Chemical-Specific Health Consultation

for

Joint EPA/ATSDR National Mercury Cleanup Policy Workgroup

Action Levels For Elemental Mercury Spills

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ATSDR Chemical Specific Health Consultation – Mercury

Executive Summary

In 2000, the Agency for Toxic Substances and Disease Registry (ATSDR) provided tables of action level guidelines for indoor air concentrations of elemental or metallic mercury in response to a request from both the U.S. Environmental Protection Agency (EPA) and the state of Michigan. The action levels had been previously developed for individual sites and situations, but the tables summarized these guidelines in a succinct package for use by field personnel. The request was prompted by several small spills in homes caused by replacing or relocating natural gas regulators containing mercury. The homes affected included those serviced by utility companies in both Chicago and Detroit. The guidelines were designed to help risk managers at spill scenes in homes or other locations make decisions regarding cleanup, relocation, etc. Throughout the years, these action level guidelines have been widely disseminated by users. A workgroup has been formed jointly by EPA and ATSDR to develop consistent cleanup guidance for mercury spills, including not only public health actions but also cleanup and sampling methods. As part of that joint effort, EPA has requested that ATSDR update the 2000 guidelines to be included in a more comprehensive guidance. This health consultation is intended to provide that update.

The health consultation provides detailed justifications for action levels based on the ATSDR Chronic Minimal Risk Level and EPA Reference Concentration. The recommended action levels for mercury in residential settings remain 1 ug/m^3 for normal occupancy and 10 ug/m^3 for isolation (e.g., evacuation, limited access, etc.) of the residents from exposure to the mercury. Action levels for settings other than residential are based on residential levels and adjusted for the condition based on the presumed exposure. Sections that describe when action levels should be adjusted to meet site specific conditions are included. The most useful features of the 2000 tables have been retained; new sections have been added that address issues related to the tables that have recurred during the past 11 years. Additional information to help on-scene risk managers communicate risk is provided. Technological advances in detecting environmental mercury are also considered.

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1.0 Introduction

1.1 Background: Elemental, also called metallic, mercury is common in our environment due in part to its unique properties and multiple uses in our daily lives [Baughman 2006; Gochfeld 2003; Risher 2007; Song 2009]. Mercury in its elemental state can pose a hazard to humans. The hazard for any person is based on how sensitive that person is to the effects of mercury, how long that person is exposed to mercury, and how much mercury is present, among other factors. These factors as they pertain to mercury spills are discussed below. Mercury is persistent in the environment, and is considered a hazard primarily under chronic exposure scenarios under most conditions. Mercury cleanups are difficult and pose substantial challenges [MacLehose 2001] to risk managers, such as the U.S. Environmental Protection Agency's (EPA) On-scene Coordinators (OSC). Throughout the years, various EPA Regions have established guidance for conducting these cleanups. EPA's Office of Emergency Management convened a National Workgroup to harmonize this guidance and invited the Agency for Toxic Substances and Disease Registry (ATSDR) to join the Workgroup [EPA 2011]. Many of the guidance documents developed by the various regional offices included "Suggested Action Levels for Indoor Mercury Vapors in Homes or Businesses with Indoor Gas Regulators". This guidance was developed by ATSDR for public health and environmental professionals in 2000 [ATSDR 2000]. The National Workgroup requested that ATSDR revise these action levels to reflect advances in technology and knowledge gained through experiences since ATSDR provided them. EPA and ATSDR staff formed a Subgroup of the National Workgroup. The Subgroup determined that an ATSDR chemical-specific health consultation would be the most effective way to accomplish this task. The health consultation will be included in the National Policy upon finalization of that policy. The Subgroup requested that the list of action levels be expanded to include other exposure settings such as schools and vehicles such as school buses.

Mercury is a conductive metal and a liquid at room temperature, physical properties that make the substance a unique asset in many industrial and consumer applications [HSDB 2005]. Mercury is also used in some of the rituals and practices of certain religious sects [Alison Newby 2006; Garetano 2006, 2008; Rogers 2007, 2008]. When spilled, mercury's viscosity is similar to that of water—it flows and collects in the same way and locations that water would if spilled. However, mercury is unusually dense compared with water; a milliliter (mL)of mercury weighs more than 13 grams (g) while a milliliter of water weighs only 1 gram. Mercury has a low vapor pressure at standard temperature and pressure, so the liquid vaporizes slowly at room temperatures [HSDB 2005; NIOSH 2007]. Elemental mercury may combine with oxygen to form a mercuric oxide skin on its outer surface. Mercuric oxide does not vaporize, but the shell formed in this manner is fragile. The slightest movement can break this oxide shell and free the elemental mercury contained inside [EPA 2005]. Mercury amalgamates with other metals and is attracted to sulfur-based compounds [Yamamoto 2007]. Mercury is unusual in the number and properties of other compounds it forms. This health consultation evaluated metallic mercury (elemental mercury or quicksilver) only. Other forms of mercury have different properties and different hazards that are not addressed here except as they relate to metallic mercury. In American homes with no known mercury spill, concentrations in the 0.01–0.1 ug/m^3 range have been reported, with typical ambient (outside air) concentrations approximately a factor of 10 less than that [Carpi 2001; Garetano 2008; Johnson 2003].

1.2 Health Implications: The primary route of exposure to metallic mercury is inhalation of its colorless and odorless vapors [ATSDR 1999; Bose-O'Reilly 2008; Lee 2009]. Ingested elemental mercury can be absorbed poorly through the intestinal walls. Dermal exposure or absorption of metallic mercury through the skin is considered a minor exposure route [ATSDR 1999; Ellis 2009]. Some case studies report dermal irritation after prolonged contact with mercury [De Capitani 2009], however, this dermal irritation does not seem to cause greater absorption.

The organ or organ system in humans most sensitive to all forms of mercury changes somewhat over our life spans. For a developing fetus or young child, the most sensitive endpoint is considered to be the developing central nervous system (CNS) [Abbaslou 2006; Baughman 2006; Bensefa-Colas 2010; Bose-O'Reilly 2008, 2010; Grant 2010]. While data about humans are limited, several animal studies report CNS effects in offspring after maternal exposure to mercury (see Section 2.2.1.6 of the ATSDR Toxicological Profile) [ATSDR 1999; Morgan 2002]. As humans mature, our CNS system completes its development and we become less sensitive to the effects of mercury on our CNS. That is, a greater exposure (i.e., either higher concentration, more frequent exposure events, or longer duration of exposure events) is required to produce effects on the CNS. For this reason, our most sensitive populations are young children and developing fetuses; women who are confirmed or suspected to be pregnant also require consideration as a sensitive population to protect the fetus. The age at which young children become less sensitive to the CNS effects of mercury is unclear but the concern is usually for pre-school children. Individuals that have matured beyond this window of greater vulnerability for the CNS may experience effects on the kidneys before the effects on the CNS become evident.

Consequently, the next human organ most sensitive to the effects of mercury tends to be the kidney; inorganic forms of mercury are excreted almost exclusively through the kidneys [Baughman 2006; Bensefa-Colas 2010; Franko 2005; Opitz 1996; Samir 2011]. Generally speaking, the concentration of mercury that may pose a CNS threat to the young is less than the concentration that could affect the kidneys in older children or adults under the same conditions of exposure. In animals, acute mercury exposures (as long as 14 days in duration) of approximately 0.05 mg/m^3 may cause significant CNS effects; exposures in the 0.5–0.86 mg/m^3 range more commonly cause significant CNS effects. Typically, acute exposures of ~3 mg/m^3 affect the kidneys (see Figure 1A) [ATSDR 1999]).

