Transportation regulations 49 CFR Part 173.164.
[18] Adapted from *Safe management of wastes from health-care activities*, 2nd Edition, World Health Organization, Geneva, expected release in 2010.

- The transporter should have a routing plan, emergency response or contingency plan, and emergency phone numbers before transporting mercury waste. The transporter should also have a spill kit, PPE, first-aid kit, fire extinguisher, labels, and extra containers in the passenger compartment for use in case of a spill.

Off-Site Transport of Mercury Waste:

- Before transporting the waste, the transporter should inspect all the waste containers to ensure that they are packed and labeled properly.

- Whether transporting the mercury waste in a registered vehicle or in the generator's own vehicle, the waste containers should be placed in the back of the vehicle (cargo compartment of a truck or lorry, back trunk or boot of a car) and not in the passenger section.

- All waste containers should be firmly secured such that the containers do not tip over, slide, or shift during accelerations, stops, turns, and driving over bumps and holes on the road.

- Containers should not be stacked more than 1.5 meters high to avoid crushing items.

- The transport vehicle should be kept locked whenever there is waste in the vehicle except during inspection, loading, and unloading.

- The transporter should transport the waste as soon as possible using the safest or most direct route to the storage facility. If the transporter collects mercury waste from multiple facilities, the routing plan should reflect the shortest and safest route to minimize time and distances traveled. The transporter should transfer the waste only to the storage facility or to another licensed transporter.

- The transport vehicle should be kept clean and maintained in good running condition.

- Ideally, the registered vehicle should be used to transport mercury and other hazardous wastes only. However, if the vehicle is used to transport other types of wastes, the vehicle should have a sealed, bulk container that is used only for mercury and other hazardous wastes and that can be removed from or lifted on to the vehicle chassis.

MANIFEST SYSTEM:

- A manifest form or consignment note must accompany the movement of mercury waste.

- The manifest or consignment note should identify the source of the waste, the transporter, the storage facility, and the relevant government authority.

- The generator, transporter, and storage facility should each have copies of the manifest or consignment note. Each copy should contain the signatures of the persons handling the waste from the generator to the storage facility, as well as the names of the responsible persons representing the generator, transporter, and storage facility. Copies of the manifest or consignment note should be kept by the generator, transporter, and storage facility.

- The generator should keep a copy of the manifest or consignment note for at least five years from the date of shipment. The licensed transporter should keep a copy of the manifest and other records of each shipment for at least five years from the date of shipment, and these records should be made available to the regulatory authority as may be required by law.

INTERMEDIATE STORAGE AT A CENTRAL FACILITY

1.0 General Design Guidelines for Intermediate Storage

These general guidelines relate to a centralized facility that will be used for intermediate storage, i.e., until such time as long-term storage (terminal storage) or mercury treatment and disposal facilities become available in the country.

These guidelines do *not* apply to facilities used for mercury processing or other operations that require opening of mercury containers, such as mercury scrap grading, mercury recovery from mercury-rich wastes, transferring elemental mercury to other containers (except for emergencies), etc. These processing facilities require other occupational and environmental safety features beyond the scope of these guidelines.

The guidelines are based on several sources.[19] The following general points should guide the design of an intermediate, centralized storage facility for mercury waste:

SITING AND PREPARATION:

- The intermediate storage facility should be at least 150 meters away[20] from schools, healthcare facilities, residences, densely populated areas, food processing facilities, animal feed storage or processing facilities, agricultural operations, bodies of water (lakes, river, ocean, etc.), and environmentally sensitive areas.

- The storage facility should be located in a secure area to prevent theft.

[19] "Technical Guidelines for the Environmentally Sound Management of Waste consisting of Elemental Mercury and Wastes Containing or Contaminated with Mercury," 5th Draft, Secretariat of the Basel Convention, Geneva, May 14, 2010; "Development of Options Analysis and Pre-Feasibility Study for the Long Term Storage of Mercury in Asia and the Pacific," (Draft Report), March 18, 2010; "U.S. Department of Energy Interim Guidance on Packaging, Transportation, Receipt, Management, and Long-Term Storage of Elemental Mercury," Oak Ridge National Laboratory, prepared for the U.S. Department of Energy, Washington, DC, November 13, 2009; "Terminal Storage Options of Mercury Wastes in the Philippines," Ban Toxics!, March 31, 2009; "Meeting DNSC's Mercury Challenge," Defense National Stockpile Center, Defense Logistics Agency, June 14, 2007; "Mercury flows and safe storage of surplus mercury," Concorde East/West Sprl, prepared for European Commission Directorage General for Environment, Brussels, August 2006; "Mercury Stewardship Storage of Mercury," Quicksilver Caucus, October 2003; "Preliminary Analysis of Alternatives for the Long Term Management of Excess Mercury," EPA/600/R-03/048, U.S. Environmental Protection Agency, August 2002.

[20] See Appendix D

- The storage facility should be accessible to trucks and other vehicles that transport mercury waste.

- The storage facility should be located in an area that is not prone to natural disasters, such as flooding, typhoons, hurricanes, brush fires, and earthquakes. If this is not possible, measures should be taken to withstand or ameliorate the effects of natural disasters, such as building an earthquake-resistant structure or conducting seismic retrofitting, building on higher elevations in flood plains, maintaining fire lines and using fire-resistant materials to prevent brush fires, etc.

- Where possible, the location should have a cool climate to minimize mercury volatilization and a dry atmosphere to reduce corrosion.

OVERALL DESIGN REQUIREMENTS:

- The size of the storage area should be sufficient to hold safely the anticipated volume of mercury waste from the region being served. The estimated maximum volume should account for the different types of waste (elemental mercury, contaminated broken glassware, undamaged mercury thermometers and sphygmomanometers, other mercury-containing medical devices, fluorescent lamps, dental amalgam), their respective packaging, and the necessary space needed for shelving or storage racks, aisles, transport carts, etc. NOTE: When using an existing facility, the size of the existing storage space should determine the maximum volume of mercury waste that can be stored safety in the facility taking into consideration the types of mercury waste, their packaging, and other necessary space. Storage facilities should not exceed the maximum limit.

- The storage facility should be very secure with closely controlled access and an intrusion detection and alarm system.

- The facility should have static or natural ventilation. This should be supplemented by air conditioning to control temperature and humidity.

- Fires pose a high catastrophic potential. The storage facility should have a heat, smoke and fire detection and alarm system, and a fire suppression system. It should comply with national building code requirements for fire prevention. Fire extinguishers should be installed, inspected regularly, and recharged when needed. The kinds of fire extinguishers available should be consistent with the classes of fires that may be possible in the facility (e.g., paper, cardboard, or plastic fires; combustible liquid fires; electrical fires; etc.). Furthermore, selection of fire extinguishers should take into consideration the need for personnel safety, limiting the spread of mercury droplets and vapor, mercury cleanup and recovery after the fire, and avoiding stress corrosion of containers and shelves.

