



## **7.0 DEPOSITION MODELING ANALYSIS**

Deposition modeling was conducted in support of a Human Health Risk Assessment (HHRA) for mercury and lead. This section describes the parameters that were used to conduct the deposition modeling, the results (i.e. air concentrations and deposition fluxes) of which were then further analyzed as part of the HHRA.

Based on an MDEQ request, the deposition modeling for both mercury and lead was conducted using three years of meteorological data from MBS International Airport (Station #14845) covering 2004-2006. This data contains the appropriate precipitation data necessary for performing deposition modeling.

The results of the HHRA for mercury and lead, which are based upon the deposition modeling results, are presented in full detail in Appendix H and therefore, the results of the deposition modeling are not discussed within this application support document.

### **7.1 SOURCES INCLUDED IN DEPOSITION MODELING**

The AQD has requested that deposition modeling be performed to determine the potential for increased risk to sensitive populations from emissions of mercury (Hg) and lead (Pb) as a result of installing the new ASCPC boiler. Consistent with R 336.1228, the deposition modeling will only include emissions from the new ASCPC boiler as no other facility sources of Hg and Pb will experience a change in emissions as a result of the proposed project.

#### **7.1.1 Mercury and Lead Emissions**

Emission rates of mercury and lead were presented in Section 3 for the new ASCPC boiler, and these are the rates that have been used in the deposition modeling. Table 7-1 presents the total emission rates of each pollutant, and a brief discussion of mercury emission partitioning for deposition modeling is included in Section 7.3.



**Table 7-1. Modeled Emission Rates for Deposition**

<b>Pollutant</b>	<b>Emission Rate (lb/hour)</b>	<b>Modeled Rate (gram/sec)</b>
Mercury	0.00735	0.000926
Lead	0.0654	0.00824

## **7.2 DEPOSITION RECEPTOR GRIDS**

Due to the breadth of the area for which the MDEQ-AQD requested deposition modeling, separate receptor grid systems were required for both the mercury and the lead deposition analyses. These grid systems are described below.

### **7.2.1 Mercury**

Representatives from NTH, SAFRISK, and MDEQ met on April 24, 2007 to discuss the issue of mercury deposition. During this meeting it was decided by MDEQ representatives that it would be best for consistency purposes if the deposition modeling for mercury follow the guidance outlined in the USEPA document *Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities* (EPA530-R-006). This guidance recommends that the receptor grid cover the area within 10 km of the facility. Further, it recommends the receptor grid spacing used for depositional modeling purposes be tiered and include 100-m spacing from the source out to a distance of 3 km, and 500-m spacing from the source out to a distance of 10 km.

During this meeting, the MDEQ requested that the receptor grid cover all sentinel and fishable water bodies that may be impacted. However, it was also concluded by MDEQ that the receptor grid should not include either the Saginaw River or Saginaw Bay. The resulting grid has been modified and extends further than 10 km from the source in certain directions in order to fully contain some key water bodies. Therefore, the receptor grid used for the mercury dispersion and deposition modeling will be a Cartesian grid extending the following distances:

- North: 10km
- East: 14km
- South: 14km
- West: 12km



### **7.2.2 Lead**

During the meeting with MDEQ on April 24, 2007 it was also decided that depositional modeling for lead would only include deposition within residential areas. Consequently, the receptor grid for the lead deposition modeling does not include water bodies and other areas that are zoned for non-residential activity. While it was originally agreed that the receptor grid for lead deposition would include 50-meter spacing out to 3 km and 100-meter spacing from 3 km to 5 km, this grid created over 20,000 receptors. Therefore, SAFRISK did an analysis and determined that by using numerical interpolation methods, a less dense grid could be used that would produce nearly identical results, thus requiring about half the receptors.

