

HWC Risk Assessments: Ruled by Uncertainty

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ABSTRACT

The U.S. EPA's Human Health Risk Assessment Protocol (HHRAP) provides official guidance on modeling the environmental fate of a variety of compounds that may be emitted from Hazardous Waste Combustion facilities (HWCs). The HHRAP also provides guidance on estimating the risk of potential adverse human health and environmental consequences of such emissions. The overall results of performing such a risk assessment are often dominated by the estimated effects of a few compounds and exposure pathways. The magnitude of these impacts are often strongly dependent on a few key modeling parameters about which there is either a large degree of uncertainty or variability. Examples are given of risk estimates for compounds that frequently dominate overall risk estimates such as hexavalent chromium, dioxins and furans, mercury and PAHs. Modeling steps where significant uncertainties arise for these compounds include the assumed emission rates for compounds undetected in standard testing, and the modeling of food chain uptake and biotransfer rates. In some cases, the use of HHRAP guidance demonstrably violates mass conservation. At times historical measurements can better define the critical parameters, and benchmark the modeling results. Although the HHRAP provides very specific guidance and the necessary default parameters for performing a multi-pathway risk assessment, it is often the handling of these key yet indefinite modeling parameters that determine the overall outcome of the evaluation.

Key Words

Hazardous Waste Combustion, Risk Assessment, Uncertainty, Multi-pathway, Mercury, Dioxin

INTRODUCTION

Many Hazardous Waste Combustion (HWC) facilities have been required to perform extensive multi-pathway risk assessments to estimate the potential adverse health effects caused by the public's indirect exposure to compounds emitted by the facility. The U.S. EPA's Human Health Risk Assessment Protocol¹ (HHRAP) provides official guidance on how to perform such assessments. These risk assessments can include over 100 compounds each requiring about 30 parameters to predict their atmospheric, terrestrial, aquatic, and biological transport and fate. Despite the expansive nature of the overall modeling, the final risk and hazard estimates are usually dominated by the impact of a few pathways and compounds. The magnitude of these impacts are often strongly dependent on a few key modeling parameters about which there is

either a large degree of uncertainty or variability, a lack of basic knowledge, or fundamental inaccuracies in modeling assumptions.

Although the HHRAP provides very specific guidance and the necessary default parameters for performing a multipathway risk assessment, it is often the handling of key yet indefinite modeling parameters that determine the overall outcome of the evaluation. For the purpose of summarization, it is convenient to classify the uncertainties that can dominate the overall result of a HWC risk assessment as such: (1) uncertainties in measured or estimated COPC emission rates, (2) uncertainties in generic fate and transport modeling parameters and COPC properties, (3) uncertainties in site-specific fate and transport modeling parameters. Mercury is subject to all three of these uncertainties resulting an extremely wide range of possible risk estimates due to mercury emissions.

It should be noted that in almost any risk assessment perhaps the greatest general uncertainties (that will not be discussed further in this paper) are those associated with the assumed toxicities of the relevant COPCs. The Cancer Slope Factors (CSFs) and Reference Doses and Concentrations (RfDs and RfCs) that define the final step in estimating potential risks are generally derived from either occupational epidemiology or animal model toxicology. The derivation of the values of these parameters used in risk analyses frequently include conservative uncertainty and modifying factors in ranging from tens to thousands.

DOMINATING UNCERTAINTIES

Uncertainty in Emission Rates

The long chain of estimation estimations and calculations that go into a multi-pathway risk assessment begins with the quantification of COPC emission rates. Assumptions and uncertainties that are introduced into the analysis at this stage carry through the entire process. For the sake of producing the most accurate estimation of potential long-term risk to human health and the environment it would be optimal to employ measured emission rates that are representative of typical operating conditions; unfortunately these are rarely available. Stack emissions may be measured under atypical conditions in order to demonstrate compliance with various regulatory waste destruction or emission limits. Trial burn tests are usually conducted under two conditions: (1) a high-temperature test, in which the emission rate of metals is maximized, and (2) a low-temperature test, in which the ability of the combustion unit to destroy principal organic hazardous constituents (POHCs) in the waste feed is challenged. Fugitive emissions from tanks, flanges, and valves can only be estimated through a combination of fundamental and empirical correlations. Along with the usual uncertainties inherent in any measurement, there are a few peculiarities of standard risk assessment practice that can amplify the significance of measurement uncertainties to the point where they dominate the overall result of the analysis.

