CPSC Staff Statement on the

Toxicology Excellence for Risk Assessment Report,

"Flame Retardant Exposure Assessment"

September 28, 2016

The report, *Flame Retardant Exposure Assessment*, presents the findings of research and analysis conducted by Toxicology Excellence for Risk Assessment (TERA), in conjunction with the LifeLine Group, under a contract with the U.S. Consumer Product Safety Commission (CPSC). TERA performed this work to estimate human exposure to nine selected flame retardant chemicals.

The selected flame retardants are:

- Tris(1,3-dichloro-2-propyl) phosphate (TDCPP)
- Tris(chloropropyl) phosphate, mixture of isomers (TCPP)
- Tris(2-chloroethyl) phosphate (TCEP)
- Triethyl phosphate (TEP)
- Triphenyl phosphate (TPP)
- 2-Ethylhexyl 2,3,4,5-tetrabromobenzoate (TBB)
- Di(2-ethylhexyl) tetrabromophthalate (TBPH)
- Tetrabromobisphenol A (TBBPA)
- Antimony trioxide (ATO)

TERA developed an approach for the exposure assessment to use available data and developed estimates of human exposure for the exposure scenarios, including home, office, child care center, and car. The focus of the work was on indoor sources, such as indoor air and household

dust. The report includes discussion and documentation for the exposure data used, assumptions, uncertainties, and limitations.

This research was completed in support of CPSC staff's work on flame retardant chemicals to assess potential for exposure from household products, and to prioritize work on specific products and chemicals.

This report will be posted on CPSC's website to keep stakeholders informed of the progress of technical research related to the agency's regulatory activities.

TERA

INDEPENDENT
NON-PROFIT
SCIENCE
FOR PUBLIC HEALTH
PROTECTION

Flame Retardant Exposure Assessment

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Final Report

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Abbreviations and Acronyms

ARG	Activity Record Generator™
ATO	Antimony trioxide
CASRN	Chemical Abstract Service Registry Number
CBAS	Computer-Based Assessment Software™
CPSC	U.S. Consumer Product Safety Commission
ECNI	Electron capture negative ionization
EFH	Exposure Factors Handbook
EPA	U.S. Environmental Protection Agency
FD	Fresh dust
GC-MS	Gas chromatography–mass spectrometry
GM	Geometric mean
GSD	Geometric standard deviation
HD	Household dust
HVS3	High-volume surface sampler
LLG	LifeLine Group
LOD	Limit of detection
LWW	Lioy-Weisel-Wainman
Max	maximum
MDL	Method detection limit
Min	minimum
PM	Particulate matter
SD	Standard deviation
SVOCs	Semi-Volatile Organic Compounds
TBB	2-ethylhexyl-2,3,4,5-tetrabromobenzoate
TBBPA	Tetrabromobisphenol A
TBPH	Bis(2-ethylhexyl)2,3,4,5-tetrabromophthalate
TCEP	Tris(2-chloroethyl) phosphate
TCPP	Tris(chloropropyl) phosphate
TDCPP	Tris(1,3-dichloro-2-propyl) phosphate
TEP	Triethyl phosphate
TPP	Triphenyl phosphate
TERA	Toxicology Excellence for Risk Assessment
WHO	World Health Organization

1 Introduction

Toxicology Excellence for Risk Assessment (TERA) was tasked by the U.S. Consumer Product Safety Commission (CPSC) to estimate human exposure to nine selected flame retardant chemicals. TERA, in conjunction with the LifeLine Group (LLG), developed an approach for the exposure assessment to utilize available data and develop estimates of human exposure for the exposure scenarios selected by CPSC including home, office, child care center, and car. The focus is on indoor sources, such as indoor air and household dust. This report includes discussion and documentation for the exposure data utilized, assumptions, uncertainties, and limitations.

Flame retardants are chemicals that are added to natural and synthetic materials to improve their resistance to ignition or reduce flame spread after ignition occurs (WHO, 1998). They are used in a variety of consumer products including upholstered furniture, mattresses, appliances, electronics, and apparel. Flame retardants have been detected in ambient and indoor air, surface and groundwater, food, house dust, and consumer products. They have also been found in human tissues and in body fluids. Flame retardants have been under scrutiny due to their health effects in animal studies, which include reproductive and developmental toxicity, chronic organ toxicity, and cancer.

Many flame retardant chemicals are semi-volatile organic compounds (SVOCs), and they are found in indoor air, especially in the particulate phase, and in household dust (Weschler and Nazaroff, 2008, 2010). Incidental ingestion of household dust is believed to be a major source of human exposure to flame retardant chemicals (Johnson et al., 2013; Lorber, 2008; Meeker and Stapleton, 2010; Stapleton et al., 2009). In the residential environment, SVOCs measured in indoor air and household dust are believed to be, at least in part, from products in CPSC's jurisdiction.

The objective of this task was to perform an exposure assessment to estimate human exposure to the chemicals in Table 1. The data for these chemicals was organized into a database in a previous task (Task Order 0015) and was used to estimate exposure. This exposure assessment will be used by CPSC staff to help determine whether flame retardant exposure from household products in the indoor environment presents a hazard to consumers. It will also be used to prioritize future work on specific products and flame retardant chemicals.

Table 1. Selected flame retardant chemicals for this report.

Flame Retardant Chemical	CASRN
Trialkyl phosphates	
Tris(1,3-dichloro-2-propyl) phosphate (TDCPP)	13674-87-8
Tris(chloropropyl) phosphate, mixture of isomers (TCPP)	13674-84-5, 76649-15-5, 76025-08-6, 6145-73-9, 26248-87-3

Flame Retardant Chemical	CASRN
Tris(2-chloroethyl) phosphate (TCEP)	115-96-8, 29716-44-7
Triethyl phosphate (TEP)	78-40-0
Aromatic phosphates	
Triphenyl phosphate (TPP)	1145-86-6
Brominated flame retardants	
2-Ethylhexyl 2,3,4,5-tetrabromobenzoate (TBB)	183658-27-7
Di(2-ethylhexyl) tetrabromophthalate (TBPH)	26040-51-7
Tetrabromobisphenol A (TBBPA)	79-94-7; 121839-52-9
Inorganic flame retardants	
Antimony trioxide (ATO)	1309-64-4

CASRN = Chemical Abstracts Service Registry Number

1.1 Exposure Concentration Data

Flame retardant exposure studies used in these assessments were compiled by TERA in two previous tasks for CPSC (Task Orders 0008 and 0010). For each of the selected flame retardants, TERA conducted a literature search that included Pubmed, Google Scholar, Science Direct, TOXNET (including Toxline), CAB Abstracts databases, government reports, and a general web search to identify studies and reports of human exposure concentrations.[1] Emphasis was on concentrations in indoor air and dust and in consumer products (including children's products, upholstered furniture, mattresses, apparel, household products, building materials, and electronics). Information from secondary and primary sources was compiled into tables by "media," with data on measured concentrations identified in ambient air, indoor air, household dust, drinking water (and surface and groundwater), consumer products, and food. Biomonitoring studies were also summarized.

In a subsequent task (Task Order 0015), TERA, in conjunction with LLG, created an Excel workbook to capture relevant key data and information from the studies for assessing indoor exposure to the specified flame retardants. See Appendix A for a description of this work and list of references included in the workbook. Emphasis was placed on data from the indoor environment. The purpose of creating the spreadsheet was to organize key information from each study with potential relevance for assessing indoor exposure to the specified flame retardants. The workbook provides a picture of the available data and evaluation of each study's quality and relevance for use in an exposure assessment. Table 2 lists the types of information captured.

[1] Literature for TDCPP, TCPP, TCEP, TEP, and TPP were searched up to August, 2014. Literature for TBB, TBPH, TBBPA, and ATO were searched up to May, 2015.

Table 2. List of flame retardant database elements (column headings) (see Appendix A for further information).

Database Elements	
Study Number	Lowest concentration
Reference	Highest concentration
Date Study Conducted	95th% concentration
Location (e.g., office, home, room)	Geometric Mean concentration
Chemical	Concentration Units
Indoor air, outdoor air, dust	Standard Deviation
Suspected Source	Detection Frequency
Study Objective	Limit of Detection
Methods	Limit of Detection units
Country (city/region)	Method Detection Limit
n =	Method Detection Limit units
n comments	Quality – Relevance
Average concentration	Quality – Representativeness
Mean concentration	Quality - Precision
Median concentration	Quality – Methodology

Following the data population step, each study was evaluated for study quality with regard to relevance, representativeness, precision, and methodology using the criteria listed below.

A. Relevance: With CPSC's assessment purpose of assessing human exposure to the general population as the guiding principle, the information was linked to its contribution in assessing the exposures to:
   - populations or special conditions experienced by the populations (socioeconomic, geographical, age, gender, etc.) with emphasis on life stages
   - locale, as in home, child care, office, etc.
   - the physics of the product or media governing potential for release, transfer, binding, accumulation or uptake of the chemicals
   - product type
   - prospective relationship to biomonitoring data
   - other

B. Representativeness: How can the information be applied in terms of
   - chemicals to which it may be applied (all, presumably all, specific ones)
   - relationship to pyrolytic forms of chemicals
   - relationship to degradates or metabolites of parent chemical
   - geographical, year data were collected, or other situation which favors the application of the information to contemporary U.S. population

- utility in prospective assessments
- utility in relation to biomonitoring or other retrospective exposure profiles
- other

C. Precision: This relates to any situation in the publication that limits the data precision. For example, if data were summarized and original data not available or inadequately described for exposure assessment purposes, that precision issue will be pointed out. Issues related to number of measurements or duplicates or other methodology will be pointed out when suggestive of limitations or significant excellence.

D. Methodology: This relates to any element of the methodology that constrains or limits the application of the information to the exposure assessment.

The resulting database provided a standardized description of exposure data from 108 studies. Utilizing our quality indicators and evaluations, TERA used the database to identify candidate studies for the exposure assessments. TERA reviewed these studies and selected the best study per environment/media and per chemical to create the distributions. These choices were often influenced by how much information the study authors provided in the publications, and particularly the way in which they reported results. Some authors report only maximum concentrations or high percentile values, which made use of their data problematic. All else equal, preference was given to those studies where the mean (or geometric mean [GM]) and standard deviation (SD) were reported so that variability was disclosed and parametric distributions could be created.

1.2 Observations from Data Assembly

We noted a number of observations in reviewing the available data on flame retardant chemicals compiled for CPSC.

- Specific flame retardant uses are changing over time.
- Flame retardant uses change to reflect regulatory decisions and evolving understanding of potential risks.
- There is no single methodology for collection or detection and quantification of individual flame retardant concentrations in any given media. Reporting in the research publications varies in terms of detail of methodology, use of standards, and reporting of results.
- Flame retardant concentrations have been measured in many different media: products, surfaces of products, dust, particulates in air, indoor air, outdoor air, outdoor soils, and indoor surfaces.

We also noted that exposure to flame retardants will vary depending on many determinants.

- Era – related to product use and market dynamics and regulatory pressures (e.g., cathode-ray screens).
- Age of receptor – reflected in activity profiles.
- Economics – related to types of products in the environments in which people spend time (e.g., age of furniture, electronics and bedding)

- Unique activities – large amount of time spent in specific environments (e.g., frequent plane travel, competitive gymnasts' time in gymnastic centers)
- Special sites - home/office/child care in relation to stationary sources (e.g., mining areas). Page intentionally left blank.

1.3 Strategy for the Exposure Assessment

The available literature provides information relevant to flame retardant concentrations in various media in selected environments, such as "child care center," "home," "office," "car," "outdoors," "gymnastic center," and an array of specialty workplaces and geographies. Some studies evaluated specific products, such as plastic toys, mattresses, food, or water.

The objective of this report is to consider possible exposures to each of the nine flame retardants in contemporary living scenarios for the general U.S. population. Therefore, we focused on flame retardant concentrations found in dust and air of places people typically spend time and for which data are available. These include child care, home, office, and car environments. Exposure contributions from specific consumer products, food, water, outdoor air, or soil are not considered. Data representing indoor environments where the source of contamination is thought to be from nearby mines or industries were not used because we did not think these were representative of the general population's exposure to flame retardant usage. The general exposure estimates developed in this report could be refined to address exposure contributions from diet, to unique environments (e.g., gymnastics facilities), or specific products (e.g., cuddly toys or plastics) for the relevant subpopulations.

1.4 Guiding Principles for Data and Methods

Table 3 below indicates data availability for each of the four environments addressed by this report.

Table 3. Availability of data on the flame retardants for the four subject environments and two media. Shaded cells indicate no adequate data for the exposure assessment.

Flame Retardant	Environment Media							
	Child Care		Home		Office		Car	
	Dust	Air	Dust	Air	Dust	Air	Dust	Air
TDCCP	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
TCPP	No	Yes	Yes	Yes	No	Yes	No	No
TCEP	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
TEP	No	No	Yes	Yes	No	Yes	No	Yes
TPP	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
TBB	Yes	Yes	Yes	Yes	Yes	No	Yes	No
TBPH	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No
TBBPA	Yes	No	Yes	No	Yes	Yes	No	No
ATO	No	Yes	Yes	No	No	No	No	No

***** Saito et al. (2007) sampled air from eight Japanese homes during winter for TBBPA. With a detection level (LOD) of 173 pg/m^3 and method limit (MDL) of 1.2 ng/m^3, no TBBPA was detected in any sample. Air concentrations of TBBPA were thus not included in the exposure assessment for home environments.

The use of the exposure related data for this assessment are guided by the following principles.

- Utilize full data distributions of exposure factors wherever possible, avoiding selection of a particular point within the data set (mean, 75th percentile, 95th percentile, or maximum level).
- Chemical data from the most competent and relevant study are used for each medium (dust and indoor air) to be considered for the exposure scenarios for each chemical. References are given with commentary on limitations as necessary.
- Utilize exposure factors consistent with those emphasized by other agencies conducting exposure assessments relevant to the U.S. population. In essence, this means preferential use of the U.S. Environmental Protection Agency (EPA) Exposure Factors Handbook (EFH) (U.S. EPA, 2011) information where possible, including values that are derived and default assumptions.
- Flame retardant concentration will be applied only to the medium and environments to which they directly apply. For example, measurement of a given flame retardant in dust from homes will be applied to the exposure assessment for dust in homes, but will not be extrapolated to dust in office or child care environments.

Our exposure assessment methods are guided by the following principles.

- Construct exposure assessments that present the distribution of oral, inhalation, and dermal exposure for each of the considered population subgroups.
    - Infants (<1 year)
    - Toddlers (1 - <3 years)
    - Children (3 - <12 years)
    - Juveniles (12 - <18 years)
    - Adults (≥18 years)
- These exposure distributions are presented graphically, displaying exposures for all population percentiles. Values for exposure at the 25th, 50^{th,} and 75th population percentiles are given in the results tables.

The exposure estimates are created for each season and by (age) year and then combined appropriately to form the age-related population subgroups. Age groups for each exposure factor reflect natural "break points" wherein one age group is characteristically different from another age group. For example, the natural break point characterizing height is different between teenage males and females; in general, males enter a growth spurt later than do females. As exposure assessments are calculated on a seasonal/annual basis, values are drawn from the appropriate age grouping.

The environmental scenarios and activity profiles were constructed to accomplish the goal to characterize overall exposure to flame retardants that people may encounter given reasonably contemporary chemical uses and U.S. markets. The environmental scenarios used were child care, home, office, and car environments. All were apportioned in appropriate age-related profiles.

2 Methods

2.1 Probabilistic Approach

This exposure assessment was conducted using a probabilistic approach. This is in contrast to a deterministic assessment, wherein just one value represents each parameter in an algorithm. For example, in calculating the absorbed exposure across a given area of skin,

$$\text{Amount absorbed by a given skin area} = Conc_{medium} * M_{medium} * Abs$$

where:

$Conc_{medium}$ is the concentration of the chemical in a given medium in contact with the skin;
M_{medium} is the mass of the medium; and
Abs is the rate of absorption of the chemical on that skin surface.

Using a deterministic approach one would utilize only one value for each of these three parameters, yielding a single result. In a deterministic assessment, multiple values exist for a parameter (e.g., the maximum value, average, or mean), and the assessor must choose one value to represent the parameter.

In a probabilistic approach, any of these parameters might be represented by multiple values or even a distribution of values depending upon the available data. These distributions of values are used in the exposure assessment calculations. For each flame retardant, the data distributions are presented along with applied assumptions. The probabilistic approach repeats the calculation as many times as the assessor determines is necessary, and for each repetition a different value is chosen (randomly in our approach) from the array of values for each parameter. All of the values in a distribution are ultimately drawn for use in the calculations, yielding a distribution of possible exposure "answers," which can be graphed as in the example below in Figure 1.

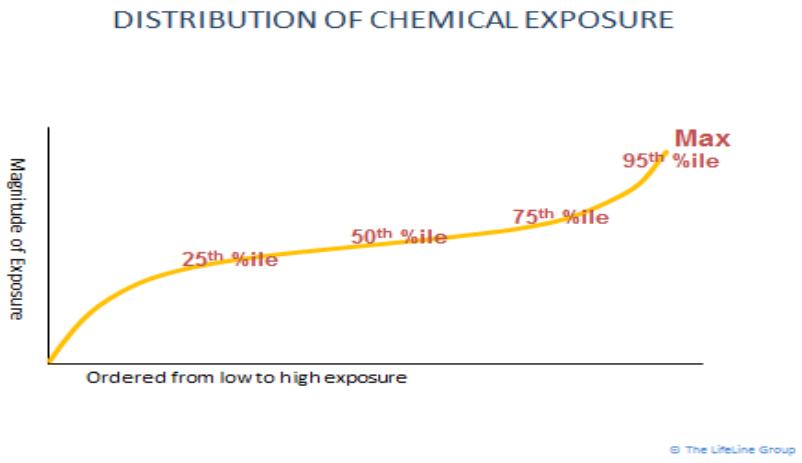

Figure 1. Hypothetical distribution of chemical exposure.