In order to be consistent with the HHRA Protocol guidance, and given the size of the facility, it was determined that the same receptor spacing should be used for the lead receptor grid as was used in the mercury grid. In addition, since the majority of the residential areas are a good distance away from the proposed ASCPC boiler, a larger receptor grid was used (20 km x 20 km) than what was originally discussed in the April 24, 2007 meeting with MDEQ (only 5 km radius). As discussed above, the HHRA Protocol recommends using the 100-meter spacing out to a distance 3 km from the source. However, it was determined that this spacing should be continued out to 5 km in order to provide more dense receptor spacing into the nearest densely populated residential areas. This was also done because, unlike the mercury grid which included on-site receptors as well as offsite, the lead grid removed receptors from the Consumers secured property (because there are no residences on Consumers property). The grid system used in the lead deposition is as follows:

- Fence Line Receptors: Receptors were placed on the facility fence line at 50 meter spacing.
- Near-field Cartesian Receptor Grid: Receptors were placed at 100 meter spacing from the fence line outward to 5 km from an approximate facility central location (271,155 East, 4,835,439 North).
- Far-field Cartesian Receptor Grid: Receptors were placed at 500 meter spacing from the boundary of the Near-field grid out to 10 km from the center point.



The use of this receptor grid configuration contains a total of 11,074 receptors. Printouts of the mercury and lead deposition modeling receptor grids are provided in Appendix F with the deposition modeling supporting information.

### 7.3 DEPOSITION MODELING DESCRIPTION

This section will provide a discussion of the AERMOD deposition parameters that have been used to conduct the mercury and lead deposition modeling.

#### 7.3.1 Mercury Partitioning

Both wet and dry deposition modeling was conducted to determine the total deposition of mercury. This required that the emissions of mercury be partitioned into the three forms of mercury that are known to encompass the total mercury emissions. These three forms are: vapor phase elemental mercury ( $Hg^0$ ), vapor phase divalent mercury or reactive gaseous mercury ( $Hg^{2+}$  or RGM), and particle bound mercury ( $Hg_p$ ). USEPA documentation indicates that the mercury partitioning for coal-fired utility boilers can be approximated as indicated in Table 7-2. This distribution, however, will substantially over predict the nearby mercury deposition for the proposed unit. The fabric filter and wet scrubber will be very effective in removing the particulate form of mercury, and activated carbon will be very effective in removing the reactive gaseous mercury. Thus, it is expected that the majority of the mercury that will pass through the control system will be vapor phase elemental mercury, and this phase tends to be transported long distances.

**Table 7-2. Summary of Speciated Mercury Emission Rates for Coal-Fired Boilers**

Hg Form	Symbol	% of Total Hg Emissions
Elemental Vapor	$Hg^0$	50%
Divalent Vapor	$Hg^{2+}$	30%
Particle Bound	$Hg_p$	20%
Totals		100%

Source: Mercury Study Report to Congress, December 1997. USEPA document EPA452/R-97-005.



As indicated in the various documentation regarding mercury deposition modeling (1997 Report to Congress; 2005 HHRA Protocol), the divalent forms of mercury (which includes the divalent vapor and the particle bound mercury) will deposit much closer to the source of emissions than the elemental form.

Once the total mercury emission rate was determined for the new boiler, the total rate was divided according to the partitioning provided in Table 7-2 to establish the rates of each form of mercury. As each of the forms of mercury have different emission rates and varying parameters used to determine the rates of both dry and wet deposition and depletion, separate modeling runs were required for each form of mercury (i.e. three separate runs).

Table 7-3 presents the modeled emission rates for each form of mercury that were used in the deposition modeling analysis.