1.3 Health Guidance Values: Both ATSDR and EPA have developed health guidance values (HGVs) for inhaled mercury vapors, based on a 1983 study of workplace exposures [Fawer 1983]. The workers in the study were exposed in their workplace to mercury vapors. The workers in the Fawer cohort came from three different types of workplaces: fluorescent tube manufacture; chloralkali plants; and acetaldehyde production. The authors reported a Lowest Observed Adverse Effect Level (LOAEL) of 26 ug/m^3 of exposure averaged over a period of 15 years [Fawer 1983]. As discussed below, the effect noted in the study was a slight tremor in the hands. ATSDR has defined a Minimal Risk Level (MRL) for chronic exposures (more than 365 days) to mercury of 0.2 ug/m^3. In developing the MRL, the workplace average from Fawer was adjusted from a 40-hour to a 168-hour exposure per week (i.e., 24 hours/day, 7 days/week), and then divided by an uncertainty factor of 30 (3 for use of a minimal LOAEL and 10 for human variablliy) to account for the LOAEL and individual sensitivities. {It should perhaps be noted that the concentration in the Fawer study as well as many other occupational studies was averaged over a typical workday and their results may not be completely representative of continuous or significantly longer durations of exposure such as may be found in a residential setting.} Thus, an MRL is an estimate of the level of daily exposure to a hazardous substance (in this case, metallic mercury), sustained through a specific route and duration of exposure, that is unlikely to cause measurable risk for adverse, noncancerous health effects (metallic mercury is not considered carcinogenic [cancer causing]) [ATSDR 1999]. EPA used the same study as their primary reference to develop a Reference Concentration (RfC) of 0.3 ug/m^3 using slightly different assumptions and somewhat different justifications for the same uncertainty factors. EPA also cites other supporting studies in a weight of evidence approach [EPA 1995]. Please see the IRIS record available at www.epa.gov/iris for the details of their derivation. The RfC is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily inhaled exposure of the human population (including sensitive subgroups) that is unlikely to cause an appreciable risk of harmful effects during a lifetime. For further information, see Section 2.5, Chapter 7, and Appendix A of the ATSDR Toxicological Profile for Mercury and the EPA's Integrated Risk Information System (IRIS) on the Internet at www.epa.gov/iris/. ATSDR considers the RfC and the MRL for chronic exposures to be within the uncertainties of the derivations and the same value for all practical purposes.

Within the limits of this health consultation, an *action level* is an indoor air concentration of mercury vapor that should prompt public health and environmental officials to consider implementing response actions. The various suggested action levels provided in this document are intended as recommendations, not as regulatory values or cleanup values, although some of the recommended action levels may correspond to present or future values adopted by regulatory authorities. The following discussion is intended to confirm that these action levels should not be considered as "bright line" indicators of toxicity or predictors of adverse health effects. These action levels are provided primarily to prevent adverse health effects by identifying environmental concentration associated with any level of toxicity. The secondary purpose is to identify when precautions should be implemented to prevent adverse health effects and when such precautions may be stopped with a reasonable expectation of no adverse effects. Risk managers, such as EPA OSCs and their state and local counterparts, should determine whether a recommended response action is necessary based on the actual conditions and circumstances they encounter at the exposure site.

2.0 Discussion

In the course of this discussion, the reader may find it useful to refer to Tables 1 and 2 found towards the end of this consultation. In the tables, the sections of this consultation that bear on the development of the recommended action levels are provided in the right hand column. As the discussion progresses, there are 4 key elements in this approach to bear in mind; these elements are adjusted to the assumed conditions of exposure in each scenario. These elements are explained in the various sections and summarized here:

- Visible mercury cannot be left readily accessible after a clean up is complete (Section 2.1);
- Experience has shown concentrations of 6 ug/m^3 or above are usually associated with the presence of liquid mercury that may not have been discovered (Section 2.1);

- Urinary levels in some humans begin to increase at environmental concentrations as low as 10 ug/m^3; this consult treats exposure to that concentration, if not terminated, as a threshold that could cause effects in some people (Section 2.2.2) ;
- The benefits to human health of cleaning transient spills to a concentration below 1 ug/m3 under most conditions typically do not outweigh the potential consequences to overall quality of life for individuals in that environment (Section 2.2.1).

2.1 "Visible" Mercury: Because of metallic mercury's unique properties and appearance, it has long attracted the attention of humans of all ages. Liquid mercury is shiny and flows easily over the hand. It flows together to make large beads and splits apart to make smaller beads—the beads can take any shape. It feels heavy to the touch, but splatters readily. For all these reasons, liquid mercury may be kept, shared, and distributed by non-professional persons who are not aware of the hazard. If visible mercury is not contained appropriately, it is a likely hazard because it may fall into the hands of our most sensitive population [Hudson 1987]. Visible mercury should therefore be considered an attractive nuisance [Azziz-Baumgartner 2007; Baughman 2006; CDC 2005; Johnson 2004; MacLehose 2001; Nickle 1999; Risher 2003].

ATSDR is often asked how much mercury is required for it to become visible to humans. While visual acuity (i.e., how well one sees objects) varies by individuals, it must be remembered that the air concentrations of mercury associated with the HGVs discussed in section 1.3 are small and mercury is very dense. In a room that is 3 meters (roughly 10 feet) square with a 3 meter [m] ceiling, approximately 5 micrograms [ug] of vaporized mercury would elevate the air concentration of mercury in the room to the ATSDR MRL (3 m x 3 m x 3 m = 27 m^3 x 0.2 ug/m^3 = 5.4 ug). Five micrograms equates to less than a nanoliter of liquid mercury (5 x 10^{-6} g x 1 mL/13.5 g = 3.7 x 10^{-7} mL or ~0.4 nL). For comparison, the most popular brand of oral thermometer in the United States contains approximately 0.3 milliliters of mercury, or about 4 grams (4,000,000 micrograms) of liquid mercury. A nanoliter (nL) of liquid would be 6 orders of magnitude or 1 million times smaller than the volume in a thermometer and effectively invisible to most humans. Therefore, if an uncontained bead of mercury can be seen in most indoor spaces, it is possible that enough vapors are present in that space for the concentration to be greater than the HGV described previously. Multiple factors such as relative humidity, surface area of the liquid, barometric pressure, and temperature can influence vaporization of a liquid. Many of these factors can change over time and by location. During an indoor release, most of these factors would likely be fairly constant in a state that would promote vaporization. Because mercury is much denser than air, stable conditions are likely to stratify (layer) the mercury vapors in a confined space like the room described previously. In addition, different materials likely to be found in indoor environments may have different affinities for mercury vapors, which can also affect how much mercury is available in the indoor air. The actual concentration at any given point in a room at any given time would be expected to vary [Lui 2011; EPA 2005; Winter 2003]. Air-monitoring instruments are required to determine the existence of, and often to find the source of, mercury in a room [CDC 2005]. The experience of EPA staff has been that concentrations as low as 6 ug/m^3 typically indicate that liquid mercury is present in a room [Nickle 1999; Nold 2011].

Because mercury is an attractive nuisance fascinating to many people and even a microscopic amount of it can contaminate many individual spaces, the initial criteria for all mercury cleanup actions must be that no visible mercury remains. This is indicated in both tables 1 and 2 in the 2 columns on the right. Removing the liquid mercury also reduces the source of the vapors in the space, meaning that any residual vapor concentrations in the area should decrease over time after the source is removed [Azziz-Baumgartner 2007; Baughman 2006; CDC 2005; Cizdziel 2011; Risher 2007; Tominack 2002]. All of the action levels [i.e., usually less than 1 or less than 3 ug/m^3 in Tables 1 and 2]. recommended here that terminate cleanup actions as opposed to implementing protective measures assume that all visible mercury has been removed from the location of the spill. The importance of this key action in protecting public health cannot be overemphasized.

