MICHIGAN DEPARTMENT OF ENVIRONMENTAL QUALITY

INTEROFFICE COMMUNICATION

TO: File for Mercury and Mercury Compounds (CAS # 7439-97-6)

FROM: Robert Sills, AQD Toxics Unit Supervisor

SUBJECT: ITSL Derivation for Mercury (Hg) and Mercury Compounds

DATE: June 2, 2015

The ITSL for mercury and mercury compounds to provide protection from chronic inhalation exposure is 0.3 ug/m^3 with an annual averaging time. The ITSL for mercury and mercury compounds to provide protection from acute inhalation exposures is 1 ug/m^3 with a 24-hour averaging time. These ITSLs apply to elemental mercury and all inorganic mercury species, combined. Sources emitting various forms should be summed (as Hg emissions) to determine total mercury emissions, and modeled ambient air impacts of total mercury should be compared to these ITSLs.

As with all ITSLs, the mercury ITSLs are protective for inhalation exposure only. These ITSLs are not intended to, and may not, ensure protection from mercury deposition impacts, fish bioaccumulation, and exposure to fish eaters. The latter concern has been, and should continue to be, evaluated by AQD on a case-by-case basis, using such risk assessment tools such as MPCA's MMREM model, the EPA (2005) HHRAP methodology, and the EPA (2001) Mercury Maps methodology.

Mercury Forms in Air Emissions

Mercury in emissions to the air from sources subject to AQD Permits to Install (PTI) may exist in different forms, which may not be well characterized for specific emission sources. The EPA (2005) HHRAP Protocol for Hazardous Waste Combustion Facilities provides a useful summary of mercury speciation from sources. Stack emissions include both vapor and particulate forms of mercury. Most of the total mercury emitted from the stack is in the vapor phase, although particulates in emissions can bind up some fraction of the mercury (EPA, 2005). Vapor mercury emissions are thought to include both elemental (Hg0) and oxidized (Hg^{+2}, a.k.a., Hg(II) or reactive gaseous mercury (RGM)) chemical species. Particulate mercury emissions are thought to be composed primarily of oxidized compounds, due to the relatively high vapor pressure of elemental mercury. True speciation of mercury emissions from the various source types is still uncertain and thought to vary not only among source types, but also between individual plants (EPA, 2005). Total mercury exiting the stack is assumed to consist entirely of elemental and divalent species, with no emissions of organic mercury (e.g., methyl mercury; MeHg). Particularly in the combustion of wastes containing chlorine, much of the exit stream is thought to be divalent, e.g., mercuric chloride ($HgCl_2$). The divalent fraction is split between vapor and particle-bound phases. The data on mercury speciation in stack emissions is very limited (EPA, 2005).

For mercury emissions from hazardous waste combustion facilities, estimates for the percentage of vapor and particle-bound mercury emissions range widely from 20 to 80 percent. EPA (2005) recommends a default assumption of 80% total mercury in the vapor phase and

20% in the particle-bound phase. Of the 80% in the vapor phase, it may be assumed that 20% of the total is in the elemental form and 60% is in the divalent form. Of the 20% of the total mercury emissions that is particle-bound, it may be assumed that 99-100% is in the divalent form (EPA, 2005). Mercury emissions from cement kilns may be predominantly in the form of RGM, as has been found for one facility in Michigan (up to 90% RGM). The fraction of coal combustion emissions in oxidized form (i.e., mercuric chloride) is thought to be less than the fraction in oxidized form from other emission sources (including waste incineration) (EPA, 2005). For small, medium and large coal-fired power plants and oil-fired utility boilers, EPA (1997; Mercury Study Report to Congress; Volume III, Table 4-9) recommended an assumption for model plants (when lacking facility-specific speciation data) of a 50/30/20 speciation profile (50% Hg0 (elemental mercury); 30% Hg2+; 20% Hg(P) (particulate mercury)); for municipal waste combustors, they recommended a 60/30/10 speciation profile. Recommended model plant profiles for other facility types were also provided (EPA, 1997; Volume III, Table 4-9).

Mercury emissions to the atmosphere may be transported short or long distances before being removed by wet or dry deposition. Residence time in the atmosphere has been estimated to range from 60-90 days to 0.3-2 years (ATSDR, 1999). Elemental mercury may predominantly undergo long-range transport; it may be oxidized to Hg(II) by atmospheric ozone but this process does not occur rapidly. AQD screening level development addresses maximum near-source levels and public health protection before greater dispersion occurs at distances downwind. Therefore, the focus is on the forms that may be emitted rather than atmospheric transformations.

EPA (1997) reported that ambient air total mercury concentrations in the U.S. are approximately 1-4 ng/m^3 in rural areas, and 10-170 ng/m^3 in urban areas, predominantly in the form of Hg0. Atmospheric mercury is predominantly (>90%) in the form of Hg0 (Liu et al., 2010; Liu et al., 2007). MDEQ (2008) provides an estimated background level of Hg0 of 1.5 ng/m^3 or less. Hg(II) can range from 1-25% of the total (the higher fractions occur in urban areas); methylmercury may comprise 0-21% of the total (generally % MeHg is on the low end of this range) (EPA, 1997). Studies in Michigan in the 1990s indicate that vapor-phase mercury is the predominant form; particulate-phase mercury may comprise approximately 1-10% of the total Hg (EPA, 1997).