- The storage facility should have at least four distinct and separate functional areas:
  1. *Receiving area* for receiving and presorting waste, re-labeling if necessary, and signing documents
  2. *Inspection area* for checking for leaks, repackaging, secondary containment, and re-labeling if necessary
  3. *Storage area* specific for mercury waste
  4. *Administrative and record-keeping area*.

- PPE, spill cleanup kits, first-aid medical supplies, and wash areas should be located in the receiving area, inspection area, and near but not in the storage

area. The PPE, spill kits, first-aid supplies, and wash areas should be easily accessible to personnel. Spill kits should include absorbent pads, plastic liners, vapor suppression and decontamination agents. The PPE should include:

- Rubber or nitrile gloves
- Safety goggles
- Respiratory protection: self-contained breathing apparatus (SCBA) for large spills, fit-tested full- or half-facepiece air-purifying respirator with mercury vapor cartridges, face mask with sulfur or iodide impregnated activated carbon, face mask made of sandwiched activated charcoal-impregnated cloth, or other mask designed specifically for mercury
- Polymer or rubber-based, protective full-body suits for large spills and protective coveralls
- Disposable shoe covers
- Helmets.

- The drains in the receiving, inspection, and storage areas should be connected to a separate wastewater collection system and not to the regular sewer system nor to surface water. Drains in the storage facility should have an easily accessible and replaceable drain trap to capture mercury in the event of a spill.

RECEIVING AREA:

- The receiving area should have a sign to guide and instruct waste generators and transporters.

- The receiving area should have: a presort table for incoming waste; a cart made of impervious material such as steel, rubber or hard plastic (do not use aluminum carts); spill kits and emergency supplementary containers for leaking containers or broken packaging; PPE for the staff; and a separate table or counter for signing documents.

- A cart should be used to transfer the waste to the inspection area and to move the waste around the facility.

INSPECTION AREA:

- The inspection area should be located near the receiving and storage areas. Because of the possibility that leaking containers may be brought in, the inspection area should have engineered spill-control features including containment dikes or bunding on the floor.

- The inspection area should have a mercury vapor detection probe (see mercury vapor monitors below), detector tubes[21], or other methods to detect leaking mercury containers.

- The inspection area should have local exhaust ventilation, such as a fume hood or enclosed hood, built in accordance to national guidelines. Ideally, the hood should be connected to an activated carbon filter or other device specifically designed to remove mercury before the air is discharged. The minimum average face velocity of the hood, when in use, should be about 0.5 meters per second.

[21] Examples of mercury detection tubes (which are generally cheaper than continuous mercury monitors) include AUER/MSA (http://www.msanet.com/), Dräger (http://www.draeger.com/GC/en/index.jsp), Gastec (http://www.gastec.co.jp/english/index.php), Matheson-Kitagawa (http://www.mathesontrigas.com/pdfs/products/Model-8014-Kitagawa-Precision-Detector-Tubes.pdf), and Sensidyne, LP (http://sensidyne.com/index.php).

The exhaust stack should be at least 15 meters away from any fresh air intakes to the building and should extend at least 3 meters above the roof line. When the hood is in use, the exhaust air velocity should be at least 15 meters per second to overcome downdraft effects.

- The inspection area should have a spill control tray or containment device over which the waste should be inspected. The containment volume of the tray should be large enough to hold the maximum amount of liquid mercury expected by the facility to be received for inspection.

- The inspection area should have emergency supplementary containers to be used for leaking containers, packaging to replace broken or inadequate packaging, labels for re-labeling containers, spill kits, and PPE for the staff.

STORAGE AREA:

- The storage area specific for mercury waste should be clearly marked with warning signs on all doors leading to the storage area. Copies of the spill response and emergency procedures should be on display in the storage area and kept with the spill cleanup kits and PPE.

- The storage area for mercury waste should have continuous or periodic monitoring of mercury levels in ambient air using mercury vapor monitors.[22] Periodic monitors should sample mercury levels at least daily. The monitoring equipment should be able to detect mercury in air in parts per billion.[23]

- The storage area specific for mercury waste should have engineered spill-control features to prevent mercury spills from exiting the area; these should include:
  - Flooring that does not have cracks, seams, or other openings where mercury could get lodged in
  - A floor sealant system that is impervious to mercury and makes it easy to collect spilled mercury[24] such as a durable (6 mm thick) plastic flooring or seamless epoxy-coated concrete
  - Suitable containment dikes incorporated into the floor sealant on all doors of the storage area.

- Mercury waste from health facilities may be segregated according to the following risk categories based on the amounts of available mercury:[25]

[22] Examples of continuous monitors include Tekran Continuous Emission Monitors (http://www.tekran.com/), Lumex Mercury Analyzers (http://www.lumex.biz/), Mercury Instruments Mercury Vapor Monitors (http://www.mercury-instrumentsusa.com/), Mercury Instruments GmbH (http://www.mercury-instruments.com/EN/index-en.html), Brooks Rand Labs (http://www.brooksrand.com/), Arizona Instrument (http://www.azic.com/industry_mercury.aspx), and PS Analytical (http://www.psanalytical.com/index.html). The monitors can be supplemented with mercury passive samplers for workers (e.g, SKC Inorganic Mercury Passive Sampler, http://www.skcinc.com/index.asp).

[23] The exposure limit of 0.02 mg per m^3 is equivalent to 2.4 ppb at 20°C or 68°F. The equipment should be able to detect at this level.

[24] The Hawthorne Mercury Storage Site in Nevada uses "Terra-Nap flooring and ramps" (D. Lynch, Defense National Stockpile Center, presented at the "Commodity-Grade Mercury Stakeholder Meeting," July 24, 2007.

[25] Typical fluorescent lamps contain around 5 to 10 mg of mercury each. The mercury released by breaking only one sphygmomanometer or by breaking 100 thermometers is equivalent to the mercury released by breaking 10,000 fluorescent lamps. Since mercury from only one thermometer is enough to contaminate a 20-acre lake such that the fish would be unsafe to eat ["The Mercury Problem: Fast Facts," in *Going Green: A Resource Kit for Pollution Prevention in Health Care*, Health Care Without Harm, Washington, DC, 2002], a release involving a number of thermometers and sphygmomanometers could potentially be a grave environmental and public health problem.

- Risk Level 1 (highest risk): elemental mercury, unbroken sphygmomanometers, and medical devices containing large amounts of mercury (gastro-intestinal tubes, esophageal dilators, large mercury float switches and relays from electrical equipment)
- Risk Level 2: unbroken mercury thermometers, small mercury switches and small relays from electrical equipment
- Risk Level 3: broken glassware contaminated with mercury, mercury cleanup waste
- Risk Level 4: fluorescent lamps, compact fluorescent bulbs, dental amalgam.

- Shelving and storage racks for Risk Levels 1 and 2 should be fitted with plastic containment trays or shelves made of a material impervious to mercury such as steel. The containment volume of each tray should be at least 125% of the total volume of liquid mercury stored on the tray. An option is the use of slightly sloped storage rack for containers of elemental mercury to facilitate discovery of leaks. This is not necessary if continuous monitoring of mercury levels is conducted.