2.2 Residential Settings

2.2.1 Normal Occupancy: Because elemental mercury is primarily an inhalation hazard, any cleanup should be focused on minimizing this exposure pathway. Cleaning any area in a typical residential setting to make the indoor air concentration meet the MRL or RfC would require removing virtually every nanoliter of liquid mercury from that area. This exacting task could lead to difficult risk-management decisions, such as the considerable loss of personal property that is contaminated to the extent that cleanup is not feasible (e.g., the cleaning process would destroy the property or exceed the cost of replacing the article with similar articles). This loss of property could be severe enough to cause a substantial lifestyle change that could increase the potential for adverse health outcomes [Nickle 1999]. ATSDR prefers that no person be exposed to a concentration of a toxic substance greater than the recommended HGVs, such as the RfC or MRL. However, given the extraordinary measures required to remove enough liquid mercury to reach the HGV concentrations, the human health benefit of such a removal action may not always be warranted by the threat [ATSDR 2008; CDC 1995; Nickle 1999; Risher 2003].

The principal study (i.e, Fawer, 1983) upon which both of the HGVs for mercury discussed in section 1.3 was based used a very sensitive method of measuring the adverse health effect in the workers. Tremor reported in the study could only be measured when a small weight was suspended from the study worker's hand. The tremor did not cause debilitating harm or contribute in any way to a lower quality of life for the workers. Because many of the participants worked in the facilities in the study before adequate protective emission controls were in place, the long-term workers likely may have been exposed to much higher levels of mercury than was reported in the study. However, the workers clearly had been exposed to sufficient mercury to cause a measurable tremor in their hands, which represents a systemic effect.

The lowest concentration of mercury reported in the scientific literature considered to be the most significant by ATSDR in the ATSDR Toxicological Profile (Table 1; ATSDR 1999) associated with adverse human health effects is 10 ug/m^3 [Ngim 1992]. This study was essentially a survey of symptoms among dentists, nurses, and aides who worked with dental amalgams that contained mercury for 8–10 hours per day during a 6-day work week. The authors of the study simulated preparing the amalgams, measured the concentration in the breathing zone, and reported the concentration from the simulation as the exposure of the survey participant. How accurately the simulation reflected both historical conditions and current practices is unknown. While both EPA and ATSDR chose to use other studies to develop their respective HGVs, both agencies agree that Ngim [1992] is an essential supporting study [ATSDR 1999; EPA 1995; Ngim 1992].

Although ATSDR and EPA have established HGVs with no appreciable risk of human harm, a range of uncertainty exists regarding the concentration at which a person may actually experience health effects. The closer air levels are to the RfC or the MRL, the less likely any exposure is to cause adverse health effects. The closer air levels are to the lowest concentrations known to cause any level of harm to humans (the lowest toxic concentration level for humans [TCLo]), the more likely any exposure is to cause harm. In many cases, response action will be initiated quickly enough to recover the liquid mercury and stop exposures in short order. Applying HGVs, such as the RfC or MRL, that are intended for chronic exposures to situations involving shorter term exposures could be overly conservative in many cases. Historically, ATSDR has recommended 1 ug/m^3 as the residential level requiring cleanup. This concentration is a factor of 10 lower than the human TCLo [Ngim 1992], and a factor of 26 lower than the concentration which is the point of departure for the HGV of both ATSDR and EPA [Fawer 1983]. {It should be noted that the concentrations in these studies were averaged over a typical workday and their results may not be completely representative of continuous or significantly longer durations of exposure such as a residential setting.} This concentration is within a factor of 10 of the HGV concentrations described earlier. This concentration is also approximately 100 times that expected to be seen from the many other sources of mercury in our environment [ATSDR 1999; Cairns 2011; Carpi 2001; Cizdziel 2011; Garetano 2008; Johnson 2003; Lyman 2009; Song 2009]. Studies indicate that 1 ug/m^3 is approximately an order of magnitude lower than the concentration (i.e., 10 ug/m3) where results of urinary levels of mercury appear tobegin to increase in concentration.. [Hryhorczuk 2006; Tsuji 2003]. Experience in previous removal actions by EPA has shown an action level of 1 ug/m^3 generally causes significantly less disruption of lifestyles and fewer potential consequences for individuals or families involved in the spill event [Nickle 1999]. ATSDR's standard practice has been to recommend this value (1 ug/m^3) unless the exposed population is particularly susceptible to the effects of mercury (e.g., a mercury spill in a neonatal intensive care unit or a dialysis center).

2.2.2 Isolation/Relocation: ATSDR is often asked at what level of mercury in indoor air persons should be isolated from the exposure to mercury. Isolation in this sense may include, but not be limited to:

- reducing the time persons spend in a particular area;
- closing the ventilation system connections leading to and from a specific portion of a building;
- reducing the emission rate of vapors from the source; or,
- relocating some or all of the persons who normally occupy the building.

All of these isolation techniques have some negative implications, whether relatively minor, such as reducing the time spent in a given room, or potentially significant, such as persons leaving their home entirely. To complicate matters further, it is common for the persons involved to be uncertain as to when the release occurred. Before isolating an area and incurring those negative implications, ATSDR suggests that, in most cases, the threat to the persons involved should be certain. Due to uncertainty about the duration of exposure before the spill was discovered, continued exposure to mercury levels that could be harmful should be minimized [Azziz-Baumgartner 2007]. Some studies have indicated that urinary levels of mercury in humans begin to increase at mercury concentration levels 10 ug/m^3 or higher. [Hryhorczuk 2006; Tsuji 2003]. Based on this and the Ngim study discussed above, ATSDR will consider the mercury concentration level of 10 ug/m^3 as the TCLo in humans for this health consultation. At the TCLo, adverse effects are possible for susceptible persons, depending on the duration of exposure [ATSDR 1999; Cherry 2002; Hryhorczuk 2006; Ngim 1992; Tsuji 2003]. Therefore, ATSDR usually recommends risk managers consider the need to isolate humans from the spill when a concentration level ≥10 ug/m^3 is determined.

As with the other action levels described in Tables 1 and 2, conditions at the scene may indicate that a higher, or rarely a lower, concentration than 10 ug/m^3 is acceptable before isolation measures are truly required. In addition, the risk manager at the scene (e.g., an EPA OSC) may have reasons to seek relocation of residents other than mercury contamination, such as physical hazards caused by removal techniques or necessary curing of sealants.

2.2.3 Personal Belongings: The hazardous state for this form of mercury is predominantly a vapor; therefore, it can be highly mobile in the indoor environment. Both the liquid and the vapor may collect in porous materials, such as fabric, rubber, and home furnishings. The mercury may invade cracks and crevasses of appliances, flooring, and electronics. In many settings, these belongings represent a substantial investment on the part of the owner who will have an understandable desire to salvage whatever is possible. The challenge of determining what can be saved and what must be disposed of lies in the uncertainties associated with the exposure. For instance, how much time does a child spend sleeping with a favorite stuffed animal and breathing whatever vapors their companion emits? How often does a refrigerator cycle on or off, and who is normally nearby and affected by that heating? How large is the room where the home computer is off-gassing mercury? We do not have the data to answer these kinds of questions and to address all of the possible permutations without analyzing specific conditions and personal habits at a site. This level of detailed analysis, which could change from person to person or structure to structure, is not feasible for a non-site–specific health consultation. We must either dispose of everything contaminated or evaluate the potential risk of the contamination.