Toxicokinetics

ATSDR (1999) provides a summary of toxicokinetics for different forms of mercury. The following summary focuses on elemental mercury (Hg0) and inorganic mercury (e.g., $HgCl_2$), because they are the predominant forms in facility air emissions. Absorption is high (approximately 70-80% for inhaled elemental mercury vapor, by rapid diffusion through the lungs. The absorption of inhaled inorganic divalent mercury has been estimated to be approximately 40% in dogs. Studies on the adult distribution of elemental, inorganic and organic mercury are consistent in identifying the kidney as the organ with the highest mercury bioaccumulation. Inorganic mercury compounds can reach most organs; however, their low lipophilicity reduces their ability to penetrate barriers (e.g., blood-brain barrier, placental barrier), and the extent of accumulation in the brain and fetus is lower than metallic mercury. Metallic mercury has high lipophilicity and can be transferred readily through the placenta and blood-brain barrier. Once absorbed, elemental and inorganic mercury enter into an oxidation-reduction cycle. Metallic mercury can be oxidized to inorganic divalent mercury, and inorganic divalent mercury cations can be reduced to metallic mercury. In the plasma, the mercuric ion is predominantly nondiffusible and binds to albumin and globulin. The urine and feces are the main excretory pathways of metallic and inorganic mercury in humans, with a body burden half-

life of approximately 1-2 months. Since the ultimate toxic species for all mercury compounds is thought to be the mercuric ion, the kinetics of the parent compound is the primary determinant of the severity of parent compound toxicity. It is the differences in the delivery to target sites that result in the spectrum of effects. Thus, mercury, in both inorganic and organic forms, can be toxic to humans and other animals (ATSDR, 1999). Because inorganic salts of mercury do not readily cross the blood-brain or the placental barriers, they are less toxic to the central nervous system (CNS) and the developing fetus than either absorbed elemental mercury or organic mercury compounds. Once in the CNS, however, metallic mercury is oxidized to the mercuric ion (Hg^{+2}) which is then trapped in the CNS due to the limited ability of the mercuric ion to cross the blood-brain barrier. All mercury compounds may ultimately be oxidized to divalent (or mercuric) mercury, which preferentially deposits in the kidneys in children and adults, and all mercury compounds may cause some degree of renal toxicity (ATSDR, 1999).

Cal OEHHA (2014) noted that the mercuric ion (Hg^{+2}) does not readily cross the blood-brain barrier as do MeHg and elemental mercury, however, the blood-brain barrier is incompletely formed in fetuses and neonates. In neonates, mercuric species do not concentrate in the kidneys but are more widely distributed to other tissues. After elemental vapor exposure to pregnant adult guinea pigs, mercury concentrations were 28% higher in the brain of the fetus than in the brain of the mother (ATSDR, 1999, p. 174).

ACGIH (2001), in establishing a TLV-TWA for, “mercury inorganic forms including metallic mercury,” noted that, “…both mercury vapor and mercuric chloride could be transformed back and forth from oxidized mercury to elemental mercury, illustrating the complexity of mercury compounds’ transformation.”

Toxicology Literature Review for ITSL Derivation

Because of the relative wealth of mercury toxicity information and regulatory benchmarks established by many reputable agencies, this review focused on evaluating those available risk-based benchmarks and their underlying key studies, noting the mercury species involved in the exposures and targeted by the benchmarks.

Available Health Protective Benchmarks and Inhalation Toxicity Studies of Mercury Forms

Table 1 lists several available key health protective benchmarks for inhalation exposures to mercury.

Table 1. Available key health protective mercury inhalation benchmarks

Source	Benchmark Value (ug/m^3)	Avg. Time	Hg Species	Basis
EPA (1995) IRIS	0.3	Chronic	Hg0	Neurological effects, hand tremor; human occ. inhalation studies; LOAEL[1] (TWA)= 25 ug/m^3; LOAEL(adj)= 9 ug/m^3; HEC[2]= 9 ug/m^3; UF[3]=30 (10 for combined UF_H[4] and UF_L[5]; 3 for UF_{db}[6]); (Fawer et al., 1983; etc.)
ATSDR (1999) Toxicological Profile	0.2	Chronic (1 year or longer)	Hg0	Industrial epidemiology study, duration of exposure 15.3 +/-2.6 years; increased hand tremors; LOAEL= 26 ug/m^3; time adjustments 8/24 hrs and 5/7 days; UF=30 (3 for LOAEL; 10 for human variability. (Fawer et al., 1983)
OSHA (2015)	100.	8-hr Time Weighted Average (TWA)	Inorganic and aryl compounds	
ACGIH (2001, 2014)	25.	8-hr TWA	Elemental and inorganic forms	CNS impairment, kidney damage
	100	8-hr TWA	Aryl cpds., as Hg	CNS impairment, kidney damage
	10; 30	TWA; Short-term exposure limit (STEL)	Alkyl cpds., as Hg	CNS and PNS impairment, kidney damage
NIOSH (2015)	50. 100.	TWA for 10 hr Ceiling	Inorganic and aryl compounds	
MDCH (2009); ATSDR (2012)	<1.	Action Level for recommending acceptability of home occupancy	Elemental (metallic) mercury	Applied to scenarios where attenuation over time may be assumed (e.g., indoor spill situations)
Cal OEHHA (2014)	0.6	Acute (1-hour)	Mercury and inorganic mercury compounds	Rat 1 hr/d inh. developmental study LOAEL= 1.8 mg/m^3 Hg0 to pregnant rats, for effects on motor activity of offspring (Danielsson et al., 1993)
	0.06	8-hour		Neurological effects, human occ. inh. studies; LOAEL (TWA)= 25 ug/m^3; LOAEL(adj)= 18 ug/m^3 (for 8-hr) or 9 ug/m^3 (for chronic); UF=300 (10 for UF_L; 30 for UF_H); (Fawer et al., 1983; etc.)
	0.03	Chronic		