**Table 7-3. Summary of Modeled Mercury Emission Rates for the ASCPC Boiler**

<b>Hg Form</b>	<b>% of Total Hg Emissions</b>	<b>Mercury Emission Rate (lb/hour)</b>	<b>Modeled Emission Rate (gram/sec)</b>
Elemental Vapor	50%	3.677E-03	4.633E-04
Divalent Vapor	30%	2.206E-03	2.780E-04
Particle Bound	20%	1.471E-03	1.853E-04
Totals	100%	7.355E-03	9.267E-04

### **7.3.2 Gas Dry Deposition – Control Pathway Parameters for Mercury**

In order to perform dry deposition for vapor phase emissions, several parameters need to be input into the Control (CO) Pathway of the model. In lieu of selecting user-defined parameters, default parameters are set by the model. The parameters are as follows: 1) pollutant reactivity factor (default = 0); 2) fraction of maximum green leaf area index (LAI) for autumn (default = 0.5); 3) fraction of maximum green leaf area index (LAI) for the spring transitional period (default =



0.25); and 4) a reference pollutant name (if any non-default parameters are user-defined, a pollutant name may be input).

The control pathway parameters must be defined for each pollutant model run, and Table 7-4 presents the parameters that were used in the mercury deposition modeling.

**Table 7-4. Summary of Dry Gas Deposition Control Pathway Parameters**

Hg Form	Pollutant Reactivity Factor	Green Leaf LAI (Autumn)	Green Leaf LAI (Trans. Spring)	Pollutant Reference Name
Hg <sup>0</sup>	0	0.5	0.25	None
Hg <sup>2+</sup>	1 <sup>1</sup>	0.5	0.25	HgDivInt

<sup>1</sup> A value of 1 is recommended for the pollutant reactivity factor for divalent mercury vapor in the USEPA's User's Guide for the AMS/EPA Regulatory Model (AERMOD) – Addendum (for incorporation of improved deposition algorithms) Dated 06341. Available from the EPA's SCRAM website.

### 7.3.3 Gas Dry Deposition – Source Pathway Parameters for Mercury

Several parameters must be input to the Source (SO) pathway for each pollutant run for gas deposition as well. These parameters are used in several different equations as described in the deposition background documents that are the basis for the AERMOD deposition algorithms.

The parameters are:

- Pollutant diffusivity in air ( $D_a$ ; units of  $\text{cm}^2/\text{s}$ )
- Pollutant diffusivity in water ( $D_w$ ; units of  $\text{cm}^2/\text{s}$ )
- Cuticular resistance to uptake by lipids for individual leaves ( $r_{cl}$ ; units of  $\text{s}/\text{cm}$ )
- Henry's Law constant ( $H$ ; units of  $\text{Pa m}^3/\text{mol}$ )

The values used for the mercury deposition modeling are presented below in Table 7-5 along with footnoted references from which these were obtained.



**Table 7-5. Summary of Gas Deposition Source Pathway Parameters**

Hg Form	Da (cm <sup>2</sup> /s)	Dw (cm <sup>2</sup> /s)	r <sub>cl</sub> (s/cm)	H (Pa m <sup>3</sup> /mol)
Hg <sup>0</sup>	0.07 <sup>1</sup>	3.01 E-6 <sup>2</sup>	1 E+5 <sup>1</sup>	150 <sup>1</sup>
Hg <sup>2+</sup>	0.06 <sup>1</sup>	5.25 E-6 <sup>2</sup>	1 E+5 <sup>1</sup>	6 E-6 <sup>1</sup>

<sup>1</sup> Source: M.L. Wesely, P.V. Doskey, and J.D. Shannon, 2002: *Deposition Parameterizations for the Industrial Source Complex (ISC3) Model*. ANL/ER/TR-01/003, Environmental Protection Division, Argonne National Laboratory.

<sup>2</sup> Source: *Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities* – [Publication No. EPA 530-R-05-006], September 2005. Information from companion HHRAP Database.

**7.3.4 Particulate Aerodynamic Distribution – Source Pathway Parameters (Hg & Pb)**

Particulate deposition modeling was conducted for the particle bound (Hg<sub>p</sub>) portion of the mercury emissions and for all lead emissions. AERMOD allows the use of two different methods for determining dry deposition velocities based on the predominant particle size distribution. The method used is dependant upon how much information is available for particle size breakdowns for a given source. Method 1 is used, generally, when the particle size distribution is known or if greater than 10% of the total mass has a diameter of 10 μm or larger. Method 2 is used when the particle size distribution is not well known and if less than 10% of the mass is in particles with a diameter of 10 μm or larger.