MACT vs. measured emission rates

The use of permissible or MACT-based emission rates as the basis for a risk analysis has some advantages over the use of measured emissions rates. If a MACT-based risk assessment finds that the level of COPCs in off-site media do not pose unacceptable risks to public health or the environment then, in order to produce a favorable outcome, the facility only needs to demonstrate that its emissions are below MACT limits – a requirement it needs to meet regardless of any risk assessment. However, because each of the MACT-based emission limits covers several individual COPCs (*e.g.*, the low volatility metal limit includes As, Be, total Cr and Cr⁺⁶; the mercury limit includes elemental, ionic particulate and vapor phase species; etc.) there is some methodological uncertainty as to how the various components should be apportioned within the MACT-based emission rate. Apportionment of individual COPCs within an overall MACT-based emission rate based on the ratios of their measured emission rates does not preclude some of the difficulties described above in dealing with non-detected compounds. Although there is perhaps less technical uncertainty in using permissible or MACT-based emission rates rather than measured emissions rates as the basis for a risk analysis, because the MACT-based emission rates are higher than average long-term rates, their use produces a conservative overestimation of potential risks rather than a central tendency, best-estimate. In many of the following examples estimated risks are presented for MACT-based and measured emission rates.

Treatment of Non-detected COPCs

Almost any risk assessment has to assess potential risks caused by COPCs that have been tested for in the facility's emissions but which have not been detected. Some of these COPCs are among the compounds that have been identified in the general environment as being especially potent with regard to causing adverse health and environmental effects, or as being ubiquitously present at levels near or above those which might cause such effects. Because the emissions of such compounds are often subject to regulation, it is often required that they be tested for as part of emissions monitoring, and that they be evaluated within a risk assessment. However, because it is also common for steps to have been taken to reduce their emissions it is possible that they will not be present in measurable amounts in a facility's emissions. When this is the case it is often assumed that the compound is present at one-half its detection limit for that test, but other assumption may be employed. Due to the combination of some of these compound's toxic potency, low emission rates, and relatively high analytical detection limits, it is can be the case that such COPCs may not be detected in a facility's emissions tests, yet risks due to these compounds may dominate a risk assessment depending on conservatively assumed emission rates. Of course in this situation the magnitude of the final estimated risks due to these COPCs is linearly dependent on the detection limit of the analytical method used in the testing.

In a recent HWC risk analysis Cr⁺⁶, vapor phase HgCl₂, and most of the PCDD/PCDF congeners were not detected in any of the relevant emissions' testing, yet the eventual fate of these compounds in the modeling dominated the estimated risks under various exposure scenarios.

Hexavalent chromium

Because hexavalent chromium is covered by MACT regulations for low volatility metals and is a rather potent carcinogen evaluation of potential its risks had a significant effect on the overall results of a recent risk analysis despite the fact that it was not detected in emissions testing. The estimated excess lifetime cancer risks due to Cr⁺⁶ exposures for different assumed emission rates are shown in Table 2. For example, using the maximum detection limit for Cr⁺⁶ emissions leads to the excess cancer risk due to indirect exposure to Cr⁺⁶ for subsistence farmers and their children of 1.3×10^{-6} and 3.6×10^{-7} , respectively, which account for 65% and 76% of the total estimated cancer risks for these exposure scenarios (2.0×10^{-6} for adults and 4.7×10^{-7} for children). The use of half of the average detection limit for Cr⁺⁶ emissions reduces the total estimated risks to subsistence farmers to 5.8×10^{-7} for adults and 1.5×10^{-7} for children. Thus, the risk estimates for the subsistence farmer scenario are somewhat sensitive to the treatment of non-detects. The entries based on $ND = DL_{max}$ for Cr⁺⁶ are more than double those based on $ND = DL_{avg}/2$ because the maximum detection limit among the three test runs was greater than the average detection limit.

