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Guidance for Evaluating the Cancer Potency of Polycyclic Aromatic Hydrocarbon (PAH) Mixtures in Environmental Samples

Minnesota Department of Health

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This report describes guidance for conducting risk assessments. This work was conducted by the Site Assessment and Consultation Unit, Carl Herbrandson, PhD, senior toxicologist, under the supervision of Rita Messing, PhD, with the collaboration of the Health Risk Assessment Unit, Helen Goeden, PhD, senior toxicologist, and Kate Sande, MS, Research Scientist, under the supervision of Pamela Shubat, PhD.

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Information about this work is also posted on the MDH website at Guidance for PAHs (http://www.health.state.mn.us/divs/eh/risk/guidance/pahmemo.html)

Guidance for Evaluating the Cancer Potency of Polycyclic Aromatic Hydrocarbon (PAH) Mixtures in Environmental Samples

Executive Summary

The Minnesota Department of Health (MDH) offers guidance for a wide range of risk assessment needs. Cancer potency evaluations of environmental mixtures are a necessary component of cancer risk assessments. This guidance for estimating the cancer potency of mixtures of polycyclic aromatic hydrocarbons (PAHs) is an update of 2013 guidance, which revised MDH 2001 PAH guidance on estimating health risks from carcinogenic PAHs (cPAHs).

MDH finds that the most accurate assessment of cancer risk from a mixture, one based on site-specific whole mixture toxicity information, will not likely be possible. Therefore, other approaches will be needed. Information about a similar mixture ("surrogate whole mixture potency") is preferred, but is rarely available. Summing the individual potencies of constituents of the mixture ("relative potency method") is a reasonable alternative. However, it is likely to be the least accurate site-specific method for evaluating mixture cancer potency.

As a default surrogate whole mixture alternative for the most common types of cPAH mixtures found close to an industrial or pyrogenic source MDH recommends multiplying the benzo[a]pyrene (B[a]P) concentration in a mixture by seven to estimate the cancer potency of an environmental sample. MDH recommends using a site-specific surrogate whole mixture or the relative potency method for PAHs in air or water samples taken far from the source, as such mixtures may have changed significantly in composition (fractionation). MDH makes specific recommendations on cancer risk evaluation of PAH mixtures, relative potencies of individual cPAHs, important cPAH analytes, and determining appropriate analytical detection limits in this guidance.

MDH recommends that all cPAH cancer risk evaluations include the use of age-dependent exposure estimates in combination with age-dependent adjustments to potency (as described in MDH Risk Assessment Advice for Incorporating Early-Life Sensitivity into Cancer Risk Assessments for Linear Carcinogens (http://www.health.state.mn.us/divs/eh/risk/guidance/adafrecmd.pdf)).

Finally, it is important to maintain a state-wide database of site and source-type specific cPAH concentrations so that different source-type default multipliers can be developed. This could significantly decrease analytical and cleanup costs in the future for sites with significant cPAH contamination

Introduction

Cancer potency evaluations of environmental mixtures are a necessary component of cancer risk assessments. MDH has reviewed and relied on a large number of authoritative scientific analyses to determine appropriately protective cancer risk assessments for polycyclic aromatic hydrocarbons (PAHs). Extensive reviews of potential exposures and health effects of PAHs and PAH mixtures are available from the U.S. Agency for Toxic Substances and Disease Registry (ATSDR, 1995), the International Agency for Research on Cancer (IARC, 2013, 1973) and the U.S. Environmental Protection Agency (EPA, 1986, 2009). In addition, the European Food Safety Authority (EFSA) (http://www.efsa.europa.eu/) is actively conducting research on PAH laboratory analyses and food exposures to PAHs.

Environmental exposures to PAHs are always to mixtures of PAHs. Individual PAHs are not found isolated in the environment. PAHs originate from three sources:

- diagenic - natural PAHs generated by biological processes (retene and perylene are examples of PAHs that may be from diagenic or petrogenic sources)
- petrogenic - typically, petroleum and fossil fuels (these typically include many alkylated PAHs)
- pyrogenic - products of incomplete combustion (typically the biggest component of most urban and industrial samples)

Mixtures of diagenic PAHs are generally not considered to have health impacts on people at environmental exposures levels. Short-term environmental exposures to petrogenic and pyrogenic PAHs can lead to tissue irritation (e.g., skin, respiratory, eyes, gastrointestinal). Dermal irritation can be enhanced by exposure to sunlight, sometimes causing severe irritation and rash. MDH recommends avoiding exposure of the skin and eyes, as well as short-term inhalation of large amounts of PAHs.