The number of repetitions necessary for a probabilistic approach varies with the complexity of the algorithm and the complexity of the distribution of values for each parameter. Complexity includes the number of parameters in the algorithm, the variability of values for those parameters, and the influence of some parameters over the calculation answers. As the complexity of the algorithms increases and the variability among the values within parameters increases, more repetitions are necessary to calculate the distribution of possible answers from all the possible combination of "draws" taken from the values for each of the parameters. The normative area of the distribution of exposures (25^{th} to 75^{th} percentiles) tends to stabilize first, meaning the answers in this range will not change significantly given increased iterations of the calculation. The tails of the distribution of answers represent calculations generated from draws of values all trending to the extremes (all the low values among the parameters or all of the high values among the parameters) and, thus, are more susceptible to change if more extreme values are drawn. As those extremes are rarer, one needs more iterations to be confident that the answers are stable in the tails.

For these assessments, we used the Lifeline™ suite of exposure software (see Section 2.7). We conducted 500 iterations for each calculation of each algorithm, which creates a stable range of answers in the normative area of the curve. We are reporting values for the 25^{th}, 50^{th}, and 75^{th} percentiles, the normative area of the curve. The algorithms presented in Appendix B are not simple, and if we were interested in values above the 95^{th} percentile, more iterations would be necessary.

The advantage of using probabilistic models for the exposure assessments is that the distribution reflects the variability among values in the parameters and the answers reveal the variability of the possible answers. Decision-makers can consider any point on the resulting distribution (e.g., mean, 75^{th} percentile, higher percentiles, maximum) as appropriate to the situation, regulatory policy, and/or other considerations.

2.2 Aggregate Exposure Assessment

Each of the flame retardants is considered separately in this assessment. The resulting exposure assessment for each chemical considers multiple routes of exposure (i.e., oral, dermal, inhalation). Using terminology coined by the EPA, this is considered an aggregate exposure, calculated from probabilistic exposure assessment methodology. However, as the assessment considers only one chemical at a time, it is not a cumulative exposure assessment.

Exposure assessments are presented for each of the four environments (i.e., child care, home, office, and car) as data are available. Also presented is a combined total daily exposure assessment, which considers multiple activities per day, as they take place in the child care, home, office, or car environments.

2.3 Selection and Application of Flame Retardant Chemical Concentration Data

Available data on flame retardant concentrations were compiled in separate tasks for CPSC, wherein the studies were evaluated for quality and relevance (see Section 1.1 and Appendix A). Data from the most appropriate publication were selected to represent concentrations for each flame retardant chemical

and relevant media scenario in the exposure assessments. A list of the selected studies for each of the nine flame retardants by medium and environment are presented in Table 4 below.

Table 4. Studies used to estimate exposure for nine flame retardants in selected media and environments.

ENVIRONMENT and MEDIUM		TDCPP	TCPP	TCEP	TEP	TPP	TBB	TBPH	TBBPA	ATO
CHILD CARE	Dust	Bradman et al., 2012	NAD	Bradman et al., 2012	NAD	Bergh et al., 2011	Bradman et al., 2012	Bradman et al., 2012	Harrad et al., 2010	NAD
	Air	Bradman et al., 2012	Marklund et al., 2005	Bradman et al., 2012 and 2014	NAD	Bergh et al., 2011	Bradman et al., 2012, 2014	Bradman et al., 2012 and 2014	NAD	Majestic et al., 2012
HOME	Dust	Fan et al., 2014	Fan et al., 2014	Ingerowski et al., 2001	Dodson et al., 2012	Fan et al., 2014	Brown et al., 2014	Brown et al., 2014	Fromme et al., 2014	McDonald et al., 2011[1]
	Air	Bergh et al. 2011	Marklund et al., 2005	Bergh et al., 2011	Saito et al., 2007	Bergh et al., 2011	La Guardia and Hale, 2015	La Guardia and Hale, 2015	Saito et al., 2007[2]	NAD
OFFICE	Dust	Carignan et al., 2013	NAD	Marklund et al., 2003	NAD	Bergh et al., 2011	Ali et al., 2011	Ali et al., 2011	Geens 2009	NAD
	Air	Yang et al. 2014	Yang et al., 2014	Marklund et al., 2005	Saito et al., 2007	Bergh et al., 2011	NAD	Newton et al., 2015	Ni and Zeng 2013	NAD
CAR	Dust	Carignan et al., 2013	NAD	Brandsma et al., 2014	NAD	NAD	Hassan and Shoeib 2015	Springer et al., 2012	NAD	NAD
	Air	Staaf and Ostman, 2005	NAD	Hartmann et al., 2004	Staaf and Ostman, 2005	Staaf and Ostman, 2005	NAD	NAD	NAD	NAD

NAD – no adequate data

[1]McDonald originally listed as 2010 in the Flame Retardant Exposure Assessment Database from TO15 and should have been 2011.

[2]Saito et al. (2007) sampled air from eight Japanese homes during winter for TBBPA. With a detection level (LOD) of 173 pg/m^3 and method limit (MDL) of 1.2 ng/m^3, no TBBPA was detected in any sample. Air concentrations of TBBPA were thus not included in the exposure assessment for home environments.

Ideally, all published studies would report all of the collected data for which key discussions and conclusions are made for the research. In reality, the authors choose to report their data as they see fit. For example, they may report data as point values representing a metric, such as a median, mean, geometric mean, average, maximum value, minimum value or some combination of these or other statistical descriptors. Some studies only report a single value. Where possible, we used the metrics that described the data collected in the study, such as a mean and its standard deviation, to create a parametric distribution. We then reported the type of distribution that was created (e.g., log normal) by the statistical software, we employed (Crystal Ball™). If the reported results were inadequate to create a

distribution, we noted what values were reported and which we used. In many cases only single values were available from the studies and those were indicated along with the author's description of what they represent (median, mean, or average.). Note that it was necessary to convert the measurement units as reported in the studies to the units required for entry into the exposure software. For example, air concentration measurements in ng/m^3 were converted to µg/m^3. These conversions are noted in Appendix C.

2.4 Methodology Issues Regarding Household Dust

Studies reported flame retardant concentrations in a sample of dust collected from surfaces in the room(s) or area, as described in each publication. To calculate a person's exposure in that room or area, one must estimate the mass of the chemical over a given area of the surface from which the sample was taken. The person comes into contact with the surfaces of the room and not the dust sample collected across the room's surfaces. Hence, a conversion factor needs to be applied that represents the mass of dust across the surface areas under consideration.

Exposure to dust presents a unique situation. For most other media, studies on concentrations of a chemical in a medium are measuring the concentration in the medium under the same conditions of human exposure. For example, measuring the concentration of a chemical in water would yield a concentration value directly relevant to the exposure to one's hand when immersed into that water. However, in the case of collecting household dust, one does not encounter the dust collected in a vacuum bag. That dust had been dispersed across multiple areas, such as the floor, furniture, and tables, which are the spaces and surfaces that humans actually contact.

Concentrations of flame retardants in the dust samples are reported from the published studies. Methodologies employed for collection of the samples differed among studies in ways that will affect the adjustment from chemical concentration in dust to mass across the area of the surfaces humans touch. Some of the key differences are listed below.

- Different parts/rooms of the home were sampled
- Different collection techniques were employed (e.g., various types of vacuums, sweeping)
- Collection was made after different pre-cleaning conditions
- Collection was made from different surfaces (e.g., carpet, linoleum, wood)
- Collection durations differed (e.g., vacuuming for different amounts of time)

The composition of "dust" is known to be a variable combination of fibers, mold, chemicals, soot, dirt, sand, and the "true dust," which is previously airborne particles that settled onto the surfaces. For flame retardants, the sources of the flame retardant chemical making up the concentration in the collected sample could be from multiple components of this dust - the "true dust," as well as from fabric fibers, building materials, carpet fibers, or electronic equipment.

Two issues are discussed below, which help to explain the large variations in concentrations of flame retardants in dust as seen across the studies. We use this information to guide the assessment's use of the dust concentration measurements from the exposure studies.

2.4.1 Dust Loading: Composition of the dust sample, correcting for components not bearing flame retardants.

"Dust loading" is the concept of taking the concentration of flame retardant as measured in the collected sample (e.g., mg flame retardant per gram of dust) and converting that measurement to mass over surface area by estimating the dispersion of that dust across the surface areas from which it was collected. To do this, we need to consider the weight of dust expected to exist on the various surfaces (grams of dust per unit area). This is the "dust loading."

One issue to consider is that within the reported mass of dust collected, other materials that are not flame retardant-containing dust (e.g., mold, soot, sand) are captured in the total mass collected. In other words, the flame retardant samples are diluted to some extent by these other components of the total dust collected.

The EFH (U.S. EPA, 2011) provides some guidance for dust loading and we reproduce the relevant tables below (see Tables 5-7).

Table 5. Dust Mass Loading After 1 Week without Vacuum Cleaning. Source: Exposure Factors Handbook, Table 19-34 (U.S. EPA, 2011, p. 19-50).

Table 19-34. Dust Mass Loading After 1 Week Without Vacuum Cleaning	
Location in Test House	Dust Loading (g/m^2)
Tracked area of downstairs carpet	2.20
Untracked area of downstairs carpet	0.58
Tracked area of linoleum	0.08
Untracked area of linoleum	0.06
Tracked area of upstairs carpet	1.08
Untracked area of upstairs carpet	0.60
Front doormat	43.34
Source: Adapted from Thatcher and Layton (1995).	

The values reported in Table 5 (from EFH Table 19-34) are from Thatcher and Layton (1995) and represent the "total mass" loading. Thatcher and Layton also present a "collected mass" for each total mass value (see below), representing the collected mass divided by experimentally determined surface collection efficiencies. Collection efficiencies differ depending on the surface characteristics.

Table 6 (excerpted from Table 2 in Thatcher and Layton [1995]) shows results for dust mass loading on various floor surfaces within the study home after one week without vacuuming.

Table 6. Dust Mass Loading on Various Floor Surfaces within the Study Home after One Week without Vacuuming. Source: Thatcher and Layton (1995), Table 2.

Location	Collected mass (µg/cm^2)	Total mass (µg/cm^2)
Tracked area of downstairs carpet	110	220
Untracked area of downstairs carpet	29	58
Tracked area of linoleum	6	8
Untracked area of linoleum	4	6
Tracked area of upstairs carpet	54	108
Untracked area of upstairs carpet	30	60
Front doormat	2170	4340

Table 6 shows that only approximately half of the total mass collected is actually dust. Thatcher and Layton note that other components, such as soil, other chemicals, allergens, smoke residuals, cleaners, synthetic fibers, insect parts and building materials, likely make up the remaining weight of the "total mass." The "collected mass" is the fraction of the total mass expected to be comprised of "dust."

If the chemical of interest is expected to exist only on "dust," then the total weight of the sample would represent the collected mass, as in "mass of the chemical per unit mass of the sample." In actuality, flame retardants may also be adsorbed to some of the non-dust components in the sample. Depending on how a given flame retardant is used in product manufacturing, concentrations of that flame retardant may be on an array of these sample components, not just on the dust. For example, treated carpet fibers, or particles from treated building materials could contain concentrations of a flame retardant applied during manufacturing. If the flame retardant concentration is a function of contribution from dust and airborne particles and, in addition, includes concentrations on particulates from carpet, building materials, synthetic fibers, or other flame retardant treated materials, the sample mass would be represented by a weight somewhere between the "collected mass" and the "total mass" presented in Thatcher and Layton's table.

However, the flame retardant studies generally do not provide sample identification data that would allow us to calculate the actual collected mass carrying the flame retardant in the study. We only know the total mass of the samples. Therefore, for our exposure assessments we default to the use of the "total mass," recognizing that the resulting exposure calculation may be slightly underestimated because the total mass value may dilute the concentration calculation. This approach is consistent with EPA's EFH and the table cited above from the EFH.

Use of the default of "total mass," may also be underestimated by several other considerations. Lioy, Freeman and Millette (2002) studied a number of issues related to dust deposition, including the variety of techniques utilized for collection of samples and the presentation metrics of results for toxicants in dust surface loading (µg/cm^2) or surface concentrations (µg/g) (Lioy et al., 2002). The first part of their work deals with the sample dilution issue. Their findings show a larger range of dilution than that

reported in Thatcher and Layton (1995) across the "dust" samples collected from seven U.S. cities using high-efficiency vacuum collection techniques. Table 7 presents data from Lioy et al. (2002).

Table 7. Summary data on composition of house dust and other characteristics in seven U.S. cities collected by high-efficiency vacuum cleaner. Source: Lioy et al. (2002).

Characteristic	Result
Range (% by gravimetric analysis) of fibrous particles	9–89
Range (% by gravimetric analysis) of non-fibrous particles	11–91
Size range (% non-fibrous of total particles collected)	
> 300 µm	4–83
75–300 µm	1–32
< 75 µm	0–20
Days since last cleaning (average)	14.2
Days since last cleaning (range)	1–150
No. of people living in home (average)	3.3
No. of people living in home (range)	1–10
Composition (qualitative) by polarized light microscopy	
Most frequently identified materials	Skin, soil, starch, hair, cotton, plant (> 85% of samples)
Second most frequently identified materials	Fungal material, synthetic fibers, polymers, paint, metals

Cities were San Diego, CA; Columbus, OH; Phoenix, AZ; Miami, FL; New York metropolitan area (including New Jersey); Denver, CO; Kansas City, KS. Included were 36 individual home samples and 12 sets of pooled samples. Samples were collected in the kitchen, living room, and/or bedroom, or another room other than the kitchen.

This wide range of values underscores the difficulty in calculating the dust loading factor when the researchers do not account for the surface dust loading and mass of chemical per unit surface area within the study design, or where the pertinent conditions of the study are not carefully noted in the published research. The Lioy et al. (2002) paper suggests that the dust loading variability may be greater than that shown in the Thatcher and Layton work, and hence, raises the possibility that chemical concentrations are underestimated using the EFH factors. It is noted that the pre-testing conditions of the surfaces and circumstances of area use are important factors to consider as well.

2.4.2 Dust Loading: Consideration of different surfaces in the environment and different collection methods

The second part of the study by Lioy et al. (2002) addresses the issues of dust loading and influence of surfaces and collection methodology on the measurements. Table 8 summarizes results of several researchers' work, which illustrate how surfaces and collection methodologies influence the calculation of the flame retardant concentration per unit area (i.e., dust loading range).

Table 8. Influence of collection methodology on dust loading concentrations. Source: Lioy et al. (2002).

Study	Collection Method	Dust Loading Concentration (Range)
Roberts et al., 1999	HVS3	0.32–14.4 g/m^2
Adgate et al., 1995	LWW wipe: floor	0.05–7.0 g/ m^2
Adgate et al., 1995	LWW wipe: window sill	0.12–13 g/ m^2
Adgate et al., 1995	Vacuum	0.3–99 g/ m^2
Roberts et al., 1998	HVS3: rug/typical home vacuum	< 1.0–26 g/ m^2
Roberts et al., 1998	HVS3: rug/remodeled home vacuum	< 1.0–63 g/ m^2

HVS3 = High Volume Small Surface Sampler method; LWW = "Lioy-Weisel-Wainman" method

Even on a given surface area, there are differences in dust loading. The EFH (U.S. EPA, 2011) reports dust loading for different surfaces using data from Thatcher and Layton (1995) (see Table 5 above). Tracked areas show greater loading than untracked areas and carpeted areas show greater loading than hard surfaces.

Another study, Roberts et al. (1999), reported the influences of different collection methods and some additional parameters on the dust loading (and other related metrics). The results from that paper illustrate the importance of the age and condition of the surface covering and the impact of periods between cleaning (see Table 9 below). Hence, differences in the surface materials, level of activity in and around the surface, collection methodology, and previous cleaning condition are some of the variables likely responsible for the wide variation in the dust concentrations reported in the different flame retardant studies we reviewed.

Table 9. Fine dust surface loading before and after vacuuming, percent reduction, dust collected, hours required, and deep dust loading. Source: Roberts et al. (1999), Table 1.

ID #	Fine Dust Surface Loading and Dust Finder Sensitivity			Percent Reduction (%)	Vacuum Hours	Time per Unit Area (min/m^2)	Deep Dust Collected (g)	Deep Dust Loading (g/m^2)	Carpet Age (years)	House Age (years)	Carpet Type
	First (g/m^2)	Second (g/m^2)	Third (g/m^2)								
1	0.32	0.019 H		94.1	2	7.7	186	12	18	20	P
2	1.53	0.175	0.037 H	97.6	14	21.8	959	25	13	13	ML
3	1.11	0.15	0.102 H	90.8	6	44.8	899	66	18	18	P
4	1.64	0.36 L		78	2.8	20.5	396	36	15	61	P/ML
5	5.53	2.89 L		47.7	3.3	27	1,848	84	20	50+	LL
6	1.3	1.10 L		15.4	2.5	26.3	1,175	92	15	30	S
7	0.92[1]	0.451	0.147 L	84	5	45	862	125	15	50	S
8	0.76	0.05 H		93.4	5	20.7	1,081	75	12	72	P
9	1.57	0.09 H		94.3	0.8	5.6	65	8	15	65	FA
10	14.4	0.48	0.245 L	98.3	15	19.6	6,166	171	20	20	P
11	0.36[1]	0.048 H		86.7	5	16.7	860	50	15	15	P

1 = 40% upright vacuum sample; H = high sensitivity; L = low sensitivity
Carpet Type: P = plush; ML = multilevel cut; S = shag; LL = level loop; FA = flat level loop area
Dust Sources: P = people; C = cat; D = dog; UP = unpaved parking; SO = small office; MO = mold
Dust Controls: DM = door mat; UV = upright vacuum; SR = shoe removed; CVP = canister vacuum power brush

2.4.3 Approach Used for Dust Loading

The published studies typically do not provide detail on the surface areas being considered or account for dust loading within the design of their collection methodology. Where possible, we matched the conditions of the publications with the dust loading factors presented in the EFH and other publications noted above. When specific surface information was not presented, our default assumption for dust loading is a single factor based on the average of the dust loading factors for all of the area conditions listed in Thatcher and Layton (1995) and found in the EFH Table 19-34 (Table 5 above) excluding the "front door mat" condition.