Table 1. Estimated cancer risks due to hexavalent chromium for different assumed emission rates.

Exposure scenario/ Emission rate	Cancer Risk, indirect exposure						Cancer Risk, inhalation		
	resident adult	resident child	farming adult	farming child	fishing adult	fishing child	res/fish adult	child	farm adult
Apportioned into MACT limits	2.8 E-7	1.0 E-7	4.6 E-6	1.2 E-6	3.0 E-7	1.1 E-7	1.4 E-8	4.9 E-9	1.5 E-8
Measured, with $ND = DL_{max}$	8.3 E-8	3.1 E-8	1.3 E-6	3.6 E-7	8.9 E-8	3.1 E-8	4.1 E-9	1.5 E-9	4.4 E-9
Measured, with $ND = DL_{avg}/2$	3.6 E-8	1.3 E-8	5.8 E-7	1.5 E-7	3.8 E-8	1.3 E-8	1.8 E-9	6.3 E-10	1.9 E-9

Polychlorinated Dibenzo(p)dioxins and Polychlorinated Dibenzofurans

Of the 17 PCDD/PCDF congeners that are evaluated for Toxic Equivalent Quotient (TEQ), none of the 7 PCDDs were detected in three rounds sampling and of the 10 PCDFs 7 were detected in only one round each. It is worth noting that even when these congeners are detected the amounts in each sample are on the order of tens of picograms (trillionths of a gram) in an approximate sample volume of 3.6 m³. Table 2 shows the estimated excess lifetime cancer risks due to indirect exposure to PCDD/PCDFs under various assumed emission rates. The estimated risks due to indirect exposure in the farming and fishing scenarios make up significant portions of the total estimated risks, accounting for 30% to 50% under MACT-apportioned emissions and 15% to 30% under the non-detected congeners emitted at half their detection limits.

Table 2. Overall cancer risk factors due to indirect exposure to PCDD/PCDFs with emission rates based on their MACT-based limit, and on their measured rate based on two possible treatments of non-detected congeners.

Exposure scenarios / PCDD/PCDFs emission rates	Cancer Risk, indirect exposure						Cancer Risk, inhalation		
	resident adult	resident child	farming adult	farming child	fishing adult	fishing child	res/fish adult	child	farm adult
Apportioned into MACT limits	1.9 E-7	1.0 E-7	1.8 E-5	2.8 E-6	4.1 E-6	6.8 E-7	8.0 E-9	2.8 E-9	8.5 E-9
Measured, with ND = DL/2	2.9 E-9	1.5 E-9	2.8 E-7	4.4 E-8	6.2 E-8	1.0 E-8	1.2 E-10	4.3 E-11	1.3 E-10
Measured, with ND = 0	7.8 E-10	4.2 E-10	8.0 E-8	1.2 E-8	1.8 E-8	3.0 E-9	3.2 E-11	1.2 E-11	3.5 E-11

Vapor-phase Mercuric Chloride

The atmospheric fate of mercury is strongly dependent on its chemical and physical form — elemental mercury is a relatively insoluble, unreactive gas; oxidized mercury (assumed to be present as HgCl₂) exists as either a soluble, reactive, “sticky” gas, or as attached to particulate matter. Regardless of whether a risk assessment is based on MACT limited or measured mercury emission rates, the assumed or measured apportionment of the emitted mercury among these three forms largely determines the ultimate estimated mercury exposure risk levels. The HHRAP recommended, default mercury apportionment is 20% as particle-bound HgCl₂, 60% as vapor-phase HgCl₂, and 20% as vapor-phase elemental Hg. The reference cited for this distribution is Petersen, *et al.*², which presents mercury data referenced to an original German paper of Axenfeld, *et al.*³ for “Waste Incinerators”. However, the incinerators to which these speciation values are attributed are uncontrolled municipal waste combustors rather than modern hazardous waste combustors. In order to produce a more realistic assessment of mercury impacts, the use of site-specific measurements of mercury apportionment are obviously preferable to the use of the default values.