In addition to irritation, decreased fertility, developmental neurological effects and renal toxicity have been demonstrated in laboratory animals exposed to relatively high levels of PAHs. MDH recommends evaluating the non-carcinogenic health effects from exposure to PAHs using criteria developed for individual PAHs or mixtures (e.g., total petroleum hydrocarbons). These criteria and guidance on evaluating the potency of non-carcinogenic mixtures are not discussed in this guidance.

The most studied endpoint for long term PAH exposure, and the endpoint exclusively addressed in this guidance, is cancer. Long term occupational exposures to PAH mixtures (often confounded by exposure to other materials as well) have been associated with increased incidence of lung, skin, gastrointestinal tract, bladder, and scrotal cancer. Individual carcinogenic PAHs (cPAHs) have been shown to have different cancer potencies and may induce different types of cancer in laboratory animals (e.g., oral exposure to benzo[a]pyrene or dibenzo[a,l]pyrene predominantly result in gastrointestinal tract cancers or lung cancer, respectively).

Early life exposures to a number of cPAHs (e.g., benzo[a]pyrene, dibenzo[a,h]anthracene, 7,12-dimethylbenz[a]anthracene) have demonstrated that younger animals are more sensitive than older animals, and cPAHs are generally assumed to be more potent when exposure occurs early in life (US EPA, 2005). The amount of exposure to environmental contaminants will also change over a lifetime. Therefore, MDH recommends applying age-dependent potency adjustment factors (ADAFs) in conjunction with age-specific exposure parameters when conducting cancer risk assessments. MDH offers guidance on the incorporation of ADAFs (MDH, 2010).

While there may be hundreds of different PAHs and analogues in a mixture, only a few compounds are typically analyzed when evaluating an environmental mixture. Table 1 is a list of many of the PAHs that are recommended for analysis by different environmental and health agencies. The lists were compiled

for different purposes and with different chemical structure inclusion restrictions. Analyte lists are typically limited to the fewest number of compounds necessary to economically, yet accurately evaluate a mixture for a specific purpose.

This guidance document describes and recommends three approaches for estimating the cancer potency of mixtures of polycyclic aromatic hydrocarbons (PAHs). While each method can be used to evaluate exposures to different types of environmental media, different types of data (e.g., site specific whole mixture toxicity data, surrogate whole mixture toxicity data, or individual cPAH sample data) are needed for each method of evaluation.

Evaluating Cancer Potency

Evaluating the cancer potency of a PAH mixture can be difficult. Three methods are recommended. Each method has advantages depending on: the availability or expense of compiling biological data on the cancer potency of a site-related or surrogate PAH mixture; and the availability or expense of sample analysis for a relatively long list of cPAHs.

- ***Site specific whole mixture potency evaluation:***

A site specific whole mixture evaluation uses known or experimentally determined cancer potency data on environmental samples collected from the site being evaluated to estimate the potency of all site samples. This is the method with the least uncertainty and the best choice for evaluating the potential health impacts of an environmental PAH mixture. However, mixture cancer potency data are not readily available for most sites, and obtaining the data experimentally can be expensive. Therefore, this method is typically impractical. Limited analytical data of site-specific samples are needed to evaluate a site using this method.

- ***Surrogate whole mixture potency evaluation:***

A surrogate whole mixture evaluation uses available mixture potency data from a similar source (surrogate) to estimate the potency of all site samples. This method can be reasonably accurate and may be the easiest and cheapest option for evaluating mixture potency. However, determining whether the surrogate mixture and the site mixture are similar with respect to cancer potency can be problematic: what constituents should be used to evaluate the similarity of the potencies; how similar do the mixtures need to be to consider one a surrogate for the other's cancer potency? Generally, limited analytical data of site-specific samples are needed to evaluate a site using this method.

