A human health risk assessment of exposure to polycyclic aromatic hydrocarbons (PAHs) in coal-tar sealcoats

by
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ABSTRACT

MOCKA, COREY ADAM. A human health risk assessment of exposure to polycyclic aromatic hydrocarbons (PAHs) in coal-tar sealcoats. (Under the direction of Dr. Stephen Graham and Ms. Linda Taylor).

Polycyclic aromatic hydrocarbons (PAHs) are organic molecules that consist of two or more fused benzene rings. They are natural components of coal or petroleum products and also formed by the incomplete combustion of organic matter, making them ubiquitous environmental contaminants. The United States Environmental Protection Agency (EPA) currently classifies seven PAHs as B2 chemicals (probable human carcinogens) and, considering their presence in most environmental exposure media (e.g., soil, sediment, water, air) PAHs are a significant concern to environmental and human health professionals. Coal-tar sealcoats are black, shiny coatings that are adhered to driveway and parking lots to increase pavement life and improve aesthetics. Recent studies by the United States Geological Survey (USGS) have determined that certain PAH concentrations in settled dust on the coal-tar seal coated parking lots were 5,300 times greater than concentration limits recommended for designated superfund sites. The research herein consisted of two parts: (1) background research on recent coal-tar sealant data to determine individual PAH concentrations, and (2) an initial human health risk assessment (HHRA) for selected exposure pathways. In order to determine the exposure point concentration (EPC) of PAHs, two calculation methods were used based on the EPA's 1993 relative potency factors (RPFs) and the more recent 2010 RPFs. This comparison of RPFs was essential to demonstrate the impact of the EPA possibly implementing an expanded PAH risk assessment. Of the three scenarios examined, worker exposure to volatilized PAHs in the air presented the largest LADD and cancer risk values of 3.25E-06 mg/kg-day and 2.37E-05, respectively, when using the 2010 RPF values for the calculations. These results have upheld the hypothesis of the potential PAH risk of certain populations that may become exposed to coal tar sealcoats.

DEDICATION

This work is dedicated to all of the educators that have assisted me from high school, to college, to graduate school. Without their dedication to the sciences, I would not have the academic foundation necessary to complete this research.

BIOGRAPHY

Mr. Corey A. Mocka grew up in a suburb south of Boston, Massachusetts and obtained a Bachelors of Science Degree in Chemistry at Suffolk University in 2008. He began his career in North Carolina working as a contractor for the US EPA at the National Risk Management Laboratory, Air Pollution Prevention and Control Division. During this time he began attending graduate school at North Carolina State University. In 2012, Mr. Mocka accepted a position with the North Carolina Department of Environment and Natural Resources (DENR) in the Division of Air Quality. Mr. Mocka currently resides in Raleigh, NC with his fiancée, Elizabeth, and their dog, Murphy.

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Thank you to Dr. Brian Magee of ARCADIS US for helping me form this thesis, directing me to the appropriate sources, and igniting my interests in human health risks assessments. I owe an enormous amount of gratitude to Dr. Stephen Graham of the US Environmental Protection Agency for his guidance both throughout the data reduction process as well as the valuable career advice. Finally, thank you to Ms. Linda Taylor of North Carolina State University for doing the hardest job of all, being my advisor throughout the program. On a personal level, I am forever indebted to my fiancée, Elizabeth, for her continuing support throughout all of my numerous endeavors.

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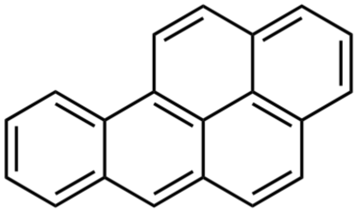
1. Background

1.1. Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons (PAHs) are organic compounds that consist of two or more fused benzene rings. They are a natural component of coal or petroleum products and can also be formed by the incomplete combustion of organic matter (Van Metre et al. 2006). Benzo[a]pyrene shown in Figure 1 is the one of the most commonly studied PAHs do to the availability of toxicity data.

Figure 1. Benzo[a]pyrene



The primary anthropogenic sources of PAHs include: vehicle exhaust, tobacco smoke, coal, coal-tar, and charred food (EPA 2008). Previous experiments have indicated that some PAHs are probable human carcinogens. Exposure to PAHs has also been known to produce reproductive problems and birth defects (note: these experiments were done with animals not humans).

The United States Environmental Protection Agency (EPA) created a list of 16 “priority” PAHs (Table 1). These priority PAHs were selected due to the availability of data related to potential health effects. In addition, these PAHs are known to be more persistent in the environment and typically have the highest concentrations at hazardous waste sites (ASTDR 1995). The highlighted compounds in Table 1 are classified by the EPA as “B2 Carcinogens” meaning they are probable human carcinogens.

Table 1. List of EPA designated 16 Priority PAHs

PAH Name (abbreviation)	Structure (# of rings)	Molecular Weight (g/mol)
Naphthalene (NAP)	2	128.17
Acenaphthene (ACE)	3	154.21
Acenaphthylene (ACY)	3	152.2
Anthracene (ANT)	3	178.23
Phenanthrene (PHE)	3	178.23
Fluorene (FLU)	3	166.22
Fluoranthene (FLT)	4	202.26
Benzo(a)anthracene[a] (BaA)	4	228.29
Chrysene[a] (CHR)	4	228.29
Pyrene (PYR)	4	202.26
Benzo(a)pyrene[a] (BaP)	5	252.32
Benzo(b)fluoranthene[a] (BbF)	5	252.32
Benzo(k)fluoranthene[a] (BkF)	5	252.32
Dibenz(a,h)anthracene[a] (DaA)	6	278.35
Benzo(g,h,i)perylene (BgP)	6	276.34
Indeno[1,2,3-cd]pyrene[a] (IPY)	6	276.34

[a] Designated as a B2 Carcinogen

1.2. Coal –Tar Sealcoat

Coal-tar is the residue that remains after coal tar distillation and it is often used as a binding agent. Sealcoats are a black shiny coating on top of driveways and parking lots that can increase pavement life and improve pavement aesthetics. It is believed that a total of 85 million gallons of coal-tar sealcoats are used each year in the United States (Mahler et al. 2012). The United States Geological Survey (USGS) recently estimated that benzo[a]pyrne concentrations in driveway dust from coal-tar sealcoats could be as high as 5,300 times greater than limits recommended at EPA superfund sites (Hawthorne 2011).

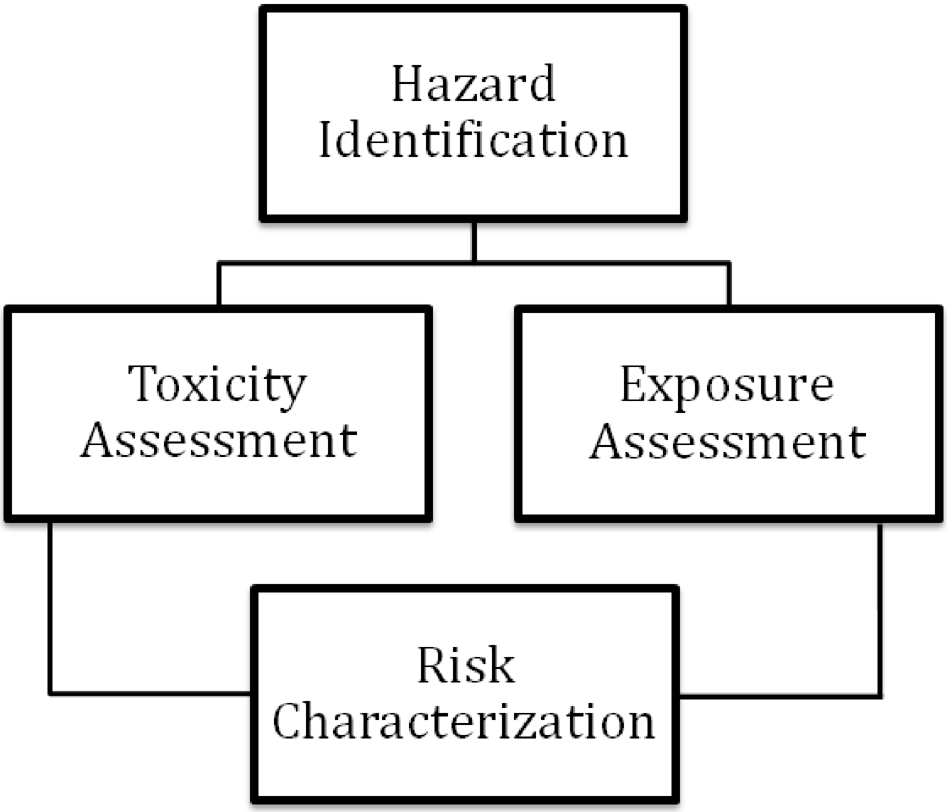
Recent experiments conducted primarily by the USGS have analyzed pavement dust, pavement concentration, water runoff, lake sediment, soil, settled house dust (SHD), and air concentrations of PAHs thought to be the result of interaction with coal-tar sealcoat (Mahler et al. 2012). Several of these investigations provide the data necessary to conduct human health risk assessments for the exposure of humans to PAH laden coal-tar sealcoats.