2.5 Illustration of Data Conversions for Application to Exposure Assessment Model Parameters Using TBB as an Example

For each scenario or environment, we selected the study that provided the most reliable and relevant concentration information. Appendix C provides information on the studies considered, data selected, and statistical methods applied to set up the distribution of values for each flame retardant in the different media and environments. Not all media and environments have been adequately studied for

the flame retardants, and some studies that have been reported are of questionable relevance or quality. Appendix C provides for each flame retardant a brief explanation of why studies were selected and others not utilized. Below we illustrate how concentration data from the selected studies were applied to the probabilistic model, using TBB as an example.

2.5.1 Dust

Only one of the TBB studies used for this assessment considered and reported dust loading in the original research. Bradman et al. (2012) measured the concentration of TBB in dust samples for a specified area (m^2). Because their study design accounted for the direct measurement of the mass of TBB per unit surface area, no "dust loading" adjustments were necessary.

More typically, studies collected a mass of dust from an unspecified surface area necessitating conversion of the study report's concentration data (mass of TBB/mass of dust) to an estimate of mass of TBB per unit surface area. In these cases, we calculated the mass of chemical per unit surface area using the dust loading factors from Thatcher and Layton (1995), as reported in the EFH (EHF Table 19-34, Table 5 above).

For example, Brown et al. (2014) reported TBB concentrations in dust but did not describe the types of surfaces included in the dust collection or design. They reported a GM concentration in dust of 310 ng/g (3.1×10^{-1} µg/g) with a geometric standard deviation (GSD) of 8.59 ng/g (8.59×10^{-3} µg/g). We assumed dust loading to be best represented by the average of the conditions (excluding the front door mat) in the EFH factors (Table 5 above). Therefore, we multiplied the GM and the GSD by the dust loading factor for each type of surface area and then averaged the results.

This yields an average GM of 2.38×10^{-5} µg/cm^2 and average GSD of 6.59×10^{-7} µg/cm^2). Table 10 shows the different dust loading factors for different surface types and the calculations. Unit conversions are also presented in the table.

GM (µg/g) x Dust Loading Factor (g/m^2) = TBB mass per unit area (µg/m^2)

The units of the mass per unit area have been converted to µg/cm^2 for use in the exposure assessment software. Because no specific surface characteristics were noted in Brown et al. (2014), the average of surfaces (excluding front door mat) is used for the exposure assessment. See Table 10.

Table 10. Lognormal distribution of TBB dust concentration data in home environment reported in Brown et al. (2014) and corrected for dust loading. Type of surface not reported in study.

Dust	Reported units, ng/g	Converted units, µg/g		
Geometric Mean (GM)	3E+02	3E-01		
Geometric Standard Deviation (GSD)	8.59	8.59E-03		
Min	<6.4E-01	<6.4E-04		
Median	3.37E+02	3.37E-01		
Max	1.92E+05	1.92E+02		
Dust Loading Correction				
From EFH Table 19-34	Dust Loading Factors (g/m^2)	TBB per m^2 GM ($\mu g/m^2$)	TBB per cm^2 GM ($\mu g/cm^2$)	TBB per cm^2 GSD ($\mu g/cm^2$)
Tracked area of downstairs carpet	2.2	6.82E-01	6.82E-05	1.89E-06
Untracked area of downstairs carpet	0.58	1.80E-01	1.80E-05	4.98E-07
Tracked area of linoleum	0.08	2.48E-02	2.48E-06	6.87E-08
Untracked area of linoleum	0.06	1.86E-02	1.86E-06	5.15E-08
Tracked area of upstairs carpet	1.08	3.35E01	3.35E-05	9.282E-07
Untracked area of upstairs carpet	0.6	1.86E-01	1.86E-05	5.15E-07
Front door mat	43.34	1.34E+01	1.34E-03	3.72E-05
Average of surfaces, excluding front door mat			2.38E-05	6.59E-07

EFH = Exposure Factors Handbook (U.S. EPA, 2011)

For TBB, dust loading correction factors were also applied to the TBB concentrations in dust collected in office and child care environments, using the dust loading factors for homes. Note that for the car environment, dust loading factors from the EFH were applied to the chemical concentration somewhat differently. Instead of using the average of all of the surface conditions, we assumed the dust loading on seats is equivalent to the dust loading on carpets (tracked area of downstairs carpet) and dust loading on the dashboard was equivalent to dust loading on linoleum (tracked area). The chemical concentrations for dust in cars were multiplied by the average of these two conditions.

The true dust loading for any given environment and any given surface type may not be accurately reflected by these EFH factors or research conditions. For example, different upholstery fabrics may hold more or less dust and provide more or less non-dust particles than represented by measurements on carpets and linoleum. The age of the surface materials and collection methods are likely to influence these factors as well. In the absence of measurements by the researchers in the selected publications,

we default to the opinion of the U.S. EPA (U.S. EPA, 2011) for these factors, as they encountered these issues during their deliberations for providing default values important to exposure assessment parameters.

2.5.2 Indoor Air: Respired Particulates

Exposure to airborne chemical is possible from the chemical in volatile form as well as from the chemical adsorbed onto particles suspended in the air. Inhaled air brings the vapor and the particulates into the nasopharyngeal area where three processes leading to exposure begin. Chemicals that exist in the vapor form can be absorbed in the alveoli of the lungs. However, airborne flame retardants exist primarily on suspended air particulates and are not highly volatile; thus, data for concentrations of flame retardants in air focuses on the chemicals on air particulates. Suspended air particulates exist in a range of sizes, which determine their fate after inhalation. Particulates larger than about 10 micrometers (PM_{10}) in diameter[2] tend to fall out of suspension, although this is not a strict rule and depends on many physical conditions and the larger they are the more likely they will fall out of suspension. Particles up to 100 micrometers in diameter (PM_{100}) can be inhaled, however (Goswami et al., 2013). PM_{10} particles and smaller tend to remain suspended in the air and can be inhaled. The amount of particle that is deposited in different parts of the respiratory tract (nose, tracheobronchial or alveolar) is determined by the particle size, the structure of the human respiratory tract, and the associated airflow dynamics. Particles between about 5 and 10 micrometers in diameter tend to deposit in the nose, from which they can swallowed and absorbed systemically. Particles smaller than 5 micrometers have generally increasing penetration to and deposition in the bronchial and alveolar regions with decreasing size, and so these are often termed respirable particles. Note that there is no sharp cutoff for the size particles that can reach the alveoli; instead, the proportion changes continuously with particle size. Similarly, there is not a consistent cutoff in the literature regarding the definition of respirable. For example, almost no particulate larger than 10 micrometers penetrate beyond the nose, and so some authors describe particles less than 10 micrometers (PM_{10}) as respirable. Alternatively, since there is a peak in the deposition fraction in the alveolar region at about 2.5 micrometers, other authors describe particles of 2.5 micrometers or less as respirable. This varying definition of respirable contributes to the uncertainty of this report. The approach for addressing the varying definition of respirable is described in the next paragraph. Chemicals deposited in the alveolar region on these generally smaller particles are considered to be available for absorption into the blood stream and considered to become part of the body load for that chemical (Nieuwenhuijsen, 2003).

The exposure load received by the person inhaling the suspended air particles carrying the chemical is calculated as a function of the concentration of the chemical in/on the particles and the mass of particles reaching the lung. The concentration of the chemical on the particulates is the subject of research cited in this project. The concentrations are reported in the studies as mass per unit volume of air, such as nanograms per cubic meter (ng/m^3), and, for conformity, referred to in this report in terms of micrograms per cubic meter ($\mu g/m^3$). Where the study results reported concentration for specific

[2] Strictly speaking diameters here refer to aerodynamic diameters, which characterize how a particle settles relative to a unit density sphere.

sizes of particulates, the specific concentrations for the respirable fractions and non-respirable fractions were used. Authors of the study defined the size of the fractions they considered to be relevant to respirable fractions. In general, respirable fractions were presented as < PM_{10} when such detail was available. When no particle size was measured and reported by the study authors, the concentration was presumed to be a mix of particles sizes. The relative contribution of large and small particulates in any given study sampling could not be estimated, especially as the filtering of the air in the collection methodology differed among the studies and rarely included efforts to capture the very small (<PM_1) particulates. In those cases, a traditional assumption that 10% of the particles would be respirable and the remaining 90% would not be respirable was applied.

The mass that would be taken in by a person is a function of the breathing rate in the environment that contains the airborne chemical. Breathing rates are a function of age as well as of the exertion level of the individual in that environment. Breathing rates for different age groups were provided by the EFH (U.S. EPA, 2011), including different rates for different levels of exertion considered in the assessments of this report (i.e., resting, light and moderate). The inhaled mass of the chemical per unit time is the product of the concentration of the chemical in the air (including in or on particulates) times the volume of air inhaled per unit time.

$$\text{Inhaled mass of chemical/60 minutes} = \mu g/m^3 \times m^3/60 \text{ minutes}$$

The concentration of the chemical on suspended air particles (as reported in the cited studies) is assumed to be static within a given environment (child care, home, office, car) for the duration of a person's existence in that environment. At a given state of exertion, resting for example, the amount of air inhaled will differ among people of different ages. A child under age one will inhale, on average, 0.19 m^3/hour. A person aged 16 to 21 is expected, on average, to inhale 0.32 m^3 per/hour. Therefore, people of different ages at rest within the same room will inhale different masses of the particulates.

For a given person, the volume of air inhaled will differ as a function of the person's exertion level associated with the activity undertaken in that environment. The infant's air volume intake increases from 0.19 m^3 per hour to 0.84 m^3/hour as the exertion level changes from passive to moderate exertion. The person aged 16 to 21 will inhale 1.6 m^3/hour during moderate exertion level activities as compared to a 0.32 m^3/hour inhalation rate during passive activity.

To calculate a person's total chemical mass intake in that environment, the different exertion levels applicable for that environment (on a given day) must be considered. To do this, the activities relevant to the environment are identified, along with the exertion levels appropriate for each activity. Intake is then calculated based on the activities (and associated exertion levels), the proportion of time a person spends in an activity, and the duration of time in that environment. For example, on days where a child is in child care, it is expected that if he/she is 0-4 years of age, he/she will spend between 60 and 480 minutes there. While there, sixty percent (60%) of his/her time will be resting, 20 percent (20%) of his/her time will be doing activities of light exertion and twenty percent (20%) of his/her time will be doing activities of moderate exertion. These values are given for each environment, for each age group, and for each activity in those environments in Appendix D.

In this probabilistic assessment, exposure is calculated for a person at each age 500 times (500 iterations). For each iteration for each age (a person from age zero to 85), it is assumed when the person is in the environment on a given day, the time (number of minutes) in that environment is drawn from the distribution or point value defining the activity duration (e.g., activity of being in child care). In our example, a 1 year old's time in the child care environment is a value drawn from the triangular distribution defined as [Low = 60, Most Likely Value = 420, High = 480]. For that drawn value, 60% of the minutes are spent passively, 20% are with light exertion, and 20% are with moderate exertion. If, for example, the model drew the value of 120 minutes in the environment, the calculation for mass of chemical inhaled would be:

> [percent of time at passive exertion x minutes in environment x passive inhalation rate at age x chemical concentration] + [percent of time at light exertion x minutes in environment x light inhalation rate at age x chemical concentration] + [percent of time at moderate exertion x minutes in environment x moderate inhalation rate at age x chemical concentration] =
>
> [0.6 x 120 minutes x 0.28m^3/60 minutes x X µg/m^3] + [0.2 x 120 minutes x 0.72m^3/60 minutes x X µg/m^3] + [0.2 x 120 minutes x 1.3m^3/60 minutes x X µg/m^3]=
>
> [.336 x X ug] + [.288 x X ug] +[.520 x X ug] = 1.144 x X µg, where X is the mass in the original concentration of the chemical (as X ug/m^3)

When the concentration X ug/m^3 is given for the respirable particle, that concentration is used and the entire mass considered to be the exposure via inhalation.

When the concentration X ug/m^3 refers to a sample where particle size is indeterminate or not reported, we apply the assumption that ten percent (10%) of this mass is equivalent to the exposure via inhalation.

The same assessment is conducted for each of the environments for the person aged 1. The total number of minutes drawn for each of these four environments is summed, and any iteration (an assessment for one person) at that age, which considers a total of > 24 hours/day, is rejected and another iteration of the calculation conducted until there are 500 iterations considering 24 hours/day or less for that person at that age. This calculation is repeated in our assessment for each age through age 85 years yielding 500 iterations for each age for each person.

For TBB, the value for mass, X µg, is drawn for each iterative calculation from the lognormal distribution of TBB air concentration data created using data reported in Bradman et al. (2012) of a mean concentration of TBB in air (0.58 ng/m^3) with a standard deviation of 2.6 ng/m^3. These data were converted to µg/m^3 (5.8 x 10^{-4} and 2.6 x 10^{-3} µg/m^3, respectively) and the log normal distribution described by that mean and standard deviation applied to the exposure software. A different value was drawn from the distribution each time the calculation was done for every age across 500 persons (iterations). Since Bradman et al. did not discern the respirable particle concentrations, we assumed that 10 percent of the calculated mass being inhaled was actually respirable, becoming "inhalation exposure." Thus, the respirable particle concentration is calculated for each of the daily activity

conditions in each environment for each age group in all 500 iterations. In doing this, the distribution of possible exposures from respirable particles considers interpersonal and intrapersonal variations due to such factors as age and different durations in different environments.

2.5.3 Indoor Air: Ingested Particulates

In the description of the calculation of respired mass of a chemical in air (Section 2.5.2 Inhalation of Indoor Air) we noted that particles of approximately 10 micrometers (PM_{10}) or larger are less likely than smaller particles to be respired. When the concentration is given by authors for "the respirable particle fraction" (by whatever definition of respirable particle size they consider applicable), that concentration is used and the entire mass considered for exposure via inhalation. The author's decision about what particle size was appropriate to define as respirable was not questioned, and the entire calculated mass was assumed to be respirable. In this situation, no mass was calculated by us to represent particles left in the nasopharyngeal area for intake by swallowing.

When the concentration reported in the study refers to a sample where particle size is indeterminate or not reported, we apply the assumption that ten percent (10%) of this mass is respirable, and thus deposited in the alveolar region and absorbed systemically (See 2.5.2 above). Hence, for each of the calculations of that condition, the remaining 90% is assumed to have been inhaled and deposited in the nasopharyngeal area. It is then assumed to be collected in the mucus and swallowed. This mass is considered part of the oral ingestion exposure, added to the oral ingestion calculated from the hand-to-mouth ingestion contributed from dust.

For example, the particle sizes associated with the air concentrations reported for TBB in Bradman et al. (2012) were not characterized. Thus, in the calculations described in Section 2.5.2, 10% of the calculated inhaled mass was considered respirable and the remaining 90% of the calculated inhaled mass was considered to be swallowed. This 10%/90% assumption was used throughout the assessments where particle size was not reported. The assumption is noted when applied to the calculations.

2.6 Activity Profiles

To assess people's exposure to a chemical one must consider two key concepts: (1) the concentration of the chemical in media (air, dust, water, soil, etc.) in people's environments, and (2) the behaviors (activity profiles) that create the opportunities for people to come into contact with that chemical in those media. To calculate the exposure, human characteristics involved in the behaviors must be quantified. These personal characteristics involved in exposure have been collectively described as "exposure factors." Taken at its broadest meaning, the term could include activity patterns of the people in their environments

Activity profiles set up the scenarios that describe how people are brought into contact with the chemical and that describe their behaviors and other factors that are used to quantify the contact parameters.

2.6.1 Exposure Factors

As defined by EPA, exposure factors are related to human behavior and those characteristics that determine an individual's exposure to a chemical or agent (U.S. EPA, 2011). Exposure factors include the following:

- Anthropometric data, such as body weight and skin surface area
- Behavioral data, such as hand-to-mouth events, activity/time use patterns, and product use
- Physiological data, such as water/food consumption rates and inhalation rates

These data are not chemical-specific but can vary across individuals and across population groups. They are often sensitive to circumstances, such as season, temperature and weather, ethnicity, socioeconomics, gender, and age. Increasingly, information related to exposure factors can be obtained from the scientific literature, governmental statistics, international agencies, and industrial associations (Reina et al., 2014).

Where possible, exposure factors most relevant to the population of interest should be used in assessing exposure. Noting how exposure factors may vary widely among demographic groups, countries, and environments, several countries have initiated efforts to standardize exposure factors by developing systems to categorize the factors. Table 11 lists the countries and the format of the standardized exposure factors. Phillips and Moya (2014) and Reina et al. (2014) provide summaries of available exposure factors.

For this exposure assessment, we have examined the factors presented by other countries and those of EPA. Given our objective to assess general U.S. population exposures, we used primarily the exposure factors and information provided by EPA in their EFH, which includes data from the EPA 2008 Child Specific Exposure Factors Handbook (U.S. EPA, 2008).