[1] LOAEL = lowest observed adverse effect level

[2] HEC = human equivalent concentration

[3] UF = uncertainty factor

[4] UF_H = UF to account for intrahuman variability in sensitivity

[5] UF_L = UF for extrapolating from a LOAEL to a no-observed-adverse-effect-level (NOAEL)

[6] UF_{db} = UF to account for database deficiencies

Although EPA's IRIS database does not have a Reference Concentration (RfC) for mercuric chloride ("no data" is denoted in IRIS, as determined in 1994), there is a Reference Dose (RfD) for mercuric chloride of 3E-4 mg/kg-d, based on rat subchronic feeding and subcutaneous studies; the critical effects are autoimmune effects. This RfD is fairly similar in magnitude to the EPA (IRIS) methylmercury RfD of 1E-4 mg/kg-d, which is based on epidemiological studies and developmental neuropsychological impairment. The EPA (IRIS) does not have an RfC for methylmercury ("no data" was the 2001 determination).

The EPA (1995; IRIS) has an RfC for elemental mercury = 0.3 ug/m^3; it is assigned a "medium" confidence rating for the study, database, and RfC. The lack of human or multispecies reproductive/developmental studies precludes assigning a high confidence rating to the database, along with inadequate quantification of exposure levels (EPA, 1995). This RfC was derived with a total uncertainty factor of 30. This includes an uncertainty factor of 10 for the protection of sensitive subpopulations (including concern for acrodynia) together with the use of a LOAEL; and, a UF of 3 was used for inadequate database, particularly a lack of develop-mental and reproductive studies. For EPA's 2005 National-scale Air Toxics Assessment (NATA), EPA utilized a chronic dose-response inhalation value of 0.3 ug/m^3 for "mercury compounds," based on the IRIS RfC for elemental mercury (EPA, 2015b); and, it was implemented in NATA with an annual averaging time. Similarly, EPA OAQPS (2014) utilizes for chronic inhalation dose-response assessment of health risks for HAPs the RfC for elemental mercury; chronic inhalation values are not listed for mercuric chloride or methyl mercury. This supports the use of an annual averaging time, if the chronic ITSL is based on either the EPA RfC or the ATSDR chronic inhalation MRL. As indicated in Table 1, one of the primary key studies for the derivation of the RfC for elemental mercury was Fawer et al. (1983), which provided an occupational LOAEL for hand tremor at 26 ug/m^3 for an average of 15.3 years (EPA, 1995). In this study, ACGIH (2001) noted that, "The most important predictor of hand tremor was duration of exposure." EPA (1995) stated, "It should be noted that it is likely that the levels of mercury in the air varied during the period of exposure and historical data indicate that previous exposures may have been higher." It should be noted that EPA (1995) based the RfC on six key studies which, "…were taken together as evidence for a LOAEL based on neurological effects of low-level mercury exposure." These six studies provided TWA LOAEL values ranging from 14 to 33 ug/m^3; in deriving the RfC, EPA chose a TWA LOAEL = 25 ug/m^3 to derive the point-of-departure of 9 ug/m^3 for a LOAEL(HEC) = LOAEL(ADJ).

The ACGIH OELs for mercury are listed in Table 1. The TLV-TWA of 25 ug/m^3 (for inorganic forms including metallic mercury) is, "…intended to minimize the potential for preclinical central nervous system (CNS) changes and kidney effects, and to provide some assurance that workers will maintain their functional capacity to produce healthy children with normal cognitive and physical functions. These values also should provide significant protection against the classical signs and symptoms of mercury toxicity that may include tremors, emotional instability and irritability, peripheral neuropathy, gingivitis, stomatosis, ocular and vision changes, hearing loss, and renal impairment." "It is not possible to unequivocally determine an exposure level for absolute protection of reproduction function in either male or female workers." (ACGIH, 2001). It is interesting to note that this TLV-TWA (25 ug/m^3) is identical to the TWA LOAEL that was utilized by EPA (1995) for RfC derivation (see the previous paragraph). A potential acute ITSL derived from this TLV-TWA / 100 (following the standard calculation and AT approach in Rule 232) would be 0.25 ug/m^3 (8-hour AT), which would be even lower than the EPA (1995; IRIS) RfC of 0.3 ug/m^3 for chronic health protection, which would be illogical.

ATSDR has developed oral acute and intermediate MRLs for inorganic mercury (**Table 2**); it may be noted that they differ by only a factor of 3.5.