- Shelving and storage racks should be able to support the weight of mercury waste and have back-and-side cross bracing or back-and-side panels to prevent sway. The shelves and racks should not be above shoulder height.

- In areas of seismic activity, additional bracing, straps, and cushioning of containers are necessary to prevent movement and breakage of containers, especially for Risk Levels 1 and 2.

- In facilities that store other types of hazardous waste, mercury waste should not be stored near incompatible chemicals such as acetylene, alkali metals (lithium, sodium), aluminum, amines, ammonia, calcium, fulminic acid, halogens, hydrogen, nitric acid with ethanol, oxalic acid, and oxidizers.

- Lighting, aisle space, stacking, arrangements of containers, and placement of labels and markings should be designed to facilitate inspection of the storage area.

- The storage area should be designed to facilitate the transfer of mercury waste to a long-term (terminal) storage facility or a treatment and disposal facility in the future.

ADMINISTRATIVE AND RECORD-KEEPING AREA:

- The administrative and record-keeping area should be separated from the receiving, inspection, and storage areas. Records should be maintained in good order and kept in a secure location.

- The administrative and record-keeping area should maintain copies of MSDSs and international chemical safety cards which should be readily available to the staff.

- The storage facility should be a non-smoking facility. There should be no eating in the storage area.

2.0 General Procedures for Intermediate Storage

MANIFEST SYSTEM:

- A manifest form or consignment note must accompany the movement of mercury waste.

- The manifest or consignment note should identify the source of the waste, the transporter, the storage facility, and the relevant government authority.

- Copies of the manifest or consignment note should be kept by the generator, transporter, and storage facility.

- Copies of the manifest or consignment note should be kept by the storage facility until the waste is removed from the facility. The copies should be made available to the relevant government authority according to national regulations.

STORAGE FACILITY PROCEDURES:

- Storage facilities should comply with licensing and registration requirements and other provisions under the country's laws and regulations. In order to receive a license, the storage facility may be required to submit an ambient air monitoring plan, proof of liability insurance or guarantee bond, emergency preparedness and emergency response plan, description of waste management practices and other procedural guidelines, personnel training, and overall facility design. The storage facility may be inspected to ensure compliance with building, fire, electrical, and other health and safety codes prior to licensing. The regulatory authority may assign a unique identifier number or code to each storage facility.

- Storage facilities should submit periodic reports regarding safety issues (including accidents and spills), storage conditions, capacity, and monitoring data to the designated government authority, as may be required by the country's laws and regulations.

- Storage facilities should have a hazardous waste management plan which establishes procedures for receiving waste, internal transport, waste inspection, re-labeling, repackaging, supplementary containment, storage, facility inspection, general cleaning (housekeeping), spill control, spill cleanup, emergency procedures, worker safety (including hazard identification, hazard mitigation, proper use of PPE, ergonomic techniques for handling waste, and medical surveillance), reporting, and record-keeping.

- All storage facility staff should be familiar with all aspects of the hazardous waste management plan, receive initial and periodic refresher training, and be equipped to handle spills and other emergencies.

- When receiving the waste, the containers should go through an initial visual inspection to determine the condition of the packaging and containers without opening the primary and secondary containers. If a leak or breakage is suspected, the waste should be brought immediately to the inspection area.

- After the initial inspection, the waste should be brought to the inspection area for a more detailed inspection of the physical integrity and seal of the primary and secondary containers, to check for possible breakage of contents and proper labeling, and to validate the amount of mercury waste (e.g., weight of containers, number of bags, number of fluorescent lamps, etc.). If outer containers have to be opened to test for suspected leaks, this should be done under the fume hood (local exhaust ventilation). Mercury probes or detector tubes could also be used to verify suspected leaks.

- The storage facility should have clear guidelines on repackaging and supplementary containment if outside packaging is inadequate or if primary or secondary containers are broken. If there are indications of a leak in the primary

and/or secondary container, the waste should be placed in an air-tight supplementary container of the appropriate size and strength.

- The storage facility should have clear labeling guidelines that describe when a label should be replaced. The labels should say "Hazardous Mercury Waste" and include the content (chemical form, composition, or description of the waste), warnings, special handling procedures if necessary, emergency numbers, and the name and contact information of the generator. The storage facility should add the following information to the existing label or in an additional label: UN number or hazardous substance identification number used by the country for mercury, hazardous waste description (toxic, corrosive for elemental mercury), date that the waste was received, and an identification code that links to a specific record with additional details about the waste, measured quantity, the transporter, and the generator.

- The storage area for mercury waste should be routinely monitored, including daily readings of mercury levels in ambient air; weekly inspections for leaks and corroded or broken containers, and improper methods of storage, as well as routine tests of the burglar alarms, fire alarms, fire suppression systems, and exhaust ventilation; and monthly inspections of the condition of the PPE and wash units, spill kit contents, flooring (to check for cracks), and files. Inspection logs including the inspection dates, observations, name, and signature of the inspector should be kept and made available to regulatory authority as may be required by law.

- During facility inspection, if a container is found to show signs of losing its physical integrity, the container should be removed from the shelf, carefully inspected under the fume hood, placed inside a supplementary container, and then re-labeled before being returned to the shelf.

- Records should be kept until such time that the mercury waste is transferred to a long-term (terminal) storage facility or to a treatment and disposal facility. The records should be linked to an identifier number or code on the mercury waste labels.

- The records should include the name and contact information of the source of mercury waste (including generator identification number if available), the quantities (number of containers, weights, approximate volumes) and descriptions of the waste (including composition and information on how the mercury waste was generated), special handling procedures or warnings if appropriate, the date when the waste was received, name and contact information of the transporter (including transporter identification number if available), the name of the person receiving and inspecting the waste, any notes or observations on the condition of the waste when received, any corrective actions taken (e.g., repackaging or re-labeling), the manifest or consignment note, and appropriate signatures.

- Records of accidents, spills, worker injuries, and chemical exposure should also be kept by the storage facility and made available to relevant government authorities, as may be required under the country's laws and regulations.

- Due to the significant risk of adverse health effects as a result of exposure to mercury at the facility, a health surveillance or medical monitoring program should be established.

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UNDP GEF Global Healthcare Waste Project

With inputs from S. Khalil, G. McRae, PhD,
T. Schettler, MD, M. Rathi, PhD, and D. Sarmiento

21 July 2010

Appendix A

FIRST AID FOR EXPOSURE TO MERCURY[26]

What should I do if someone becomes ill from breathing Mercury?
Take proper precautions to ensure your own safety before attempting rescue (e.g. wear appropriate protective equipment). Remove source of contamination or move victim to fresh air. If breathing is difficult, oxygen may be beneficial if administered by trained personnel, preferably on a doctor's advice. DO NOT allow victim to move about unnecessarily. Symptoms of pulmonary edema can be delayed up to 48 hours after exposure. Immediately transport victim to an emergency care facility.