Table 11. Nationalized exposure factor compendia.

Country	Agency	Name	Format	Last Update	Availability?
United States	U.S. EPA	Exposure Factors Handbook (EFH)	pdf	2011	http://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=236252
United States	U.S. EPA	Expo-Box	online searchable database	as needed	http://www.epa.gov/expobox Individual tables from the 2011 EFH are available for download
United States	U.S. EPA	Child Specific Exposure Factors Handbook[1]	pdf	2008	http://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=199243

Country	Agency	Name	Format	Last Update	Availability?
Canada	G. Mark Richardson and Stantec Consulting	Canadian Exposure Factors Handbook	pdf	2013	http://www.usask.ca/toxicology/docs/cef
European Union	EU Commission	ExpoFacts	online searchable database	2012	http://expofacts.jrc.ec.europa.eu/
Australia	Department of Health	Australian Exposure Factors Guide	pdf or Word Doc	2012	http://www.health.gov.au/internet/main/publishing.nsf/content/health-pubhlth-publicat-environ.htm
Japan	National Institute of Advanced Industrial Science and Technology	Japanese Exposure Factors Handbook	online summary only	2007	summary page: https://unit.aist.go.jp/riss/crm/exposurefactors/english_summary.html

[1] Child specific exposure factors incorporated into the EFH

The many individual factors relevant to assessing a person's probability of being exposed to a chemical and the extent of that exposure can be gleaned from information sources, such as those presented in Table 11, or must be estimated for the assessment at hand. For each factor, there is both intra-individual and inter-individual variation, resulting in many values for each factor. In assembling these factors for use in an exposure assessment algorithm, a given statistical representation of the group of values for a factor can be used, or the entire group of values (the distribution of values) can be used in probabilistic exposure assessment models. For this project, where possible, we applied the entire distribution of values. For each flame retardant assessment, we report the specific exposure factors used in the exposure assessments. Because this exposure assessment on flame retardants is focused on U.S. population groups, our data source for exposure factors was primarily EPA's EFH (U.S. EPA, 2011). A few factors not provided by EPA's EFH were supplied by the default factors in the LifeLine™ software. Those factors and data sources are noted for those cases.

Note that it is NOT necessary for the age breaks to be consistent with the age categories desired for the exposure assessment. For each factor, the natural "breaks" in values will change at different age intervals, some of which can be gender specific. Consider, for example, children's growth spurts. The models calculate exposure stepwise, year-by-year, applying values from the appropriate value grouping for each exposure factor. When the series of yearly exposure assessments are completed, they are then grouped into the age categories of interest to CPSC.

2.6.1.1 Hand-to-mouth Activity

Concentrations of flame retardants measured in surface dust provide an opportunity for two types of exposure. The first is via direct contact by the dust in or on the surface being contacted by the skin. The second is via oral exposures, which result from indirect contact to dust in or on environmental media via hand-to-mouth activity. The hand touches the medium and is "loaded" with some amount of the chemical or dust containing the chemical. Some fraction of that "load" transfers to the body via hand-to-mouth activity. The unloading of the chemical is defined, in part, by the number of contacts per hour and the proportion of the hand inserted into the mouth. We used values from the EFH (U.S. EPA, 2011) or the Activity Record Generator (ARG) of the LifeLine™ software for the number of hand-to-mouth events expected per hour, appropriate to the age group. One-half of the hand surface is conservatively estimated to be in the mouth at some point during the hand-to-mouth event. See Table 12.

These hand-to-mouth factors are used where dermal and oral routes are considered and data on the flame retardant concentrations in surface dust were available.

Table 12. Hand-to-Mouth Contact - events per hour and proportion of hand inserted in mouth. Source: EFH (U.S. EPA, 2011) except where noted.

Age	Events/hour (Mean)	Proportion of hand in or on mouth (ARG defaults)[1]
<1 month	30[1]	0.5
1 to < 3 months	30[1]	0.5
3 to < 6 months	28	0.5
6 to < 12 months	19	0.5
1 to < 2 years	20	0.2
2 to < 3 years	13	0.2
3 to < 6 years	15	0.2
6 to < 11 years	7	0.2/0.05[2]
11 to < 16 years	1[1]	0.05
16 to < 21 years	1[1]	0.05
≥ 21 years	1[1]	0.05

ARG = Activity Record Generator
[1]LifeLine default assumptions, based on professional judgement
[2] 0.2 for 6 years, 0.05 for 7 to <11 years

The exposure via hand-to-mouth activity is calculated as:

For one hand-to-mouth event:

> Mean value of surface of hand (m^2) x concentration of flame retardant on surface of medium in the environment ($\mu g/m^2$) = Mass "loaded" onto hand (μg).

Loaded Mass x Proportion of Hand inserted into mouth = Mass Transferred into Mouth = Mass of oral exposure for 1 hand-to-mouth activity event.

For total hand-to-mouth exposure per person per hour:

Mass of oral exposure for 1 hand-to-mouth activity event x number of events/hour

The mean value of the surface of the hand is a function of age that is provided by EFH Table 7-2 "Recommended Values for Surface Area of Body Parts: Mean Surface Area by Body Part (m^2)." The values increase with age. The concentration of the flame retardant on the surface of a medium in the environment is given in the data of the study selected for the environment and medium under consideration.

The mean number of hand-to-mouth events per hour is given by EFH Table 4-1, "Summary of Recommended Values for Mouthing Frequency and Duration for ages 3 months to 11 years." Values for other ages are provided as default assumptions by The LifeLine Group as used in the ARG Software. The proportion of hand inserted into the mouth is provided as default assumptions by The LifeLine Group as used in the ARG Software.

2.6.1.2 Inhalation Rates

Particulates and gases can enter the body when inhaled. The delivery is defined by the age-related rates of inhalation under different levels of activity. The activities considered in the assessment each have assigned levels of exertion assumed. For example, sleeping would use the "resting" level while play may use values from one or more of the higher exertion levels. We used values from Table 6.2 of the EFH (U.S. EPA, 2011) or the ARG, where appropriate. See Table 13.

The level of exertion used for each activity profile considered in the exposure assessments is listed as part of the activity-related factors noted for that activity profile, as detailed in Appendix D.

Table 13. Inhalation rates (m^3/hour) by age groups for different levels of activity. Based on m^3/minute values converted to m^3/hour by multiplying by 60 minutes/hour. Source: EFH, Table 6-2 (U.S. EPA, 2011, p. 6-47).

Age	Resting	Light Activity	Moderate
<1 month	0.19	0.46	0.84
1 to < 3 months	0.19	0.46	0.84
3 to < 6 months	0.19	0.46	0.84
6 to < 12 months	0.19	0.46	0.84
1 to < 2 years	0.28	0.72	1.3
2 to < 3 years	0.29	0.72	1.3
3 to < 6 years	0.27	0.66	1.3

Age	Resting	Light Activity	Moderate
6 to < 11 years	0.29	0.66	1.3
11 to < 16 years	0.32	0.78	1.5
16 to < 21 years	0.32	0.72	1.6
21<31 years	0.25	0.72	1.6
31<41 years	0.26	0.72	1.6
41<51 years	0.29	0.78	1.7
51<61 years	0.30	0.78	1.7
61<71 years	0.29	0.72	1.6
71<81 years	0.30	0.72	1.5
>=81 years	0.29	0.72	1.5

2.6.2 Activity Factors

Activity factors are dependent on the type of activity and ages of people doing those activities. These factors include duration of the activity, activity frequency, clothing worn, frequency of contact with a given medium, and contact duration.

Each environment (child care, home, office, car) is treated as an "activity" (spending time in child care environment, spending time in home environment; spending time in office environment; spending time in car environment). A listing of the values used for activity profile factors are presented in Appendix D.

2.6.3 Activity Profile Modeling

The ARG is one component of the LifeLine™ suite that allows the user to evaluate potential dietary and non-dietary exposures and risks across a community or population. The ARG assists the user to define a population's activities that provide the exposure opportunities. To use the ARG, the user defines activities of interest, defines the age ranges of the population or community of interest, and provides information on hand-to-mouth events, exertion level, probability of performing the activity, the activity duration, frequency of the activity, and clothing worn during the activity. The user also provides information on the material that is contacted during the activity including surface characteristics, the percentage of the body that contacts the material, the contact rate, and contact duration.

Once the activity information is entered, the ARG generates an activity profile, which is a simulation of the activities across the community or population and which is formatted appropriately for use in the exposure models. The activity profile file is then used in the Community Based Exposure and Risk Assessment Software© (CBAS) to investigate potential exposures and risks to the population of interest to substances of concern in the environment where these activities occur. In this case, the "community" is the general U.S. population and the age-specific subgroups (infants, toddlers, children, juveniles, and adults).

We note that there were some studies of flame retardant exposure relevant to specific subgroups (i.e., gymnasts, frequent flyers, commuters), but as these do not represent the general U.S. population, we

did not develop exposure profiles or exposure estimates for these subgroups. Time spent in cars is part of the "general population" overall exposure profile and is included in the exposure assessments when chemical concentration data are available for this environment.

The software provides interfaces where the assessor can select appropriate details to represent important parameters for the exposure assessment. For example, we assume clothing and shoes can block the skin's contact with surface dust containing the flame retardant. An area of exposed skin is available for contact and the rate of absorption differs across different body areas. The screen shot shown as Figure 2 below illustrates, as an example, the capacity to define the clothing/shoe coverage and parts of the body that can come into contact with surface dust.

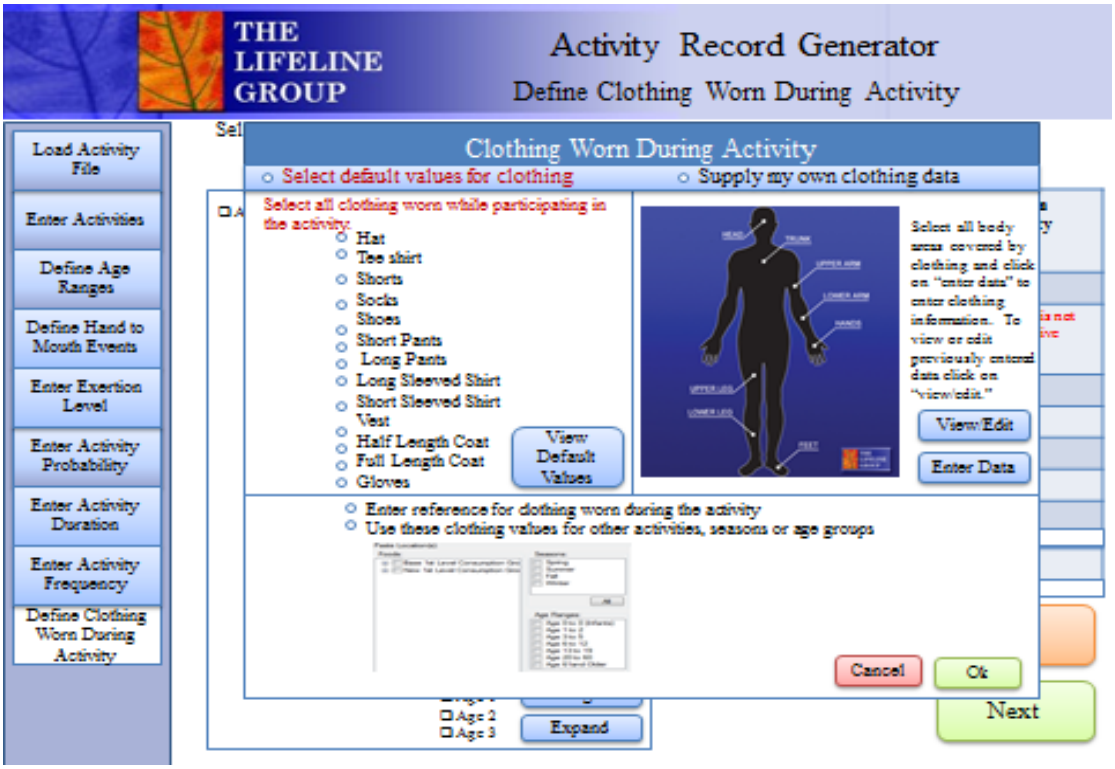

Figure 2. Screen shot of Activity Record Generator data input screen for clothing worn.

2.7 Exposure Assessment Model

The CBAS is the model in the LifeLine™ software that brings together the activities, the chemical concentrations, and the exposure factors to calculate the exposure from that chemical, under the circumstances presented by the chemical concentrations in those environments. The CBAS is a probabilistic exposure model, so the exposure "answers" are presented as a distribution of possible answers that reflect the variability and ranges of values for the different parameters in the calculations. The variability reflects the variations in activities, as well as inter-individual and some intra-individual variability of these factors. With this distribution, one can consider the mean exposure or any other point of interest, such as higher percentiles of the population's exposure. Figure 3 illustrates the components of CBAS.

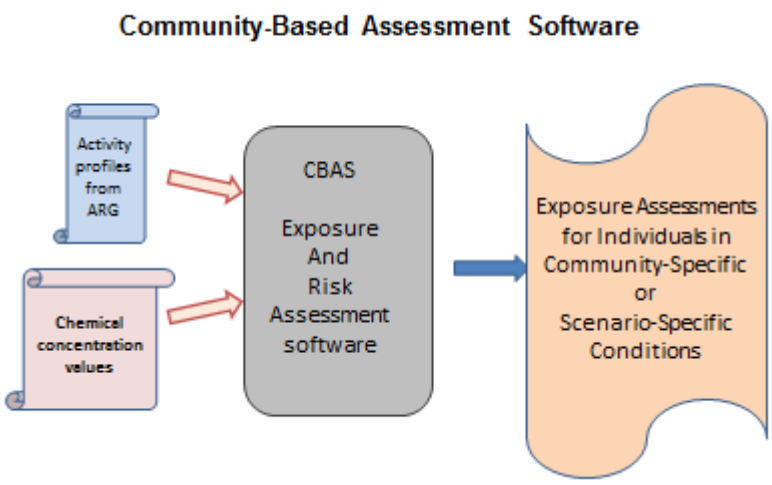

Figure 3. Components of the Community Based Exposure and Risk Assessment Software© (CBAS).

An exposure assessment for a single chemical occurring in multiple products and multiple media begins with inserting two types of information files into the CBAS.

- The *chemical concentration distributions* for all of the media in which the chemical occurs (and that are relevant for the objectives of the assessment).
- The *activity profiles*, which describe the situations by which people are in contact with those media.

Other files within the CBAS are then customized as necessary to utilize the exposure factors selected to best represent the community or scenarios being considered in the assessment. CBAS then calculates exposure for the "community" by considering one "modeled" individual at a time. For each individual, CBAS starts at birth and calculates a daily exposure, progressing day by day through 85 years of life. For each daily exposure, CBAS utilizes values drawn from the files of exposure factors and age-dependent activity profiles appropriate for that age. This process is repeated 500 times, creating day-by-day exposures for 500 modeled individuals representing the U.S. population groups. The calculations utilize draws from the distribution of values in the different data sets. Hence, the exposure assessments for a given age/day across the thousands of individuals will reflect the variation in those data sets. The results are then grouped according to the defined age groupings, and the variation that will be experienced across individuals in that age grouping can be displayed. From that exposure distribution, the range, mean, maximum, and any percentile of interest are seen. Those values are available in data file formats and easily depicted graphically, as in Figure 4 below.

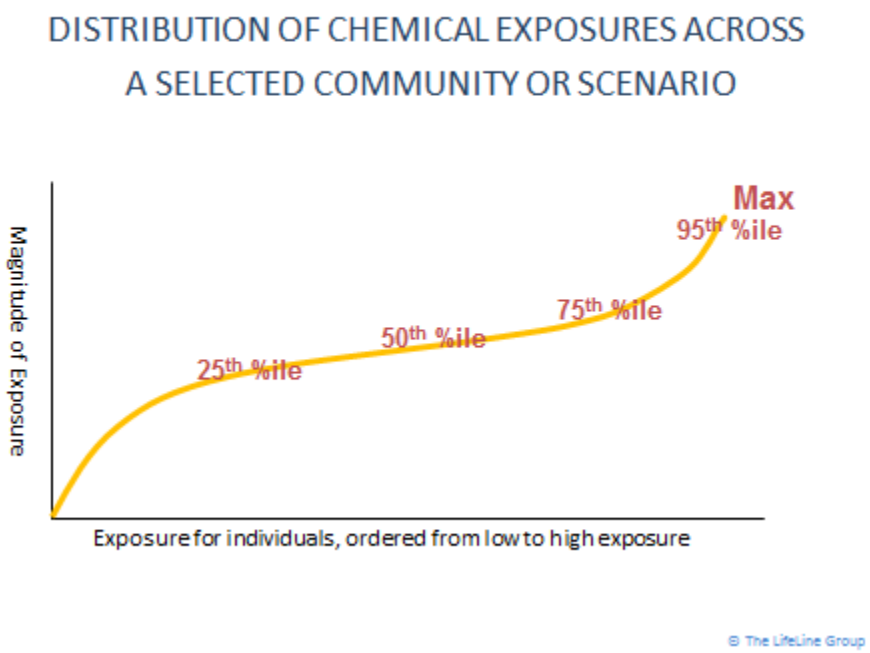

Figure 4. Distribution of chemical exposure across a selected community or scenario.

CPSC requested that we develop distributions for central tendency. The probabilistic model is set for 500 iterative calculations for each exposure assessment. This provides stable results in the normative area of the exposure assessment distribution (25^{th} to 75^{th} percentile or broader—the area of interest for the CPSC objectives. If one were interested in the extreme tail of the assessment (95^{th} percentile or higher), a larger number of iterative calculations (one or several thousand) would be necessary to stabilize that area of the distribution.