The ultimate goal of evaluating a contaminated belonging would be to ensure that the mercury concentration in the breathing zone of the person using the contaminated items under normal use patterns will not exceed 1 ug/m^3 for a time sufficient to cause harm. The preferred method to assess the amount of contamination is to bag small-to-medium items, heat the bag to what might be reasonably anticipated to be maximum temperatures of normal use, and take headspace readings within the bag [Baughman 2006; Nickle 1999]. Large items, such as couches, recliners, and mattresses, with porous surfaces that come in contact with mercury can raise the vapor concentrations more than smaller items in the same room. For larger items, such as appliances and electronics, typically the vapors from the cooling vents have been measured for mercury concentrations. These concentrations would normally be much higher than the readings after the vapors have dispersed into the room. The higher readings would be observed because the same number of molecules of vapor would be contained in a smaller space (e.g., at the point of emission at the vent or contained within a bag).

The suggested action levels developed in 2000 recommended that the elevated readings in the headspace or the point of emission should be less than 10 ug/m^3 [ATSDR 2000]. Because ATSDR wanted to ensure that the belongings had actually been contaminated before they were deemed a threat, that suggested level was based primarily on the human TCLo and the technical limitations of the survey instruments available at the time. Extensive field testing by EPA's Environmental Response Team has demonstrated that newer instruments are both more sensitive and less prone to yielding false positives due to interferences. Therefore, measurements can now detect lower concentrations with the same level of confidence as higher levels that were measured previously [EPA 2005].

Generally speaking, EPA's experience has shown that when liquid mercury comes in direct contact with porous objects or objects that generate heat under normal operation, those objects are not recoverable. ATSDR recommends that such objects be disposed of appropriately [Nickle 1999].

The recommended action level for the residential setting is ≤1 ug/m^3; the 10 ug/m^3 suggested in 2000 has generally worked well in reducing the vapors from belongings in a home (when belongings have been exposed only to mercury vapors) to support this action level [Nickle 1999]. When an unusually large object, such as a freezer, is used in a small room, such as a typical utility room, the contamination level in the room may exceed the 1 ug/m^3 limit even when the freezer does not exceed the 10 ug/m^3 limit for personal belongings. Likewise, when several items, such as clothing, that do not exceed the 10 ug/m^3 headspace limit are placed in a small room, such as a second bedroom in a mobile home, the home may exceed the 1 ug/m^{3-}limit. Obviously, appliances not in use when tested may exceed the action level during normal use.

The site risk manager's professional judgment determines when a lower action level is necessary. EPA's experience has shown that concentrations in the 1–3 ug/m^3-range in the headspace/vent emission usually will allow levels in even smaller rooms to remain at or below 1 ug/m^3. Experience has also shown that these action-level concentrations indicate that minimal or no contact between the contaminated item and liquid mercury has occurred. Finally, EPA's experience has also shown that concentrations >6 ug/m^3 in indoor air usually indicate the presence of liquid mercury that may not have been discovered [Nickle 1999; Nold 2011]. Therefore, ATSDR recommends headspace readings for belongings that may have been contaminated byvapors from a mercury spill that are in the range of 3-6 ug/m3 be considered protective of human health

2.2.4 Conditions when other concentrations should apply: Under some conditions, ATSDR will consider concentrations in non-occupational settings above 1 ug/m3 as safe for human health [ATSDR 2008]. Examples of these conditions are when other mechanisms can be put into place to reduce exposure durations for sensitive persons, or when a population is less sensitive (e.g., healthy adults). These conditions usually occur when the methods required to achieve lower concentrations may possibly cause more harm (e.g., increased property damage and potential harmful lifestyle changes as described earlier) than would the short duration of exposure to slightly higher mercury levels (when the source of the mercury vapors has been controlled [e.g., removal of visible mercury]). Conditions vary from site to site, which may suggest the need for modification; however, ATSDR has never considered an exposure level in a residential setting at a concentration >10 ug/m^3 as acceptable for long-term use. Again, use of these higher levels normally implies that all visible mercury has been removed, indicating that all point sources are removed or isolated. Subsequently, with no mercury source to continue vaporizing levels are expected to decline with time.

Persons in whom the CNS is developing (e.g., fetuses, infants, and young children) are the population considered most sensitive to mercury exposure and, thus, require greater protection [Bensefa-Colas 2010; Bose-O'Reilly 2008; Opitz 1996]. No evidence indicates that persons with deteriorating nervous systems are more susceptible to the effects of mercury than healthier adults; however, a person's underlying conditions may mask the more subtle effects of mercury. Prolonged exposure to mercury also affects the kidneys [ATSDR 1999; Baughman 2006; Bensefa-Colas 2010; Franko 2005; Opitz 1996; Samir 2011]. Under almost all conditions, removing visible mercury from the indoor environment until a residual concentration of 1 ug/m^3 is reached would be protective of even the most sensitive population.

If a person has an underlying condition that makes them more susceptible to the effects of mercury than healthier persons, a concentration less than 1 ug/m^3 mercury in a residential setting may be considered necessary. An invalid with poorly functioning kidneys who normally lives in a space where mercury has been spilled is an example of this situation. An infant born prematurely who is struggling to complete its development may be more susceptible to mercury contamination than an infant born at full term. When OSCs are faced with similar unusual conditions, consulting with public health officials and the healthcare provider for the person is warranted.

Inhaling elemental mercury from a spill may contribute to the overall body burden of mercury. Persons with already high systemic levels of mercury may be more susceptible to adverse effects due to the contribution of the new exposure [Goldman 2001; CDC 2001]. Persons likely to have high systemic levels of mercury include those who work with mercury in occupational settings. Other persons likely in this category are those who routinely eat more than the recommended two meals of fish per week [EPA/FDA 2004]. These persons should be advised to consult their personal healthcare provider regarding the additional exposure to mercury due to the spill. Risk managers may need to consider isolating these persons at a lower concentration of mercury than suggested in section 2.2.2 earlier. No adverse effect would be expected at the normal occupancy level suggested in section 2.2.1.

2.3 Commercial and Occupational Settings

2.3.1 Workplaces covered by the Occupational Safety and Health Administration regulations in Subpart Z: Occupational settings where mercury exposure is anticipated are addressed by various occupational standards. The Occupational Safety and Health Administration (OSHA) does not have a specific standard for mercury in Title 29 of the Code of Federal Regulations (29 CFR). However, general requirements, such as the Hazard Communications Standard (29 CFR 1910.1200), Respiratory Protection Standards (29 CFR 1910.134), and a health and safety program for workers who might be exposed to a "Subpart Z" hazard (29 CFR 1910.1000, Table Z-2), do apply. See http://www.osha.gov/SLTC/mercury/index.html for a complete list of standards applicable to mercury exposure. Industrial hygiene recommendations and best practices by the American Conference of Governmental and Industrial Hygiene (ACGIH), the National Institute for Occupational Safety and Health (NIOSH), and OSHA include periodic monitoring of the workplace air, biological exposure indices to monitor worker's individual body burdens, periodic medical monitoring, and engineering controls to reduce mercury concentration at any given workstation [HSDB 2005]. See http://www.osha.gov/SLTC/healthguidelines/mercuryvapor/recognition.html for these guidelines. In addition, workers are presumed to be healthy adults with exposure durations of 40-hour workweeks for 40 years. Under these conditions, which obviously include responders and others workers subject to the requirements of OSHA's Hazardous Waste Site Operations and Emergency Response Standard [29 CFR 1910.120]), the occupational standards would be expected to protect human health. OSHA established the Permissible Exposure Limit (PEL), the only legally enforceable federal U.S. standard, as a ceiling (i.e., level not to be exceeded) value of 100 ug/m^3 (actual standard is 1 mg/10 m^3). NIOSH set a Recommended Exposure Limit (REL) of 50 ug/m^3 as a 10-hour, time-weighted average. The American Conference of Governmental and Industrial Hygienists (ACGIH) recommended the most recent occupational exposure standard as the Threshold Limit Value–Time Weighted Average (TLV-TWA) of 25 ug/m^3. ACGIH has also recommended biological exposure indices (BEI) in both urine and blood [ACGIH 2008; HSDB 2005].