What do I do if someone gets Mercury on their skin?
Avoid direct contact. Wear chemical protective clothing, if necessary. Quickly and gently blot or brush away excess chemical. Wash gently and thoroughly with water and non-abrasive soap for 5 minutes or until the chemical is removed. Remove contaminated clothing, shoes and leather goods (e.g. watchbands, belts). Obtain medical advice. Completely decontaminate clothing, shoes and leather goods before re-use or discard.[27]

What do I do if someone gets Mercury in their eyes?
Avoid direct contact. Wear chemical protective gloves, if necessary. Quickly and gently blot or brush away excess chemical. Immediately flush the eye(s) with lukewarm, gently flowing water for 5 minutes or until the chemical is removed, while holding the eyelid(s) open. Obtain medical advice immediately.

What do I do if someone swallows Mercury?
NEVER give anything by mouth if the victim is rapidly losing consciousness, is unconscious or is convulsing. Have victim rinse mouth thoroughly with water. DO NOT INDUCE VOMITING. Obtain medical attention immediately.

Is there anything else I need to know about first aid?
Provide general supportive measures (comfort, warmth, rest).

Some recommendations in the above sections may be considered medical acts in some jurisdictions. These recommendations should be reviewed with a doctor and appropriate delegation of authority obtained, as required. All first aid procedures should be periodically reviewed by a doctor familiar with the material and its conditions of use in the workplace. Mercury can accumulate in the body and cause significant long-term health effects. Medical advice should be sought following any exposure.

Note: For information on symptoms and medical treatment:
http://emedicine.medscape.com/article/819872-overview
http://www.atsdr.cdc.gov/mhmi/mmg46.html
http://www.wrongdiagnosis.com/m/mercury_poisoning/treatments.htm

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[26] From the "First Aid for Exposure to Mercury," Canadian Centre for Occupational Health and Safety, http://www.ccohs.ca/oshanswers/chemicals/chem_profiles/mercury/firstaid_mercury.html; see also "Medical Management Guidelines for Mercury," Agency for Toxic Substances and Disease Registry, http://www.atsdr.cdc.gov/MMG/MMG.asp?id=106&tid=24

[27] Materials should be treated thoroughly with decontaminant solution (see footnote on Section 2.0), then washed with soap and water, dried, and inspected carefully.

Appendix B

ESTIMATING ACH TO REDUCE MERCURY CONCENTRATIONS BELOW THE EU LIMIT

How many air changes per hour (ACH) are needed to reduce the mercury concentration in air below the EU limit (20 µg/m^3) after the release of mercury from one broken thermometer? One mercury thermometer has about 1 g of Hg. During breakage, the liquid mercury can be found in the form of small spheres. The evaporation rate can be modeled based on mass transfer from a sphere to a flowing air stream. For the purpose of this estimation, a reference space of 100 m^3 at 25°C is assumed. Also, a 20" electric fan rated at 2100 CFM is assumed to be placed next to the spill area to generate an air velocity (*V*) of about 5 m/sec thereby volatilizing the liquid mercury.

If one ball of mercury is formed, the sphere will have a diameter (*D*) of 0.52 cm, a surface area (*A*) of 8.5x10^{-5} m^2, and a density (ρ) of 13.5 g/cm^3. Mercury has the following properties: viscosity (µ) of 1.53 centipoise, kinematic viscosity of 1.13 x 10^{-7} m^2/s, and an air-vapor diffusivity (δ) of 1.4 x 10^{-5} m^2/s. To estimate the mass transfer coefficient *h*, the following correlation for mass transfer past single spheres can be use:[28,29]

Range	Equation
$Sc = 0.6 \text{ to } 3200$	$Sh = Sh_0 + 0.347(ReSc^{0.5})^{0.62}$
$ReSc^{0.5} = 1.8 \text{ to } 600000$	$Sh_0 = \begin{cases} 2.0 + 0.569(GrSc)^{0.25} & GrSc < 10^8 \\ 2.0 + 0.0254(GrSc)^{0.333}Sc^{0.244} & GrSc > 10^8 \end{cases}$

The Schmidt (*Sc*), Reynolds (*Re*), Grashof (*Gr*), and Sherwood (*Sh*) numbers are dimensionless parameters defined as follows:

$$Sc = \frac{\mu}{\rho\delta} \qquad Re = \frac{\rho VD}{\mu} \qquad Gr = \frac{gD^3\Delta\rho}{\rho}\left(\frac{\rho}{\mu}\right)^2 \quad Sh = \frac{hD}{\delta}$$

where *g* is gravitational acceleration and Sh_0 is the Sherwood number when *Re*=0. Although *Sc* (0.0080) is outside the range, it is assumed that the correlation holds at this lower Schmidt number. The convective evaporation flux E_f is given by

$$E_f = \frac{E}{A} = h(\rho_i - \rho_\infty)$$

where *E* is the evaporation rate, *A* is the surface area, *h* is the mass transfer coefficient, ρ_i is the vapor density at the mercury-air interface, and ρ_∞ is the vapor density in the air stream which can be considered negligible in relation to ρ_i. Assuming an ideal gas, the evaporation rate can be given by

$$E = hA(MW)\frac{P_v}{RT}$$

where *(MW)* is the molecular weight, P_v is the vapor pressure at the interface, *R* is the ideal gas constant, and *T* is the temperature. From this, one obtains an evaporation rate of 5.5x10^{-5} g/min. The required air changes per hour for a 100 m^3 reference space is given by the equation

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[28] R.E. Treybal, *Mass-Transfer Operations*, Third Edition, New York: McGraw-Hill Book Company, 1980.
[29] R. Steinberger and R.E. Treybal, "Mass Transfer from a Solid Soluble Sphere to a Flowing Liquid Stream," *AIChE Journal*, 6(2), 227-232 (1960).

$$ACH_{100} = \frac{60000\ E}{\rho_i (REL) Q_{100}}$$

where ACH_{100} is the required air changes per hour for the 100 m^3 room, E is in g/min, (REL) is the regulatory exposure limit for mercury in ppmv (0.002), and Q_{100} is the room space (100 m^3). For the evaporation rate of one ball of mercury, the required ACH_{100} is about 2. If one were to assume that mercury breaks into 5 smaller balls of equal size, the resulting evaporation rate is 1.1×10^{-4} g/min, with a corresponding required ACH_{100} of 4. If mercury breaks into 10 even smaller balls of equal size, the corresponding ACH_{100} needed is 6 (this value is used in the final equation below). Many regulatory authorities require laboratories to have an *ACH* of between 4 to 12. On the other hand, if 75% of the mercury is recovered and removed, the remaining mercury in the form of one ball would require a corresponding ACH_{100} of 0.3; this shows the importance of removing as much of the mercury as possible.