The LifeLine™ exposure software, including the ARG and CBAS used in these assessments, are freely available from The LifeLine Group. Associated tutorials and other background information are available at www.TheLifeLineGroup.org or by contacting the authors of this report.

3 Results

This section presents the results from the probabilistic exposure assessment runs. Data were selected based upon a careful evaluation of the available studies. Preference was given to studies that reported data with metrics that provided an opportunity to construct parametric distributions of possible concentration values. Results from the published data were converted into appropriate units for use in the exposure model and for consistency in this report. The exposure software requires input concentrations to be expressed in micrograms. Many of the studies reported their findings in nanograms; therefore, we present the results of the probabilistic assessment in nanograms.

Appendix C includes a detailed presentation of the studies considered, data selected, and statistical methods applied to set up the distribution of values for each flame retardant in dust and/or air for the different environments.

For some environment/media combinations, adequate data were not available. Because of this, the combined exposures may not reflect actual total exposure to the flame retardant. Table 3 in Section 1 shows the data availability for each flame retardant environment/media.

As adequate data were available, the probabilistic assessment considered multiple exposure routes (inhalation, oral, and dermal) from air and dust concentrations for each of the four environment types (child care, home, office, and car). Inhalation exposures were calculated using air concentration data. Oral exposure reflects ingestion of dust from hand-to-mouth activity and ingestion of air particles from mucocilliary clearance. Dermal exposure utilized data from dust. Factors for the activity profiles are detailed in Appendix D.

Adequate contaminant concentration data were limited for some chemicals in some media and so results do not always include all routes of exposure for each environment for each chemical. Where adequate chemical contaminant concentration data were available, daily exposures were calculated and reported below for all flame retardants considering:

- exposures from child care environment only
- exposures from the home environment only
- exposures from the office environment only
- exposures from the car environment only
- exposure from a combination of all environments

Because CPSC is interested in the general exposures across the population, the quantitative results are presented for the 25^{th}, 50^{th}, and 75^{th} percentiles of exposure for these scenarios. A graphical representation of the full range of exposures across all percentiles of the population groups are presented when exposures were more than minimal (>0.01 ng/kg/day).

Caution should be use in interpreting the results of these exposure assessments. Exposure estimates may appear low or high relative to other environments or flame retardant assessments. However, the actual human health risk depends upon the toxicity of the chemical. Lower exposures to more toxic chemicals may have greater health risk than larger exposures to less toxic chemicals.

3.1 TDCPP Results

TDCPP concentration data were available for air and dust in child care, home, office, and car environments.

Table 14. TDCPP chemical concentration and type of value used for each media and environment for the exposure assessment. Note that units are in µg/area.

Study	Medium	Data from Study	Data Application
Child Care			
Bradman et al., 2012	Dust	25th, 50th, 75th percentiles 2.57E-04, 6E-04, 1.1E-03 µg/cm^2	Authors reported 25th, 50th, and 75th percentile values. No dust mass/area correction needed because study incorporated area distribution of chemical mass. Used author's three concentration percentiles as point values
Bradman et al., 2012	Air	Mean and SD 5.9E-04 ,3.6E-04 µg/m^3	Mean and SD as reported by the authors used to create log normal distribution using Crystal Ball™. Derived distribution used for exposure assessment with 10%/90% default assumption for respired/ingested fractions.
Home			
Fan et al., 2014	Dust	Median values from each of two study designs reported: 2.7 and 2.0 µg/g	Averaged the two median values and corrected for dust loading using EFH factors (all but front door mat) yielding mass over area of 1.8 E-04 µg/cm^2, used as point value.
Bergh et al., 2011	Air	Mean 3.1E-03 µg/m^3	Mean value as reported used as point value with 10%/90% default for respired/ingested fractions.
Office			
Carignan et al., 2013	Dust	GM 6.06 µg/g	GM corrected for dust loading using EFH factors (all but front door mat) yielding mass over area of 4.65E-04 µg/cm^2 used as point value
Yang et al., 2014	Air	Median 6.3E-04 µg/m^3	Median as reported by the authors used as point value with 10%/90% default assumption for inspired/ingested fractions.
Car			
Carignan et al., 2013	Dust	GM (GSD) 12.5 (6.5) µg/g	GM (GSD) corrected for dust loading using EFH untracked area of downstairs carpet factor only, because only car seat fabric sampled in study. Corrected mass over area GM (GSD) of 7.25E-04 (3.77E-04) µg/cm^2 used to create log normal distribution using Crystal Ball™.
Staaf and Ostman, 2005	Air	Single value 5E-03 µg/m^3	5E-03 µg/m^{3}used as point value with 10%/90% default for respired/ingested fractions.

GM = geometric mean; GSD = geometric standard deviation

Tables 15-18 and Figures 5-8 present the results of the probabilistic modeling for TDCPP exposures for the modeled environments. These show the results of the full range of exposures across all percentiles of the population groups for the modeled environments.

Table 15. Results of probabilistic exposure assessment of TDCPP exposure by age group in the child care environment.

Age Group (years)	Child Care Percentile (ng/kg/day)		
	25th	50th	75th
<1	0.02	0.02	0.03
1 - <3	0.02	0.02	0.02
3 - <12	0.01	0.01	0.01
12 - <18	0.01	0.01	0.01
>= 18	0.01	0.01	0.01

Table 16. Results of probabilistic exposure assessment of TDCPP exposure by age group in the home environment.

Age Group (years)	Home Percentile (ng/kg/day)		
	25th	50th	75th
<1	0.07	0.07	0.07
1 - <3	0.08	0.09	0.10
3 - <12	0.03	0.04	0.05
12 - <18	0.01	0.02	0.02
>= 18	0.01	0.02	0.02

Table 17. Results of probabilistic exposure assessment of TDCPP exposure by age group in the office environment.

Age Group (years)	Office Percentile (ng/kg/day)		
	25th	50th	75th
<1	NA	NA	NA
1 - <3	NA	NA	NA
3 - <12	NA	NA	NA
12 - <18	NA	NA	NA
>= 18	0.01	0.01	0.01

NA = Not Applicable

Table 18. Results of probabilistic exposure assessment of TDCPP exposure by age group in the car environment.

Age Group (years)	Car Percentile (ng/kg/day)		
	25th	50th	75th
<1	0.03	0.04	0.04
1 - <3	0.04	0.04	0.05
3 - <12	0.01	0.02	0.02
12 - <18	0.01	0.01	0.01
>= 18	0.01	0.01	0.01

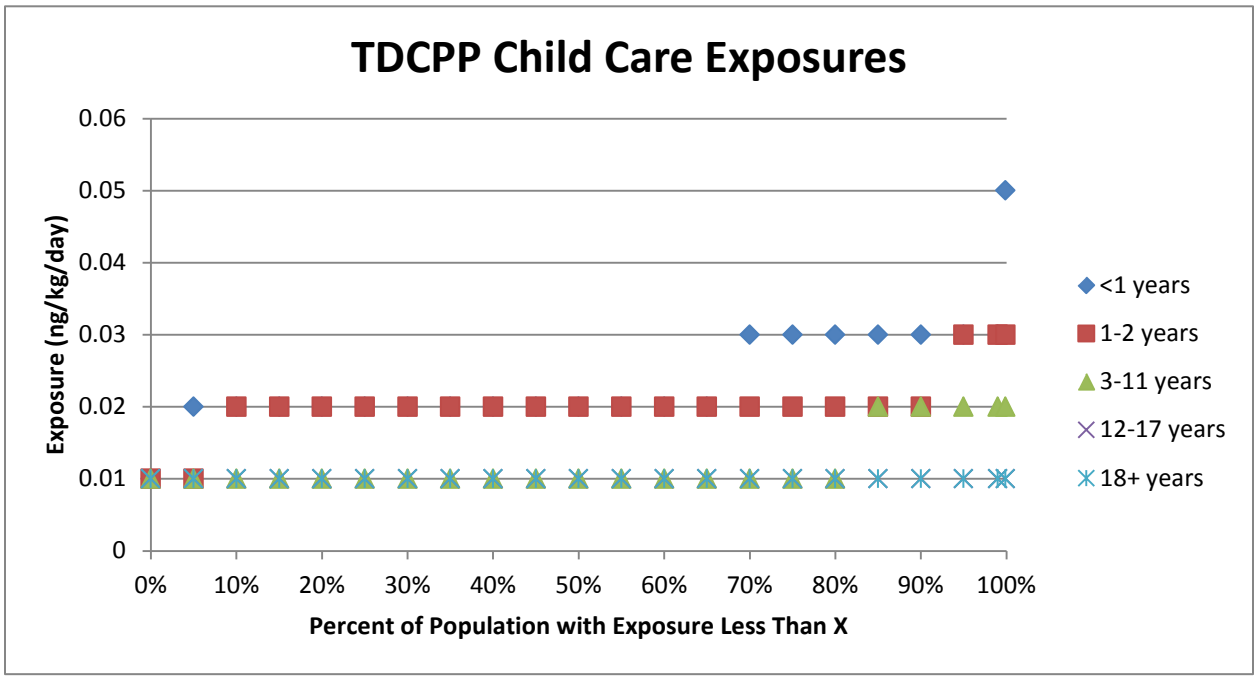

Figure 5. The full range of exposures across all percentiles of the population groups for TDCPP from the child care environment.

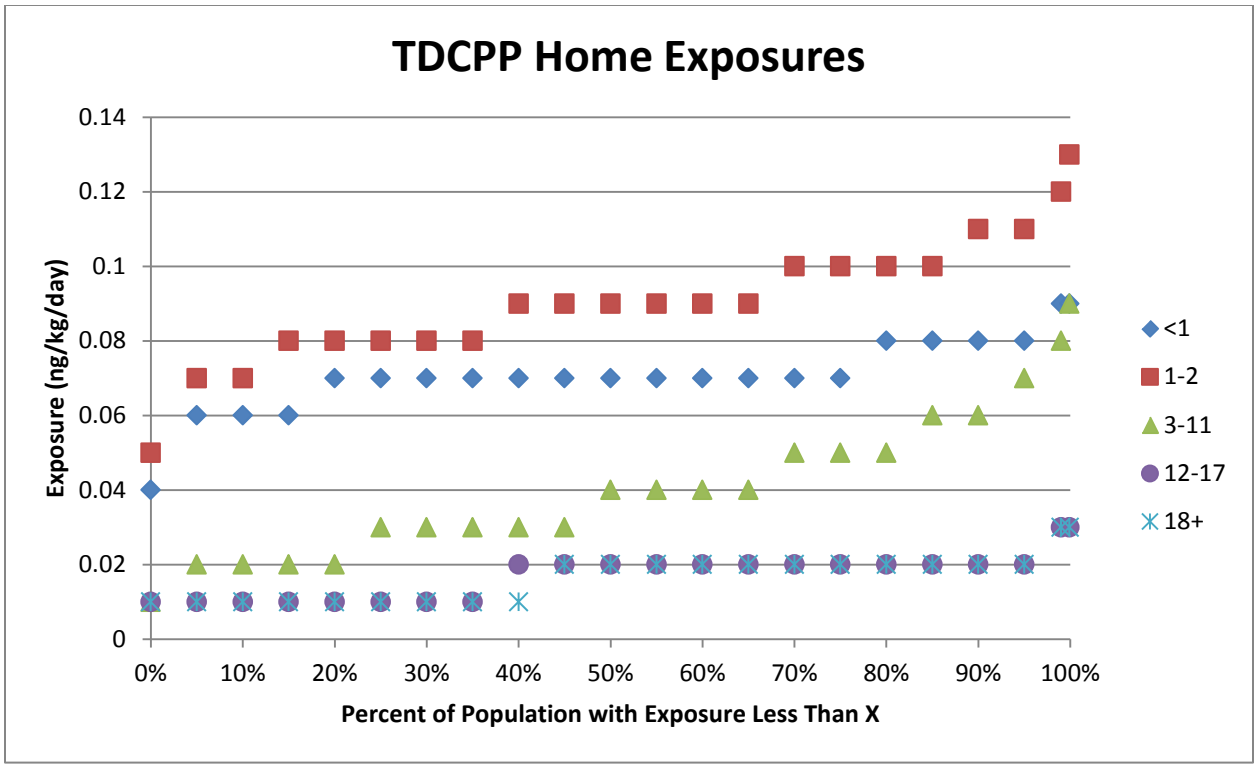

Figure 6. The full range of exposures across all percentiles of the population groups for TDCPP from the home environment.

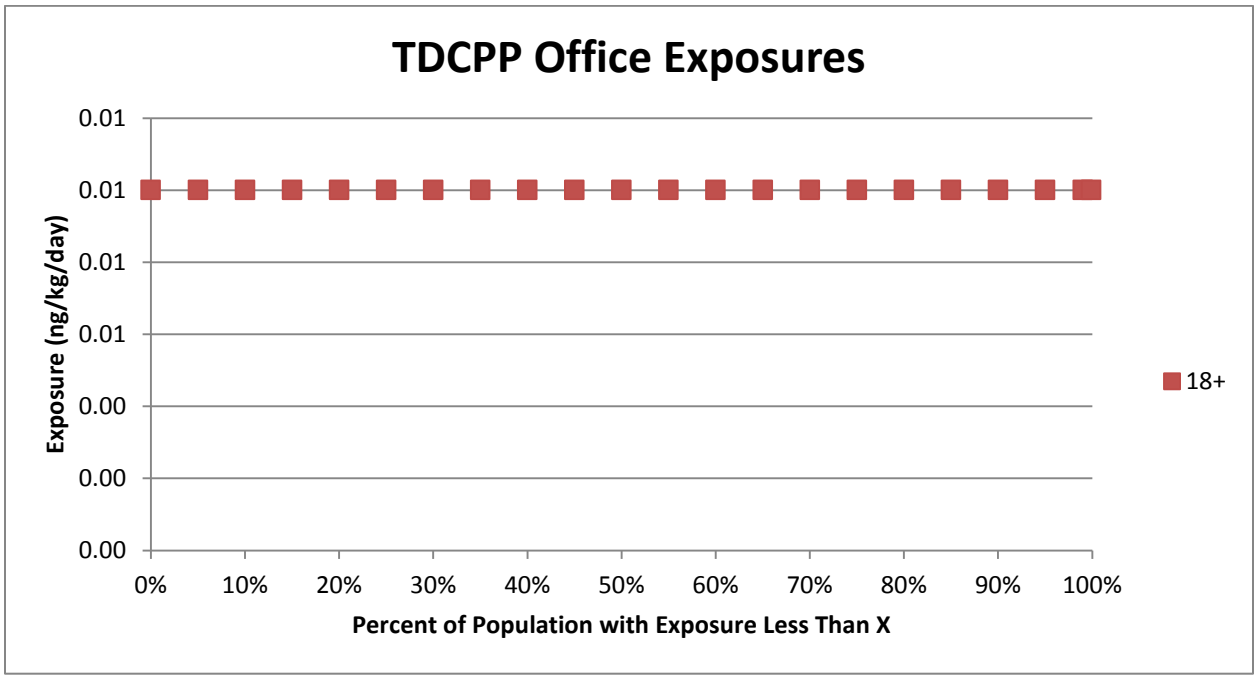

Figure 7. The full range of exposures across all percentiles of the adult population for TDCPP from the office environment.

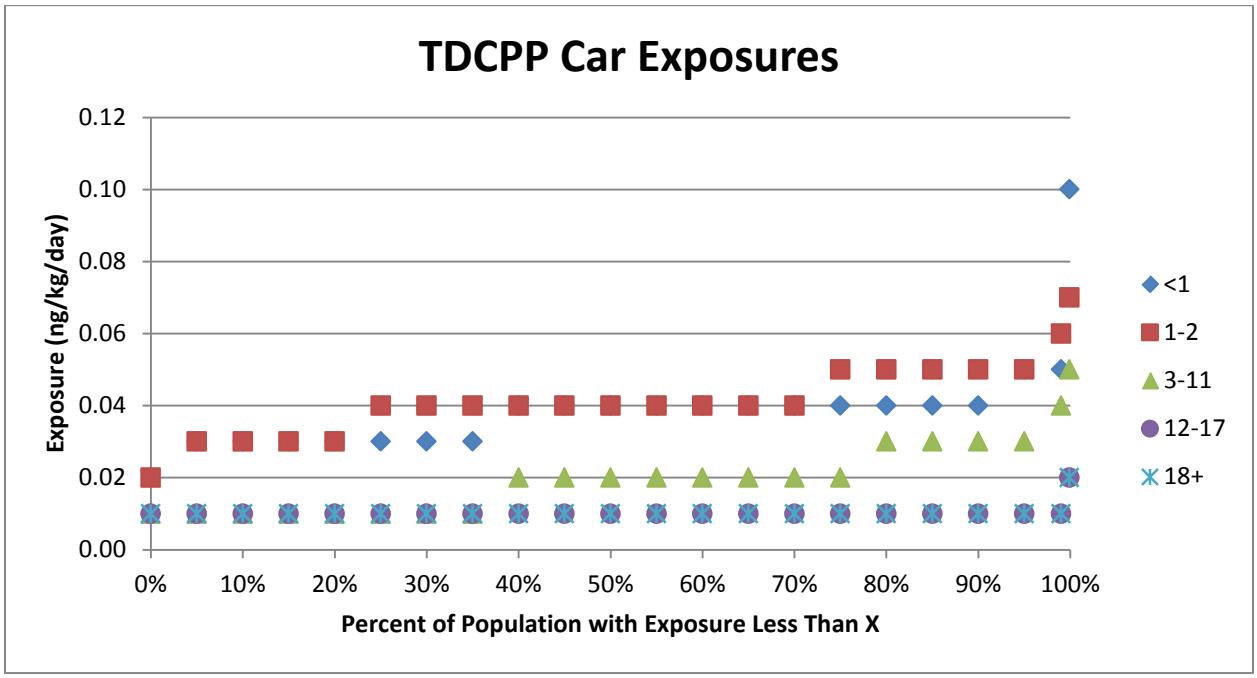

Figure 8. The full range of exposures across all percentiles of the population groups for TDCPP from the car environment.