Furthermore, the recent coal-tar data has already been used to enact several political and industrial reforms. Austin, TX was the first municipality to ban coal-tar sealcoats in 2006. Since then, Texas, Washington, Minnesota, Illinois, and Massachusetts have all introduced bills to end the used of coal-tar sealcoat. On a consumer level, Home Depot and Lowes voluntarily stopped selling coal-tar sealant products. Interestingly, approximately 20 years ago, the coal-tar industry petitioned the EPA not to include coal-tar sealant in anti-pollution laws (Hawthorne 2011).

1.3. Human Health Risk Assessment Process

According to Risk Assessment Guidance for Superfund (RAGS), the human health risk assessment (HHRA) process consists of four parts: hazard identification, toxicity assessment, exposure assessment, and risk characterization (US EPA 1989). The hazard identification step (Figure 2) in this procedure has already been completed in previous research, particularly the studies conducted over the past several years by the USGS. The USGS has provided the exposure media concentration data for which this HHRA is based. The toxicity assessment of this HHRA will compare the individual PAH relative potency factors and evaluate how they affect the human health risk estimates. The PAH exposure assessment conducted here solely focuses on two routes of exposure: ingestion and inhalation. This risk assessment incorporates each of these steps in order to characterize risk of the possible cancer and non-cancer health endpoints involving coal-tar sealcoat that contains PAHs.

Figure 2. HHRA Process



1.4. Relative Potency Factors

One of the concerns when completing a cancer risk assessment involving PAHs is the overall lack of toxicity data for the individual compounds as well as the uncertainties in the combined effects from simultaneous exposure to several PAHs. Thus, the EPA has recommended use of relative potency factors (RPF). According to the EPA, "doses of component chemicals that act in a toxicologically similar manner are added together, after scaling the doses relative to the potency of an index chemical" (EPA 2010). Benzo[a]pyrene is the only PAH where robust dose-response data for exposure route exist making the toxicity of PAHs related back to BaP using RPF values.

The EPA released a document in 1993 that lists the standard RPF values for seven PAHs that are used for all cancer risk assessments. In 2010, the EPA published an updated document that listed the average RPF values that have been deduced from various research over the years following the initial 1993 publication. Not only were the RPFs updated from the original seven PAHs, a total of 17 other PAHs were added to the list as well. Table 2 lists the original 7 PAH RPFs as well as their proposed average RPF values from 2010. The EPA, however, has not mandated that the updated RPF values be used in risk assessments. An objective of this research shows how the current use of the RPF system may present additional uncertainties for PAH based risk assessments.

Table 2. PAH Relative Potency Factors

PAH	RPF (EPA 1993)	Average RPF (EPA 2010)
BaP	1	1
BaA	0.1	0.2
BbF	0.1	0.8
BkF	0.01	0.03
CHR	0.001	0.1
DBahA	1	10
IPY	0.1	0.07
		+ 17 other PAHs with RPFs of 0.0009 to 30

1.5. Proposed Scenarios

An initial human health risk assessment was performed for the exposure scenarios listed in Table 3. Based on the availability of current data, one risk assessment will involve the ingestion of settled house dust (SHD) that has been introduced into the home from coal-tar sealcoat. The other two scenarios involve the inhalation of PAHs that have volatized from the surface of a recently coal-tar sealcoated parking lot. Detailed information about the data sources and experiments are listed in Section 2.

Table 3. HHRA Exposure Scenarios

Scenario	Description	Data Source
1	Adult ingestion of PAH laden settled house dust from coal-tar seal-coated parking lots	1
2	Adult inhalation of volatilized PAHs from recently coal-tar seal-coated parking lots	2
3	Adult worker inhalation of volatilized PAHs from coal-tar sealcoat applications	2

1. Mahler et al. (2010)
2. Van Metre et al. (2012)

2. Data Sources

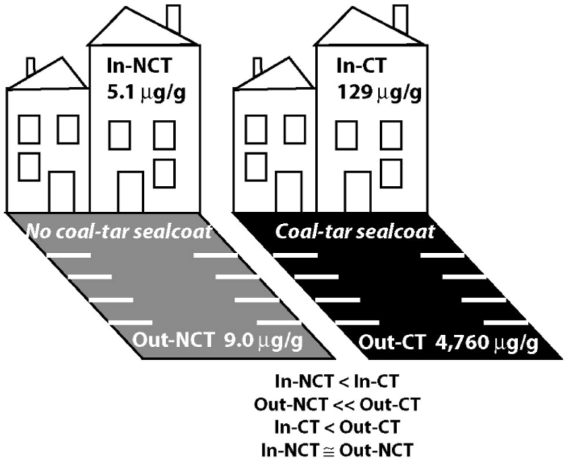
One of the challenges in using secondary PAH data is the lack of authors reporting the individual PAH concentrations in the environmental media. Most papers reference a “total PAH concentration” which is the sum of all PAHs that were analyzed in the experiment. This combined value is an important uncertainty when using such data to perform cancer risk calculations because, as shown by the wide-ranging toxicity of PAHs, individual PAH concentrations are needed to reflect the distinctive toxicity characteristics of the actual mixture. This theory becomes clearer in the following sections describing the risk calculations. For this work, however, two sources were used to separate total PAH concentrations into individual members for the settled house dust and air.

2.1. PAHs in Settled House Dust

Mahler et al. (2010) investigated the relationship between PAH concentrations in SHD and coal tar based parking lot sealcoats. Two sets of apartment complexes were examined in Austin, TX. The first had coal-tar-based seal coated parking lot and the other did not (ex. asphalt, concrete, etc.). First, the residents and apartments were screened in order to account for activities that might influence the concentrations of PAHs in the household. For example, the residents were screened for: tobacco use, cleaning habits, and use of specific cooking sources. SHD was collected using established American Society for Testing Materials (ASTM) methods typically over a surface volume ranging from 1.6 to 13 m^2. The collected dust was then separated based on particle size using a sieve, extracted, and analyzed via GC/MS for PAHs. The authors reported in the article the “T-PAH” value representing the total PAH concentration of 16 EPA priority pollutants. The schematic in Figure 3 compares the PAH concentrations in SHD with corresponding coal-tar-based seal coated parking lots (Out-CT) and non coal-tar-based seal coated parking lots (Out-NCT). On average, there were 129 µg/g of PAHs in the SHD of apartments that had a coal-tar seal coated parking lot outside compared to a PAH concentration of 5.1 µg/g in SHD of apartments with the non coal-tar seal coated parking lots. Note that measurements made on the CT and NCT products indicated the concentration of PAHs in the coal-tar sealant itself is about three orders of magnitude greater than the non coal-tar sealcoat.

In addition to the total PAH concentration, the Mahler et al. (2010) study provided the SHD concentrations of individual PAHs including ACE, BaP, FLT, NPTH, BaA, PHE, and FLU. Although not all of these PAHs were utilized in the current assessment, an exposure point concentration was calculated for each PAH in order to establish the risk associated with the adult ingestion of PAH laden settled house dust (Section 4.1).