To estimate the required air changes per hour (*ACH*) needed to reduce the mercury levels to a concentration below the EU limit (20 µg/m^3) after the release of mercury from one broken thermometer in a room of some volume *Q*, the following equation can be used:

$$ACH = \frac{600}{Q}$$

where Q is in m^3. Hence a 50 m^3 room would need 12 ACH.

After a mercury spill involving one thermometer, as much mercury as possible should be collected and removed. An electric fan or blower operating at the highest setting can then be placed next to the spill area to volatilize as much mercury as possible. The fan or blower should be pointed in such a way as to move the mercury vapors towards the local exhaust vent or chemical fume hood. The exhaust fan or fume hood should be capable of achieving the required *ACH* to keep mercury levels below the EU limit while releasing the remaining mercury vapors out of the building. If an exhaust fan is not available, a second electric fan or blower can be placed on a window or door in such a way as to pull the vapors out of the facility.

Appendix C

SOME USEFUL DATA ON MERCURY

CAS #	7439-97-6
UN #	2024 (liquid mercury compounds); 2025 (solid mercury compounds); 2028 (mercury)
Molecular weight	200.59 g per mol
Melting point	-38.87^0C
Boiling point	356.73^0C
Density of mercury	13.5 g per cm^3 at 25^0C
Vapor pressure of mercury	0.26 Pa at 20^0C or $2x10^{-3}$ mmHg at 25^0C
Relative vapor density of mercury	6.93 (air=1)
Occupational exposure limit (EU)	0.02 mg/m^3 in air
Threshold Limit Value (ACGIH)	0.025 mg/ m^3 in air (8-hr day, 40-hr wk ave)
Conversion factors for mercury vapor in air	1 ppm (v/v) = 8.18 mg/m^3; 1 mg/ m^3 = 0.122 ppm
Solubility in water	62 µg per liter at STP
K_{ow} partitioning coefficient	5.95
Volume corresponding to 23.5 kg[30]	1.7 liters Hg (not including container weight)
Density of dental amalgam	11 g per cm^3
Amount of mercury in a thermometer	about 1 g (range: 0.5 - 1.5 grams)
Typical dimensions of a fever thermometer	length 110 mm x diameter 4.3 mm
Typical weight of a fever thermometer	about 5 g
Amount of mercury in a sphygmomanometer	range: 80 - 200 grams
Typical dimensions of a sphygmomanometer	5 cm x 12 cm x 35 cm
Amounts of mercury in fluorescent lamps[31]	10 - 50 mg (non-mercury reduced linear lamps) 4.4 - 10 mg (4ft linear, T12, low efficiency) 1.4 - 5 mg (4ft linear, T5 & T8, high efficiency) 10 - 15 mg (circular, T9, low efficiency) 5 - 9 mg (circular, T5, high efficiency) 1 - 5 mg, up to 25 mg (compact fluorescent lamps) 25 mg (75W) and 225 mg (1500W) high intensity discharge lamps, Hg or sodium vapor lamps Up to 500 mg/4 ft (neon signs)
Conversion factor for plastic bag thickness	1 mil = 25 microns

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Equation to estimate the maximum height of mercury in a container so as not to exceed the yield strength of the container[32]

$$h < 3400\ \sigma\ t / D$$

where h (in cm) should be the maximum height of mercury in the container, σ (in MPa) is the tensile strength of the material that the container is made of, t (in cm) is the thickness of the container wall, and D (in cm) is the diameter of the container. Typical tensile strengths for plastics are: 47 – 79 MPa for PET (or polyethylene terephthalate); about 65 MPa for polycarbonate; 26 – 53 MPa for HDPE; 12 – 43 MPa for polypropylene; and 8.6 – 27 for LDPE. The tensile strengths for steel are 250 MPa for structural steel and 502 MPa for stainless steel.

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[30] Original recommended NIOSH weight limit for manual lifting under ideal conditions.

[31] "Mercury in Lighting Equipment," Alicia Culver (Green Purchasing Institute, Berkeley, CA), presented at the EEB Conference, Brussels, Belgium, June 27, 2008; Environment Canada, "Fluorescent Lamps" website: http://www.ec.gc.ca/mercure-mercury/default.asp?lang=En&n=2486B388-1

[32] Based on calculating the hoop stress assuming a thin walled cylinder and using the von Mises criterion.

Appendix D

SAMPLE MATERIAL SAFETY DATA SHEET[33]

Mercury

ACC# 14020

Section 1 - Chemical Product and Company Identification

MSDS Name: Mercury
Catalog Numbers: 13-410, 13-411, 13-480, 13-481, 13-482, 13-485, 13501, M139-1LB, M139-5LB, M140-14LB, M140-1LB, M140-5LB, M141-1LB, M141-6LB
Synonyms: Colloidal mercury; Hydrargyrum; Metallic mercury; Quick silver; Liquid silver.
Company Identification:
Fisher Scientific
1 Reagent Lane
Fair Lawn, NJ 07410
For information, call: 201-796-7100
Emergency Number: 201-796-7100
For CHEMTREC assistance, call: 800-424-9300
For International CHEMTREC assistance, call: 703-527-3887

Section 2 - Composition, Information on Ingredients

CAS#	Chemical Name	Percent	EINECS/ELINCS
7439-97-6	Mercury	100	231-106-7

Section 3 - Hazards Identification

EMERGENCY OVERVIEW

Appearance: silver liquid.
Danger! Causes irritation and possible burns by all routes of exposure. Corrosive. Harmful if inhaled. May be absorbed through intact skin. May cause central nervous system effects. This substance has caused adverse reproductive and fetal effects in animals. Inhalation of fumes may cause metal-fume fever. May cause liver and kidney damage. Possible sensitizer.
Target Organs: Blood, kidneys, central nervous system, liver, brain.

Potential Health Effects
Eye: Exposure to mercury or mercury compounds can cause discoloration on the front surface of the lens, which does not interfere with vision. Causes eye irritation and possible burns. Contact with mercury or mercury compounds can cause ulceration of the conjunctiva and cornea.
Skin: May be absorbed through the skin in harmful amounts. May cause skin sensitization, an allergic reaction, which becomes evident upon re-exposure to this material. Causes skin irritation and possible burns. May cause skin rash (in milder cases), and cold and clammy skin with cyanosis or pale color.
Ingestion: May cause severe and permanent damage to the digestive tract. May cause perforation of the digestive tract. May cause effects similar to those for inhalation exposure. May cause systemic effects.
Inhalation: Causes chemical burns to the respiratory tract. Inhalation of fumes may cause metal fume fever, which is characterized by flu-like symptoms with metallic taste, fever, chills, cough,

[33] Adapted from Fisher Scientific: https://fscimage.fishersci.com/msds/14020.htm

weakness, chest pain, muscle pain and increased white blood cell count. May cause central nervous system effects including vertigo, anxiety, depression, muscle incoordination, and emotional instability. Aspiration may lead to pulmonary edema. May cause systemic effects. May cause respiratory sensitization.
Chronic: May cause liver and kidney damage. May cause reproductive and fetal effects. Effects may be delayed. Chronic exposure to mercury may cause permanent central nervous system damage, fatigue, weight loss, tremors, personality changes. Chronic ingestion may cause accumulation of mercury in body tissues. Prolonged or repeated exposure may cause inflammation of the mouth and gums, excessive salivation, and loosening of the teeth.