For the purposes of this modeling, it has been estimated that the aerodynamic distribution of particulate emissions from the new boiler and associated baghouse will be similar to that provided in Chapter 1.1 – *Bituminous and Subbituminous Coal Combustion (9/98 revision)* of the AP-42 document. Specifically, the aerodynamic distribution of particulate has been used that is listed in Table 1.1-6 of Chapter 1.1 for a dry bottom pulverized coal boiler with baghouse add-on control (see Table 7-6 below). Although Table 1.1-6 estimates that only 8% of the total mass of particulates emitted will have a diameter greater than 10 um, the particulate distribution is available and modeling has been conducted using Method 1 to estimate the dry deposition of particle bound mercury and lead in order to provide more accurate results.

The following is a discussion of how the size distributions are used to determine the model input parameters in the Source (SO) pathway for the new ASCPC boiler stack.



7.3.4.1 Expected Particle Size Distributions

Particle bound mercury ( $Hg_p$ ) is typically the result of mercury (mainly divalent) attaching to particles contained in the flue gas. Therefore, it is reasonable to assume that the size distribution for the particle bound mercury will be similar to the particle size distribution within the flue gas exiting the boiler exhaust stack after treatment and release from the new baghouse that will control particulate emissions. Similarly, lead emissions will be in particulate form and is assumed to have the same size distribution.

The mean particle size ( $D_{mean}$  or  $D_{mm}$ ) for each of the particle size ranges has been calculated according to the following formula, which is Equation 3-1 obtained from Chapter 3 of the September 2005 Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities (2005 HHRA Protocol). As noted below in Table 7-6, the overall lower and upper bounds for the particle size distribution have been assumed to be 0  $\mu m$  and 30  $\mu m$ , respectively.

$$D_{mean} = \left[ 0.25 \times (D_1^3 + D_1^2 \times D_2 + D_1 \times D_2^2 + D_2^3) \right]^{(1/3)}$$

Where:

- $D_{mean}$  (or  $D_{mm}$ ) = mass mean particle diameter for the particle size category,  $\mu m$
- $D_1$  = lower bound cut of the particle size category,  $\mu m$
- $D_2$  = upper bound cut of the particle size category,  $\mu m$

The following is an example calculation for the mean particle size for the size category between 15  $\mu m$  and 30  $\mu m$ . As shown in the example calculation, the mean particle size for this particle size category is equal to 23.30  $\mu m$ .

$$D_{mean} = \left[ 0.25 \times (15 \mu m^3 + (15 \mu m^2 \times 30 \mu m) + (15 \mu m \times 30 \mu m^2) + 30 \mu m^3) \right]^{(1/3)}$$

$$D_{mean} = \left[ 0.25 \times (50,625 \mu m^3) \right]^{(1/3)} = \left[ 12,656.25 \mu m^3 \right]^{(1/3)} = 23.30 \mu m$$



Table 7-6 summarizes the mean particle diameters and the associated mass fractions of particulate emissions for each particle range based upon aerodynamic distribution information contained in Table 1.1-6 of the AP-42 document.

**Table 7-6. Summary of Particle Size Distribution for ASCPC Boiler <sup>1</sup>**

Lower Range of Particle Diameter (µm)	Upper Range of Particle Diameter (µm)	Mean Particle Diameter For Cumulative Range <sup>2</sup> (µm)	Cumulative Mass % < Lower Range of Particle Diam	Fraction of Mass Within Range
15	30	23.304	97.0%	0.03
10	15	12.664	92.0%	0.05
6	10	8.163	77.0%	0.15
2.5	6	4.478	53.0%	0.24
1.25	2.5	1.942	31.0%	0.22
1	1.25	1.130	25.0%	0.06
0.625	1	0.827	14.0%	0.11
0	0.625	0.394	n/a	0.14
<b>Totals</b>		-----	<b>100%</b>	<b>1.00</b>

<sup>1</sup> Based Upon Table 1.1-6 of the AP-42 for a Pulverized Coal Fired Boiler (w/ Baghouse Control)

<sup>2</sup> Mean particle sizes represent the mean size for the size ranges associated with a given mass %. For the fraction above 15 µm in diameter, the upper bound of the size range has been assumed to be 30 µm. For the fraction less than 0.625 µm in diameter, the lower bound of the size range has been assumed to be zero µm.