Table 2. ATSDR (1999) oral MRLs

Route / form	Duration	MRL value	Basis
Oral / inorganic mercury	Acute	0.007 mg/kg-d	Mercuric chloride gavage dosing of rats for 14 d; kidney toxicity
Oral / inorganic mercury	Intermediate	0.002 mg/kg-d	Mercuric chloride gavage dosing of rats for 26 weeks; kidney toxicity.
Oral / methylmercury	Chronic	0.0003 mg/kg-d	Seychelles Islands epidemiology study; 66 months fish ingestion exposure and neonatal testing; neurobehavioral development.

ATSDR (1999) reported that most of the studies on inhalation exposure concerns involved mercury vapor, which they termed "metallic mercury." These studies have found, in humans and animals, systemic toxicity with the major target organs being the kidneys and CNS. They found no studies concerning effect levels following inhalation exposure to inorganic salts of mercury (e.g., mercuric or mercurous salts, oxides). Further, they report that information on inhalation exposures to organic mercury compounds (e.g., alkyl mercury compounds) in humans is limited to case reports and includes only qualitative data on gastrointestinal, renal, muscular, and neurological effects (ATSDR, 1999; p. 33). They derived a chronic inhalation Minimal Risk Level (MRL) of 0.2 ug/m^3 for metallic mercury; they did not derive any inhalation MRLs for inorganic mercury due to the lack of sufficient information. The chronic inhalation MRL was based on the study by Fawer et al. (1983) who found a significant increase in the frequency in the average velocity of naturally occurring tremors compared to controls, in a group of 26 mercury-exposed workers (from 3 industries) exposed to low levels of mercury for an average of 15.3 years (range, 1-41 years). The LOAEL (26 ug/m^3) was TWA adjusted (8hr/24 hr X 5d/7d) to 6.2 ug/m^3, and UFs of 10 (for intrahuman variability in sensitivity; UF_H) and 3 (for use of a minimal-effect LOAEL; UF_L) were applied, resulting in the chronic inhalation MRL of 0.2 ug/m^3 (ATSDR, 1999). They noted that although this MRL is based on experimental data from an adult working population, these is no experimental or clinical evidence to suggest that it would not also be sufficiently protective of neurodevelopmental effects in developing embryos/fetuses and children, the most sensitive subgroups for metallic mercury toxicity. ATSDR (1999) considered Ngim et al. (1992) for derivation of a chronic inhalation MRL because the authors, "…attributed adverse neurological effects to a lower average level of exposure than did the Fawer et al. (1983) study; however, this study was not used in deriving the chronic inhalation MRL due to uncertainties concerning the study protocol, including methodological and reporting deficiencies." (ATSDR, 1999).

The EPA (1995; IRIS) used the same key study and endpoint as ATSDR (1999) for their RfC derivation (Fawer et al, 1983), along with other co-key studies. The EPA (1995) estimated the LOAEL as 25 mg/m^3, and derived the LOAEL (adj) of 9 mg/m^3 by applying factors of MVho/MVh (= 10 m^3/d / 20 m^3/d) and 5d/7d. The EPA then applied a total UF=30 (10 for sensitive subpopulations including the concern for acrodynia, together with the concern for the use of a LOAEL; 3 for database gaps including developmental and reproductive studies) to derive the RfC of 0.3 ug/m^3.

Cal OEHHA (2014) has established acute, 8 hr, and chronic Reference Exposure Levels (RELs) of 0.6ug/m^3, 0.06 ug/m^3, and 0.03 ug/m^3, respectively, for "mercury and inorganic compounds." The acute REL is intended to address short term maternal effects during pregnancy, which may result in long-lasting neurobehavioral effects in the offspring, an effect upon which the acute REL is based, and is protective for, "intermittent one-hour exposures." The 8-hour and chronic RELs are intended to address impairment of neurobehavioral functions in the nervous system.

The acute REL is based on a study (Danielsson et al., 1993) of pregnant rats exposed by inhalation for 1 hr/d during gestational days 11-14 and 17-20. Tests of motor activity in offspring found a LOAEL (no NOAEL was identified) of 1.8 mg/m^3, based on a significant dose-dependent neurobehavioral deficit compared to controls. Cal OEHHA derived the acute REL of 0.6 ug/m^3 from this LOAEL by applying a UF_L = 10 (the effects were regarded as severe), UF_A = 30 (10 for toxicodynamic differences, 3 for toxicokinetic differences), and UF_H = 10, for a cumulative UF = 3000 (note: no time adjustment was applied for the 1-hour exposure duration). The typical use of an UF of 3 for toxicodynamic differences was increased to 10, as Cal OEHHA reasoned:

> [It] reflect[s] the potentially greater developmental susceptibility of humans versus rats. This is based, in part, on Lewandowski et al. (2003) who used a comparative approach to analyze in vivo and in vitro data on the responses of neuronal cells of rats, mice, and humans to MeHg. Their analysis suggests that humans may be up to 10-fold more sensitive to MeHg than are rats.

Cal OEHHA (2014) derived an 8-hr REL of 0.06 ug/m^3 and a chronic REL of 0.03 ug/m^3 based on the same set of occupational epidemiology studies of neurotoxic effects (Fawer et al., 1983, etc.) as utilized by EPA (1995) in deriving the RfC of 0.3 ug/m^3. Cal OEHHA differed from the EPA in the use of uncertainty factors applied to the same LOAEL of 25 ug/m^3. Cal OEHHA applied a total UF = 300 for both the 8-hr and chronic RELs, while EPA (1995) applied a total UF = 30 in deriving the RfC. Cal OEHHA applied a UF_L = 10, and UF_H = 30, to the 8-hr time-adjusted exposure of 18 ug/m^3 and the chronic time-weighted adjusted exposure of 9 ug/m^3.