Table 19 and Figure 9 show the results of the combination of all exposures from the modeled scenarios.

Table 19. TDCPP exposure estimates for combined exposures from the child care, home, office and car scenarios, by age group.

Age Group (years)	Combined Percentile (ng/kg/day)		
	25th	50th	75th
<1	0.12	0.12	0.13
1 - <3	0.13	0.15	0.16
3 - <12	0.04	0.06	0.08
12 - <18	0.02	0.02	0.03
>= 18	0.02	0.03	0.04

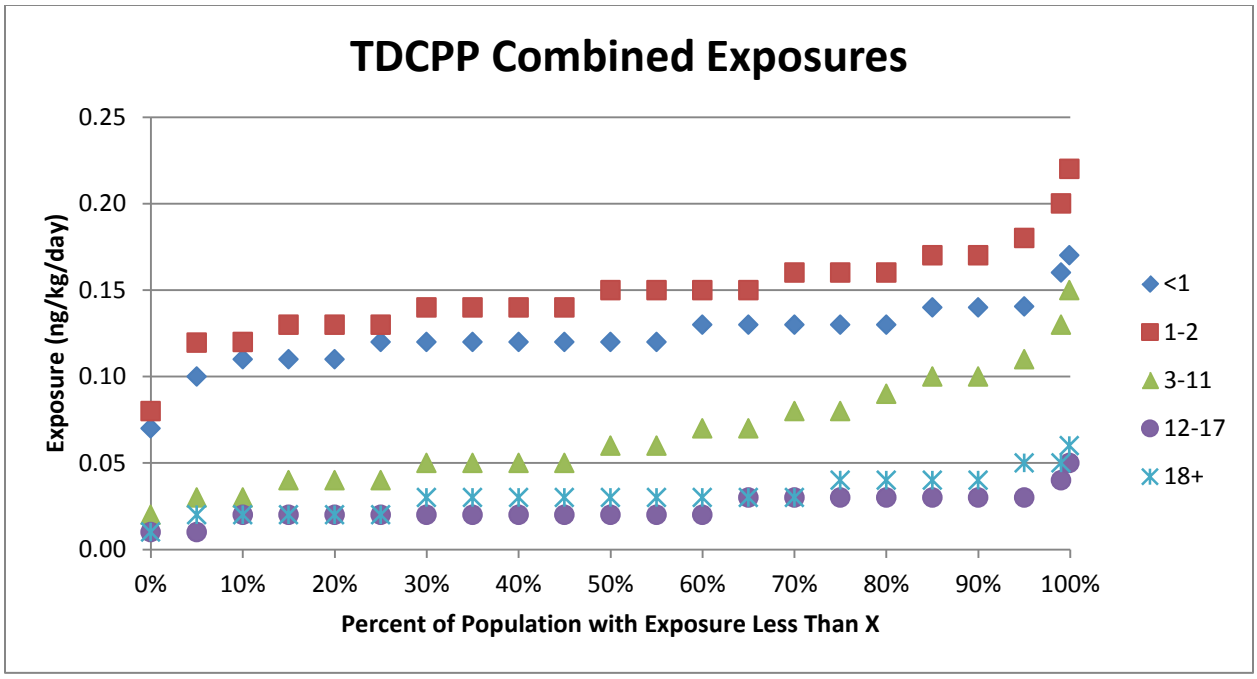

Figure 9. The full range of exposures across all percentiles of the population groups for TDCPP from all exposures.

3.1.1 Discussion of TDCPP Results

TDCPP exposures in child care, home, office, and car environments were informed by studies providing concentration values for dust and air in each of these environments. Overall, the highest exposures were experienced by children through 12 years, especially for the 1 to <3 years group. Exposures in the home were highest for the 1 to <3 years group, followed by car and child care centers. This age group also experienced the highest exposures when all four environments were combined.

Infants and children in the 1-<3 years groups have frequent hand-to-mouth events and a relatively large proportion of their body surfaces are in contact with surfaces in the home, car and child care centers that could have contaminated dust on the surfaces. Because the exposure is expressed in terms of mass of chemical per kg body weight per day, the exposures are likely to be higher for young children as their body weights are lower than older children and adults.

Adults experienced the highest exposures in the office setting, although this exposure and the combined exposures to them from all environments were relatively low as compared to all other age groups. Comparatively, exposures are low for adults in the home and car environments.

3.2 TCPP Results

TCPP concentration data (Table 20) for air were available for the child care and office environments. Dust and air concentrations were available for the home environment. No data were available for cars.

Table 20. TCPP chemical concentration and type of value used for each media and environment for the exposure assessment. Note that units are in µg/area.

Study	Medium	Data from Study	Data Application
Child Care			
Marklund et al., 2005	Air	Mean value 2.8E-02 µg/m^3	Mean value as reported used as point value with 10%/90% default for respired/ingested fractions.
Home			
Fan et al., 2014	Dust	Median value 1.1 µg/g	Mean value corrected for dust loading using EFH factors (all but front door mat) yielding mass over area of 8.43E-05 µg/cm^2, used as point value.
Marklund et al., 2005	Air	Average of: average of two samples from bedroom 3.8E-02µg/m^3 and average of two samples from living room 2.1E-01 µg/m^3 = 1.24E-01 µg/m^3	1.24E-01 µg/m^3used as point value with 10%/90% default for respired/ingested fractions.
Office			
Yang et al., 2014	Air	Median 7.76E-03 µg/m^3	7.76E-03 µg/m^3 used as point value with 10%/90% default for respired/ingested fractions.

Tables 21-23 and Figures 10-12 present the results of the probabilistic modeling for TCPP exposures for the modeled environments. These show the results of the full range of exposures across all percentiles of the population groups for the modeled environments.

Table 21. Results of probabilistic exposure assessment of TCPP exposure by age group in the child care environment.

Age Group (years)	Child Care Percentile (ng/kg/day)		
	25th	50th	75th
<1	0.69	0.76	0.84
1 - <3	0.47	0.54	0.62
3 - <12	0.12	0.17	0.27
12 - <18	0.06	0.08	0.09
>= 18	0.06	0.08	0.10

Table 22. Results of probabilistic exposure assessment of TCPP exposure by age group in the home environment.

Age Group (years)	Home Percentile (ng/kg/day)		
	25th	50th	75th
<1	2.59	2.74	2.91
1 - <3	3.14	3.49	3.84
3 - <12	0.98	1.33	1.92
12 - <18	0.51	0.61	0.72
>= 18	0.48	0.58	0.70

Table 23. Results of probabilistic exposure assessment of TCPP exposure by age group in the office environment.

Age Group (years)	Office Percentile (ng/kg/day)		
	25th	50th	75th
<1	NA	NA	NA
1 - <3	NA	NA	NA
3 - <12	NA	NA	NA
12 - <18	NA	NA	NA
>= 18	0.03	0.03	0.04

NA – not applicable

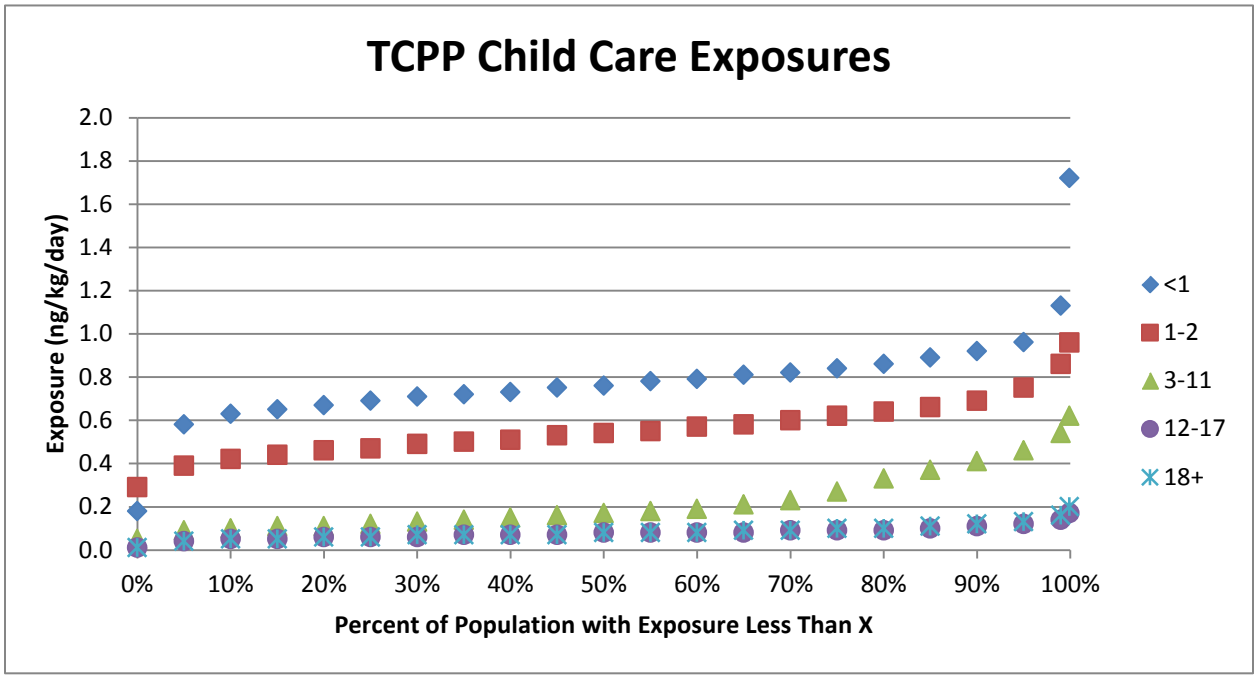

Figure 10. The full range of exposures across all percentiles of the population groups for TCPP from the child care environment.

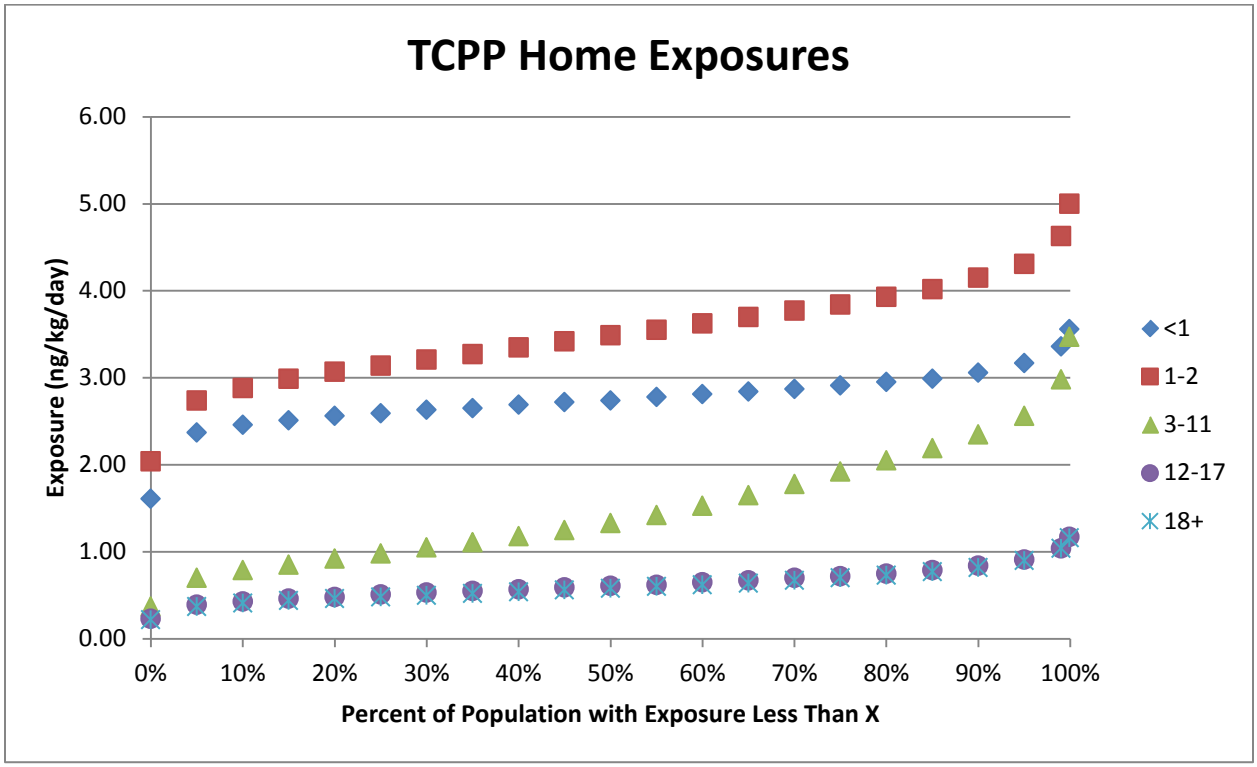

Figure 11. The full range of exposures across all percentiles of the population groups for TCPP from the home environment.

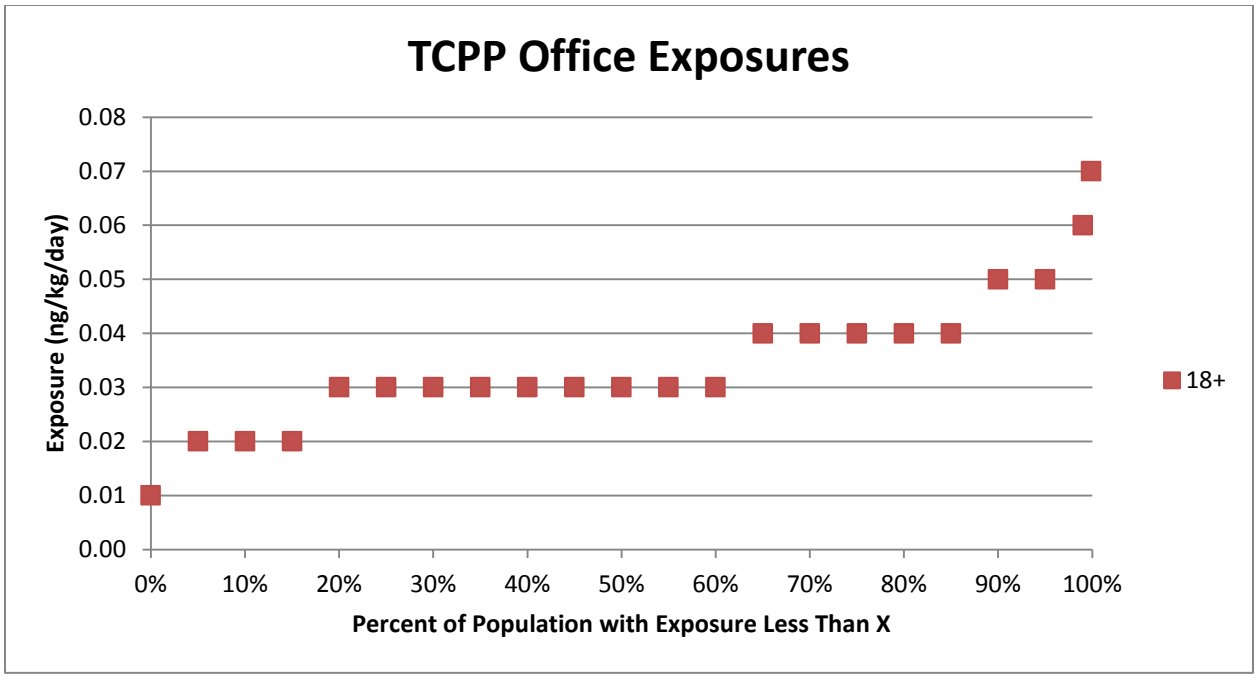

Figure 12. The full range of exposures across all percentiles of the adult population for TCPP from the office environment.

Table 24 and Figure 13 show the results of the combination of all exposures from the modeled scenarios.

Table 24. Results of probabilistic exposure assessment of TCPP exposure by age group in all environments, combined.