Figure 3. PAH Concentrations in SHD (Mahler et al. 2010)

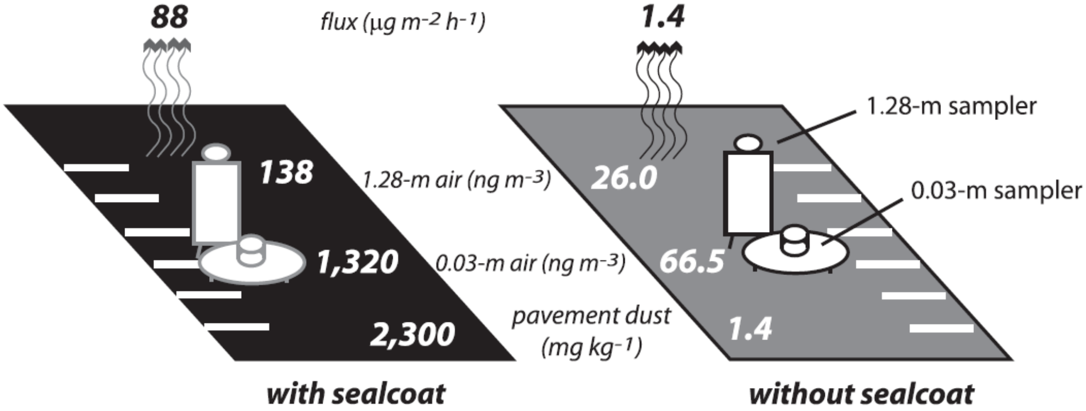


2.2. PAH Volatilization above Coal-Tar Sealcoat

As seen in research, the PAH concentrations in coal-tar sealcoat is significantly higher than non coal-tar sealcoats. Knowing this information, Van Metre et al. (2012 and 2012b) measured the total and individual PAH concentrations in the air above pavement that had been freshly covered with PAH coal-tar sealcoat. Two coats of a tar-emulsion pavement sealer were applied to a 16 x 16 m section of parking lot in Austin, TX. Two air samplers were set up near the center of the parking lot. One measurement representing ground level was collected at a height at 0.03 m and the other at or near breathing level was collected at a height of 1.28 m. Air sampling was conducted using polyurethane foam (PUF) during the afternoon hours on the 5, 6, 45, 149, 232, 328, and 376 days after application. The PAHs were extracted from the PUF using the standard soxhlet extraction method and solid phase extraction (SPE) cleaned up the extract. All samples were analyzed on a GC/MS for 19 commonly measured PAHs. A full table of results is shown in Appendix A. Figure 4 summarizes the annual mean T-PAH concentrations found at the 1.28 m and 0.03 m sampling height as well as the PAH concentration in the pavement dust.

The authors reported T-PAH data as a summation of the various individual PAH concentrations. The concentrations for the most prevalent PAHs in the background research were used in the risk assessment presented within this paper. Two exposure scenarios were examined using this data: (1) the exposure of a worker applying the coal tar sealcoat for a living and (2) adult exposure to PAH volatilization from the coal-tar sealcoat.

Figure 4. Average PAH Concentrations in Air above Recently Applied Coal-Tar Sealant Over One Year (Van Metre et al., 2012)



3. Methods

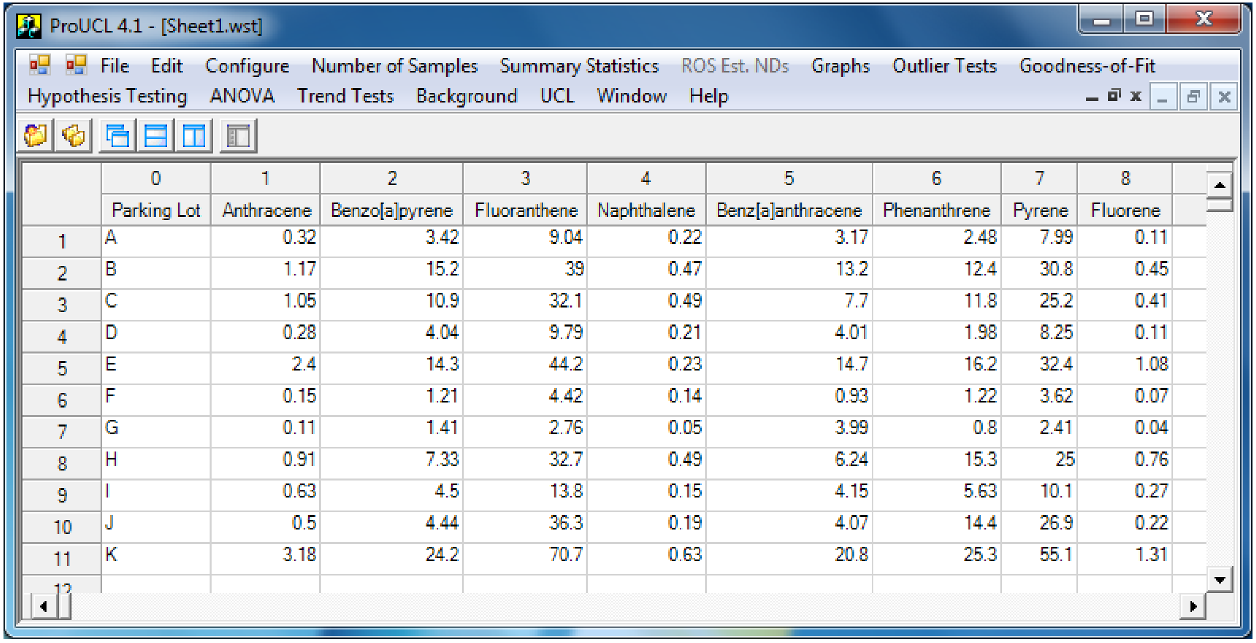
3.1. Estimation of PAH Concentrations in SHD

The upper 95% confidence level (UCL) of the mean exposure concentrations were calculated using EPA's ProUCL statistical software (version 4.1.01) (add footnote for website where downloaded from). The raw settled house dust data from Mahler et al. (2010) was downloaded from the publisher's website into an excel file and adjusted for the desired PAHs in SHD only (i.e., the pavement dust data was not included). This SHD data (Table 4) was imported into the EPA ProUCL program as show in Figure 5. The UCL function was executed (UCL > ALL; Options: UCL=0.95, Bootstrap Operations= 2000) and the output is shown in Appendix B. After the ProUCL software completed various statistical analyses to calculate the 95% upper confidence level, the software then recommended the most ideal value to use. In all instances, the recommended value for the UCL was selected to be used as the exposure point concentration in this assessment, and represents a conservative, upper limit concentration.

Table 4. PAH Concentrations in SHD (Mahler et al 2010)

	PAH Concentration in SHD (µg/g)							
Parking Lot	**ACE**	**BaP**	**FLT**	**NAP**	**BaA**	**PHE**	**PYR**	**FLU**
A	0.32	3.42	9.04	0.22	3.17	2.48	7.99	0.11
B	1.17	15.2	39	0.47	13.2	12.4	30.8	0.45
C	1.05	10.9	32.1	0.49	7.7	11.8	25.2	0.41
D	0.28	4.04	9.79	0.21	4.01	1.98	8.25	0.11
E	2.4	14.3	44.2	0.23	14.7	16.2	32.4	1.08
F	0.15	1.21	4.42	0.14	0.93	1.22	3.62	0.07
G	0.11	1.41	2.76	0.05	3.99	0.8	2.41	0.04
H	0.91	7.33	32.7	0.49	6.24	15.3	25	0.76
I	0.63	4.5	13.8	0.15	4.15	5.63	10.1	0.27
J	0.5	4.44	36.3	0.19	4.07	14.4	26.9	0.22
K	3.18	24.2	70.7	0.63	20.8	25.3	55.1	1.31
95% UCL	1.78	12.18	38.24	0.4	12.25	14.11	29.44	0.824