From Table 7-6, the mean particle diameter for each range ( $D_{mean}$  or  $D_{mm}$ ) was used as Source (SO) pathway model inputs for both mercury and lead. The mass fractions listed in the far right column of Table 7-6 were also used as input for the lead deposition modeling. For mercury, both the mean particle diameter for each range and the mass within each range was used to develop "surface area weighted" mass fractions that were in turn used as input for the mass fractions of each particle diameter (because  $Hg_p$  is emitted as a "particle bound" material, dependent on the amount of surface area of fly ash that it can adhere to).

As indicated in Chapter 3 of the 2005 HHRA Protocol, to determine the mass weighting for each of the mean particle sizes for particle-bound materials that have condensed onto the surface of



particulate matter, the mass fraction must be expressed as a fraction of the total surface area of the particle bound mercury. Fractional areas have been assigned to each of the mean particle sizes presented in Table 7-6 according to the methodology contained in Chapter 3, Section 3.2.3 of the 2005 HHRA Protocol. The following is a brief summary of this procedure, followed by an example calculation for the 23.30  $\mu\text{m}$  mean particle size.

1. Determine the mean particle radius by dividing the mean diameter by 2.
2. Determine the ratio of the surface area to the volume. Treating the particle as a sphere, this parameter is calculated by dividing 3 by the radius ( $S/V = 3/\text{radius}$ ).
3. Determine a mass weighted proportion of available surface area. This parameter is calculated by multiplying the S/V ratio for a given mean particle size by the weight (mass) fraction associated with the mean particle size.
4. Sum the proportion of available surface areas for all of the mean particle sizes.
5. Divide the proportion of available surface area for each mean particle size by the total proportion of available surface area to determine a fraction surface area value for each of the mean particle sizes.

Example calculation:

$$Radius_{23.30 \mu\text{m}} = \frac{23.30 \mu\text{m}}{2} = 11.65 \mu\text{m}$$

$$S/V \text{ Ratio}_{23.30 \mu\text{m}} = \frac{3}{\text{radius}} = \frac{3}{11.65 \mu\text{m}} = 0.257$$



$$\text{Proportion of available surface area}_{23.30 \mu\text{m}} = S/V * \text{mass fraction} = 0.257 * 0.03 = 0.0077$$

The sum of all proportions of available surface areas = 4.39 , therefore:

$$\text{Fraction of surface area}_{23.30 \mu\text{m}} = \frac{0.0077}{4.39} = 0.0018$$

Thus, the mass-weighted fractional area associated with the particle bound mercury having a mean particle diameter of 23.30 μm is equal to 0.0018. The preceding calculations were repeated for each of the mean particle sizes presented in Table 7-6. Table 7-7 presents the mass-weighted fractional surface area associated with each of the mean particle sizes presented in Table 7-6. These values were used as the mass fractions in the Source (SO) pathway parameters for the new ASCPC boiler for the Hg<sub>p</sub> model run for particle dry deposition.

**Table 7-7. Surface Area Weighting of Mass Fractions for Particle-Bound Mercury Modeling for the ASCPC Boiler (based on Baghouse Control) <sup>1</sup>**

Mean Particle Diameter (μm) <sup>2</sup>	Mean Particle Radius (μm)	Surface Area / Volume	Fraction of Total Mass	Proportion Available Surface Area	Fraction of Total Surface Area <sup>2</sup>
23.304	11.65	0.257	0.030	0.0077	0.0018
12.664	6.33	0.474	0.050	0.0237	0.0054
8.163	4.08	0.735	0.150	0.1102	0.0251
4.478	2.24	1.340	0.240	0.322	0.0732
1.942	0.97	3.090	0.220	0.680	0.1547
1.130	0.56	5.312	0.060	0.319	0.0725
0.827	0.41	7.258	0.11	0.798	0.1817
0.394	0.20	15.239	0.14	2.133	0.4856
<b>Totals</b>	----	----	----	4.39	1.00

<sup>1</sup> Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities (Section 3.2.3). USEPA Office of Solid Waste and Emergency Response. EPA530-R-05-006, September 2005.