Section 4 - First Aid Measures

Eyes: Get medical aid immediately. Do NOT allow victim to rub eyes or keep eyes closed. Extensive irrigation with water is required (at least 30 minutes).
Skin: Get medical aid immediately. Immediately flush skin with plenty of water for at least 15 minutes while removing contaminated clothing and shoes. Wash clothing before reuse.[34] Destroy contaminated shoes.
Ingestion: Do not induce vomiting. If victim is conscious and alert, give 2-4 cupfuls of milk or water. Never give anything by mouth to an unconscious person. Get medical aid immediately. Wash mouth out with water.
Inhalation: Get medical aid immediately. Remove from exposure and move to fresh air immediately. If breathing is difficult, give oxygen. Do NOT use mouth-to-mouth resuscitation. If breathing has ceased apply artificial respiration using oxygen and a suitable mechanical device such as a bag and a mask.
Notes to Physician: The concentration of mercury in whole blood is a reasonable measure of the body-burden of mercury and thus is used for monitoring purposes. Treat symptomatically and supportively. Persons with kidney disease, chronic respiratory disease, liver disease, or skin disease may be at increased risk from exposure to this substance.
Antidote: The use of d-Penicillamine as a chelating agent should be determined by qualified medical personnel. The use of Dimercaprol or BAL (British Anti-Lewisite) as a chelating agent should be determined by qualified medical personnel.

Section 5 - Fire Fighting Measures

General Information: As in any fire, wear a self-contained breathing apparatus in pressure-demand, MSHA/NIOSH (approved or equivalent), and full protective gear. Water runoff can cause environmental damage. Dike and collect water used to fight fire. During a fire, irritating and highly toxic gases may be generated by thermal decomposition or combustion.
Extinguishing Media: Substance is nonflammable; use agent most appropriate to extinguish surrounding fire. Use water spray, dry chemical, carbon dioxide, or appropriate foam.
Flash Point: Not applicable.
Autoignition Temperature: Not applicable.
Explosion Limits, Lower: Not available.
Upper: Not available.
NFPA Rating: (estimated) Health: 3; Flammability: 0; Instability: 0

Section 6 - Accidental Release Measures

[34] Clothes should be washed separately by hand using decontaminant solution (see footnote in Section 2.0), followed by soap and water, dried, and then inspected carefully before reuse. Do not use a washing machine.

General Information: Use proper personal protective equipment as indicated in Section 8.
Spills/Leaks: Absorb spill with inert material (e.g. vermiculite, sand or earth), then place in suitable container. Avoid runoff into storm sewers and ditches which lead to waterways. Clean up spills immediately, observing precautions in the Protective Equipment section. Provide ventilation.

Section 7 - Handling and Storage

Handling: Wash thoroughly after handling. Remove contaminated clothing and wash before reuse.[35] Minimize dust generation and accumulation. Keep container tightly closed. Do not get on skin or in eyes. Do not ingest or inhale. Use only in a chemical fume hood. Discard contaminated shoes. Do not breathe vapor.
Storage: Keep container closed when not in use. Store in a tightly closed container. Store in a cool, dry, well-ventilated area away from incompatible substances. Keep away from metals. Store protected from azides.

Section 8 - Exposure Controls, Personal Protection

Engineering Controls: Facilities storing or utilizing this material should be equipped with an eyewash facility and a safety shower. Use only under a chemical fume hood.
Exposure Limits

Chemical Name	ACGIH	NIOSH	OSHA - Final PELs
Mercury	0.025 mg/m3 TWA; Skin - potential significant contribution to overall exposure by the cutaneous route	0.05 mg/m3 TWA (vapor) 10 mg/m3 IDLH	0.1 mg/m3 Ceiling

OSHA Vacated PELs: Mercury: 0.05 mg/m3 TWA (vapor)
Personal Protective Equipment
Eyes: Wear appropriate protective eyeglasses or chemical safety goggles as described by OSHA's eye and face protection regulations in 29 CFR 1910.133 or European Standard EN166.
Skin: Wear appropriate protective gloves to prevent skin exposure.
Clothing: Wear appropriate protective clothing to prevent skin exposure.
Respirators: A respiratory protection program that meets OSHA's 29 CFR 1910.134 and ANSI Z88.2 requirements or European Standard EN 149 must be followed whenever workplace conditions warrant respirator use.

Section 9 - Physical and Chemical Properties

Physical State: Liquid
Appearance: silver
Odor: odorless
pH: Not available.
Vapor Pressure: 0.002 mm Hg @ 25C
Vapor Density: 7.0
Evaporation Rate: Not available.
Viscosity: 15.5 mP @ 25 deg C
Boiling Point: 356.72 deg C
Freezing/Melting Point: -38.87 deg C

[35] Clothes should be washed separately by hand using decontaminant solution (see footnote in Section 2.0), followed by soap and water, dried, and then inspected carefully before reuse. Do not use a washing machine.

Decomposition Temperature: Not available.
Solubility: Insoluble.
Specific Gravity/Density: 13.59 (water=1)
Molecular Formula: Hg
Molecular Weight: 200.59

Section 10 - Stability and Reactivity

Chemical Stability: Stable under normal temperatures and pressures.
Conditions to Avoid: High temperatures, incompatible materials.
Incompatibilities with Other Materials: Oxygen, sulfur, acetylene, ammonia, chlorine dioxide, azides, chlorates, nitrates, sulfuric acid, halogens, rubidium, calcium, 3-bromopropyne, ethylene oxide, lithium, methylsilane + oxygen, peroxyformic acid, tetracarbonylnickel + oxygen, copper, copper alloys, boron diiodophosphide, metals, nitromethane, sodium carbide, aluminum, lead, iron, metal oxides.
Hazardous Decomposition Products: Mercury/mercury oxides.
Hazardous Polymerization: Will not occur.

Section 11 - Toxicological Information

RTECS#:
CAS# 7439-97-6: OV4550000
LD50/LC50: Not available.

Carcinogenicity: CAS# 7439-97-6: Not listed by ACGIH, IARC, NTP, or CA Prop 65.