- ***cPAH relative potency evaluation:***

A cPAH relative potency evaluation relies on analytical data for site samples to establish a cPAH mixture potency. Detection limits for each cPAH must be at or below a pre-determined concentration to assure that each cPAH is appropriately evaluated. The accuracy of this method is less certain because it makes assumptions about the impact that interactions between PAHs and other mixture constituents may have on the cancer potency of the whole mixture. This method is likely the best method for evaluating the cancer potency of an environmental PAH mixture when there are no whole mixture potency data available and no reasonable surrogate potency data. While this method relies heavily on analytical data, if the PAH mixture is homogeneous over a site, a cPAH fingerprint can be developed with analytical results from a limited number of samples. This fingerprint can then be applied across the site by indexing the cPAH potency to the concentration of a commonly analyzed PAH (or PAHs).

A brief technical discussion of the methods for conducting each type of cancer potency evaluation for PAH mixtures follows:

1. Site-specific whole mixture potency evaluation

While site-specific whole mixture potency evaluations have been incorporated in ecological assessments, MDH is not aware of sites where these have been used to evaluate a mixture's cancer potency to people. In a site-specific whole mixture potency evaluation, the potency of the mixture of interest is tested in laboratory animals. Study design will affect the usefulness of the data.

The site-specific whole mixture potency from the study should be reported as a function of the concentration of an index PAH in the site-specific mixture. This potency can be age-adjusted for exposure and sensitivity to calculate site-specific criteria, or to calculate cancer risk based on exposure to site material. Equations are similar to *Equations 1* and *2*, below. While this method of evaluating cancer risk will likely be the most accurate method, the cost of conducting animal toxicity studies with site-associated materials typically excludes this option from consideration for site work.

2. Surrogate whole mixture potency evaluation

If site-specific whole mixture potency data are not available, potency of a similar, surrogate mixture may provide the best estimate for the potency of the site media (e.g., sediment, soils). If the source of the surrogate mixture and its composition are determined to be similar to site materials, available published or reviewed potency data from the surrogate mixture may be used as a substitute for site-specific mixture potency data. An example of this is using mixture potency data from available studies of coal tar mixtures to approximate potency for mixtures from another site where the primary source was known to have been coal tar. In this example, the coal tar mixture with available data would be presumed to be a reasonable surrogate for the mixture of concern. The quality of available potency studies, as well as the match between the surrogate and the site materials will affect the usefulness of a surrogate.

Similar sources (e.g., two different manufactured gas plant residues, or two different diesel exhausts) may be anticipated to have similar potencies. Data on the absolute potency of the surrogate mixture and, minimally, surrogate mixture concentrations of a standard list of commonly measured, semi-volatile and nonvolatile PAHs (e.g., 15 carcinogenic and noncarcinogenic PAHs included on the EPA List of Priority Pollutants, Table 1, below) should be available. The surrogate mixture potency data must be of sufficient quality to allow calculation, with reasonable confidence, of a surrogate mixture cancer slope factor (CSF). Site samples should also be analyzed for the standard list of PAHs. Ratios of constituent PAHs from both site and surrogate mixtures should be similar. Upon request, MDH may be able to review the appropriateness of potency data developed from site-specific or surrogate whole mixture studies.

Because the individual cPAHs responsible for the potency of the surrogate mixture are not determined in mixture potency studies, the concentrations are typically reported as the concentration of a specific index PAH found in the environmental mixture.

Benzo[a]pyrene (B[a]P) potency equivalence is typically used as the index of the cPAH concentration in the surrogate and in analyzed environmental samples. The relative potency of the surrogate, expressed as the mixture B[a]P potency equivalence (B[a]P PEQ), is calculated using Equation 1:

$$\text{B[a]P PEQ}_{surrogate}\ \{\text{unitless}\} = \text{CSF}_{surrogate} / \text{CSF}_{bap} \qquad \textit{Equation 1.}$$

Where:

$\text{CSF}_{surrogate}$ $\{(\text{mg B[a]P / kg body weight / d})^{-1}\}$ = the cancer slope factor of the surrogate mixture in relationship to the mixture B[a]P concentration

CSF_{bap} $\{(\text{mg B[a]P / kg body weight / d})^{-1}\}$ = the cancer slope factor for B[a]P

The surrogate mixture B[a]P PEQ and individual sample B[a]P concentration data can be used to determine a sample B[a]P PEQ ($C_{bap\ peq}$) using Equation 2:

$C_{bap\ peq}$ {mg B[a]P PEQ / kg media} = C_{bap} * B[a]P $PEQ_{surrogate}$ *Equation 2.*