2.3.2 Workplaces not covered by Subpart Z: In some occupational settings, such as many commercial retail settings, medical offices, and schools, exposure to mercury is not an expected hazard. Which settings are covered by the various requirements in Subpart Z vary from standard to standard. For example, to quote the hazard communications standard 29 CFR 1910.1200(b)(2)), the HazComm standard applies to "…any chemical which is known to be present in the workplace in such a manner that employees may be exposed under normal conditions of use or in a foreseeable emergency." A mercury spill in an occupational setting is not likely to be a normal condition and, if the mercury is not used in the normal work at the setting, it would be unlikely to be a foreseeable emergency. A more detailed list of exemptions in 29 CFR 1910.1200(b)(6)(ii) specifically excludes any setting "…when the hazardous substance is the focus of remedial or removal action being conducted under CERCLA in accordance with the Environmental Protection Agency regulations."

In these settings, the protections associated with the occupational standards and recommended guidelines described earlier (e.g., medical monitoring, engineering controls, hazard communications) are not typically available [Risher 2003]. Without these additional protective measures, applying the occupational standards to these situations is inappropriate. However, the exposure duration in most workplaces would be roughly the same. Therefore, the underlying assumption for residential exposures (exposure for 24 hours, 7 days a week, for non-employed persons living in the home or 16 hours, 7 days a week for persons employed outside the homes and school-aged children not being homeschooled) would not reasonably apply. Adjusting the 1 ug/m^3 residential action level discussed earlier from a 168-hour exposure (24/7) or a 112-hour exposure (16/7) to a 40-hour exposure, which is more typical in a commercial or public workplace, would yield an equivalent protection in the 3–4 ug/m^3-range (i.e., 168 hours is about 4 times longer than 40 hours and 112 is about 3 times longer). The exposure for non-employees, such as customers or clients in businesses or students in a school, would be even more transient. Although these non-employees could be more susceptible than presumably healthy adult workers, a concentration in this 3–4 ug/m^3-range should be safe for them as well [CDC 1995; Nickle 1999; Ratcliffe 1996].

2.3.3 Conditions when other concentration may apply: The interaction between mercury and the developing CNS is poorly understood. Therefore, mercury exposures should be minimized for workers in all settings who are confirmed or suspected to be pregnant, or may become pregnant. In commercial settings, such as maternity wards, dialysis clinics, pre-kindergarten daycare, and pediatric intensive care units, susceptible populations reasonably may be expected to spend prolonged periods of time. In those cases, minimizing mercury exposures or lowering the acceptable residual concentration should be considered.

When considering response operations during a mercury spill, balancing the risks associated with specific settings may be necessary. For instance, if a mercury spill occurs in a commercial setting that provides essential life-saving services to a community and is the sole source for those services, disrupting these services may cause greater harm than exposure to the mercury. Exposure to mercury at levels as high as occupational levels for only a few hours is not likely to cause serious harm to a person, whereas missing a scheduled dialysis treatment may cause significant harm. The risk manager at the scene should consult with public health authorities in the community if this kind of circumstance is suspected.

2.4 Schools and Educational Settings: Schools can pose a significant challenge during mercury cleanup. First, schools commonly provide a community setting in which many children could be exposed to a single source of liquid mercury discovered in or brought to the school. Second, the school environment can actually be a source of mercury—the fascinating chemical and physical properties of mercury can make it seem a useful teaching tool. Other potential exposure locations in a school include utility rooms and ventilation spaces where mercury may be used in temperature or pressure controls. Third, school areas, such as buses, gyms, cafeterias, and hallways, are commonly used by many people; they may walk through spilled mercury and spread contamination to other areas. Fourth, schools have multiple appliances (e.g., classroom computers and computer labs) that can produce heat. A classroom with 1–5 computers not in use may be safe; however, 5 computers turned on and producing their normal amount of heat in the air may generate enough mercury vapors in the room from a spill to pose a risk to staff and students [ATSDR 1997; CDC 1995, 2005; EPA 2010; Gordon 2004; Mercury in Schools 2004;

Nickle 1999; Taueg 1992; Tominack 2002]. Additionally, the length of exposure duration may be too short to likely harm the seemingly most sensitive population (i.e., the students).

Many school systems have programs to remove hazards, including mercury, in their schools. However, students can bring mercury to the school and share it with their fellow students, a contingency that school officials must recognize and address.

The exposure scenario at most schools, even with after-school programs, is typically much closer to a workday type of exposure (i.e., 7–10 hours) than a residential setting; however, the longest time most students will spend in any given school building will be commonly 3–5 years. Some private schools may offer more extended instructional opportunities, both in the number of hours per day and in the number of years (i.e., number of grade levels taught). Staff at these schools may be in the same setting for a considerably longer time (e.g., a 40-year work lifetime; 10–12 hour days), depending on their personal habits and regional turnover rates. Students or staff could be pregnant. Risk managers should be aware of the potential for these unique circumstances within a school.

Consideration should be given to closing or isolating areas of schools with mercury concentrations of ≥10 ug/m^3, depending on the exposures, pending removal of the hazard. Given the variables associated with exposures in educational settings, ATSDR recommends a range ≤3 ug/m^3 before resuming normal operations of the school. This recommendation is based on the residential action levels discussed earlier and adjusted for a normal school day. Presuming all visible mercury in the setting has been removed, this action level is considered appropriate.

2.5 Vehicles

The scenario for persons exposed to mercury while in vehicles is challenging to estimate because it depends on many factors. The purpose of the vehicle (e.g., a school bus versus a family van), the habits of the individual users (e.g., how much time does Mom spend in the car in a hot parking lot waiting for the kids to get out of school?), the sensitivity of the individual passengers (e.g., is Mom in the previous example pregnant?), and the number of passengers routinely in the vehicle are probably the biggest considerations. However, the intended use in any given period may greatly influence the potential hazard posed by mercury in a vehicle. For instance, a spill in a family vehicle that is used soon after for a prolonged vacation may cause more intense exposure than otherwise might be expected. Given all the possible variables, the most sensitive anticipated use of a vehicle should determine the action level for that vehicle.

For family vehicles, the exact exposure scenario depends on the habits of the principle drivers, but some exposure to most of the family is possible at some point. The duration of exposure on any given day is likely to be only a small fraction of the 24-hour period, but this could be offset by much longer duration exposures for transient periods (e.g., the family vacation). Because most of the family could be exposed while in the vehicle, the entire spectrum of sensitivities must be considered. The vehicle itself will be a fairly confined space with variable air-change rates (e.g., use of the air conditioner compared to open windows). Other than the transient exposure scenario of the family vacation, the length and intensity of the exposure duration should allow a higher spectrum of action levels than has been discussed up to this point.