ATSDR (1999) notes that the CNS is the most sensitive target organ for metallic mercury exposure; acute, intermediate, and chronic duration exposures elicit similar neurological effects. The most prominent symptoms include tremors, emotional instability, insomnia, memory loss, neuromuscular changes, headaches, polyneuropathy, and performance deficit in tests of cognitive function. No studies were located regarding neurological effects in animals following chronic inhalation exposure to inorganic mercury (ATSDR, 1999).

Texas (TCEQ, 2015) does not have Final Development Support Documents (DSDs) for any mercury forms, for Effects Screening Levels (ESLs) or inhalation Reference Values (ReVs).

Acute exposure concerns and Occupational Exposure Limits (OELs)

NIOSH (2015) has established a Recommended Exposure Limit (REL) for mercury vapor at 0.05 mg/m^3 (TWA), and 0.1 mg/m^3 (Ceiling); they also report an OSHA PEL of 0.1 mg/m3 (TWA). This NIOSH REL was established by NIOSH (1978) noting that 1.2 to 8.5 mg/m^3 causes cough, chest pain and dyspnea, leading to bronchitis and pneumonitis; “At low levels, the onset of symptoms resulting from chronic exposure is insidious; fine tremors of the hands, eyelids, lips and tongue are often the presenting complaint…Psychic disturbances such as insomnia, irritability, and indecision occur; headache, excessive fatigue, anorexia, digestive disturbances, and weight loss are common...” ACGIH (2001) established a TLV-TWA for, “mercury, all forms except alkyl” at 0.1 mg/m^3 (for aryl compounds, as Hg) and a TLV-TWA at 0.025 mg/m^3, as Hg, for inorganic forms including metallic mercury. “The recommended TLVs…are intended to minimize the potential risk of adverse health effects and to ensure that workers maintain their functional capacity. This functional capacity includes the ability to produce healthy children whose cognitive and physical functions are within the norm. Data clearly indicate that mercury can affect both male and female reproductive outcomes.” (ACGIH, 2001). A potential ITSL based on the ACGIH TLV-TWA (for inorganic forms of mercury, including metallic mercury)

divided by 100 (as per Rule 232(1)(c)) would be 25 ug/m^3 / 100 = 0.25 ug/m^3 (8 hr AT). A potential ITSL based on the NIOSH Ceiling Limit (for metallic vapor) divided by 100 (as per Rule 232(1)(c)) would be 100 ug/m^3 / 100 = 1 ug/m^3 (1 hr AT).

ATSDR (1999) provides an inhalation Minimal Risk Level (MRL) only for chronic (1 year or longer) duration; an inhalation MRL for acute or intermediate durations is not available.

Health-based recommendations are available from MDCH (2009) and ATSDR (2012) for interpreting short-term sampling results in homes. An action level is an indoor air concentration of mercury vapor that should prompt public health and environmental officials to consider implementing response actions (ATSDR, 2012). The recommended action levels for mercury in residential settings are: "less than 1 ug/m^3" for "normal occupancy for most sensitive persons," and, "greater than 10 ug/m^3" for isolation (e.g., evacuation, limited access, etc.) of the residents from exposure to the mercury. Since these are intended to address spill situations, they reflect an assumption that clean-up or mitigation will occur over a reasonable length of time, and that vapor levels will decline and the chronic inhalation MRL will be attained (Bush, personal communication, 2015). The action level of >10 ug/m^3 is based on the lowest concentration reported in the scientific literature as compiled by ATSDR (1999) associated with adverse human health effects (ATSDR, 2012). This study (Ngim et al., 1992) was 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; it is regarded as a lowest toxic concentration (TC_{LO}) (ATSDR, 2012). The adverse effects reported included impaired performance on several neurobehavioral tests, and higher aggression than controls, with exposure levels ranging from 0.0007 to 0.042 mg/m^3 and an average of 0.014 mg/m^3 (ATSDR, 1999). However, as previously mentioned, ATSDR (1999) did not use Ngim et al. (1992) in deriving the chronic inhalation MRL because, "…the design and reporting of this study limits its usefulness in deriving an MRL for metallic mercury," and noting the, "…uncertainties concerning the study protocol, including methodological and reporting deficiencies." More details about those concerns are provided in ATSDR (1999). The action level of 10 ug/m^3 is also where urinary levels of mercury appear to begin to increase in concentration (ATSDR, 2012). The action level of <1 ug/m^3 is an order of magnitude below both the TC_{LO} noted above, and the level where urinary mercury begins to increase (ATSDR, 2012). Historically, ATSDR has recommended 1 ug/m3 as the residential level requiring cleanup (ATSDR, 2012). This level (1 ug/m^3) is also 26 times lower than the point of departure for the derivation of the ATSDR chronic inhalation MRL and the EPA RfC (ATSDR, 2012). The action level of <1 ug/m^3 is regarded as a level that is safe for human health, including the most sensitive populations of pregnant women and/or children under the age of 6 years to live in the affected building, for the duration of a clean-up of reasonable length of time (i.e., days vs. weeks) (MDCH, 2009; ATSDR, 2012).