Where:

C_{bap} {mg/kg} = the concentration of B[a]P in individual samples

Data from a US National Toxicology Program (NTP) rat feeding study described in Culp et al. (1998) have been used to calculate CSFs for B[a]P and for coal tar mixtures. Gaylor et al. (2000) used these data to calculate a (human adjusted) CSF of 1.2 (mg B[a]P/kg/d)$^{-1}$ for B[a]P in the most sensitive tissue (forestomach). The California Office of Environmental Health Hazard Assessment (CA, OEHHA, 2010) performed a similar analysis using data from the forestomach as well as oral cavity data, and developed a human-adjusted B[a]P CSF of 1.7 (mg B[a]P/kg/d)$^{-1}$. Schneider et al. (2002) used the NTP data for the coal tar mixtures to calculate a human-adjusted CSF for all tissues of 11.5 (mg B[a]P/kg/d)$^{-1}$ based on ingestion of B[a]P in the coal tar mixtures. Coal tar and to a lesser extent B[a]P have been shown to be oral carcinogens in multiple tissues. For developing a B[a]P PEQ for coal tar (B[a]P $PEQ_{coal\ tar}$) MDH recommends using CSFs developed from data on cancer in all sensitive tissues. Therefore, the CA OEHHA B[a]P CSF and the Schneider et al. coal tar CSF are used in calculating a B[a]P $PEQ_{coal\ tar}$.

Using CSFs developed from the NTP data:

$CSF_{coal\ tar}$ = 11.5 (mg B[a]P / kg / d)$^{-1}$ (Schneider et al., 2002);
CSF_{bap} = 1.7 (mg B[a]P / kg / d)$^{-1}$ (CA OEHHA, 2010)

B[a]P $PEQ_{coal\ tar}$ {unitless} = $CSF_{coal\ tar}$ / CSF_{bap}
B[a]P $PEQ_{coal\ tar}$ = 11.5 / 1.7 = 6.76 rounded to 7

Site-specific sample concentrations can be converted to B[a]P PEQs ($C_{bap\ peq}$) using Equation 2:

$C_{bap\ peq}$ {typically, mg/kg environ. media} = B[a]P $PEQ_{coal\ tar}$ * C_{bap} {mg/kg environ. media}
$C_{bap\ peq}$ {mg/kg environ. media} = 7 * C_{bap} {mg/kg environ. media} *Equation 3.*

$C_{bap\ peq}$ for each sample can be directly compared to media-specific criterion for B[a]P. Criteria should be exposure and sensitivity adjusted by age (see MDH 2010 guidance)

While a surrogate whole mixture potency evaluation of an environmental PAH mixture is not as desirable as a site-specific whole mixture potency evaluation of the site-specific mixture, it can be a reasonable method for estimating the potency and risk from exposure to some PAH mixtures.

Schneider et al. (2002) reviewed the carcinogenicity PAHs in environmental mixtures and concluded that a reasonable potency for most PAH mixtures from industrial sources in soil ($CSF_{ind\ soil}$) is 11.5 (mg B[a]P/kg/d)$^{-1}$ (all tissues and adjusted for humans). This is about 7 times the potency of B[a]P in the mixture (see calculation, above). In 2002, the European Commission (EC) approved the use of 10 times B[a]P potency alone for evaluating cPAH potency in food (European Commission – SCF 2002). In addition, the EC also recommended chemical analysis of an extended list of cPAHs so that fingerprints of contamination and the presence of potent cPAHs can be noted and possibly associated with various food manufacturing processes. The EC has since retracted the mixture potency guidance, in part because some food samples with apparent PAH cancer potency did not contain detectable levels of B[a]P (European Commission - EFSA, 2008). Required detection limits for cPAHs (including B[a]P) in food are lower than required detection limits in environmental media such as soil and sediments. Furthermore, environmental samples typically offer a range of concentrations over which detection of low concentrations of B[a]P may be possible. Inability to detect B[a]P at sites with environmental PAH contamination should not be an issue if appropriate methods are used.

Given that cancer potency screening of environmental samples is not very precise, and that the screening criteria are not “bright lines”, MDH recommends using a B[a]P-PEQ of 7 times the B[a]P concentration

as a policy option for default evaluation of most environmental pyrogenic PAH samples. While the use of this criterion is likely to be protective for diagenic and petrogenic PAH mixtures as well, this guidance is only intended for application to pyrogenic PAH mixtures.