The method used to measure mercury in HWC stack gasses is the U.S. EPA Method 0060 Multi-Metals Sampling Train which includes a glass fiber filter and a series of liquid impingers designed to selectively collect the three forms of mercury. The added complication to the usual Non-detected COPC is that the detection limits can vary widely among the various mercury forms. In a recent application of the method at a HWC, the only form of mercury that was detected in the sack testing was elemental mercury, and the most critical form of mercury with respect to its eventual fate and transport, vapor-phase HgCl₂, had a detection limit that was from 10 to 30 times the limits for the other two forms. Under these conditions it is difficult to argue that the use of site-specific measurements produces a more useful description of the apportionment of the mercury species than default values for similar facilities. The solution that allowed the use of some information from the measurements was to use the detection limit for particulate bound mercury, the particle loading in the sampling train and a variety of particle to vapor partitioning parameters to place an upper bound on the vapor-phase HgCl₂ concentrations.

Uncertainty in Generic Modeling Parameters and COPC Properties

These uncertainties concern modeling parameters and COPC properties that do not vary appreciably among assessments at different facilities but which may lead to dominating yet uncertain risk estimates. Among these are uncertainties regarding the particle size distribution of stack emissions and the size dependence of atmospheric deposition velocities; and the partitioning factors used to estimate COPC concentration in soils, suspended and benthic sediments, and in plants and vegetables many of which are derived from correlations with measured octanol-water partitioning ratios, K_{ow} . Uncertainties in a few other such key parameters are linked to significant COPC and exposure pathway risk estimates, and so dominate the overall uncertainty in specific scenarios. The examples below relate to the modeling of COPCs as they enter and progress through the food chain to humans.

PCDD/PCDFs, Soil, and Chicken

Estimated cancer risks for subsistence farmers and their children are dominated by exposure to PCDD/PCDFs through consumption of local meat and dairy products. Under current HHRAP guidance the specific exposure pathway that accounts for most of the risk passes through the direct ingestion of contaminated soil by chickens and the subsequent consumption of these chicken and their eggs by humans. The critical and uncertain parameters in this portion of the risk analysis is the chicken's assumed soil consumption rate and the associated biotransfer factor from PCDD/PCDFs in ingested soil to PCDD/PCDFs in chickens and eggs.

After an error in the original HHRAP guidance in the calculation of the biotransfer factor from the original research results by Stephens *et al.*⁴ was corrected in an Errata memorandum⁵, the External Peer Review⁶ of the guidance noted that the factors were still in error relative to the original research, being too high by a factor of 10. The review additionally noted that there was still significant uncertainty regarding the biotransfer of PCDD/PCDFs from soils into chicken and their eggs. This uncertainty is significant with respect to the overall risk assessment results because, using the current HHRAP guidance, the corrected values for $Ba_{chicken}$ and Ba_{egg} , and MACT-based emission rates, 60% of the calculated cancer risk for subsistence farmers and 50% of the risk for their children is due to PCDD/PCDF exposure by the pathway of soil consumption by chickens.