Age Group (years)	Combined Percentile (ng/kg/day)		
	25th	50th	75th
<1	3.15	3.33	3.53
1 - <3	3.73	4.12	4.56
3 - <12	1.12	1.53	2.32
12 - <18	0.51	0.62	0.74
>= 18	0.60	0.71	0.87

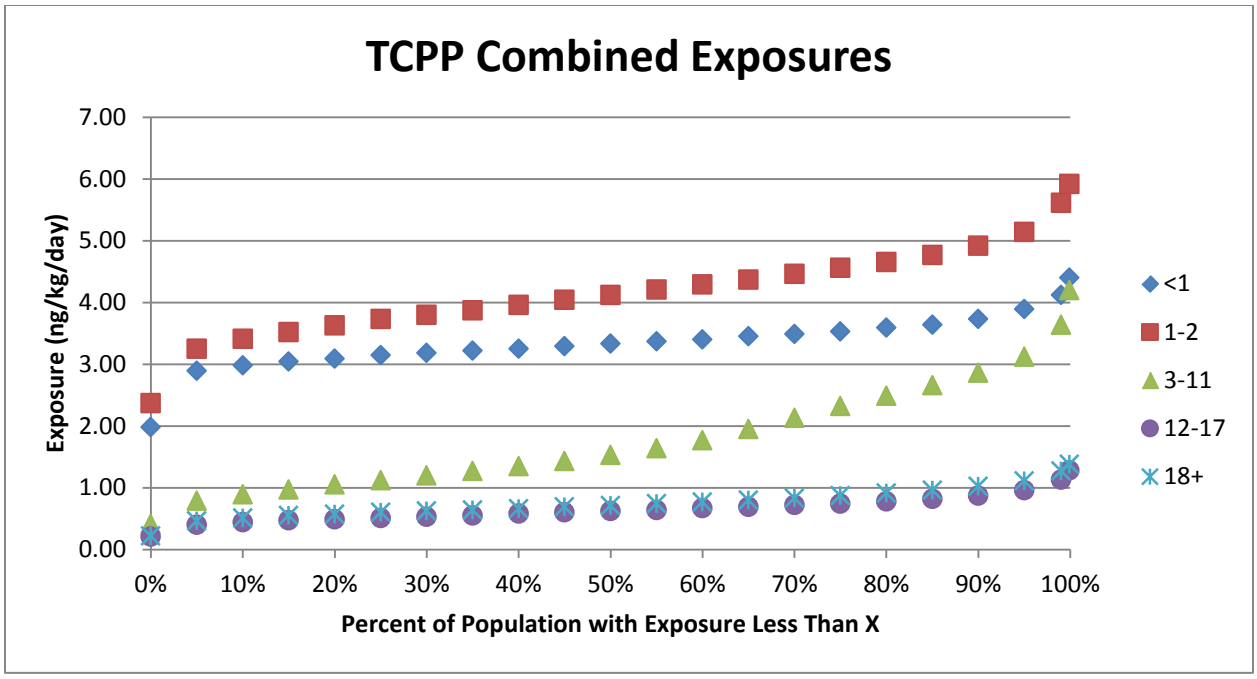

Figure 13. The full range of exposures across all percentiles of the population groups for TCPP from all combined exposures.

3.2.1 Discussion of TCPP Results

Significant data gaps complicate the conclusions that can be drawn from the exposure assessments for TCPP. No data were available measuring concentrations of TCPP in the dust of child care facilities, offices, or cars. Without these data, exposures are not considered for dermal contact with the dust on floors and other surfaces, or for the exposures consequential to hand-to-mouth events when hands are loaded with TCPP from the floors or other surfaces. Dust can be a notable source of children's exposures in child care, home, and car environments. Data for both dust and air concentrations of TCPP in the home environment are available, and the highest exposures are experienced by infants and children 1 to <3 years old. Children in this age group have frequent hand-to-mouth events and a relatively large proportion of their body surfaces are in contact with surfaces that could have contaminated dust on the surfaces. Because the exposure is expressed in terms of mass of chemical per kg body weight per day, the exposures are expected to be higher for young children as their body weights are lower than older children and adults.

When considering the exposures from all three environments, the infants and children 1 to <3 years experienced the highest exposures. Combined exposures for approximately sixty percent of the children 3-11 years are low but the remaining percentage of children experience four to six-fold higher exposure levels, and the highest exposures in this group approach those of the young children (1 to 3 years). As this is a very broad age grouping (3-11 years), the differences in exposure are likely to be from a combination of higher body weight for older children, less time spent in the home and child care center per day, less hand-to-mouth activity for older children, and less body surface contact with contaminated surfaces.

Data were not available to estimate exposures from dust and air in cars.

Exposures to teens and adults were relatively low for all scenarios. This reflects the lower concentrations of TCPP in office air as compared to other environments, higher adult body weights, and less time spent per day in the home and child care centers where air concentrations were higher and dust concentrations contributed to the exposure (home environment). There also were no data to assess exposure for the office setting from dust. Dust can be an important source of exposure, so the exposure calculated for the office environment is likely underestimated.

3.3 TCEP Results

Table 25. TCEP concentration data were available for dust and air in child care, home, office, and car environments.

Study	Medium	Data from Study	Data Application
Child Care			
Bradman et al., 2012	Dust	Median 8.38E-01 µg/m^2	Median 8.38E-01 µg/m^2 used. No dust mass/area correction needed because study incorporated area distribution of chemical mass.
	Air	Mean and SD 2.69E-03 (3.89E-03) µg/m^3	Mean and Standard Deviation as reported by the authors used to create log normal distribution using Crystal Ball™. Derived distribution used for exposure assessment with 10%/90% default assumption for respired/ingested fractions.
Home			
Ingerowski et al., 2001	Dust	Median 6.0E-01 µg/g	Median corrected for dust loading using EFH factors (all but front door mat) yielding mass over area of 4.6E-05 µg/cm^2 used as point value
Bergh et al., 2011	Air	Mean 8.3E-03 µg/m^3	Mean of 8.3E-03 µg/m^3 as reported by the authors used as point value with 10%/90% default assumption for respired/ingested fractions.
Office			
Marklund et al., 2003	Dust	48 mg/kg (4.8E01 µg/g) reported as an average of two samples from office linoleum.	The average dust concentration (4.8E01 µg/g) corrected for dust loading with EFH factors for tracked and untracked linoleum (0.08 and 0.06 g/m^2, respectively) yielding mass over area calculations of 3.84E-04 and 2.88E-04 µg/cm^2. Both values were used as point values in the exposure assessment.
Marklund et al., 2005	Air	730 ng/m^3 (7.30E-01 µg/m^3) reported as average of two samples from office.	7.30E-01 µg/m^3 used as point value with 10%/90% default assumption for respired/ingested fractions.
Car			
Brandsma et al., 2014	Dust	Mean dashboard concentration = 2.8 µg/g Mean seat dust concentration = 6.0E-01 µg/g	Each mean was corrected for dust loading. We assumed that dust loading on seats is equivalent to EFH dust loading on carpet and dust loading on dash board equivalent to dust loading on untracked linoleum. Corrected mass over area = 3.48E-05 µg/cm^2 for seats, and 1.68E-05 µg/cm^2 for dashboard. The average of these is 2.58 E-05 µg/cm^2, which was used as point value in assessment.
Hartmann et al., 2004	Air	Three individual values were reported: 4.3, 9.4 and 7.4 ng/m^3	We used the average of these three individual values, 7.0E-03 µg/m^3 with 10%/90% default assumption for respired/ingested fractions.

Tables 26-29 and Figures 14-17 present the results of the probabilistic modeling for TCEP exposures for the modeled environments. These show the results of the full range of exposures across all percentiles of the population groups for the modeled environments.

Table 26. Results of probabilistic exposure assessment of TCEP exposure by age group in the child care environment.

Age Group (years)	Child Care Percentile (ng/kg/day)		
	25th	50th	75th
<1	0.06	0.07	0.08
1 - <3	0.04	0.05	0.06
3 - <12	0.01	0.02	0.03
12 - <18	0.01	0.01	0.01
>= 18	0.01	0.01	0.01

Table 27. Results of probabilistic exposure assessment of TCEP exposure by age group in the home environment.

Age Group (years)	Home Percentile (ng/kg/day)		
	25th	50th	75th
<1	0.17	0.19	0.20
1 - <3	0.21	0.23	0.26
3 - <12	0.07	0.09	0.13
12 - <18	0.03	0.04	0.05
>= 18	0.03	0.04	0.05

Table 28. Results of probabilistic exposure assessment of TCEP exposure by age group in the office environment.

Age Group (years)	Office Percentile (ng/kg/day)		
	25th	50th	75th
<1	NA	NA	NA
1 - <3	NA	NA	NA
3 - <12	NA	NA	NA
12 - <18	NA	NA	NA
>= 18	2.53	3.06	3.67

NA = not applicable

Table 29. Results of probabilistic exposure assessment of TCEP exposure by age group in the car environment.

Age Group (years)	Car Percentile (ng/kg/day)		
	25th	50th	75th
<1	0.05	0.05	0.06
1 - <3	0.05	0.06	0.06
3 - <12	0.02	0.03	0.03
12 - <18	0.01	0.01	0.01
>= 18	0.01	0.01	0.01

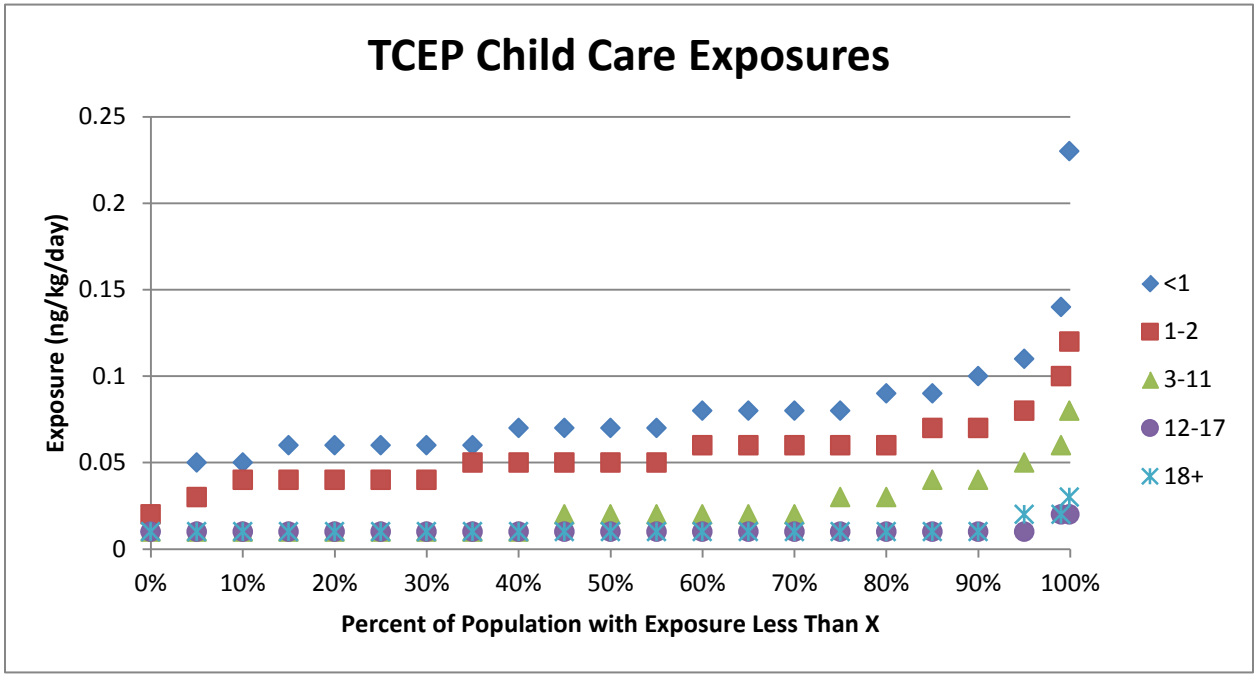

Figure 14. The full range of exposures across all percentiles of the population groups for TCEP from the child care environment.

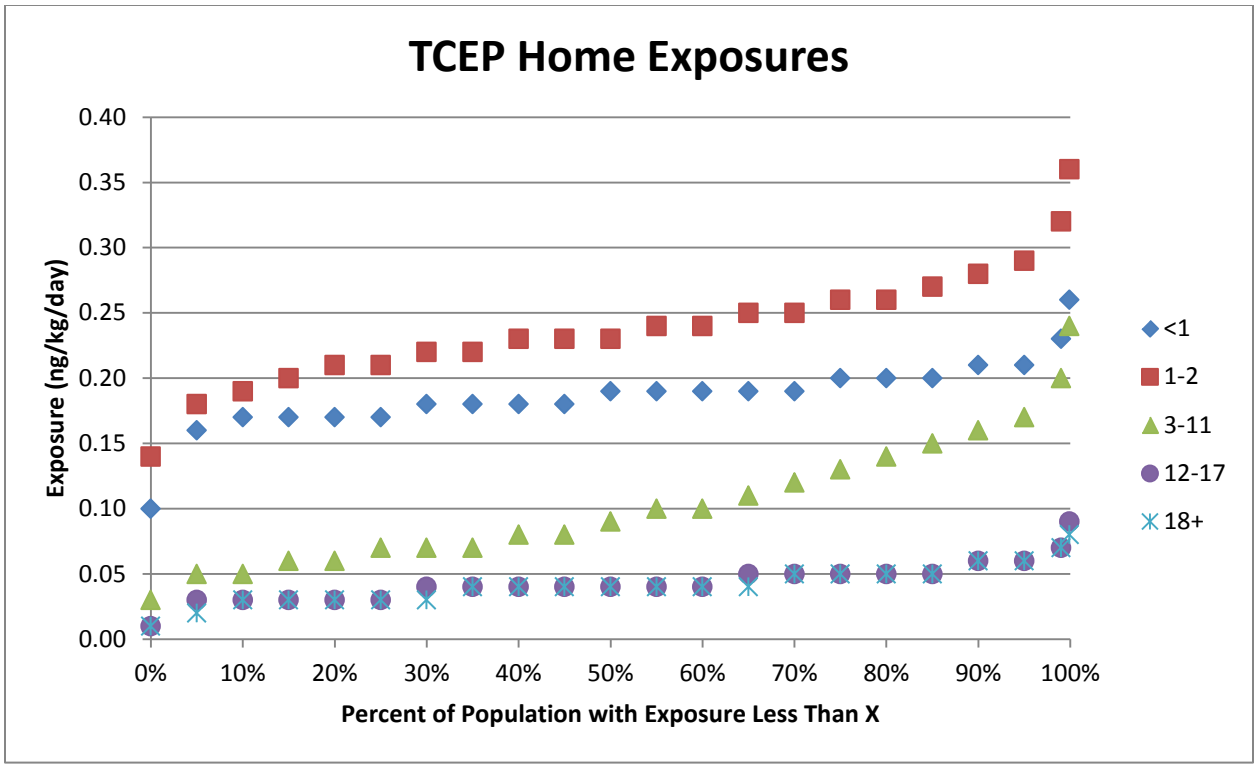

Figure 15. The full range of exposures across all percentiles of the population groups for TCEP from the home environment.

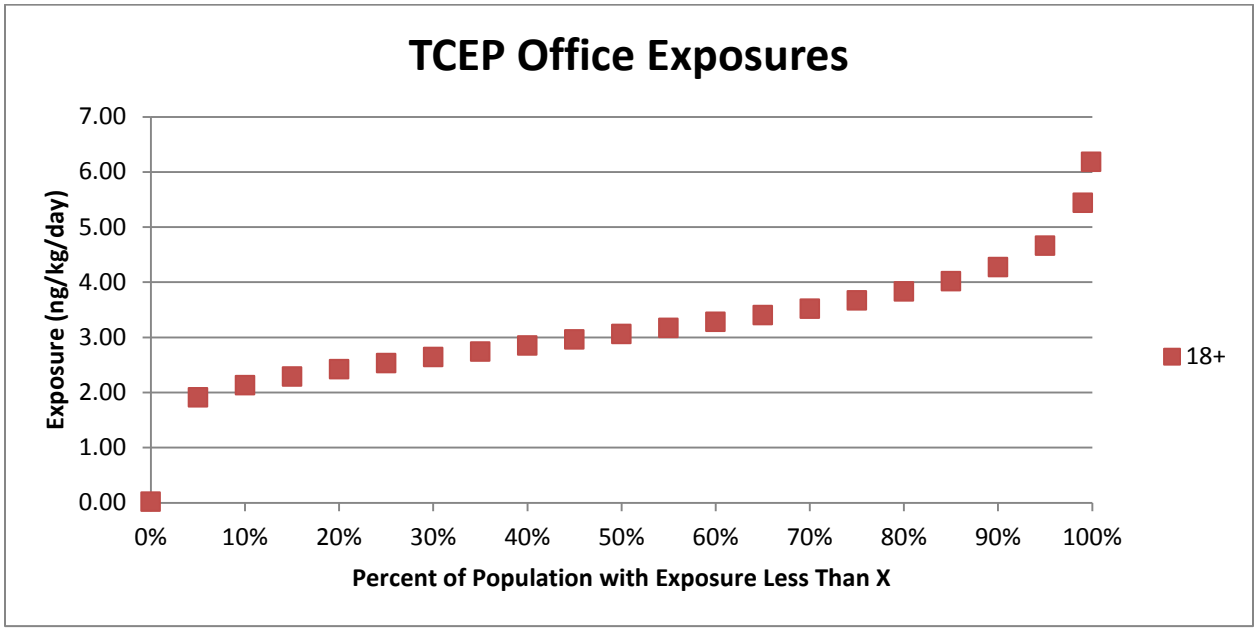

Figure 16. The full range of exposures across all percentiles of the adult population for TCEP from the office environment.