The EPA (1995; IRIS) noted that acrodynia is the most widely recognized form of hypersensitivity to mercury poisoning. This uncommon syndrome has been generally associated with short-term exposures and with urine levels of 50 ug/l or more, however, in some cases it has occurred without urine mercury elevated above background levels. The EPA (1995) felt that the chronic RfC level is adequate to protect children from risk of acrodynia because such exposures of long duration would be expected to raise urine levels by only 0.12 ug/l against a background level of up to 20 ug/l (i.e., such exposures would not add significantly to the background level of mercury in those exposed) (EPA, 1995). It should be again noted that the RfC derivation includes an uncertainty factor of 10 for the protection of sensitive subpopulations (including concern for acrodynia) together with the use of a LOAEL; an UF of 3 was used for lack of a sufficient database, particularly developmental and reproductive studies. EPA OAQPS (2014) and EPA (2015b) list the following acute inhalation dose-response values:

Mercury compounds: IDLH/10 = 1000 ug/m^3
Mercury (elemental): AEGL-2 (10 min) = 3100 ug/m^3; AEGL-2 (30 min) = 2100 ug/m^3;
AEGL-2 (1 hour) = 1700 ug/m^3; AEGL-2 (4 hours) = 670 ug/m^3;
AEGL-2 (8 hours) = 330 ug/m^3; ERPG-2 = 2000 ug/m^3; REL = 0.6 ug/m^3.

Mercuric chloride: TEEL-0 = 35 ug/m^3; TEEL-1 = 120 ug/m^3. It may be noted that further information on the reported TEEL-0 was not provided.

The US DOE (2015) provides the following Protective Action Criteria (PAC) values (based on AEGLs, ERPGs, or TEELs) for emergency planning, for mercury vapor: PAC-1 = 150 ug/m^3; PAC-2 = 1700 ug/m^3; PAC-3 = 8900 ug/m^3.

The TEELs (Temporary Emergency Exposure Levels; DOE, 2015) are concentrations at which most people will begin to experience health effects with exposure for a given duration. TEELs are developed by the US Department of Energy for use in emergency planning. TEELs are defined for a 15-minute period, and they pertain to "nearly all individuals," and are defined as the level "below which" certain health effects are not expected (DOE, 2008). A TEEL-0 is the threshold below which most people will experience no appreciable risk of health effects (DOE, 2008). A TEEL-1 is the maximum concentration ion air below which it is believed nearly all individuals could be exposed without experiencing other than mild transient adverse health effects or perceiving a clearly defined, objectionable odor (DOE, 2008). TEEL-1 levels may be associated with notable discomfort, irritation, etc., which are not disabling and are reversible, when exposure is for more than 1 hour, for the general population including susceptible individuals. An occupational STEL could be translated into a TEEL-1, and a TWA designed for an 8-hour workshift could be used as a TEEL-0 (DOE, 2008). An Acute Exposure Guidance Level 2 (AEGL-2) is a concentration associated with irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape, in the general population including susceptible individuals (EPA, 2015a). EPA (2010) developed the above Interim AEGL-2 values based on a point-of-departure of 4 mg/m^3 exposure to rats for 2 hrs/d for 10 days (gestation days 6-15), which was a NOAEL for developmental effects; the next higher dose level (8 mg/m^3) resulted in increased resorption, decreased litter size and decreased neonatal weight (Morgan et al., 2002). A total uncertainty factor of 3 was applied. It was noted that human monitoring studies (AIHA, 2002) showed some effects at concentrations of 0.4 to 2 mg/m^3 only with chronic exposures (EPA, 2010). AEGL–1 values were not recommended, "…because mercury vapor has no odor or warning properties at concentrations that may cause extensive damage." (EPA, 2010).

As described previously, Cal OEHHA (2014) has derived an acute REL of 0.6 ug/m^3, which is based on 1-hr/d exposures during gestation, for elemental mercury and inorganic mercury compounds. It is an option for AQD to adopt this value as a potential acute ITSL = 0.6 ug/m^3 (1-hr AT). However, it is noted that this REL value was extrapolated from animal studies utilizing a relatively large total uncertainty factor of 3000, in lieu of a substantial amount of human toxicity information, and that this value and AT would be more restrictive in permit review than the chronic ITSL of 0.3 ug/m^3 based on the EPA RfC and several human occupational co-key studies.

Determination of Initial Threshold Screening Levels

The chronic ITSL for protection from long-term noncancer effects is the same as the EPA (1995) RfC = 0.3 ug/m^3. This value is very similar to the ATSDR chronic inhalation MRL (0.2 ug/m^3), which was derived from the same key studies. It is noted that Cal OEHHA (2014) has derived a

ten-fold more restrictive chronic REL (0.03 ug/m^3) based on the same key studies and critical effects as EPA (1995) and ATSDR (1999); the added stringency is due to different justifications for the use of uncertainty factors. Since the Cal OEHHA REL is based on the same key studies as the RfC and MRL, and the case is not compelling that the additional stringency of the REL is needed in an ITSL to ensure health protection, AQD will defer to the EPA (IRIS) RfC in this case in establishing the chronic ITSL. The chronic ITSL is therefore 0.3 ug/m^3 with an annual averaging time; this should be applied to mercury and inorganic mercury emissions.