The Peer Review describes three sources of uncertainty in the extrapolation from Stephens' experimental data to the HHRAP's default parameters are summarized here. The first source of uncertainty is that the soil intake rate, $Qs_{chicken}$, is based on an untested assumption that 10% of a chicken's diet is comprised of soil. While this value is similar to one derived for wild turkeys, it might only be applicable to "free range" chickens. A more typical value for chickens kept by current-day farmers might be 2 to 3%. The second source of uncertainty is that the default Ba values are derived from experimental results for exposures to very high soil concentrations of PCDD/PCDFs, and with the assumption that the transfer characteristics of PCDD/PCDFs from soil are similar to the transfer characteristics from grain. Data for more realistic exposure

scenarios in the same study and by other researchers produce much lower transfer rates. Third, even the use of the corrected HHRAP default values for $Ba_{chicken}$ and Ba_{egg} results in estimated levels of PCDDs and PCDFs in chickens and eggs that are too high in relation to the estimated levels for beef and pork (based on typically measured ratios of PCDD/PCDFs concentrations in these foods⁷⁻⁹). The Peer Review Report concludes that: (1) the values for $Ba_{chicken}$ and Ba_{egg} should perhaps be reduced by “at least one order of magnitude;” and (2) “that these data gaps are sufficiently large so that regulatory decisions should not be made without more detailed evaluations of these issues”.

Applying a reduction factor of ten to the product of $Qs_{chicken}$ with $Ba_{chicken}$ and Ba_{egg} would result in decreases in the *total* estimated cancer risks to subsistence farmers of 54%, and to their children of 45%. Based on the great uncertainty in the values of these parameters, the likelihood that they are significantly overestimated, and their significant impact on the overall risk assessment for subsistence farmers, the cancer risks for these exposure scenarios are probably overestimated.

The Limited use of the Metabolism Factor

The HHRAP guidance (section 5.4.4.7) includes a metabolism factor, MF , designed to account for the fact that many organic compounds are broken down in the digestive tracts of various animals, and as such are not passed upwards through the food chain to humans. However, the default assumption is that the MF is only effectively applied to the COPC bis(2-ethylhexyl)phthalate for which an MF value of 0.01 is used for beef, milk and pork, *i.e.* only 1% of this COPC remains in the animal. For all other compounds and pathways the value is assumed to be 1 meaning essentially that no metabolism is assumed to take place despite the fact that many volatile organic COPCs are readily metabolized. For example recent work by Hofelt *et al.*¹⁰ found that an MF of 0.01 should also be applied in the calculation of PAH concentrations in beef, milk, pork, poultry, and eggs. In the risk assessment that prompted the research that led to this conclusion exposure to two PAHs through the consumption of livestock led to an unacceptable estimated cancer risk to subsistence farmers.

Violations of Conservation of Mass

The HHRAP guidance relies heavily on K_{ow} -based correlations to derive parameters that estimate the concentrations of organic COPCs in animal products from the rate of the animal's pollutant intake. However, under many circumstance the use of such parameters demonstrably violates the conservation of mass for these compounds. An example of such an instance is the use of Ba_{egg} , the parameter used to estimate the concentration of a pollutant in a hen's egg from the rate at which the chicken takes in the pollutant. For the chemical di-n-octylphthalate, the guidance lists a value of 17,000 day/kg for Ba_{egg} . Assuming that the chicken eats feed at the default rate of 0.2 kg/day, and that the feed contains di-n-octylphthalate at a concentration of 1 mg/kg. The rate at which the chicken takes in di-n-octylphthalate is thus $(0.2 \text{ kg/day}) \times (1 \text{ mg/kg}) = 0.2 \text{ mg/day}$. Multiplying this intake rate by Ba_{egg} yields a predicted concentration be eggs of 3,400 mg/kg $(0.2 \text{ mg/day} \times 17,000 \text{ day/kg})$. Assuming that the chicken lays one egg per day and that an egg

weighs 60 g, yields an amount of di-n-octylphthalate leaving the chicken of 204 mg/day (0.06 kg/day \times 3,400 mg/kg). This output rate is more than 1,000 times the assumed intake rate, and thus is physically impossible!