Figure 5. Input Section of ProUCL



	0	1	2	3	4	5	6	7	8
	Parking Lot	Anthracene	Benzo[a]pyrene	Fluoranthene	Naphthalene	Benz[a]anthracene	Phenanthrene	Pyrene	Fluorene
1	A	0.32	3.42	9.04	0.22	3.17	2.48	7.99	0.11
2	B	1.17	15.2	39	0.47	13.2	12.4	30.8	0.45
3	C	1.05	10.9	32.1	0.49	7.7	11.8	25.2	0.41
4	D	0.28	4.04	9.79	0.21	4.01	1.98	8.25	0.11
5	E	2.4	14.3	44.2	0.23	14.7	16.2	32.4	1.08
6	F	0.15	1.21	4.42	0.14	0.93	1.22	3.62	0.07
7	G	0.11	1.41	2.76	0.05	3.99	0.8	2.41	0.04
8	H	0.91	7.33	32.7	0.49	6.24	15.3	25	0.76
9	I	0.63	4.5	13.8	0.15	4.15	5.63	10.1	0.27
10	J	0.5	4.44	36.3	0.19	4.07	14.4	26.9	0.22
11	K	3.18	24.2	70.7	0.63	20.8	25.3	55.1	1.31

3.1. RPF Calculations

As described in Section 1, RPF values are necessary to relate various PAHs to benzo[a]pyrene because the dose-response data for BaP are well studied and allows for the combining of adverse effects associated with simultaneous exposure to several individual PAHs. Table 2 lists several of the RPF values used in these risk assessment calculation (The remaining can be found in the EPA 2010 document). For both the inhalation exposure scenario and the ingestion exposure scenario, Equation 1 was used to convert the PAH concentrations into its BaP “equivalent” concentration. This process was executed using both the EPA 1993 and EPA 2010 RPF values to compare their respective estimated health risks. The sum of the individual equivalent concentrations was then used as the exposure point concentration (EPC) in the lifetime average daily dose calculations. The extensive list of data used for calculating BaP equivalents using RPF values is included in the various risk assessment sections of this paper.

$$\sum[PAH]_i \times RPF_i \qquad (1)$$

3.2. Calculating the Lifetime Average Daily Dose (LADD)

The lifetime average daily dose was calculated according to Equation 2. The units on the variables are listed in Table 5 and vary depending on the exposure route.

$$LADD = \frac{EPC \times IR \times EF \times ED}{BW \times AT} \qquad (2)$$

Table 5. LADD Parameter Units

Acronym	Definition	PAH Ingestion Units	PAH Inhalation Units
LADD	Lifetime Average Daily Dose	mg/kg-day	mg/kg-day
EPC	Exposure Point Concentration	µg/g	ng/m^3
IR	Ingestion or Inhalation Rate	g/day	m^3/day
EF	Exposure Frequency	Days/year	Days/year
ED	Exposure Duration	Years	Years
BW	Body Weight	kg	kg
AT	Averaging Time	Days	Days

3.3. Calculation the Cancer Risk

The dimensionless cancer risk is calculated by multiplying the LADD by the benzo[a]pyrene slope factor shown in Equation 3. This cancer slope factor as been established by EPA’s Integrated Risk Information System (IRIS) program (IRIS 1987)

$$\text{Cancer Risk} = \text{LADD} \times 7.3\ (\text{mg/kg-day})^{-1} \qquad (3)$$

4. Results and Discussion

4.1. Scenario 1: Ingestion of PAH Laden SHD by Adults

4.1.1. Calculation of Exposure Point Concentrations using RPF Values

The 95% UCL results from ProUCL were input into Equation 1 in order to determine the total BaP equivalents. According to Table 6, the sum of the individual PAH concentrations results in total BaP equivalents. Using the 2010 and 1993 RPF values, the final concentrations were 18.40 µg/g and 13.41 µg/g, respectively. These values are considered the probably exposure point concentrations for the exposure of adults to PAH laden house dust. Although the overall sum of concentrations only differs by approximately 5 µg/g, the use of the 2010 RPF values added in the concentrations of AC and FA whereas they were not present using the 1993 RPF values.

Table 6. Calculation of EPC for Ingestion of SHD

PAH	Average RPF (EPA 2010)	Standard RPF (EPA 1993)	UCL PAH in SHD (µg/g)	PAH in SHD-EPA 2010 RPFs (µg/g)	PAH in SHD-EPA 1993 RPFs (µg/g)
ACE	0.4	N/A	1.78	0.71	~~**0**~~
BaA	0.2	0.1	12.25	2.45	1.225
FLT	0.08	N/A	38.24	3.06	~~**0**~~
PHE	N/A	N/A	14.11	~~**0**~~	~~**0**~~
PYR	N/A	N/A	29.44	~~**0**~~	~~**0**~~
BaP	1	1	12.18	12.18	12.18
FLU	N/A	N/A	0.824	~~**0**~~	~~**0**~~
NAP	N/A	N/A	0.4	~~**0**~~	~~**0**~~
			Total BaP Equivalents (µg/g)	18.40	13.41

4.1.2. Calculation of Cancer and Non-Cancer Risk Related to PAH Laden SHD

The exposure point concentrations calculated in the previous section were placed into Equation 2 in order to determine the LADD, cancer risk, and non-cancer risk. The calculation parameters in Table 7 use the EPA recommended ingestion rate and body weight (cite exposure factors handbook). Cancer risk was computed using the 1993 and 2010 RPF values resulting in a cancer risk of 1.72E-08 and 2.37E-08, respectively.

Table 7. Risk of Cancer from SHD with PAHs

Parameter	EPA 1993 EPC	EPA 2010 EPC	Units
Exposure Point Conc.	0.01	0.02	mg/kg
Ingestion Rate	0.00003	0.00003	kg/day
Exposure Frequency	350	350	days/year
Exposure Duration	30	30	years
Body Weight	70	70	kg
Averaging Time	25550	25550	days
LADD	2.36E-09	3.24E-09	mg/kg-day
Cancer Risk	1.72E-08	2.37E-08	Dimensionless

The cancer risk related to the ingestion of SHD remains low using both RPF methods with a calculated of approximately 1 in 50 million people. This result suggests that the PAH concentration in settled house dust alone will be limited contributor to estimated cancer risks. The non-cancer LADD in Table 8 was calculated using an EPC of 0.11 mg/kg, i.e., the sum of the individual PAH concentrations in Table 6. This EPC is higher than those listed in Table 6 because it takes into account all of the PAHs listed in the table, even those without RPF values. This results in a non-cancer LADD of 1.92E-08 mg/kg-day, which is approximately one order of magnitude greater than the cancer LADD.

Table 8. Calculation of Non-Cancer LADD

Parameter	Total PAH EPC	Units
Exposure Point Concentration	0.11	mg/kg
Ingestion Rate	0.00003	kg/day
Exposure Frequency	350	days/year
Exposure Duration	30	years
Body Weight	70	kg
Averaging Time	25550	days
LADD	1.92E-08	mg/kg-day

4.2. Scenario 2: Adult Inhalation of PAHs from Coal-Tar Sealcoats

4.2.1. *Calculation of EPC for Adult Inhalation of PAHs*

The annual average PAH concentration measured 1.28 meters above a parking lot with new coal tar sealcoat was used to calculate the inhalation risk of PAHs from the sealcoat. The complete data can be found in Appendix A and the annual average PAH concentration is listed along with corresponding RPF values in Table 9. Once again the total BaP equivalents were determined using the 1993 and 2010 RPF values in order to establish an exposure point concentration. Somewhat surprisingly, the EPC calculated using EPA's 2010 RPF value is over 50 times greater than that calculated with EPA's 1993 RPF values. This is largely due to the fact that the updated RPF values include fluoranthene, driven largely by its relatively high concentrations in the breathing zone. An important observation that once again questions the validity and completeness of these risk calculations is the fact that there were 779.87 ng/m^3 of phenanthrene released from the fresh coal tar sealcoat; however, the EPA did not establish RPF values in the 1993 or the 2010 document. Phenanthrene, therefore, could not be included in any cancer risk calculations.

An important factors used in Scenario 2 was the indoor to outdoor PAH concentration. Since the study by Van Metre et al. (2012) only accounts for the ambient air concentration above the freshly coated pavement, the indoor to outdoor PAH ratio of 0.89 was used (Naumova 2002) and assumes a uniform and limited removal/decay of the individual PAHS as they enter indoor built environments.