Epidemiology: Intraperitoneal, rat: TDLo = 400 mg/kg/14D-I (Tumorigenic - equivocal tumorigenic agent by RTECS criteria - tumors at site of application).
Teratogenicity: Inhalation, rat: TCLo = 1 mg/m3/24H (female 1-20 day(s) after conception) Effects on Embryo or Fetus - fetotoxicity (except death, e.g., stunted fetus).
Reproductive Effects: Inhalation, rat: TCLo = 890 ng/m3/24H (male 16 week(s) pre-mating) Paternal Effects - spermatogenesis (incl. genetic material, sperm morphology, motility, and count).; Inhalation, rat: TCLo = 7440 ng/m3/24H (male 16 week(s) pre-mating) Fertility - post-implantation mortality (e.g. dead and/or resorbed implants per total number of implants).
Mutagenicity: Cytogenetic Analysis: Unreported, man = 150 ug/m3.
Neurotoxicity: The brain is the critical organ in humans for chronic vapor exposure; in severe cases, spontaneous degeneration of the brain cortex can occur as a late sequela to past exposure.
Other Studies:

Section 12 - Ecological Information

Ecotoxicity: Fish: Rainbow trout: LC50 = 0.16-0.90 mg/L; 96 Hr; Unspecified Fish: Bluegill/Sunfish: LC50 = 0.16-0.90 mg/L; 96 Hr; Unspecified Fish: Channel catfish: LC50 = 0.35 mg/L; 96 Hr; Unspecified Water flea Daphnia: EC50 = 0.01 mg/L; 48 Hr; Unspecified In aquatic systems, mercury appears to bind to dissolved matter or fine particulates, while the transport of mercury bound to dust particles in the atmosphere or bed sediment particles in rivers and lakes is generally less substantial. The conversion, in aquatic environments, of inorganic mercury cmpd to methyl mercury implies that recycling of mercury from sediment to water to air and back could be a rapid process.
Environmental: Mercury bioaccumulates and concentrates in food chain (concentration may be as much as 10,000 times that of water). Bioconcentration factors of 63,000 for freshwater fish and 10,000 for salt water fish have been found. Much of the mercury deposited on land, appears to revaporize within a day or two, at least in areas substantially heated by sunlight.

Physical: All forms of mercury (Hg) (metal, vapor, inorganic, or organic) are converted to methyl mercury. Inorganic forms are converted by microbial action in the atmosphere to methyl mercury.
Other: No information available.

Section 13 - Disposal Considerations

Chemical waste generators must determine whether a discarded chemical is classified as a hazardous waste. US EPA guidelines for the classification determination are listed in 40 CFR Parts 261.3. Additionally, waste generators must consult state and local hazardous waste regulations to ensure complete and accurate classification.
RCRA P-Series: None listed.
RCRA U-Series: CAS# 7439-97-6: waste number U151.

Section 14 - Transport Information

	US DOT	Canada TDG
Shipping Name:	MERCURY	MERCURY
Hazard Class:	8	8
UN Number:	UN2809	UN2809
Packing Group:	III	III

Section 15 - Regulatory Information

European/International Regulations

European Labeling in Accordance with EC Directives
Hazard Symbols: T N
Risk Phrases:
R 23 Toxic by inhalation.
R 33 Danger of cumulative effects.
R 50/53 Very toxic to aquatic organisms, may cause long-term adverse effects in the aquatic environment.
Safety Phrases:
S 1/2 Keep locked up and out of reach of children.
S 45 In case of accident or if you feel unwell, seek medical advice immediately (show the label where possible).
S 7 Keep container tightly closed.
S 60 This material and its container must be disposed of as hazardous waste.
S 61 Avoid release to the environment. Refer to special instructions /safety data sheets.

Section 16 - Additional Information

MSDS Creation Date: 6/15/1999
Revision #10 Date: 1/13/2009

The information above is believed to be accurate and represents the best information currently available to us. However, we make no warranty of merchantability or any other warranty, express or implied, with respect to such information, and we assume no liability resulting from its use. Users should make their own investigations to determine the suitability of the information for their particular purposes. In no event shall Fisher be liable for any claims, losses, or damages of any third party or for lost profits or any special, indirect, incidental, consequential or exemplary damages, howsoever arising, even if Fisher has been advised of the possibility of such damages.

International Chemical Safety Card[36]

Mercury

MERCURY		**ICSC: 0056**
Date of Peer Review: **April 2004**		
	Quicksilver Liquid silver	
CAS #	7439-97-6	Hg
RTECS #	OV4550000	Atomic mass: 200.6
UN #	2809	
EC #	080-001-00-0	

TYPES OF HAZARD / EXPOSURE	ACUTE HAZARDS / SYMPTOMS	PREVENTION	FIRST AID / FIRE FIGHTING
FIRE	Not combustible. Gives off irritating or toxic fumes (or gases) in a fire.		In case of fire in the surroundings: use appropriate extinguishing media.
EXPLOSION	Risk of fire and explosion.		In case of fire: keep drums, etc., cool by spraying with water.
EXPOSURE		**STRICT HYGIENE! AVOID EXPOSURE OF (PREGNANT) WOMEN! AVOID EXPOSURE OF ADOLESCENTS AND CHILDREN!**	**IN ALL CASES CONSULT A DOCTOR!**
Inhalation	Abdominal pain. Cough. Diarrhoea. Shortness of breath. Vomiting. Fever or elevated body temperature.	Local exhaust or breathing protection.	Fresh air, rest. Artificial respiration if indicated. Refer for medical attention.
Skin	MAY BE ABSORBED! Redness.	Protective gloves. Protective clothing.	Remove contaminated clothes. Rinse and then wash skin with water and soap. Refer

[36] From http://www.inchem.org/documents/icsc/icsc/eics0056.htm

			for medical attention.
Eyes		Face shield, or eye protection in combination with breathing protection.	First rinse with plenty of water for several minutes (remove contact lenses if easily possible), then take to a doctor.
Ingestion		Do not eat, drink, or smoke during work. Wash hands before eating.	Refer for medical attention.

SPILLAGE DISPOSAL	**PACKAGING & LABELLING**
Evacuate danger area in case of a large spill! Consult an expert! Ventilation. Collect leaking and spilled liquid in sealable non-metallic containers as far as possible. Do NOT wash away into sewer. Do NOT let this chemical enter the environment. Chemical protection suit including self-contained breathing apparatus.	Special material. Do not transport with food and feedstuffs. **EU Classification** Symbol: T, N R: 23-33-50/53 S: (1/2-)-7-45-60-61 **UN Classification** UN Hazard Class: 8 UN Pack Group: III
EMERGENCY RESPONSE	**STORAGE**
Transport Emergency Card: TEC (R)-80GC9-II+III	Provision to contain effluent from fire extinguishing. Separated from food and feedstuffs. Well closed.