One can make similar demonstrations for other organic COPCs and animal products such as di-n-octylphthalate in milk where the rate of this compound leaving the cow is many-fold higher than the animal's intake rate. Should risks estimated to be caused by exposure to organic COPCs in livestock and dairy products dominate overall risk estimates, the basis of the underlying calculations would be entirely spurious. The reason that such erroneous and meaningless calculations is the unchecked use of correlations and models, and the failure to account for metabolism of organic compounds as discussed above.

Uncertainty in Site-specific Modeling Parameters

These uncertainties concern non-emission-rate modeling parameters for which default values may be available but which may vary widely among risk assessments for various facilities. Examples of such parameters include properties of the area surrounding a facility that effects the dry deposition rate of COPCs, properties of the soil surrounding the facility that determine the partitioning of COPCs between the soils and groundwater, and other properties of the soil and local topography that determine the rate of soil erosion into nearby water bodies. Perhaps one of the most complex steps in the transport of COPCs through the food chain to humans is the transformation of soluble mercury into methylmercury and the accumulation of this compound in fish tissue. The portion of the HHRAP guidance that describes this process includes simple transformation factors applied to the mercury as it enters a water body from the watershed soils and flowing waters, and a Bioaccumulation Factor (BAF) to estimate the fish tissue concentration from the water concentration.

However, the biochemical process of methylation, and the bioaccumulation within edible fish tissues depend not only on the levels and forms of mercury in the various media, but also on the physical and chemical conditions present in the watershed, its surface and ground waters, its benthic sediments, and on the specific types of micro-organisms and fish that are present in the system. The fact that this topic is the subject of major, current research efforts underlines both the scientific complexities and the modeling uncertainties associated with the process. The proper modeling of these processes would require a great deal of site-specific information that is neither readily available nor easily measured.

The HHRAP default BAF for the transfer of mercury from water to fish of 6,800,000 mg/kg methyl mercury in fish per mg/L total dissolved mercury in water is based on several research programs that sought to define this quantity and that are referenced in the EPA's Mercury Report to Congress¹¹. This BAF value is found specifically in Appendix D of the Report in section D.3.4.1 and is derived from dissolved *methylmercury* concentrations in water rather than total mercury, hence the HHRAP-recommended value is inappropriate. Furthermore, the variety of BAF values cited in the Report are strongly dependent on various waterbody properties that are not routinely measured. The estimation of a BAF even within well

characterized lakes is still not entirely possible; the Peer Review Comments on the HHRAP explicitly address this issue:

“...major data gaps and limitations associated with fate and transport modeling are...noted [as]: mercury behavior in watersheds, and mercury bioaccumulation in fish...We believe that these data gaps are sufficiently large so that regulatory decisions should not be made without more detailed evaluations of these issues” U.S. EPA, 2000a, page 100).

The solution to obtaining a more representative and less uncertain BAF for the estimation of mercury concentrations in fish in a recent risk assessment was to use previously acquired measurements of mercury levels in the waterbody and fish of interest and deriving a site-specific BAF of 480,000 mg/kg total mercury in fish per mg/L total mercury in water. Due to the increasing interest in assessing hazards due to consumption of mercury in fish, many states have performed such measurements, and these may be the best indication of local conditions.

The total Hazard Index in the risk assessment for subsistence fishers was almost entirely due to exposure to the estimated incremental mercury concentrations in local fish. Because the mercury concentrations were strongly dependent on three uncertain modeling parameters: assumed emission rates, speciated stack measurements that had non-detects for the most important species (HgCl₂ vapor), and the bioaccumulation factor, eight possible concentrations could be used for risk evaluation based on which assumptions were chosen. These are shown in Table 3.

Table 3. Estimated incremental mercury levels in local fish based on various modeling assumptions.