The default value for surrogate whole mixture evaluation (i.e., 7 times the B[a]P concentration) is not recommended when the original PAH mixture has been substantially changed in the environment (fractionation). Significant fractionation is likely to occur in ambient air or in groundwater down gradient from a PAH source and is dependent on the chemical/physical properties of the individual constituent PAHs, distance and speed traveled, and other factors. Therefore, the policy of using 7 times the B[a]P concentration as a default method for evaluating whole mixture cPAH potency should be evaluated whenever groundwater plumes or ambient air are the media of interest. It may be possible in some circumstances to develop temporally or spatially restricted default B[a]P-PEQs for some mixtures or at some sites.

Even if a site-specific or surrogate whole mixture potency method is used to evaluate PAH cancer potency at a site, MDH recommends analysis of an extended list of MDH Priority cPAHs (described in the relative potency evaluation section below) in a few samples so that cPAH fingerprints can be developed for different PAH source-types. These data could be used to develop protective default multipliers for different source-types, and potentially could lead to a subsequent reduction in analytical and cleanup costs at similar sites.

3. cPAH relative potency evaluation

In this approach, each individual cPAH is presumed to contribute to the potency of a mixture in proportion to its own potency and its concentration in the mixture. The potencies of individual cPAHs can be very different. The easiest way to add the potencies of individual cPAHs in an environmental sample is to convert the potency of each cPAH into a unitless relative potency factor (RPF). Previous MDH guidance referred to these factors as potency equivalence factors (PEFs). The concentration of each cPAH times the RPF can then be considered as a concentration of the index cPAH.

B[a]P is used, by convention, as the index PAH, and relative potencies of individual cPAHs are determined relative to the potency of B[a]P. As a result, cPAHs that have been experimentally determined to be more potent than B[a]P have RPFs greater than 1, and cPAHs that are less potent than B[a]P have RPFs less than 1. For example: a cPAH ten-fold more potent than B[a]P has an RPF of 10.

The amount of an individual cPAH found in an environmental sample, as well as the relative potency of the cPAH, determines its presumed contribution to the total cancer potency of the sample. Environmental PAH mixture composition can vary greatly. For some mixtures it may be important to measure the concentration of the most potent cPAHs, while for other mixtures, high concentrations of less potent cPAHs may drive the mixture potency calculations. Therefore a fingerprint of the concentrations of most cPAHs in an environmental mixture should be determined. If the mixture across the site or across an area of the site is homogeneous, a cPAH fingerprint from a couple of samples can be used to calculate the estimated potency of additional samples using data from only a small number of analytes. Using this method, cPAH fingerprints can be determined by analyzing samples with optimum PAH concentrations, and the ratios of constituents can then be applied to samples that may be below analytical detection limits for some cPAHs.

The RPFs for individual MDH Priority cPAHs are listed in Table 2. RPFs cited in Table 2 are (1) average RPFs from draft EPA PAH Mixture Guidance (US EPA, 2010); (2) calculated from MDH-reviewed CSFs; and (3) California Office of Environmental Health Hazard Assessment potency equivalents (CA OEHHA, 2010). MDH currently recommends an adult (not age-adjusted) cancer slope factor for B[a]P of 1.7 $(mg/kg/d)^{-1}$ and an inhalation exposure adult (not age-adjusted) cancer slope factor of 3.9 $(mg/kg/d)^{-1}$ [equivalent to an adult unit risk of $1.1x10^{-3}$ $(\mu g/m^3)^{-1}$]. If children are likely to be exposed, cancer potency should be age-adjusted in conjunction with age-dependent exposures. Typically, these adjustments are coordinated during the development of environmental media exposure criteria (MDH, 2010).