AQD is also establishing an acute ITSL at 1 ug/m^3, with 24 hr averaging time, based on the ATSDR/MDCH occupancy action level for responding to mercury spills; this level was based on the human occupational studies and in particular the TC_{LO} of 14 ug/m^3 TWA-LOAEL from Ngim et al. (1992). Under Rule 229(2)(b), an ITSL may be based on any alternative methodology that is appropriate based on toxicological grounds. The ATSDR/MDCH action level of <1 ug/m^3 is regarded as a level that is safe for human health and acute (peak) exposures, including the most sensitive populations of pregnant women and/or children under the age of 6 years to live in the affected building, for the duration of a clean-up of reasonable length of time (i.e., days vs. weeks) (MDCH, 2009; ATSDR, 2012). Support for the protectiveness of this acute ITSL includes that it is well below the ACGIH TLV-TWA of 25 ug/m^3 as well as the NIOSH Ceiling Limit of 100 ug/m^3. It is also well below the rat developmental LOAEL (1.8 mg/m^3) of Danielsson et al. (1993) which formed the basis (with a total UF = 3000) for the Cal OEHHA acute REL of 0.6 ug/m^3. It may also be noted that this acute ITSL is not as stringent as candidate ITSLs that could be derived from the Cal OEHHA acute REL (0.6 ug/m^3, 1 hr AT) or derived as the OEL/100 as per Rule 232(1)(c) (resulting in candidate ITSLs of 0.25 ug/m^3 with 8 hr AT, and 1 ug/m^3 with 1 hr AT). The chosen AT associated with the acute ITSL is 24 hours, which is regarded as fairly consistent with the MDCH/ATSDR application of the action level and their presumption that clean-up or mitigation would occur within a reasonable amount of time. This ITSL value and AT is consistent with the MDCH/ATSDR action level (<1 ug/m^3) for the acceptability of home occupancy in situations (such as mercury spills) where further attenuation over time may be anticipated.

It may be noted that both ITSLs (0.3 ug/m^3, annual AT; 1 ug/m^3, 24 hr AT) are substantially higher than the estimated background Hg0 level in Michigan of 1.5 ng/m^3 or less (MDEQ, 2008).

The ITSLs of 0.3 ug/m^3 (annual AT) and 1 ug/m^3 (24 hr AT) should be applied to emissions and ambient air impacts of combined *elemental and inorganic forms of mercury*. These ITSLs are protective of the public health for direct inhalation exposure, but they do not necessarily provide sufficient protection for the environment and public health via atmospheric deposition, methylation, and bioaccumulation in aquatic environments, and indirect pathways of human exposure via fish consumption. AQD has historically evaluated a number of specific and hypothetical mercury air emission sources and modeled their estimated deposition, bioaccumulation, and indirect human exposure potential via recreational fish consumption. The results have varied, depending on the mercury form and emission rate and the characteristics of local watersheds and water bodies. Multiple small emission sources (e.g., less than 5-10 lbs/yr each) can collectively contribute to significant local and statewide mercury deposition loading. It may be noted that MDEQ and EPA are in the process of establishing a statewide Total Maximum Daily Load (TMDL) for mercury in inland waters of the state, accounting for all sources of mercury inputs, large and small. However, in AQD's New Source Review permitting program, the focus is typically on the incremental local deposition impacts of individual emission sources. Under New Source Review, these previous assessments have found that individual sources of 5-10 lb/yr or less of total mercury air emissions have generally not been solely associated with a significant or meaningful incremental impact to fish mercury levels or to

human exposure via fish consumption. Therefore, to provide needed guidance to the regulated community and AQD permitting staff, the posting of these ITSLs should be accompanied by a footnote that reads as follows:

> "Besides the assessment of mercury ambient air impacts in comparison to the ITSLs, larger individual sources of mercury emissions undergoing permit review (e.g., greater than 5 to 10 lbs/yr) may be evaluated on a case-by-case basis to address concerns for deposition and bioaccumulation, taking into account site-specific factors such as the presence of nearby recreational fisheries and realistic exposure scenarios."

References

ACGIH. 2014. Pocket Guide. TLVs and BEIs.

ACGIH. 2001. Documentation of TLVs and BEIs. Mercury, All forms except alkyl.

AIHA (American Industrial Hygiene Association). 2002. The AIHA Emergency Response Planning Guidelines and Workplace Environmental Exposure Level Guidelines Handbook. Fairfax VA: AIHA. As cited in: EPA (2010).

ATSDR. 1999. Toxicological Profile for Mercury. US Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry. March 1999. http://www.atsdr.cdc.gov/toxprofiles/tp46.pdf

ATSDR. 2012. Chemical-Specific Health Consultation for Joint EPA/ATSDR National Mercury Cleanup Policy Workgroup. Action Levels for Elemental Mercury Spills. March 22, 2012. http://www.atsdr.cdc.gov/emergency_response/Action_Levels_for_Elemental_Mercury_Spills_2012.pdf

Bush, personal communication, 2015. Personal communication between Christina Bush, Toxicologist, Michigan Department of Health and Human Services, and Robert Sills, Toxics Unit Supervisor, Michigan Department of Environmental Quality.