Table 9. EPC Calculation for PAH Inhalation by Adults

PAH	Average RPF (EPA 2010)	Standard RPF (EPA 1993)	Annual Average PAH (ng/m^3)	PAHs in Air- EPA 2010 RPFs (ng/m^3)	PAHs in Air- EPA 1993 RPFs (ng/m^3)
ACE	0		93.63	**~~0~~**	**~~0~~**
BaA	0.2	0.1	1.53	0.31	0.15
BbFA	0.8	0.1	0.50	0.40	0.05
BkFA	0.03	0.01	0.40	0.01	4.04E-03
CHR	0.1	0.001	2.82	0.28	2.82E-03
FLU	0.08		136.99	10.96	**~~0~~**
PHE	0		779.87	**~~0~~**	**~~0~~**
PYR	0		71.07	**~~0~~**	**~~0~~**
Total BaP Equivalents (ng/m^3)				11.99	0.21

4.2.2. *Calculation of Cancer and Non-Cancer Risk of PAH Inhalation*

Table 10 demonstrates that the EPC, LADD, and cancer risk are all approximately two orders of magnitude greater when using the EPA 2010 RPF values. Using these values, the cancer risk involved with PAH inhalation to adults is 1.20E-5. Simply put, the risk of developing cancer from the PAH coal-tar sealant in air is 1 in 100,000 based on these calculation parameters.

Table 10. Risk of cancer from PAH Inhalation by Adults

Parameter	EPA 1993 EPC	EPA 2010 EPC	Units
Exposure Point Conc.	2.10E-07	1.20E-05	mg/m^3
Inhalation Rate	20	20	m^3/day
Exposure Frequency	350	350	days/year
Exposure Duration	35	35	years
Body Weight	70	70	kg
Averaging Time	25550	25550	days
LADD	2.87E-08	1.64E-06	mg/kg-day
Cancer Risk	2.10E-07	1.20E-05	Dimensionless

Table 11 describes the calculation of non-cancer risk for adult inhalation of PAHs using the top 8 commonly detected PAHs (see Appendix A) as the EPC. As stated previously, the non-cancer LADD allows for the inclusion of phenanthrene, the PAH with the highest average annual concentration in air above coal-tar sealed parking lots. The cancer LADD calculation resulted in a lifetime average BaP equivalent dose of 2.87E-08 mg/kg-day (EPA 1993 RPFs) and 1.64E-06 mg/kg-day (EPA 2010 RPFs) whereas the non-cancer LADD T-PAH dose was estimated to be 1.75E-04 mg/kg-day.

Table 11. Non-cancer LADD calculation for PAH inhalation by Adults

Parameter	Top 8 PAH EPC	Units
Exposure Point Concentration	1.28E-03	mg/m^3
Inhalation Rate	20	m^3/day
Exposure Frequency	350	days/year
Exposure Duration	35	years
Body Weight	70	kg
Averaging Time	25550	days
LADD	1.75E-04	mg/kg-day

4.3. Scenario 3: Adult Worker Inhalation of PAHs from Coal-Tar Sealcoats

4.3.1. Calculation of EPC for Worker Inhalation of PAHs

This scenario focused on a potential workers exposure to volatile exposure on a daily basis. The same data set that was used in Scenario 2 was applied to this scenario as well; however, the average *daily* PAH concentration was used instead of the average *annual* PAH concentration. Therefore, in Appendix A, the PAH concentration in air was used to calculate the EPC in was used to calculate the EPC in Table 12. Once again, even though 4,330 ng/m^3 of phenanthrene were present during the initial coal-tar sealcoat application process, the concentration was not used to derive the EPC for estimating cancer risk due to the lack of an RPF value. In Scenario 2, the indoor to outdoor PAH ratio was not used since the worker was assumed entirely outside while applying the sealcoat. The EPC concentration using 2010 RPF values was about 70 times greater than the EPC concentration derived using the 1993 EPA RPFs. Furthermore, the exposure of a worker was 33.17 ng/m^3, almost three times that estimated for a typical adult.

Table 12. EPC Calculation for PAH Inhalation by Adult Workers

PAH	Average RPF (EPA 2010)	Standard RPF (EPA 1993)	Average Daily PAHs (ng/m^3)	PAHs in Air- EPA 2010 RPFs (ng/m^3)	PAHs in Air- EPA 1993 RPFs (ng/m^3)
ACE	0		499.00	~~0~~	~~0~~
BaA	0.2	0.1	3.80	0.76	0.38
BbFA	0.8	0.1	0.86	0.69	0.09
BkFA	0.03	0.01	0.34	0.01	3.40E-03
CHR	0.1	0.001	3.30	0.33	3.30E-03
FLU	0.08		392.00	31.36	~~0~~
PHE	0		4,330.00	~~0~~	~~0~~
PYR	0		208.00	~~0~~	~~0~~
Total BaP Equivalents (ng/m^3)				33.17	0.47

4.3.2. *Calculation of Cancer and Non-Cancer Risk of PAH Inhalation*

Adhering to the observation from Scenario 2, the EPC, LADD, and cancer risk in Table 13 are all two orders of magnitude greater using the EPA 2010 RPFs. The cancer risk for a worker of 2.37E-05 is the highest out of all three scenarios. Once again, when comparing the two calculation methods, the estimated risk associated with the 1993 method is not above typical risk levels of concern (i.e., 1E-05 to 1E-06). The non-cancer LADD in Table 14 estimated to be 5.56E-04. Again, this included the top 8 most common PAHs found in Van Metre's study.

Table 13. Risk of cancer from PAH Inhalation by Adult Workers

Parameter	EPA 1993 EPC	EPA 2010 EPC	Units
Exposure Point Conc.	4.73E-07	3.32E-05	mg/m^3
Inhalation Rate	20	20	m^3/day
Exposure Frequency	250	250	days/year
Exposure Duration	35	35	years
Body Weight	70	70	kg
Averaging Time	25550	25550	days
LADD	4.63E-08	3.25E-06	mg/kg-day
Cancer Risk	3.38E-07	2.37E-05	Dimensionless

Table 14. Non-cancer LADD calculation for PAH inhalation by Adult Workers

Parameter	Top 8 PAH EPC	Units
Exposure Point Concentration	5.68E-03	mg/m^3
Inhalation Rate	20	m^3/day
Exposure Frequency	250	days/year
Exposure Duration	35	years
Body Weight	70	kg
Averaging Time	25550	days
LADD	5.56E-04	mg/kg-day

4.4. Uncertainty

All of the calculations in Scenarios 1 through 3 are dependent on the variable input. For example, one could speculate on whether or not the average body weight of an adult is actually 70 kg in the year 2012. Furthermore, the “standard” inhalation and ingestion rates were used in the scenarios, but as EPA’s Exposure Factors Handbook shows, these rates vary depending on age, weight, sex, and activity level. Another discrepancy might be the exposure frequency and exposure duration values. Although the body weight and inhalation/ingestion rates are considered “standard”, exposure length is dependent on the analyst’s discretion.

Another considerable uncertainty is the fact that the data presented typically represents the upper limit of exposure. Finally, this assessment does not take into account other various PAH sources (vehicle exhaust, tobacco smoke, or other combustion processes) or various other sources and routes of exposure that are certain to modify the EPC values.

5. Conclusions

The results of the HHRA indicate that parking lots with PAH laden coal-tar sealcoats are of concern to certain groups depending on the scenario and computation method (Table 15). Although the SHD scenario indicated no cause for immediate alarm, the ability of PAHs to adhere to dust and then enter the household is worthy of attention. Scenario 3 resulted in the highest EPC, LADD, non-cancer risk, and cancer risk indicates that a worker applying coal-tar sealcoat over a lifetime is exposed to high levels of PAHs. Furthermore, the importance of estimating appropriate PAH relative potency factors were amplified based on the various risk comparisons. The EPA has yet to establish RPF values for all PAHs resulting in the exclusion possible harmful compounds. Furthermore, if the EPA was to move from the standard 1993 RPF values to the newer 2010 average RPF values, the change of exposure point concentration computations could result in major differences in estimated risk as confirmed by Scenarios 2 and 3. Overall, the PAH concentrations in coal-tar sealcoat provide an additional PAH exposure route that when combined with other PAH sources, might increase the potential risk of cancer. This initial analysis of the data lends additional support to those public policy entities that are concerned with possible adverse health effects related to coal-tar sealcoat.