The cPAH relative potency evaluation method requires analysis of many cPAHs in an environmental mixture. Chemical analysis of these cPAHs is difficult and achieving required detection limits can be challenging. MDH recommends analysis of MDH Priority cPAHs in Table 2 for evaluating sample potency or developing a site and source-specific fingerprint. The results of *Equation 4* ($C_{bap\ peq}$: B[a]P potency equivalence concentration) can be directly compared to a media-specific B[a]P criterion (e.g., Minnesota Pollution Control Agency (MPCA) B[a]P Soil Reference Value, MPCA B[a]P Inhalation Screening Value, MDH health-based guidance for drinking water):

$$C_{bap\ peq}\ \{\text{typically, mg B[a]P PEQ / kg media}\} = \sum (C_i * RPF_i) \qquad \textit{Equation 4.}$$

For:

i = all MDH Priority cPAHs (Table 2)

Where:

C_i {typically, mg i / kg media} = individual cPAH concentrations
RPF_i = individual cPAH relative potency factors

Prior to analyzing environmental samples for MDH Priority cPAHs, laboratory detection limits should be evaluated. Method detection limits (MDLs) for each MDH Priority cPAH should be less than or equal to five percent of the cPAH (B[a]P) criterion:

$$MDL_x\ \{\text{mg / kg media}\} = 0.05 * \text{Health Criterion}_{B[a]P} / RPF_x. \qquad \textit{Equation 5.}$$

Where: x = each MDH Priority cPAH

If one or more MDH Priority cPAHs are analyzed at higher detection limits, the potency of the mixture may be underestimated. Therefore, prior to deciding to evaluate a site using the cPAH relative potency approach, detection limits should be reviewed, and a statistical analysis of the uncertainties that may be incurred as a result of elevated detection limits is recommended.

Chemical analysis of cPAHs can be difficult and expensive. In addition there is limited availability of some cPAH analytical standards. MDH has restricted the recommended list of analytes to cPAHs that can be analyzed in a competent laboratory. However, care and experience will be necessary to assure proper quantification of a number of cPAHs; especially cPAHs with a molecular weight of 302 (which include the benzofluoranthrenes), benzo[c]fluorene, dibenz[a,h]anthracene, chrysene, cyclopenta[c,d]pyrene, 5-methylchrysene, and 6-nitrochrysene.

The EPA is expected to finalize their cPAH relative potency guidance in the near future. MDH anticipates that the release of EPA guidance will not impact the MDH Priority cPAH list (Table 2, below). However, it is expected that the EPA Guidance will contain newer and better RPFs for a number of the MDH

Priority cPAHs. MDH will review and update cPAH RPFs as soon as possible following release of updated information from the EPA.

Summary and Conclusions

- While site-specific whole PAH mixture cancer potency data are rarely available, this type of an analysis is likely to provide the most accurate assessment of the cancer potency of a PAH mixture.
- If a site-specific or similar surrogate whole mixture evaluation is available, it is doubtful that a summation of individual cPAH potencies (cPAH relative potency evaluation) will result in a more accurate potency estimate.
- When data are not available to allow use of a whole mixture potency evaluation (site-specific or a similar surrogate), a relative potency evaluation can provide a reasonable estimate of the cancer potency of an environmental PAH mixture.
- It is important that laboratory detection limits for individual cPAHs should be less than or equal to concentrations of interest (typically, five percent of the media-specific B[a]P criterion divided by the relative potency factor (RPF)).
- It is important that site-specific cPAH criteria and all cancer risk evaluations should include coordinated age-dependent exposure and sensitivity adjustments (MDH, 2010).
- For initial, screening or default evaluation of a site it is reasonable to assume that a PAH mixture (that has not undergone significant fractionation in the environment) is about seven (7) times more potent than suggested by the concentration of B[a]P in that media.
- Even when a whole mixture potency or default evaluation is used to evaluate mixture potency, it is beneficial to analyze a few samples for the MDH Priority cPAHs so that cPAH fingerprints and default multipliers can be developed over time for different PAH source-types.