For work vehicles, the exposure scenario can be either a vehicle that is used primarily to commute to a work location with a duration equal to a fraction of a full day (e.g. similar to the family vehicle above), or a vehicle that, for all intents and purposes, is the work location with a duration closer to an normal workday (e.g., sales and service vehicles, some construction equipment). In this instance, the population being exposed can be assumed to be a healthy adult. The occupied working area of the vehicle would be similar to a family vehicle or smaller and could be relatively open to the environment (e.g., an operator's seat on a piece of construction equipment), or closed similar to the family vehicle (e.g., the service van). For closed vehicles, concentrations higher than that of a family car would be acceptable generally. Without engineering controls and recommendations for settings protection when mercury is a known hazard, the acceptable concentration in these vehicles should not approach the occupational standards.

For multi-passenger vehicles, such as school buses or church vans, the exposure scenario would depend upon the underlying purpose of the vehicle. In other words, most passengers in a school bus would be students, and the characteristics of the population would be similar to that described earlier for the school being served. Population characteristics of the passengers in a city bus or a church van would be closer to that of the general population. For common carrier vehicles, such as airplanes or trains, the exposure duration would be relatively short for the passengers but closer to a workplace exposure for the crew. While space for individual persons may be limited, the interior of the multi-passenger vehicle over all would tend to be more spacious than other vehicle types. Air-change rates would vary significantly depending on the status and type of the vehicle. Given the high variability in the sensitivity of the population being transported, acceptable concentrations would be lower than most commercial or work vehicles. Exposure duration for most multi-passenger vehicle would be relatively short (e.g., measured in hours); however, exposure duration in a common carrier would vary over a fairly broad spectrum.

Visible mercury should not be present in any vehicle for all the reasons cited earlier in section 2.1, but primarily because it could be tracked into other settings. The risk manager should be mindful that, even in a vehicle, higher concentrations mean a source of liquid mercury is likely present. If concentrations inside the vehicle do not decline significantly with cleaning and removing potential sources, a source of liquid mercury is especially likely. Concentrations >6 ug/m^3 should raise concerns about the presence of liquid mercury in the vehicle.

Given all of these variables and concerns, ATSDR recommends an action level in the range of 3–6 ug/m^3. This is based on concerns similar to the commercial setting (such as schools and retail establishments), adjusted for the shorter and transient exposure in the vehicles, and avoidance of tracking and the nuisance hazard of liquid mercury. Pregnant women and very young children should spend the minimum time possible in a vehicle contaminated with mercury. For a transient exposure of prolonged duration, alternative transportation should be considered for sensitive persons in the family.

3.0 <u>Conclusion:</u>

For the given scenarios requested by the Action Level Subgroup, ATSDR considers the action levels in this health consultation and summarized in the following tables appropriate to protect public health. If the action levels are exceeded, the risk managers on scene should consider appropriate response actions to protect the health of persons most likely to be exposed or more sensitive to the effects of mercury.

Before selecting any specific action level or course of action, risk managers should consider the assumptions and limitations described in this health consultation as they apply to the situation encountered when responding to a release. Risk managers should consider consulting with ATSDR staff or EPA risk assessors when unusual situations or unusually sensitive persons are involved.

In all cases where cleanup actions are terminated under these schemes, the action levels recommended are based on the assumption that all liquid mercury has been removed from the scene of the exposure.

4.0 Recommendations:

In removal actions, ATSDR recommends that any liquid mercury at the scene be isolated and removed as expeditiously as possible to avoid tracking the mercury to other locations.

Each site may have site-specific concerns that should be considered before selecting an appropriate action level. Risk managers at the scene of a spill should consider consulting with regional risk assessors or public health officials at ATSDR, the State, or local authorities regarding unusual circumstances that they encounter.

ATSDR recommends the liberal use of field screening devices and methods to detect the presence of mercury in areas where a spill is suspected and to monitor the progress of cleanup. Environmental samples analyzed in a laboratory are generally unnecessary until all visible mercury is removed and confirmation is required that response activity is complete.

Samples to confirm final cleanup should be collected and analyzed in a manner equivalent to the modified NIOSH 6009 method. ATSDR considers readings from a properly calibrated Lumex Mercury Vapor Analyzer, that are representative of 8 hours of exposure at the point of sampling, as comparable to the NIOSH 6009 method in the range of 0.1-10 ug/m^3 [Singhvi, 2003] and will accept these in lieu of laboratory analysis.

Application of the action levels provided in this health consultation should be modified as necessary to reflect actual conditions at the site of a mercury release. At the request of the lead agency, ATSDR is available to review site-specific situations and assist in making any decision to modify the application at the site.

The conclusions and recommendations provided in this health consultation are based on the information available to ATSDR as of the date of the document. New or additional information may necessitate a modification of our conclusions and recommendations.

5.0 Appendices

Table 1: Suggested Action Levels for Residential Settings
Table 2: Suggested Action Levels for Other Locations.
Figure 1A, B, C: ATSDR Toxicological Profile (Figure 2-1)

6.0 References

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Table 1: Suggested Action Levels for Residential Setting

Action Level (ug/m^3)	Use of Action Level	Rationale for Action Level	Sampling Suggestions and other Considerations	Consult Section
Less than 1	Acceptable level for normal occupancy for most sensitive persons. No further response action needed	Experience has shown that response actions to reach levels lower than 1 ug/m^3 can be disruptive enough to cause more harm than benefit. 1 ug/m^3 is within an order of magnitude of health guidance values and indoor background levels. This concentration is 25 times lower than the concentrations referenced in the development of health guidance values.	No visible mercury; highest quality data.* Sampling in breathing zone of most sensitive person under normal conditions for use.	See Sections 2.1 and 2.2.1
3–6	Acceptable level for unrestricted use of family vehicles under most conditions.	Exposure duration in most vehicles is short compared with other settings, allowing a higher concentration as the “floor” of this range. Requirement for no visible mercury means the source of vapors has been removed and concentrations should continue to fall The “ceiling” of the range is based on the presumption that liquid mercury may still be present but not yet discovered.	No visible mercury; highest quality data.* Sampling in the passenger compartment under normal use conditions. Unusual use of the vehicle in this case would be extended family vacations.	See Sections 2.1 and 2.5
3–6	Acceptable level to allow personal belongings to remain in owner’s possession.	The sampling point suggested in the column to the right tends to concentrate the vapors higher than typical exposure conditions. Exposure frequency should be intermittent and the duration should be short. The 6 ug/m^3 is based on the possibility that liquid mercury i is present but may not have been discovered.	Survey instrument data generally acceptable.+ Readings should be at the vents of appliances or headspace of bags. Bags should be warmed passively to ambient conditions and appliances/ electronics should be at operating temperatures.	See Section 2.2.3
Greater than 10	Isolation of contamination from residents or evacuation of residents	Indications are that 10 ug/m^3 may be the concentration at which urinary levels of mercury begin to increase. Other studies indicate this concentration may be the lowest toxic concentration (TCLo) for humans. Continued exposure may be harmful.	Survey instrument data acceptable. + Exposure to contaminant should be minimized.	See Section 2.2.2

***Highest quality data is NIOSH 6009 analytic results or equivalent (e.g., Lumex reading averaged over 8 hours)**
+Survey instrument data is considered any real-time monitoring equipment (e.g., Jerome, MVI, VM 300)