Table 15. Summary of HHRA

	EPA 1993 RPF Values			**EPA 2010 Average RPF Values**			**No RPF**
Scenario	**EPC**	**LADD (mg/kg-day)**	**Cancer Risk**	**EPC**	**LADD (mg/kg-day)**	**Cancer Risk**	**Non-Cancer Risk (mg/kg-day)**
1	0.01 mg/kg	2.36E-09	1.72E-08	0.02 mg/kg	3.24E-09	2.37E-08	1.92E-08
2	2.10E-07 mg/m^3	2.87E-08	2.10E-07	1.20E-05 mg/m^3	1.64E-06	1.20E-05	1.75E-04
3	4.73E-07 mg/m^3	4.63E-08 mg/kg-day	3.38E-07	3.32E-05 mg/m^3	3.25E-06 mg/kg-day	2.37E-05	5.56E-04

References

ASTDR. Toxicological Profile for Polycyclic Aromatic Hydrocarbons (1995).

Hawthorne, Michael. “New Doubts Cast on Safety of Common Driveway Sealant. ” *Chicago Tribune* (January 18, 2011).

Integrated Risk Information System (IRIS). “Benzo[a]pyrene.” (1987).

Mahler, Barbara J., Peter C. Van Metre, Jennifer T. Wilson, MaryLynn Musgrove, Teresa L. Burbank, Thomas E. Ennis, and Thomas J. Bashara. "Coal-Tar-Based Parking Lot Sealcoat: An Unrecognized Source of PAH to Settled House Dust." *Environmental Science & Technology* 44.3 (2010): 894-900.

Mahler, Barbara, Peter C. Van Metre, Judy L. Crane, Alison W. Watts, Mateo Scoggins, and E. Spencer Williams. “Coal-Tar-Based Pavement Sealcoat and PAHs: Implications for the Environment, Human Health, and Stormwater Management”. *Environmental Science & Technology* 46.6 (2012): 3039-3045.

Naumova, Yelena Y., Steven J. Eisenreich, Barbara J. Turpin, Clifford P. Weisel, Maria T. Morandi, Steven D. Colome, Lisa A. Totten, Thomas H. Stock, Arthur M. Winer, Shahnaz Alimokhtari, Jaymin Kwon, Derek Shendell, Jennifer Jones, Silvia Maberti, and Steven J. Wall. "Polycyclic Aromatic Hydrocarbons in the Indoor and Outdoor Air of Three Cities in the U.S." *Environmental Science & Technology* 36.12 (2002): 2552-559.

U.S. EPA. Risk Assessment Guidance for Superfunds (1989). EPA/540/1-89/002.

U.S. EPA. Provisional Guidance for Quantitative Risk Assessment of Polycyclic Aromatic Hydrocarbons (1993).

U.S. EPA. Polycyclic Aromatic Hydrocarbons Factsheet (2008).

U.S. EPA. Development of a Relative Potency Factor (RPF) Approach for Polycyclic Aromatic Hydrocarbon Mixtures (2010). EPA/635/R-08/012A.

Van Metre, Peter, Barbara Mahler, Mateo Scoggins, and Pixie Hamiltion. “Parking Lot Sealcoat: A Major Source of PAHs in Urban and Suburban Enviornments.” USGS Factsheet 2005-3147 (2006).

Van Metre, Peter C., Michael S. Majewski, Barbara J. Mahler, William T. Foreman, Christopher L. Braun, Jennifer T. Wilson, Teresa L. Burbank, “Volatilization of polycyclic aromatic hydrocarbons from coal-tar-sealed pavement”, *Chemosphere* (2012): 1-7.

Van Metre, Peter C., Michael S. Majewski, Barbara J. Mahler, William T. Foreman, Christopher L. Braun, Jennifer T. Wilson, Teresa L. Burbank, "PAH Volatilization Following Application of Coal-tar-based pavement sealant," *Atmospheric Environment* (2012b): 108-115.

APPENDICES

Appendix A: PAHs in Air Above Sealant Data (Partial List)

Concentration of PAHs in air 1.28 meters above the surface of recently applied coal-tar-based pavement Sealant. All units are in ng/m^3. (Partial Data List from Van Metre et al. 2012b)

Sample name	Sample date	Time after sealant application (d)	Phenanthrene	Anthracene	Fluoranthene	Pyrene	Benz[*a*]-anthracene	Chrysene	Benzo[*b*]-fluoranthene	Benzo[*k*]-fluoranthene	Total 8 PAH
PIC.1-1.28 m	9/16/09	0.08	4,330	499	392	208	3.8	3.3	0.9	0.3	5,680
PIC.2-1.28 m	9/17/09	1.1	1,590	170	214	113	1.6	2.0	0.2	*0.5*	2,190
PIC.3-1.28 m	9/21/09	5	1,860	324	401	219	4.9	6.9	0.5	*0.5*	2,980
PIC.4-1.28 Average	10/2/09	16	526.5	50.1	136	62.75	*0.5*	*0.5*	*0.5*	*0.5*	821
PIC.5-1.28 m	10/31/09	45	36.8	2	12.2	5.9	*0.5*	*0.5*	*0.5*	*0.5*	60.0
PIC.6-1.28 m	2/12/10	149	20.7	1.96	3.4	1.7	*0.5*	*0.5*	*0.5*	*0.5*	27.8
PIC.7-1.28 m	5/6/10	232	77	3.84	48.3	24.7	*0.5*	1.64	0.18	*0.5*	165
PIC.8-1.28 m	8/10/10	328	122	5.16	188	108	2.64	12.5	1.3	0.25	462
PIC.9-1.28 m	9/27/10	376	22.8	1.01	26.2	9.88	*0.5*	0.7	*0.5*	*0.5*	63.8
		Average	780	94	137	71	2	3	1	0	

Appendix B: ProUCL Results

Anthracene			
General Statistics			
Number of Valid Observations	11	Number of Distinct Observations	11
Raw Statistics		Log-transformed Statistics	
Minimum	0.11	Minimum of Log Data	-2.207
Maximum	3.18	Maximum of Log Data	1.157
Mean	0.973	Mean of log Data	-0.503
Geometric Mean	0.605	SD of log Data	1.07
Median	0.63		
SD	0.981		
Std. Error of Mean	0.296		
Coefficient of Variation	1.009		
Skewness	1.516		
Relevant UCL Statistics			
Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.814	Shapiro Wilk Test Statistic	0.973
Shapiro Wilk Critical Value	0.85	Shapiro Wilk Critical Value	0.85
Data not Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	
Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	1.509	95% H-UCL	3.096
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	2.489
95% Adjusted-CLT UCL (Chen-1995)	1.604	97.5% Chebyshev (MVUE) UCL	3.134
95% Modified-t UCL (Johnson-1978)	1.531	99% Chebyshev (MVUE) UCL	4.402
Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.927	Data appear Gamma Distributed at 5% Significance Level	
Theta Star	1.049		
MLE of Mean	0.973		
MLE of Standard Deviation	1.01		
nu star	20.4		
Approximate Chi Square Value (.05)	11.15	Nonparametric Statistics	
Adjusted Level of Significance	0.0278	95% CLT UCL	1.459
Adjusted Chi Square Value	10.05	95% Jackknife UCL	1.509
		95% Standard Bootstrap UCL	1.44
Anderson-Darling Test Statistic	0.228	95% Bootstrap-t UCL	2.033
Anderson-Darling 5% Critical Value	0.748	95% Hall's Bootstrap UCL	4.227
Kolmogorov-Smirnov Test Statistic	0.122	95% Percentile Bootstrap UCL	1.472
Kolmogorov-Smirnov 5% Critical Value	0.261	95% BCA Bootstrap UCL	1.63
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	2.262
		97.5% Chebyshev(Mean, Sd) UCL	2.82
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	3.916
95% Approximate Gamma UCL (Use when n >= 40)	1.78		
95% Adjusted Gamma UCL (Use when n < 40)	1.975		
Potential UCL to Use		Use 95% Approximate Gamma UCL	1.78
Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.			
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)			
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.			