MDH Recommendations

- Determine the availability of site-specific or surrogate whole mixture cancer potency data and use these data to characterize the potency of site samples.
- If there are no site-specific or appropriate surrogate whole mixture cancer potency data, use the relative potency method or the default method to estimate sample cancer potency.
- Relative potency factors for MDH Priority cPAHs in Table 2 and *Equation 4* should be used to calculate sample cPAH cancer potencies and the result should be compared with the appropriate media-specific, age-adjusted B[a]P criterion. Use the relative potency factor approach for environmental mixtures that have undergone significant fractionation in the environment.
- For calculation of PAH mixture default cancer potency multiply the B[a]P concentration of a sample by seven (7) using *Equation 3* and compare the value to the appropriate media-specific, age-adjusted B[a]P criterion.
- Use an adult cancer slope factor for B[a]P of 1.7 $(mg/kg/d)^{-1}$ and an inhalation exposure adult cancer slope factor of 3.9 $(mg/kg/d)^{-1}$ [equivalent to an adult unit risk of $1.1x10^{-3}$ $(\mu g/m^3)^{-1}$]. Use of age-dependent exposure estimates in combination with age-dependent adjustments to potency for all cPAH risk calculations.
- Prior to chemical analysis, confirm that the laboratory detection limits for cPAHs are equal to or below levels of interest using *Equation 5*. If detection limits are above levels of interest conduct an uncertainty analysis of the impact that this could have on potency evaluations.
- If sufficient cPAH or surrogate mixture potency data are available, MDH may support the use of source-type specific default cancer potency factors or multipliers to use at sites with similar sources.
- Individual cPAHs frequently occur as part of an environmental mixture. The individual potency factors are not intended to be used as the basis of cancer slope factor calculations, rather their purpose is to be used as part of a cumulative risk assessment to estimate the cancer risk from a mixture of cPAHs.

Table 1: PAH Lists

Polycyclic Aromatic Hydrocarbons from selected Environmental and Public Health Agency Lists	CAS #	Molecular Weight			cPAH Lists				
			* - EPA - 15	ǂ- EPA – RTK,TRI	¥ - OEHHA CSF	§ - OEHHA 2009 (MDH 2001)	¶ EC "15+1"	£ - EPA Draft RPF	# - MDH Priority
Total # PAHs = 43			15	22	7	24	16	26	19
Acenaphthene	83-32-9	154.21	*						
Acenaphthylene	208-96-8	152.2	*						
Anthanthrene	191-26-4	276.34						£	#
Anthracene	120-12-7	178.23	*					£	
Benz[a]anthracene	56-55-3	228.29	*	ǂ		§	¶	£	#
11H-Benz[b,c]aceanthrylene	202-94-8	240.3						£	
Benz[e]aceanthrylene	199-54-2	252.32						£	
Benz[j]aceanthrylene	202-33-5	252.32						£	
Benz[l]aceanthrylene	211-91-6	252.32						£	
Benzo[a]pyrene	50-32-8	252.31	*	ǂ	¥		¶		#
Benzo[b]fluoranthene	205-99-2	252.32	*	ǂ		§	¶	£	#
Benzo[c]fluorene	205-12-9	216.28					¶	£	#
Benzo[g,h,i]perylene	191-24-2	276.34	*	ǂ			¶	£	#
Benzo[j]fluoranthene	205-82-3	252.32		ǂ		§	¶	£	#
Benzo[k]fluoranthene	207-08-9	252.32	*	ǂ		§	¶	£	#
Chrysene	218-01-9	228.29	*	ǂ		§	¶	£	#
Cyclopenta[c,d]pyrene	27208-37-3	226.28					¶	£	#
4H-Cyclopenta[d,e,f]chrysene	202-98-2	240.3						£	
Dibenz[a,h]acridine	226-36-8	279.33		ǂ		§			
Dibenz[a,h]anthracene	53-70-3	278.35	*	ǂ	¥	§	¶	£	#
Dibenz[a,j]acridine	224-42-0	279.33		ǂ		§			
Dibenzo[a,e]fluoranthene	5385-75-1	302.38		ǂ				£	
Dibenzo[a,e]pyrene	192-65-4	302.38		ǂ		§	¶	£	#
Dibenzo[a,h]pyrene	189-64-0	302.38		ǂ		§	¶	£	#
Dibenzo[a,i]pyrene	189-55-9	302.38		ǂ		§	¶	£	#
Dibenzo[a,l]pyrene	191-30-0	302.38		ǂ		§	¶	£	#
7H-Dibenzo[c,g]carbazole	194-59-2	267.32		ǂ		§			
7,12-Dimethylbenz[a]anthracene	57-97-6	256.34		ǂ	¥	§			
1,6-Dinitropyrene	42397-64-8	292.25				§			
1,8-Dinitropyrene	42397-65-9	292.25				§			
Fluoranthene	206-44-0	202.26	*	ǂ				£	#
Fluorene	86-73-7	166.22	*						
Indeno[1,2,3-cd]pyrene	193-39-5	276.34	*	ǂ		§	¶	£	#
3-Methylcholanthrene	56-49-5	268.35		ǂ	¥	§			
5-Methylchrysene	3697-24-3	242.31		ǂ	¥	§	¶		#
Naphtho[2,3-e]pyrene	193-09-9	302.38						£	
5-Nitroacenaphthene	602-87-9	199.21			¥	§			
6-Nitrochrysene	7496-02-8	273.29			¥	§			#
2-Nitrofluorene	607-57-8	211.22				§			
1-Nitropyrene	5522-43-0	247.25		ǂ		§			
4-Nitropyrene	57835-92-4	247.25				§			
Phenanthrene	85-01-8	178.23	*					£	
Pyrene	129-00-0	202.26	*					£	