<sup>2</sup> Values represent model input parameters for mercury in the SO Pathway.



#### 7.3.4.2 Particle Density Parameters

Lastly, to complete the information needed in the model Source (SO) pathway, a particle density ( $\text{g}/\text{cm}^3$ ) must be entered for each particle diameter entry. For purposes of this modeling, the default particle density was used as input for both the mercury and lead particle modeling runs (default =  $1.0 \text{ g}/\text{cm}^3$ ) as recommended in the USEPA's 2005 HHRA Protocol.

#### **7.3.5 Seasonal and Land Use Categories (Gas Dry Deposition) – Control Path Parameters**

The AERMOD model requires the user to input seasonal categories in the Control (CO) Pathway when performing gaseous deposition modeling in order for the model to determine certain values to be used within the deposition algorithms, which are based on land use characteristics and gas resistance terms. A seasonal category must be input for each month and can be selected from the following choices: Midsummer, Autumn, Late Autumn, Winter, and Transitional Spring. The default seasonal categories are the most representative of the seasonal weather patterns in Michigan, so the defaults were used in the gas dry deposition modeling (mercury).

The land use characteristics will vary from season to season depending upon how the land use is described. Therefore, AERMOD requires that the land use be defined in 36 ten-degree increments (sectors) for the area surrounding the facility. A 3-km radius, taking the facility source central location as the center point, was used to define the land use characteristics, as recommended in the 2005 HHRA Protocol. The deposition modeling support information in Appendix F contains an aerial photo that was used to define the 36, 10-degree wind direction sectors in the 3-mile radius. Following the aerial photo, Table F-1 lists the sectors and the representative land use category selection for each sector. Note that additional (zoomed in) aerial photography was used to determine the category for some sectors.

### **7.4 MODEL OUTPUT**

The deposition models were coded to produce PLOT output files (\*.plt), which are essentially text files that contain the high air concentration, total deposition, wet deposition, and dry deposition for each receptor location. These files were then used by SAFRISK to analyze the overall environmental impacts by means of additional models in accordance with HHRA Protocol and other USEPA guidance for risk evaluation.



Lastly, it is critical to note that the output unit values were adjusted to non-default values in the Source Pathway of the deposition models. This was done because the model defaults would not provide enough decimal places/significant figures in order to properly define the impacts and produce subsequent meaningful results for the risk evaluation of the HHRA.

The output unit for concentration values was adjusted to yield results in nanograms/m<sup>3</sup> and the output unit for deposition was adjusted to yield results in micrograms/m<sup>2</sup>.

### 7.5 DEPOSITION MODELING FILES

Table 7-8 lists the complete Lakes Environmental ISC-AERMOD View project files for the deposition modeling, which are being submitted on compact disc in Appendix G. The results of the full assessment are included as Appendix H.

**Table 7-8. Summary of the Deposition Modeling Files**

<b>Modeling File Identification</b>	<b>File Description</b>	<b>Meteorological Data</b>
<b>Mercury Deposition Files</b>		
KW04Hg2+ through KW06Hg2+	Divalent Mercury Vapor Phase Models	2004-2006
KW04_Hg0 through KW06_Hg0	Elemental Mercury Vapor Phase Models	2004-2006
KW04_HgP through KW06_HgP	Divalent Mercury Particle Models	2004-2006
<b>Lead Deposition Files</b>		
KW04_PbP through KW06_PbP	Lead Particle Models	2004-2006