IPCS
International Programme on Chemical Safety

UNEP

MERCURY ICSC: 0056

IMPORTANT DATA	
PHYSICAL STATE; APPEARANCE: ODOURLESS, HEAVY AND MOBILE SILVERY LIQUID METAL. **CHEMICAL DANGERS:** Upon heating, toxic fumes are formed. Reacts violently with ammonia and halogens causing fire and explosion hazard. Attacks aluminium	**ROUTES OF EXPOSURE:** The substance can be absorbed into the body by inhalation of its vapour and through the skin, also as a vapour! **INHALATION RISK:** A harmful contamination of the air can be reached very quickly on evaporation of this

and many other metals forming amalgams. **OCCUPATIONAL EXPOSURE LIMITS:** TLV: 0.025 mg/m³ as TWA; (skin); A4; BEI issued; (ACGIH 2004). MAK: 0.1 mg/m³; Sh; Peak limitation category: II(8); Carcinogen category: 3B; (DFG 2003).	substance at 20°C. **EFFECTS OF SHORT-TERM EXPOSURE:** The substance is irritating to the skin. Inhalation of the vapours may cause pneumonitis. The substance may cause effects on the central nervous system and kidneys. The effects may be delayed. Medical observation is indicated. **EFFECTS OF LONG-TERM OR REPEATED EXPOSURE:** The substance may have effects on the central nervous system and kidneys, resulting in irritability, emotional instability, tremor, mental and memory disturbances, speech disorders. May cause inflammation and discoloration of the gums. Danger of cumulative effects. Animal tests show that this substance possibly causes toxic effects upon human reproduction.
PHYSICAL PROPERTIES	
Boiling point: 357°C Melting point: -39°C Relative density (water = 1): 13.5 Solubility in water: none Vapour pressure, Pa at 20°C: 0.26 Relative vapour density (air = 1): 6.93	Relative density of the vapour/air-mixture at 20°C (air = 1): 1.009
ENVIRONMENTAL DATA	
The substance is very toxic to aquatic organisms. In the food chain important to humans, bioaccumulation takes place, specifically in fish.	
NOTES	
Depending on the degree of exposure, periodic medical examination is indicated. No odour warning if toxic concentrations are present. Do NOT take working clothes home.	
ADDITIONAL INFORMATION	
LEGAL NOTICE	Neither the CEC nor the IPCS nor any person acting on behalf of the CEC or the IPCS is responsible for the use which might be made of this information

Appendix E

ESTIMATION OF A SEPARATION DISTANCE BETWEEN AN INTERMEDIATE-TERM CENTRALIZED STORAGE FACILITY FOR MERCURY AND POPULATED AREAS

For the purpose of estimating how far an intermediate-term centralized storage facility should be from schools, residences, and other populated areas, a large mercury spill of 81 kg is postulated. This amount is equivalent to accidentally releasing the full mercury contents of two 3-liter steel flasks or breaking three 23.5 kg containers. It is assumed that the liquid mercury falls into a spill tray inside a fume hood with an exhaust stack velocity of 15 m/s. In order to estimate a separation distance, the estimated concentration of mercury at ground level at the location of the nearest populated area should not exceed the EU limit of 20 µg/m^3.

The evaporative flux can be estimated using the following equation:[37]

$$E_f = \frac{E}{A} = \frac{0.1268 \cdot U^{0.78} \cdot MW^{\frac{2}{3}} \cdot VP}{T}$$

Where E_f is the evaporative flux in kg/min-m^2, E is the source (or evaporation rate) in kg/min, A is the surface area of the liquid pool in m^2, U is the wind speed above the surface of the liquid pool in m/s, MW is the molecular weight of mercury, VP is the vapor pressure of mercury in kPa, and T is the pool temperature in degrees Kelvin.

Assuming that both the ambient temperature and the temperature of the pool of mercury are at 25°C and that the wind speed above the pool is at 15 m/s, an evaporative flux of 3.22x10^{-5} kg/min-m^2 is calculated.

The thickness of a pool of liquid with a contact angle less than 180° is given by:[38]

$$h = \sqrt{\frac{2\gamma(1-cos\theta)}{\frac{g}{g_c}\rho}}$$

where h is the thickness of the liquid pool, γ is the surface tension, □ is the contact angle, g/g_c is 980 dynes/g, and ρ is the density. The surface tension γ of mercury in air at 25°C is 485.5 dynes/cm and the density of mercury is 13.5 g/cm^3 at 25°C. The average contact angle of mercury on various solids is 140°.[39] Thus, the approximate thickness of a pool of mercury at 25°C is h = 0.36 cm.

For a mercury spill of 81 kg (6 liters), the surface area of a mercury pool with a 0.36 cm thickness is 1.67 m^2, corresponding to a diameter of 1.46 m. Therefore, the evaporation rate is about 0.0537 g/min given the evaporative flux calculated above.

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[37] Adapted from Appendix D in "Risk Management Program Guidance For Offsite Consequence Analysis," EPA-550-B-99-009, Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency, April 1999.
[38] P. de Gennes, F. Brochard-Wyart, and D. Quéré, *Capillary and Wetting Phenomena: Drops, Bubbles, Pearls, Waves*, translation by A. Reisinger, Springer (2002).
[39] Average contact angle of mercury on stainless steel, nickel, tungsten, borosilicate glass, quartz, and Teflon; "Contact angles of mercury on various surfaces and the effect of temperature," A. Ellison, R. Klemm, A. Schwartz, L. Grubb, and D. Petrash, *J. Chem. Eng. Data*, 1967, 12 (4), pp 607–609.

Assuming a constant release rate (source), wind speed, eddy diffusivity, flat terrain, and no chemical reactions or deposition, the point-source Gaussian plume air dispersion model can be used to estimate ground-level concentrations downwind from the spill area. In order to approximate a worst-case scenario, a wind velocity of 1 m/s (calm wind), Pasquill stability class F (extremely stable atmospheric conditions), and release height of 0 (from the ground) are assumed. The results are shown below:

Downwind distance (meters)	Mercury concentration (μg/m^3)
100	30
120	22
125	20
130	20
140	17

If one were to assume a wind velocity of 3 m/s (light breeze), Pasquill stability class D (neutral), and release height of 0, the results indicate mercury concentrations lower than 20 μg/m^3 after about 35 meters downwind distance.

Since the vapor density of mercury is 6.93 times greater than that of air, the denser-than-air gas cloud atmospheric dispersion model (DEGADIS)[40] as found in the Areal Locations of Hazardous Atmospheres (ALOHA) computer program[41] can also be employed to estimate mercury concentrations downwind. Using the ALOHA program and the same assumptions for Pasquill stability class F, one obtains the following similar results.

Downwind distance (meters)	Mercury concentration (μg/m^3)
100	31
120	22
125	21
130	19
140	17

Assuming a wind velocity of 3 m/s, Pasquill stability class D, and release height of 0, the ALOHA results show mercury concentrations below 20 μg/m^3 after about 50 meters.

These calculations suggest that a separation distance of around 150 meters (500 ft) between an intermediate-term centralized storage facility and populated areas may be appropriate.

[40] T. Spicer and J. Havens, "User's Guide for the DEGADIS 2.1 Dense Gas Dispersion Model," EPA-450/4-89-019, U.S. Environmental Protection Agency, Cincinnati, Ohio (1989).
[41] "ALOHA® User's Manual: The CAMEO® Software System," U.S. Environmental Protection Agency (Office of Emergency Management, Washington, D.C.) and National Oceanic and Atmospheric Administration (Office of Response and Restoration, Emergency Response Division, Seattle, Washington), February 2007.