Benzo[a]pyrene			
General Statistics			
Number of Valid Observations	11	Number of Distinct Observations	11
Raw Statistics		Log-transformed Statistics	
Minimum	1.21	Minimum of Log Data	0.191
Maximum	24.2	Maximum of Log Data	3.186
Mean	8.268	Mean of log Data	1.737
Geometric Mean	5.678	SD of log Data	0.961
Median	4.5		
SD	7.163		
Std. Error of Mean	2.16		
Coefficient of Variation	0.866		
Skewness	1.21		
Relevant UCL Statistics			
Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.867	Shapiro Wilk Test Statistic	0.953
Shapiro Wilk Critical Value	0.85	Shapiro Wilk Critical Value	0.85
Data appear Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	
Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	12.18	95% H-UCL	21.9
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	19.9
95% Adjusted-CLT UCL (Chen-1995)	12.66	97.5% Chebyshev (MVUE) UCL	24.82
95% Modified-t UCL (Johnson-1978)	12.31	99% Chebyshev (MVUE) UCL	34.49
Gamma Distribution Test		Data Distribution	
k star (bias corrected)	1.134	Data appear Normal at 5% Significance Level	
Theta Star	7.294		
MLE of Mean	8.268		
MLE of Standard Deviation	7.766		
nu star	24.94		
Approximate Chi Square Value (.05)	14.56	Nonparametric Statistics	
Adjusted Level of Significance	0.0278	95% CLT UCL	11.82
Adjusted Chi Square Value	13.29	95% Jackknife UCL	12.18
		95% Standard Bootstrap UCL	11.59
Anderson-Darling Test Statistic	0.279	95% Bootstrap-t UCL	13.75
Anderson-Darling 5% Critical Value	0.743	95% Hall's Bootstrap UCL	12.63
Kolmogorov-Smirnov Test Statistic	0.194	95% Percentile Bootstrap UCL	11.77
Kolmogorov-Smirnov 5% Critical Value	0.26	95% BCA Bootstrap UCL	12.48
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	17.68
		97.5% Chebyshev(Mean, Sd) UCL	21.76
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	29.76
95% Approximate Gamma UCL (Use when n >= 40)	14.16		
95% Adjusted Gamma UCL (Use when n < 40)	15.52		
Potential UCL to Use		Use 95% Student's-t UCL	12.18
Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.			
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)			
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.			

Fluoranthene			
General Statistics			
Number of Valid Observations	11	Number of Distinct Observations	11
Raw Statistics		Log-transformed Statistics	
Minimum	2.76	Minimum of Log Data	1.015
Maximum	70.7	Maximum of Log Data	4.258
Mean	26.8	Mean of log Data	2.897
Geometric Mean	18.12	SD of log Data	1.042
Median	32.1		
SD	20.94		
Std. Error of Mean	6.313		
Coefficient of Variation	0.781		
Skewness	0.733		
Relevant UCL Statistics			
Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.908	Shapiro Wilk Test Statistic	0.918
Shapiro Wilk Critical Value	0.85	Shapiro Wilk Critical Value	0.85
Data appear Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	
Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	38.24	95% H-UCL	86.08
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	71.55
95% Adjusted-CLT UCL (Chen-1995)	38.68	97.5% Chebyshev (MVUE) UCL	89.9
95% Modified-t UCL (Johnson-1978)	38.48	99% Chebyshev (MVUE) UCL	125.9
Gamma Distribution Test		Data Distribution	
k star (bias corrected)	1.094	Data appear Normal at 5% Significance Level	
Theta Star	24.49		
MLE of Mean	26.8		
MLE of Standard Deviation	25.62		
nu star	24.07		
Approximate Chi Square Value (.05)	13.9	Nonparametric Statistics	
Adjusted Level of Significance	0.0278	95% CLT UCL	37.19
Adjusted Chi Square Value	12.66	95% Jackknife UCL	38.24
		95% Standard Bootstrap UCL	36.51
Anderson-Darling Test Statistic	0.403	95% Bootstrap-t UCL	39.88
Anderson-Darling 5% Critical Value	0.744	95% Hall's Bootstrap UCL	39.76
Kolmogorov-Smirnov Test Statistic	0.237	95% Percentile Bootstrap UCL	37.01
Kolmogorov-Smirnov 5% Critical Value	0.26	95% BCA Bootstrap UCL	38.48
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	54.32
		97.5% Chebyshev(Mean, Sd) UCL	66.23
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	89.62
95% Approximate Gamma UCL (Use when n >= 40)	46.4		
95% Adjusted Gamma UCL (Use when n < 40)	50.96		
Potential UCL to Use		Use 95% Student's-t UCL	38.24
Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.			
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)			
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.			

Naphthalene			
General Statistics			
Number of Valid Observations	11	Number of Distinct Observations	10
Raw Statistics		Log-transformed Statistics	
Minimum	0.05	Minimum of Log Data	-2.996
Maximum	0.63	Maximum of Log Data	-0.462
Mean	0.297	Mean of log Data	-1.428
Geometric Mean	0.24	SD of log Data	0.739
Median	0.22		
SD	0.188		
Std. Error of Mean	0.0566		
Coefficient of Variation	0.631		
Skewness	0.582		
Relevant UCL Statistics			
Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.888	Shapiro Wilk Test Statistic	0.918
Shapiro Wilk Critical Value	0.85	Shapiro Wilk Critical Value	0.85
Data appear Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	
Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	0.4	95% H-UCL	0.569
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	0.614
95% Adjusted-CLT UCL (Chen-1995)	0.401	97.5% Chebyshev (MVUE) UCL	0.748
95% Modified-t UCL (Johnson-1978)	0.401	99% Chebyshev (MVUE) UCL	1.01
Gamma Distribution Test		Data Distribution	
k star (bias corrected)	1.865	Data appear Normal at 5% Significance Level	
Theta Star	0.159		
MLE of Mean	0.297		
MLE of Standard Deviation	0.218		
nu star	41.03		
Approximate Chi Square Value (.05)	27.35	Nonparametric Statistics	
Adjusted Level of Significance	0.0278	95% CLT UCL	0.39
Adjusted Chi Square Value	25.54	95% Jackknife UCL	0.4
		95% Standard Bootstrap UCL	0.387
Anderson-Darling Test Statistic	0.455	95% Bootstrap-t UCL	0.418
Anderson-Darling 5% Critical Value	0.736	95% Hall's Bootstrap UCL	0.381
Kolmogorov-Smirnov Test Statistic	0.204	95% Percentile Bootstrap UCL	0.388
Kolmogorov-Smirnov 5% Critical Value	0.258	95% BCA Bootstrap UCL	0.399
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	0.544
		97.5% Chebyshev(Mean, Sd) UCL	0.651
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	0.86
95% Approximate Gamma UCL (Use when n >= 40)	0.446		
95% Adjusted Gamma UCL (Use when n < 40)	0.478		
Potential UCL to Use		Use 95% Student's-t UCL	0.4
Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.			
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)			
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.			

Benz[a]anthracene			
General Statistics			
Number of Valid Observations	11	Number of Distinct Observations	11
Raw Statistics		Log-transformed Statistics	
Minimum	0.93	Minimum of Log Data	-0.0726
Maximum	20.8	Maximum of Log Data	3.035
Mean	7.542	Mean of log Data	1.714
Geometric Mean	5.552	SD of log Data	0.864
Median	4.15		
SD	6.101		
Std. Error of Mean	1.84		
Coefficient of Variation	0.809		
Skewness	1.256		
Relevant UCL Statistics			
Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.843	Shapiro Wilk Test Statistic	0.935
Shapiro Wilk Critical Value	0.85	Shapiro Wilk Critical Value	0.85
Data not Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	
Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	10.88	95% H-UCL	17.07
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	16.94
95% Adjusted-CLT UCL (Chen-1995)	11.31	97.5% Chebyshev (MVUE) UCL	20.92
95% Modified-t UCL (Johnson-1978)	10.99	99% Chebyshev (MVUE) UCL	28.75
Gamma Distribution Test		Data Distribution	
k star (bias corrected)	1.356	Data appear Gamma Distributed at 5% Significance Level	
Theta Star	5.563		
MLE of Mean	7.542		
MLE of Standard Deviation	6.477		
nu star	29.83		
Approximate Chi Square Value (.05)	18.36	Nonparametric Statistics	
Adjusted Level of Significance	0.0278	95% CLT UCL	10.57
Adjusted Chi Square Value	16.9	95% Jackknife UCL	10.88
		95% Standard Bootstrap UCL	10.44
Anderson-Darling Test Statistic	0.451	95% Bootstrap-t UCL	12.42
Anderson-Darling 5% Critical Value	0.74	95% Hall's Bootstrap UCL	11.28
Kolmogorov-Smirnov Test Statistic	0.224	95% Percentile Bootstrap UCL	10.67
Kolmogorov-Smirnov 5% Critical Value	0.259	95% BCA Bootstrap UCL	11.21
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	15.56
		97.5% Chebyshev(Mean, Sd) UCL	19.03
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	25.85
95% Approximate Gamma UCL (Use when n >= 40)	12.25		
95% Adjusted Gamma UCL (Use when n < 40)	13.31		
Potential UCL to Use		Use 95% Approximate Gamma UCL	12.25
Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.			
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)			
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.			