*- EPA-15. US EPA - PAHs on the Clean Water Act List of Priority Pollutants - http://water.epa.gov/scitech/methods/cwa/pollutants.cfm

ǂ - EPA-RTK,TRI. US EPA (2001) - Right-To-Know Act: Polycyclic Aromatic Compounds Category. http://www.epa.gov/sites/production/files/documents/2001pacs.pdf.

cPAH Lists Agency carcinogenic PAH Lists:

¥ - OEHHA CSF. California Office of Health Hazard Assessment PAH Cancer Slope Factors - http://oehha.ca.gov/tcdb/index.asp

§ - OEHHA 2009. California Office of Health Hazard Assessment http://www.oehha.ca.gov/air/hot_spots/2009/TSDCancerPotency.pdf
MDH, 2001 - Previous Minnesota Department of Health cPAH Guidance Memo

¶ - EC "15+1". European Commission - Commission Regulation (EC) No 1881/2006 - http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CONSLEG:2006R1881:20100701:EN:PDF

£ - EPA Draft RPF - PAHs with Relative Potency Factors from US EPA Draft Document (potency =0 included) - (US EPA, 2010)

- MDH Priority – List of MDH Priority Carcinogenic Polycyclic Aromatic Hydrocarbons and Relative Potency Factors, 2014

Table 2: MDH Priority Carcinogenic Polycyclic Aromatic Hydrocarbons and Relative Potency Factors

MDH Priority cPAHs n = 19	**Relative Potency Factors**
Anthanthrene	0.4
Benz[a]anthracene	0.2
Benzo[a]pyrene	1
Benzo[b]fluoranthene	0.8
Benzo[c]fluorene	20
Benzo[g,h,i]perylene	0.009
Benzo[j]fluoranthene	0.3
Benzo[k]fluoranthene	0.03
Chrysene	0.1
Cyclopenta[c,d]pyrene	0.4
Dibenz[a,h]anthracene	10
Dibenzo[a,e]pyrene	0.4
Dibenzo[a,h]pyrene	0.9
Dibenzo[a,i]pyrene	0.6
Dibenzo[a,l]pyrene	30
Fluoranthene	0.08
Indeno[1,2,3-cd]pyrene	0.07
5-Methylchrysene	1
6-Nitrochrysene	10
Secondary cPAHs (MDH guidance does not consider these Priority PAHs at this time: analytical issues, toxicological or environmental database uncertainties, or low projected impact on mixture potency)	
11H-Benz[b,c]aceanthrylene	0.05
Benz[e]aceanthrylene	0.8
Benz[j]aceanthrylene	60
Benz[l]aceanthrylene	5
4H-Cyclopenta[d,e,f]chrysene	0.3
Dibenz[a,h]acridine	0.1
Dibenz[a,j]acridine	0.1
Dibenzo[a,e]fluoranthene	0.9
7H-Dibenzo[c,g]carbazole	1
7,12-Dimethylbenz[a]anthracene	64 (air only) 150 (oral/derm)
1,6-Dinitropyrene	10
1,8-Dinitropyrene	1
3-Methylcholanthrene	5.6 (air only) 13 (oral/derm)
Naphtho[2,3-e]pyrene	0.3
5-Nitroacenaphthene	0.02
2-Nitrofluorene	0.01
1-Nitropyrene	0.1
4-Nitropyrene	0.1

Bolded PAHs from US EPA Clean Water Act List of Priority Pollutants - http://water.epa.gov/scitech/methods/cwa/pollutants.cfm

Italicized Potency Equivalence calculated from specific compound cancer slope factors (OEHHA Toxicity Criteria Database), not based on a direct relative potency comparison from a single study.

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