Cal OEHHA. 2014. TSD For Noncancer RELs. Appendix D. Individual Acute, 8-Hour, and Chronic Reference Exposure Level Summaries. December 2008; Updated July 2014. http://www.oehha.ca.gov/air/hot_spots/2008/AppendixD1_final.pdf#page=214

Danielsson BR, Fredriksson A, Dahlgren L, Gardlund AT, Olsson L, Dencker L and Archer T. 1993. Behavioural effect of prenatal metallic mercury inhalation exposure in rats. Neurotoxicol Teratol 15(6):391-6.

DOE. 2015. U.S. Department of Energy. Protective Action Criteria (PAC): Chemicals with AEGLs, ERPGs, and TEELs. Retrieved 4/23/15. http://www.atlintl.com/DOE/teels/teel.html

DOE. 2008. U.S. Department of Energy. DOE Handbook. Temporary Emergency Exposure Limits for Chemicals: Methods and Practice. http://orise.orau.gov/emi/scapa/files/doe-hdbk-1046-2008_ac.pdf

EPA. 2015a. AEGL Program. Retrieved 4/23/15. http://www.epa.gov/oppt/aegl/

EPA. 2015b. Dose-Response Assessment for Assessing Health Risks Associated With Exposure to Hazardous Air Pollutants. http://www2.epa.gov/fera/dose-response-assessment-assessing-health-risks-associated-exposure-hazardous-air-pollutants
EPA. 2014. Dose-Response Assessment for Assessing Health Risks Associated With Exposure to Hazardous Air Pollutants. OAQPS. http://www2.epa.gov/fera/dose-response-assessment-assessing-health-risks-associated-exposure-hazardous-air-pollutants

EPA. 2011. Health Effects Information Used in Cancer and Noncancer Risk Characterization for the 2005 National-Scale Assessment. http://www.epa.gov/ttn/atw/nata2005/05pdf/health_effects.pdf

EPA. 2010. Acute Exposure Guideline Levels (AEGLs) for Mercury Vapor (Hg0). Interim. http://www.epa.gov/oppt/aegl/pubs/mercury_vapor_interim_sept_2010.pdf

EPA. 2005. Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities. EPA-OSWER. EPA530-R-05-006.

EPA. 2001. Mercury Maps. A Quantitative Link Between Air Deposition and Fish Tissue. Peer Reviewed Final Report. EPA Office of Water. EPA-823-R-01-009. http://water.epa.gov/scitech/datait/models/maps/upload/2006_12_27_models_maps_report.pdf

EPA. 1997. Mercury Study Report to Congress. Volume III: Fate and Transport of Mercury in the Environment. http://www.epa.gov/mercury/report.htm

EPA. 1995. IRIS: Mercury, elemental (CASRN 7439-97-6). Integrated Risk Information System. National Center for Environmental Assessment. U.S. Environmental Protection Agency. Retrieved 2/20/2015. http://www.epa.gov/iris/subst/0370.htm

Fawer RF, de Ribaupierre Y, Guillemin MP, Berode M and Lob M. 1983. Measurement of hand tremor induced by industrial exposure to metallic mercury. Br J Ind Med 40(2):204-8.

Lewandowski T. A., Ponce R. A., Charleston J. S., Hong S., and Faustman E. M. 2003. Effect of Methylmercury on Midbrain Cell Proliferation during Organogenesis: Potential Cross-Species Differences and Implications for Risk Assessment. Toxicological Sciences 75, 124–133

Liu, B. et al. 2010. Urban-rural differences in atmospheric mercury speciation. Atmospheric Environment 44: 2013-2023.

Liu, B. et al. 2007. Temporal variability of mercury speciation in urban air. Atmospheric Environment 41: 1911-1923.

MDCH. 2009. Mercury Quick Reference Guidance Sheet. Michigan Department of Community Health. Updated August 2009.

MDEQ. 2008. Mercury Strategy Staff Report. http://www.michigan.gov/documents/deq/MDEQ_MSWG_FinalReportJan2008.pdf_222256_7.pdf

Morgan, D.L., S.M. Chanda, H.C. Price, R. Fernando, J. Liu, E. Brambila, R.W. O'Connor, R.P. Beliles, and S. Barone, Jr. 2002. Disposition of inhaled mercury vapor in pregnant rats: maternal toxicity and effects on developmental outcome. Toxicol. Sci. 66:261-273.

Ngim CH, Foo SC, Boey KW and Jeyaratnam J. 1992. Chronic neurobehavioural effects of elemental mercury in dentists. Br J Ind Med 49(11):782-90.
NIOSH. 2015. NIOSH Pocket Guide to Chemical Hazards. CDC Workplace Safety and Health Topics. Retrieved 4/23/15. http://www.cdc.gov/niosh/topics/mercury/

NIOSH. 1978. Occupational Health Guideline for Inorganic Mercury. http://www.cdc.gov/niosh/docs/81-123/pdfs/0383.pdf

NOAA. 2015. Office of Response and Restoration. Retrieved 4/23/15.

OSHA. 2015. https://www.osha.gov/SLTC/mercury/standards.html

TCEQ. 2015. http://www.tceq.texas.gov/toxicology/dsd/final.html/#im Retrieved March 9, 2015.

RS:lh