Phenanthrene			
General Statistics			
Number of Valid Observations	11	Number of Distinct Observations	11
Raw Statistics		Log-transformed Statistics	
Minimum	0.8	Minimum of Log Data	-0.223
Maximum	25.3	Maximum of Log Data	3.231
Mean	9.774	Mean of log Data	1.79
Geometric Mean	5.99	SD of log Data	1.196
Median	11.8		
SD	7.938		
Std. Error of Mean	2.393		
Coefficient of Variation	0.812		
Skewness	0.494		
Relevant UCL Statistics			
Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.904	Shapiro Wilk Test Statistic	0.887
Shapiro Wilk Critical Value	0.85	Shapiro Wilk Critical Value	0.85
Data appear Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	
Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	14.11	95% H-UCL	44.06
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	29.82
95% Adjusted-CLT UCL (Chen-1995)	14.09	97.5% Chebyshev (MVUE) UCL	37.91
95% Modified-t UCL (Johnson-1978)	14.17	99% Chebyshev (MVUE) UCL	53.8
Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.904	Data appear Normal at 5% Significance Level	
Theta Star	10.81		
MLE of Mean	9.774		
MLE of Standard Deviation	10.28		
nu star	19.89		
Approximate Chi Square Value (.05)	10.77	Nonparametric Statistics	
Adjusted Level of Significance	0.0278	95% CLT UCL	13.71
Adjusted Chi Square Value	9.692	95% Jackknife UCL	14.11
		95% Standard Bootstrap UCL	13.59
Anderson-Darling Test Statistic	0.539	95% Bootstrap-t UCL	14.31
Anderson-Darling 5% Critical Value	0.749	95% Hall's Bootstrap UCL	14.12
Kolmogorov-Smirnov Test Statistic	0.243	95% Percentile Bootstrap UCL	13.6
Kolmogorov-Smirnov 5% Critical Value	0.262	95% BCA Bootstrap UCL	13.84
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	20.21
		97.5% Chebyshev(Mean, Sd) UCL	24.72
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	33.59
95% Approximate Gamma UCL (Use when n >= 40)	18.05		
95% Adjusted Gamma UCL (Use when n < 40)	20.06		
Potential UCL to Use		Use 95% Student's-t UCL	14.11
Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.			
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)			
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.			

Pyrene			
General Statistics			
Number of Valid Observations	11	Number of Distinct Observations	11
Raw Statistics		Log-transformed Statistics	
Minimum	2.41	Minimum of Log Data	0.88
Maximum	55.1	Maximum of Log Data	4.009
Mean	20.71	Mean of log Data	2.665
Geometric Mean	14.37	SD of log Data	0.996
Median	25		
SD	15.98		
Std. Error of Mean	4.819		
Coefficient of Variation	0.772		
Skewness	0.821		
Relevant UCL Statistics			
Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.899	Shapiro Wilk Test Statistic	0.917
Shapiro Wilk Critical Value	0.85	Shapiro Wilk Critical Value	0.85
Data appear Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	
Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	29.44	95% H-UCL	60.61
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	53.05
95% Adjusted-CLT UCL (Chen-1995)	29.91	97.5% Chebyshev (MVUE) UCL	66.39
95% Modified-t UCL (Johnson-1978)	29.64	99% Chebyshev (MVUE) UCL	92.6
Gamma Distribution Test		Data Distribution	
k star (bias corrected)	1.162	Data appear Normal at 5% Significance Level	
Theta Star	17.81		
MLE of Mean	20.71		
MLE of Standard Deviation	19.21		
nu star	25.57		
Approximate Chi Square Value (.05)	15.05	Nonparametric Statistics	
Adjusted Level of Significance	0.0278	95% CLT UCL	28.63
Adjusted Chi Square Value	13.75	95% Jackknife UCL	29.44
		95% Standard Bootstrap UCL	28.35
Anderson-Darling Test Statistic	0.426	95% Bootstrap-t UCL	30.21
Anderson-Darling 5% Critical Value	0.742	95% Hall's Bootstrap UCL	30.88
Kolmogorov-Smirnov Test Statistic	0.24	95% Percentile Bootstrap UCL	28.62
Kolmogorov-Smirnov 5% Critical Value	0.26	95% BCA Bootstrap UCL	29.58
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	41.71
		97.5% Chebyshev(Mean, Sd) UCL	50.8
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	68.66
95% Approximate Gamma UCL (Use when n >= 40)	35.18		
95% Adjusted Gamma UCL (Use when n < 40)	38.51		
Potential UCL to Use		Use 95% Student's-t UCL	29.44
Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.			
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)			
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.			

Fluorene			
General Statistics			
Number of Valid Observations	11	Number of Distinct Observations	10
Raw Statistics		Log-transformed Statistics	
Minimum	0.04	Minimum of Log Data	-3.219
Maximum	1.31	Maximum of Log Data	0.27
Mean	0.439	Mean of log Data	-1.339
Geometric Mean	0.262	SD of log Data	1.142
Median	0.27		
SD	0.431		
Std. Error of Mean	0.13		
Coefficient of Variation	0.983		
Skewness	1.151		
Relevant UCL Statistics			
Normal Distribution Test		Lognormal Distribution Test	
Shapiro Wilk Test Statistic	0.846	Shapiro Wilk Test Statistic	0.963
Shapiro Wilk Critical Value	0.85	Shapiro Wilk Critical Value	0.85
Data not Normal at 5% Significance Level		Data appear Lognormal at 5% Significance Level	
Assuming Normal Distribution		Assuming Lognormal Distribution	
95% Student's-t UCL	0.675	95% H-UCL	1.641
95% UCLs (Adjusted for Skewness)		95% Chebyshev (MVUE) UCL	1.201
95% Adjusted-CLT UCL (Chen-1995)	0.701	97.5% Chebyshev (MVUE) UCL	1.521
95% Modified-t UCL (Johnson-1978)	0.682	99% Chebyshev (MVUE) UCL	2.15
Gamma Distribution Test		Data Distribution	
k star (bias corrected)	0.864	Data appear Gamma Distributed at 5% Significance Level	
Theta Star	0.508		
MLE of Mean	0.439		
MLE of Standard Deviation	0.472		
nu star	19.02		
Approximate Chi Square Value (.05)	10.13	Nonparametric Statistics	
Adjusted Level of Significance	0.0278	95% CLT UCL	0.653
Adjusted Chi Square Value	9.089	95% Jackknife UCL	0.675
		95% Standard Bootstrap UCL	0.643
Anderson-Darling Test Statistic	0.249	95% Bootstrap-t UCL	0.807
Anderson-Darling 5% Critical Value	0.75	95% Hall's Bootstrap UCL	0.763
Kolmogorov-Smirnov Test Statistic	0.164	95% Percentile Bootstrap UCL	0.657
Kolmogorov-Smirnov 5% Critical Value	0.262	95% BCA Bootstrap UCL	0.697
Data appear Gamma Distributed at 5% Significance Level		95% Chebyshev(Mean, Sd) UCL	1.006
		97.5% Chebyshev(Mean, Sd) UCL	1.252
Assuming Gamma Distribution		99% Chebyshev(Mean, Sd) UCL	1.734
95% Approximate Gamma UCL (Use when n >= 40)	0.824		
95% Adjusted Gamma UCL (Use when n < 40)	0.919		
Potential UCL to Use		Use 95% Approximate Gamma UCL	0.824
Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.			
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)			
and Singh and Singh (2003). For additional insight, the user may want to consult a statistician.			