Table 2: Suggested Action Level for Other Locations

Action Level (ug/m^3)	Use of Action Level	Rationale for Action Levels	Sampling Suggestions and other Considerations	Consult Section/ Reference
Less than 3	Normal Occupancy for commercial settings where mercury exposure is not expected in normal course of work. (e.g., 29 CFR 1910 Subpart Z does not apply)	Concentration is based on residential action level of 1 ug/m^3 adjusted for a work day (i.e., 24/7 exposure reduced to 8/5 or 40 hour workweek). Persons exposed in these settings would not expect the presence of mercury as part of their normal employment.	No visible mercury; highest quality data.* Taken in breathing zone of most sensitive person under normal conditions for use. Pregnant workers should be offered alternate worksite.	See Section 2.1 and 2.3.2
1–3	Acceptable level for schools to resume normal operations.	Concentration is based on residential action level of 1 ug/m^3 adjusted for a typical school day.	No visible mercury; highest quality data.* Taken in breathing zone of most sensitive person under normal conditions for use. Pregnant workers and students should be offered temporary alternatives to working or attending the school..	See Section 2.1 and 2.4
3–6	Acceptable level for unrestricted use of vehicles under most conditions.	Exposure duration in most vehicles is short compared with other settings, allowing a higher concentration as the “floor” of this range. Requirement for no visible mercury means the source of vapors has been removed and concentrations should continue to fall The “ceiling” of the range is based on the [illegible]	No visible mercury; highest quality data.* Sampling in passenger compartment under normal use conditions. Unusual use of the vehicle in this case would be situations where the vehicle is the workplace.	See Sections 2.1 and 2.5
Greater than 10	Isolation of contamination or evacuation of workers not covered by a health and safety program addressing exposure to mercury.	Indications are that 10 ug/m^3 may be the concentration at which urinary levels of mercury begin to increase. Other studies indicate this concentration may be the lowest concentration toxic to humans.	Survey instrument data acceptable.+ Exposure to contaminant should be minimized.	See Section 2.3.2
25	Normal Occupancy for industrial settings where mercury exposure is expected in normal course of work. (e.g., 29 CFR 1910 Subpart Z does apply).	Based on the 1996 ACGIH TLV. Assumes hazard communications programs as required by OSHA; engineering controls as recommended by NIOSH; and medical monitoring as recommended by NIOSH and ACGIH are in place.	Survey instrument data acceptable.+ Workers in these settings should be subject to OSHA standards for mercury (e.g., medical records, Subpart Z, HCS, HAZWOPER).	See Section 2.3.1
25	Upgrade responder protective ensemble to Level C during uncontrolled releases of mercury	For response, workers subject to requirements of 29 CFR 1910.120, based on the ACGIH TLV, as recommended by the 1987 NIOSH/OSHA/USCG/EPA Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities (the” 4 agency guidance manual”).	Survey instrument data acceptable.+ Uncontrolled release refers to the absence of positive engineering controls on the material.	Occupational Safety and Health Guidance Manual for Hazardous Waste Site

* - Highest quality data would be NIOSH 6009 analytic results or equivalent (e.g., Lumex reading averaged over 8 hours)
\+ - Survey instrument data would be considered any real time monitoring equipment (e.g., Jerome, MVI, VM 300, etc)

Figure 1A: ATSDR Toxicological Profile Figure 2-1 Acute Exposures (Annotated)

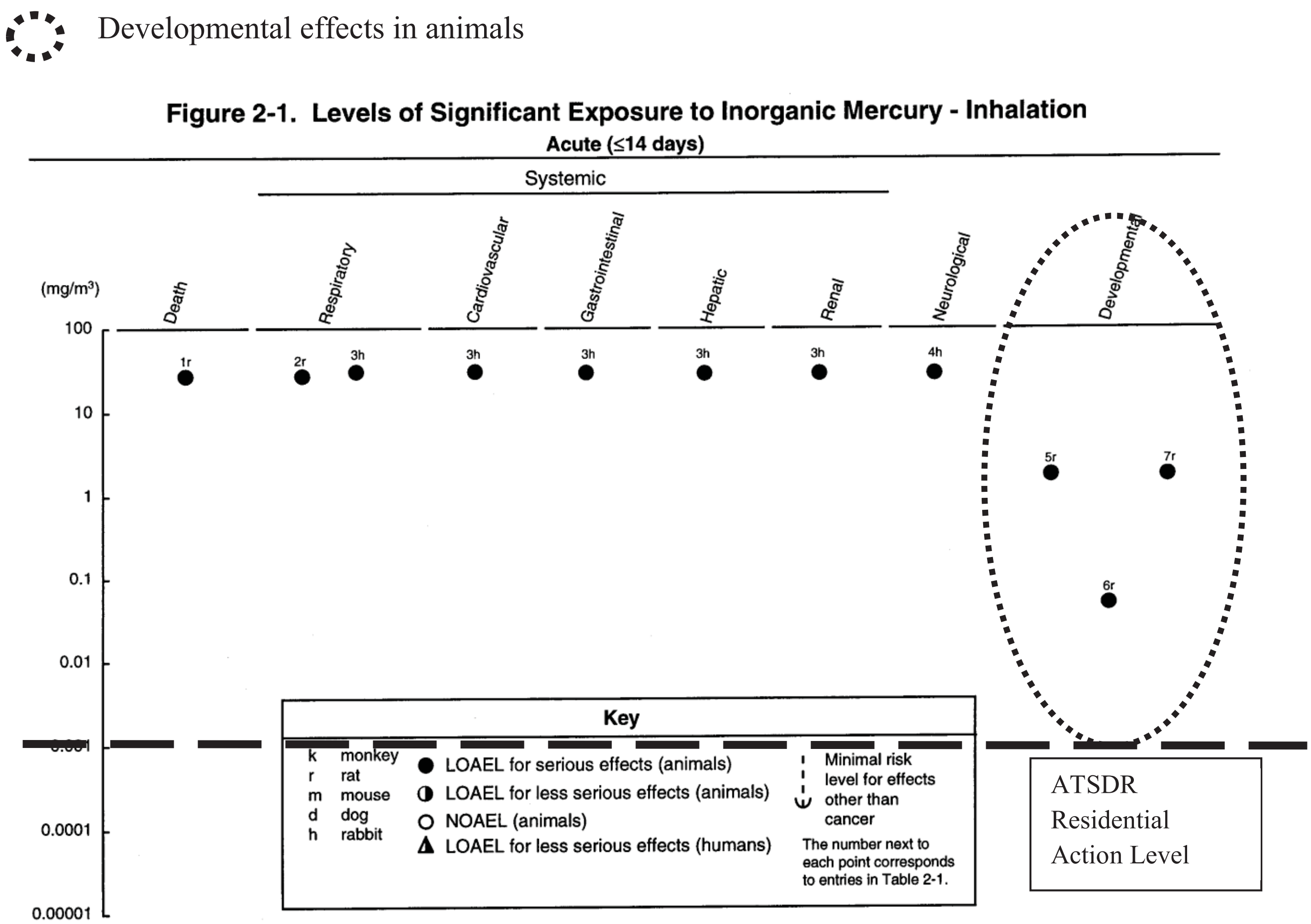

Figure 1A. Annotated insert of Figure 2-1 from the ATSDR Toxicological Profile graphing the significant inhalation studies of inorganic mercury by health effect and concentration for exposure durations of ≤14 days. Dashed line represents the ATSDR Residential Action Level recommended in this health consultation. This figure illustrates most clearly the reason for considering developmental effects as the most sensitive endpoint.