Emission rate	Emissions' Speciation	Bioaccumulation Factor	Trophic Level 4 Fish Hg Concentration (mg/kg)
MACT	HHRAP	HHRAP	5.9
		Measured	2.4
	Measured	HHRAP	0.14
		Measured	0.056
Measured	HHRAP	HHRAP	0.15
		Measured	0.058
	Measured	HHRAP	0.0034
		Measured	0.0014

The enormous range shown is indicative of the degree that significant uncertainties are determining the outcome of this multipathway risk assessment

SOLUTIONS AND CONCLUSIONS

When the overall results of a risk assessment are strongly dependent on the use of conservative default values of a few specific modeling parameters or COPC properties that have high levels of uncertainty, it is often necessary to obtain and employ more representative values. Some of these values may be difficult to obtain for technical reasons. As the standard analytical tests for COPCs in stack emissions improve, the detection limits should decrease, perhaps leading to fewer non-detected COPCs. Efforts to improve detection limits by both analytical laboratories and facilities undergoing testing should focus on the few COPCs that are likely to produce sizable estimated risks when modeled as being emitted a half of their detection limits. From the examples above, these compounds would include hexavalent chromium, specific PCDD/PCDF congeners, and vapor-phase mercuric chloride.

Whether values for other site-specific parameters exist may often be a matter of luck. Such properties as soil erosion rates, and mercury levels in waterbodies and fish tissues may have been measured for other purposes. In addition to helping define various modeling parameters, such historical local or regional measurements may exist that can be used to benchmark the modeling 0.25 mg/kg, thus placing an upper bound on the possible contribution of the facility being studied. Additionally, the level of mercury in the lake waters had been decreased significantly over the preceding few decades. If it were the case that the facility (which had been in operation for most of this period) was the major source of mercury in the lake, it would be expected, based on the modeling, that the mercury concentrations in the lake would be increasing. Because this was not to be the case, it was possible to argue that the facility was not likely a major source of mercury in the lake.

Although it may be difficult to produce such data when it does not exist, a small-scale environmental monitoring program may be more efficient and more definitive than extended modeling and uncertainty analyses. Under some conditions it may also be difficult to predict which COPC and exposure pathway may lead to uncertain yet dominant estimated risks, so it may be prudent to perform a screening level analysis prior to a full-scale multipathway risk assessment. Although the current guidance requires a full analysis of each COPC, a more efficient process might include a generic, conservative assessment of the complete set of compounds followed by a detailed, site-specific modeling of the few that dominate the overall results. Regardless any procedural changes in the required risk assessments guidance, the refinement of a few key default and site-specific modeling parameters should lead to more realistic and robust risk assessments.

Although the HHRAP provides very specific guidance and the necessary default parameters for performing a multipathway risk assessment, it is often the handling of key yet indefinite modeling parameters that determine the overall outcome of the evaluation. Under many scenarios it may be acceptable to use highly uncertain, conservative default values for parameters in a screening sense, and then replace these with less-uncertain (possibly site-specific) values for those COPCs that have unacceptable risk levels. This a pick-and-choose approach that can eventually lead to problems of regulatory ratcheting or criticism of results-oriented analysis if it is not clear that the defaults are for screening. It is also hard to think of an evaluation as a screening exercise if it requires the analysis of 100 COPCs all the way through a

multi-pathway risk assessment. As an engineer or a scientist there is the desire to produce the most “accurate” estimates of potential risks. As a consultant, there is the desire to efficiently produce a risk assessment that demonstrates that the facility is in compliance with the regulatory guidelines.

It is perhaps understandable and inevitable that uncertainty rules such multi-component, multi-pathway risk assessments. By design, when there is doubt about a critical factor in a system a well intentioned engineer will apply a safety factor to ensure that overall there is a protective margin for error. The greater the uncertainty and the greater the criticality of the parameter, the larger the safety factor. If, for example, there is a large uncertainty regarding the atmospheric dry deposition velocity of HgCl_2 vapor and it is likely that this compound may lead to significant human health risks it may be considered prudent to assume a velocity in the upper range of possible values. As more is learned about the atmospheric behavior of this species and the uncertainties in its critical parameters decrease, the need for overly-conservative “safety” factors will also decrease and the of its transport and fate may be estimated more realistically.

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