Figure 1B: ATSDR Toxicological Profile Figure 2-1 Intermediate Exposures (Annotated)

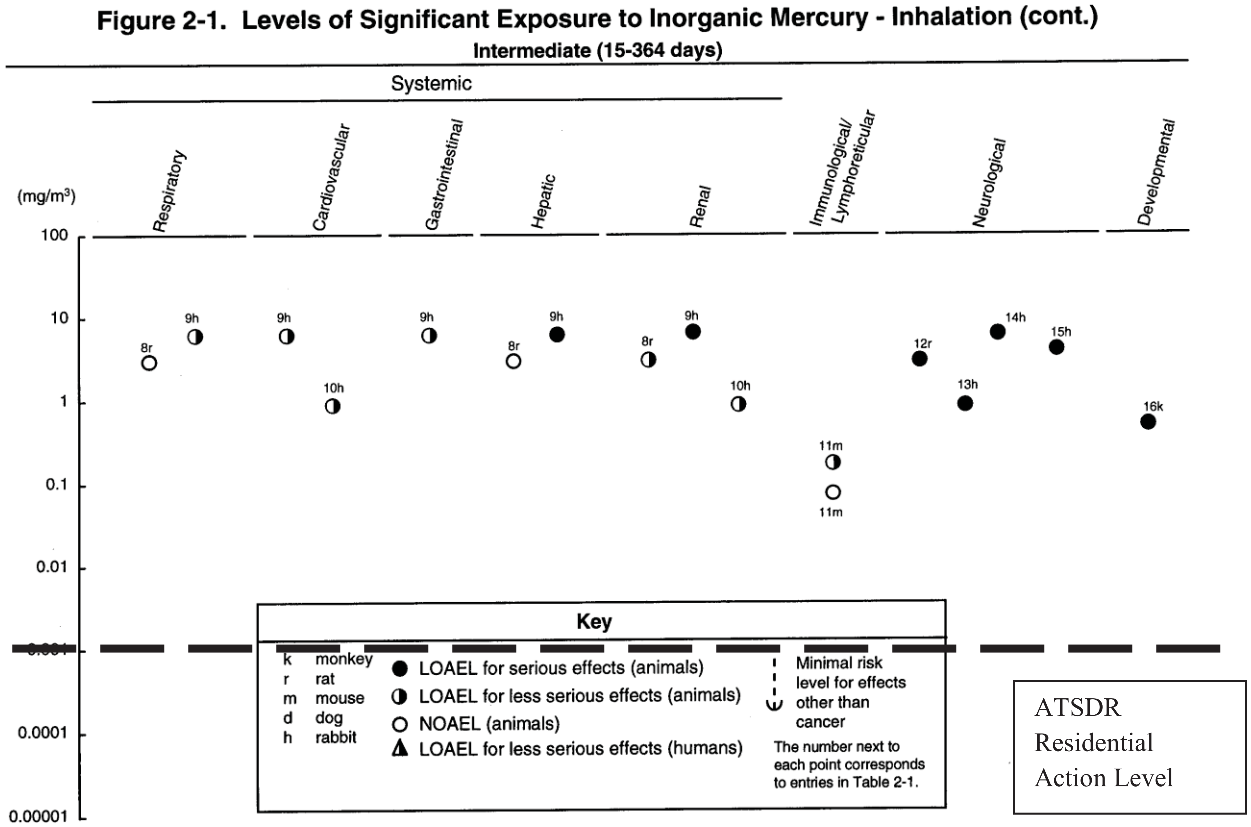

Figure 1B. Annotated insert of Figure 2-1 from the ATSDR Toxicological Profile graphing the significant inhalation studies of inorganic mercury by health effect and concentration for exposure durations of 15–364 days. Dashed line represents the ATSDR Residential Action Level recommended in this health consultation.

Figure 1C: ATSDR Toxicological Profile Figure 2-1 Chronic Exposures (Annotated)

Human Studies considered significant by ATSDR

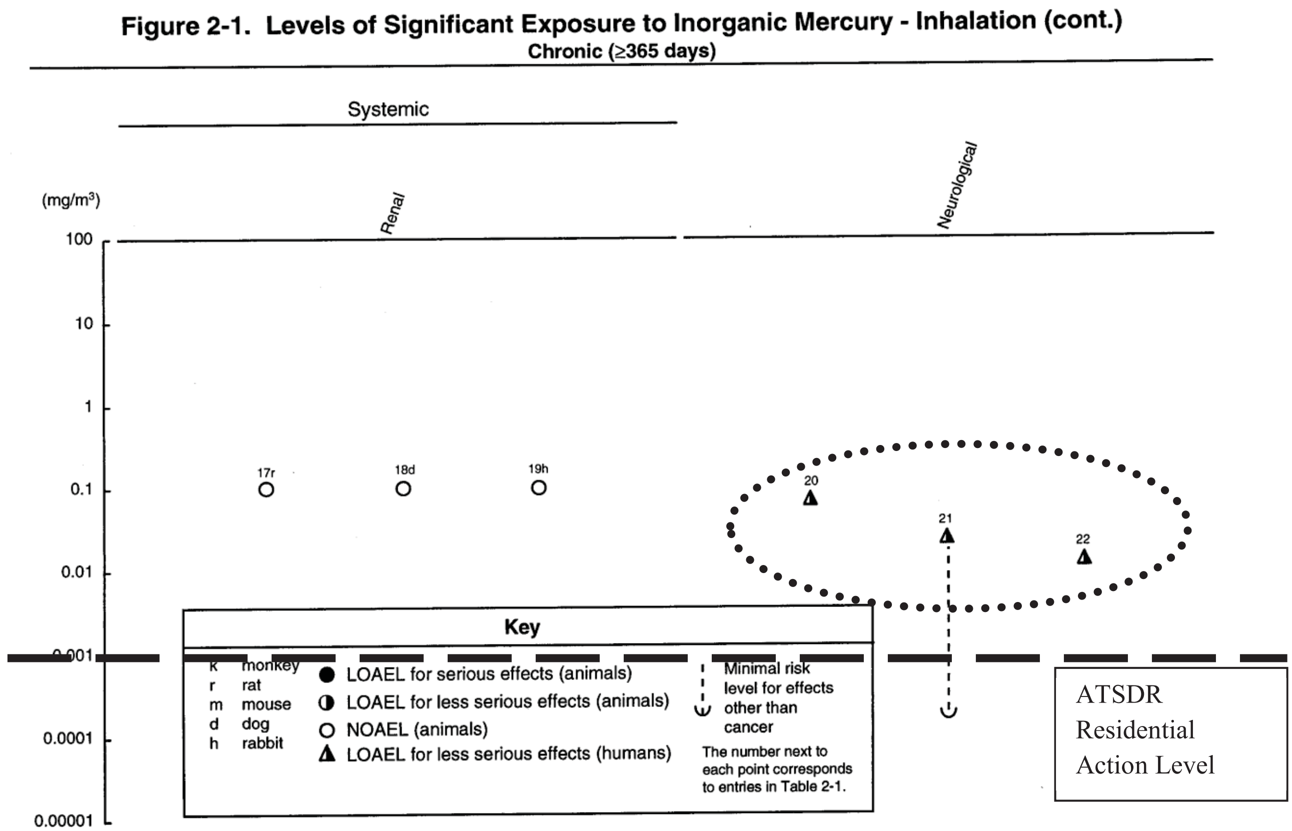

Figure 1C. Annotated insert of Figure 2-1 from the ATSDR Toxicological Profile graphing the significant inhalation studies of inorganic mercury by health effect and concentration for exposure durations of ≥365 days. Dashed line represents the ATSDR Residential Action Level recommended in this health consultation. This dotted circle indicates the three studies of humans in occupational settings that ATSDR considers most significant.