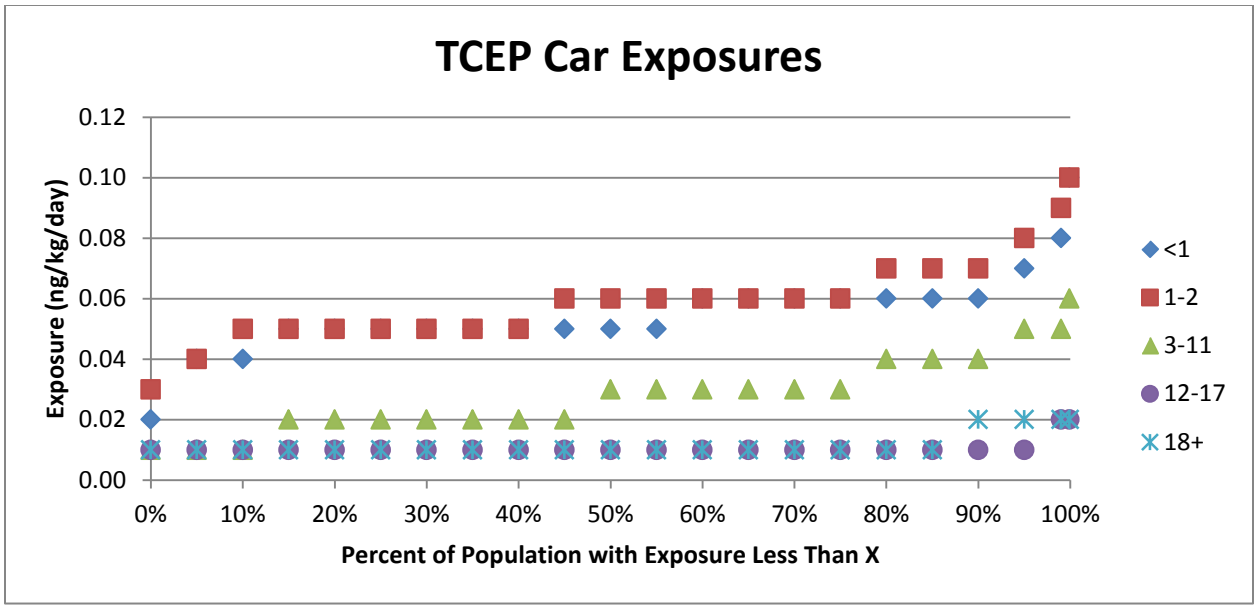

Figure 17. The full range of exposures across all percentiles of the population groups for TCEP from the car environment.

Table 30 and Figure 18 show the results of the combination of all exposures from the modeled scenarios for TCEP.

Table 30. Results of probabilistic exposure assessment of TCEP exposure by age group in all environments, combined.

Age Group (years)	Combined Percentile (ng/kg/day)		
	25th	50th	75th
<1	0.30	0.32	0.34
1 - <3	0.34	0.38	0.42
3 - <12	0.12	0.15	0.22
12 - <18	0.05	0.06	0.07
>= 18	0.09	2.10	2.78

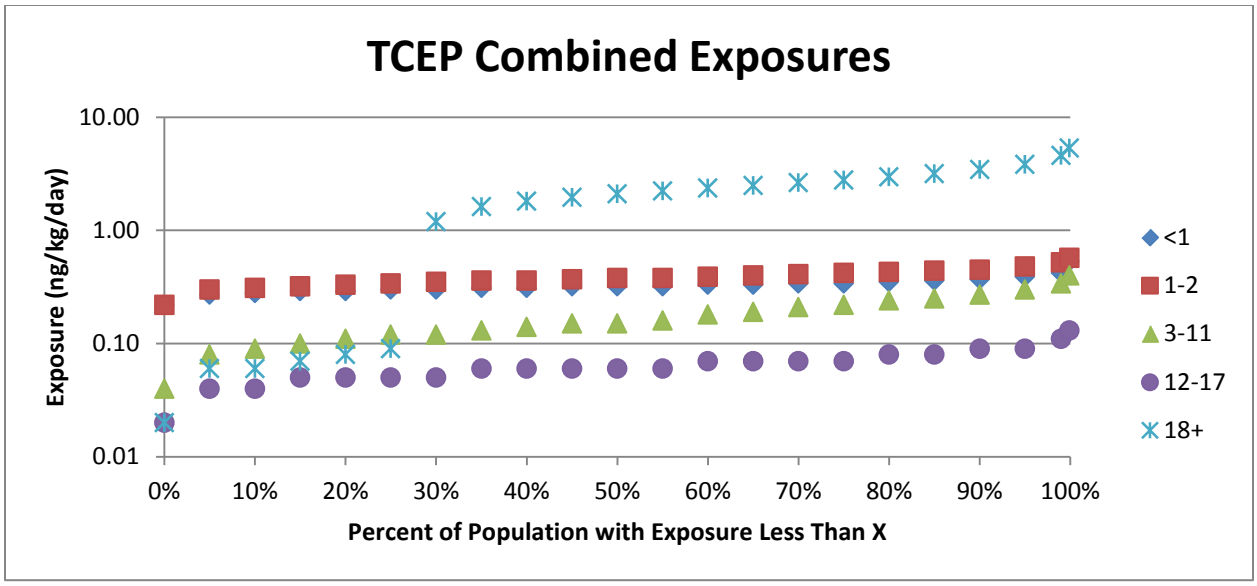

Figure 18. The full range of exposures across all percentiles of the population groups for TCEP from all exposures.

3.3.1 Discussion of TCEP Results

Data were available for TCEP concentrations in dust and air for all environments. Infants and children 1 to <3 years experienced the highest exposures in the child care center, home, and car environments. Children in this age group have frequent hand-to-mouth events and a relatively large proportion of their body surfaces are in contact with surfaces that could have contaminated dust on the surfaces. Because the exposure is expressed in terms of mass of chemical per kg body weight per day, the exposures are likely to be higher for young children as their body weights are lower than older children and adults. The younger children also spend most of their day in the home and child care environments.

Adults (people 18 and older) experienced their highest exposures in the office setting and had higher exposures relative to other population age groups in the combined environments assessment likely due to high air and dust concentrations of TCEP in the office environment. As adults spend a greater proportion of their day in the office setting, their exposures increase. The assessments of "office only" show a distribution of exposure higher than the combined exposures. In these assessments, the "office only" scenario permits far more hours of the full day in the office than when all environments are considered. When combining the exposure scenarios (car, home, and office environments), the time spent by the adult includes the car and home scenarios where the concentrations were lower; therefore the full day's exposure is lower than if those hours had been spent only in the office scenario. This wide range is plausible when a diverse population group is in an environment with high levels of a contaminant chemical. The adults (>18 years) are a very diverse population group. The activities of adults (>18 years) in this environment vary in terms of time spent per day in the environment, exertion levels in that environment and their weight. Because the exposure is expressed as mass per unit body weight per day, as a person's weight increases, their exposure per unit body weight decreases.

Together, these factors (duration, exertion, body weight) can account for large differences in exposure within the same environment, as seen here.

3.4 TEP Results

TEP concentration data (Table 31) were available for air in home, office, and car, but dust data were only available for the home. There are no data on concentrations of air or dust in child care centers.

Table 31. TEP chemical concentration and type of value used for each media and environment for the exposure assessment. Note that units are in µg/area.

Study	Medium	Data from Study	Data Application
Home			
Dodson et al., 2012	Dust	Median 2.8E-02 µg/g	Median value 2.8 x 10^{-2} µg/g corrected for dust loading using EFH factors (all but front door mat) yielding mass over area of 2.15E-06 µg/cm^2 used as point value
Saito et al., 2007	Air	Mean 2.4E-03 µg/m^3	Mean value as reported used as point value with 10%/90% default for respired/ingested fractions.
Office			
Saito et al., 2007	Air	Mean 3.2E-03 µg/m^3	Mean value as reported used as point value with 10%/90% default for respired/ingested fractions.
Car			
Staaf and Ostman, 2005	Air	Concentrations from three cars: 2.20E-1, 6E-3, 5.6E-2 µg/m^3	Average 9.4E-02 µg/m^3 of three reported values was used as point value with 10%/90% default for respired/ingested fractions.

Tables 32-34 and Figures 19-21 present the results of the probabilistic modeling for TEP exposures for the modeled environments. These show the results of the full range of exposures across all percentiles of the population groups for the modeled environments.

Table 32. Results of probabilistic exposure assessment of TEP exposure by age group in the home environment.

Age Group (years)	Home Percentile (ng/kg/day)		
	25th	50th	75th
<1	0.05	0.05	0.06
1 - <3	0.06	0.07	0.07
3 - <12	0.02	0.03	0.04
12 - <18	0.01	0.01	0.01
>= 18	0.01	0.01	0.01

Table 33. Results of probabilistic exposure assessment of TEP exposure by age group in the office environment.

Age Group (years)	Office Percentile (ng/kg/day)		
	25th	50th	75th
<1	NA	NA	NA
1 - <3	NA	NA	NA
3 - <12	NA	NA	NA
12 - <18	NA	NA	NA
>= 18	0.02	0.03	0.03

NA = not applicable

Table 34. Results of probabilistic exposure assessment of TEP exposure by age group in the car environment.

Age Group (years)	Car Percentile (mg/kg/day)		
	25th	50th	75th
<1	1.5	1.6	1.8
1 - <3	1.6	1.8	2.0
3 - <12	0.57	0.78	1.1
12 - <18	0.24	0.29	0.35
>= 18	0.28	0.34	0.41

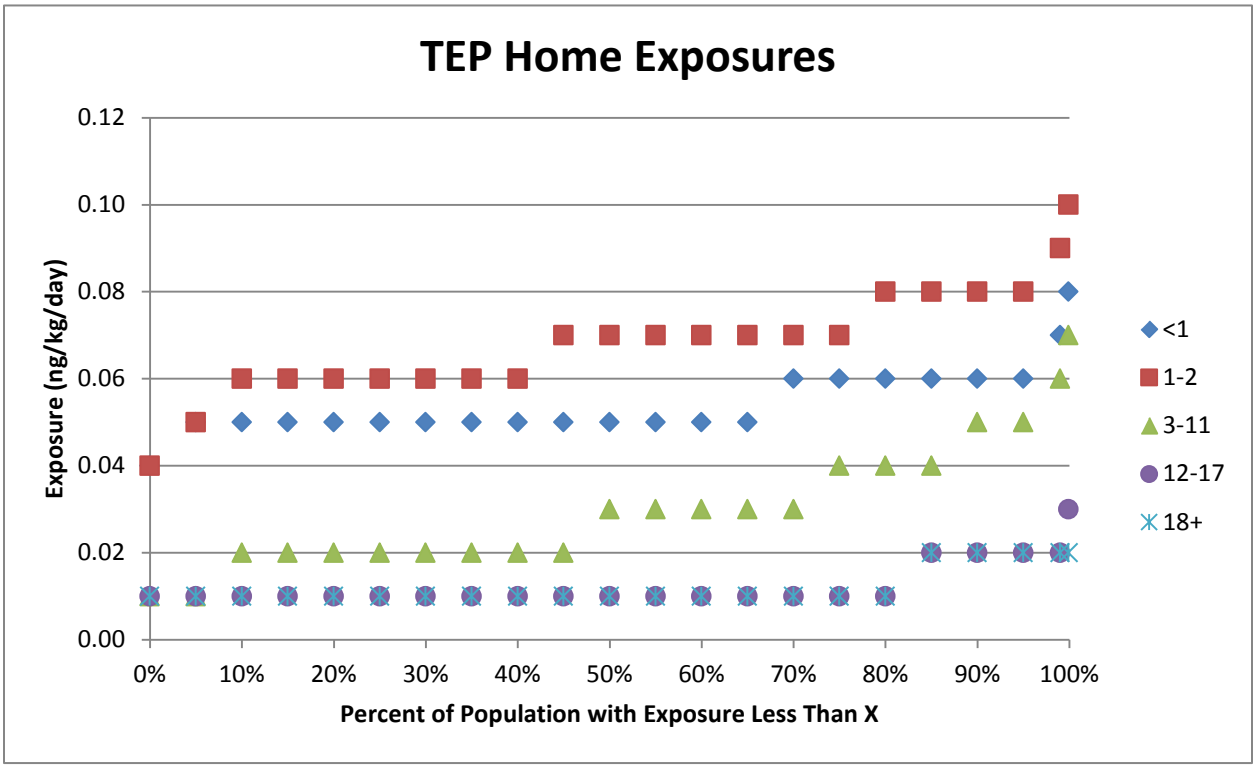

Figure 19. The full range of exposures across all percentiles of the population groups for TEP from the home environment.

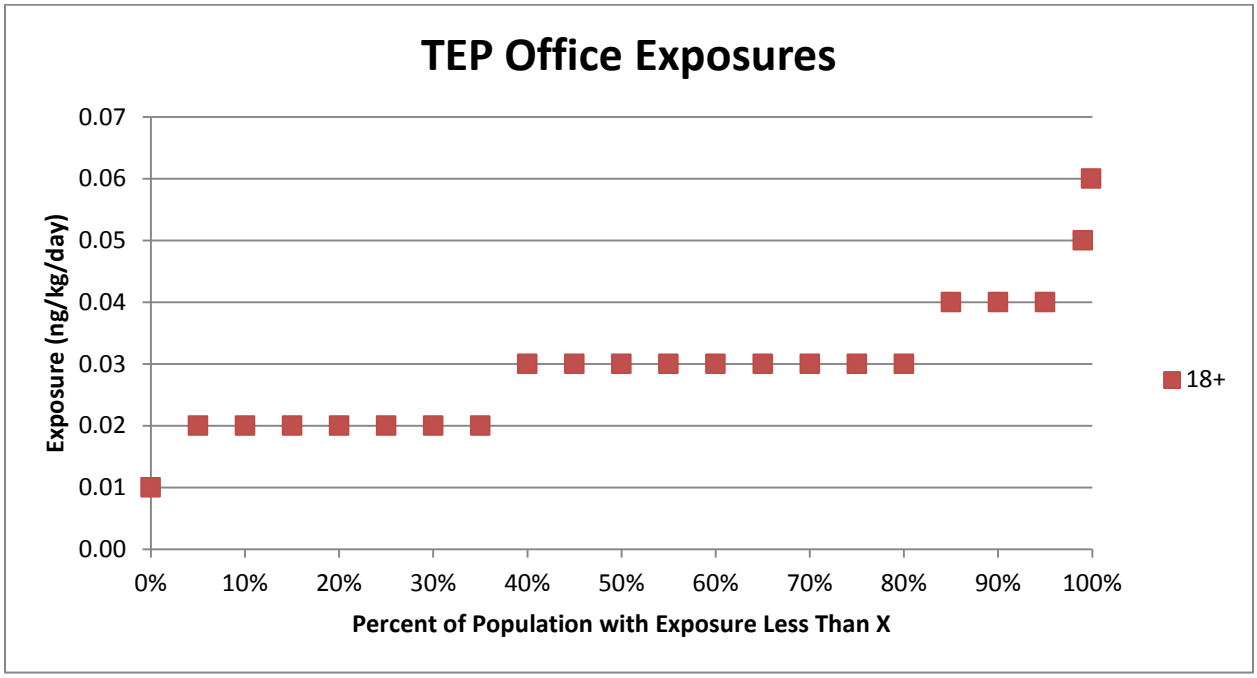

Figure 20. The full range of exposures across all percentiles of the adult population for TEP from the office environment.

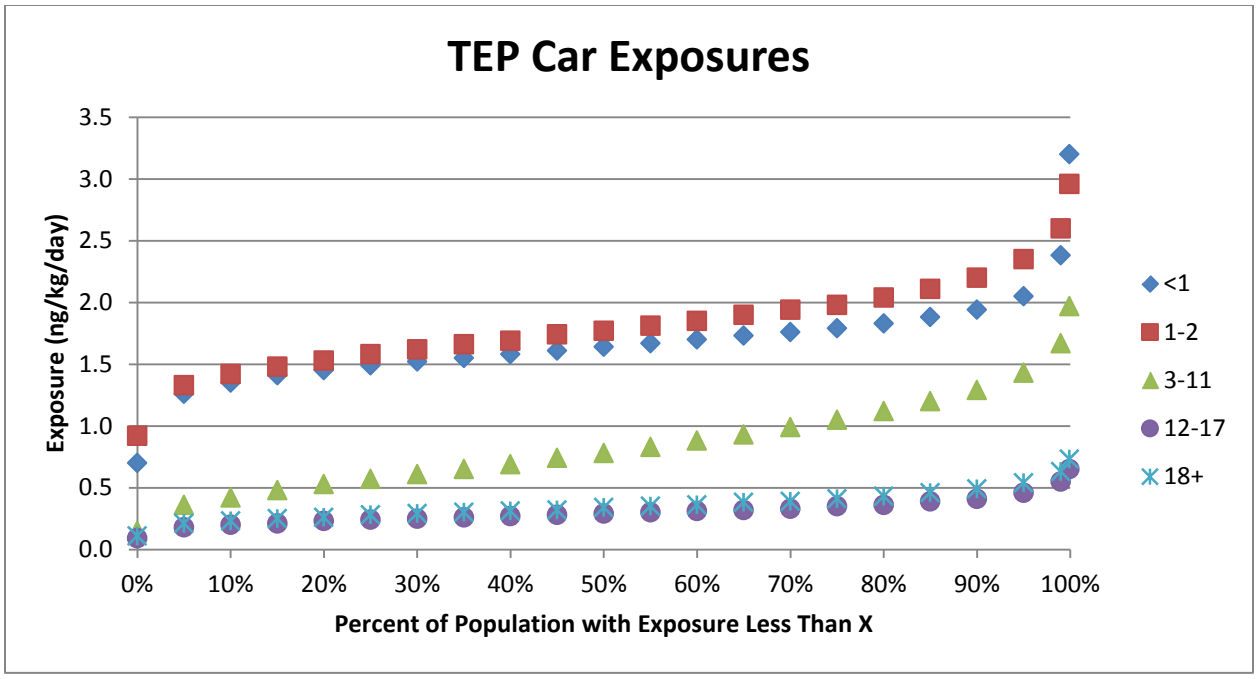

Figure 21. The full range of exposures across all percentiles of the population groups for TEP from the car environment.

Table 35 and Figure 22 show the results of the combination of all exposures from the modeled scenarios.

Table 35. TEP exposure estimates for combined exposures from the home, office and car scenarios, by age group.

Age Group (years)	Combined Percentile (ng/kg/day)		
	25th	50th	75th
<1	1.5	1.7	1.9
1 - <3	1.6	1.9	2.1
3 - <12	0.60	0.81	1.1
12 - <18	0.23	0.28	0.35
>= 18	0.28	0.35	0.42

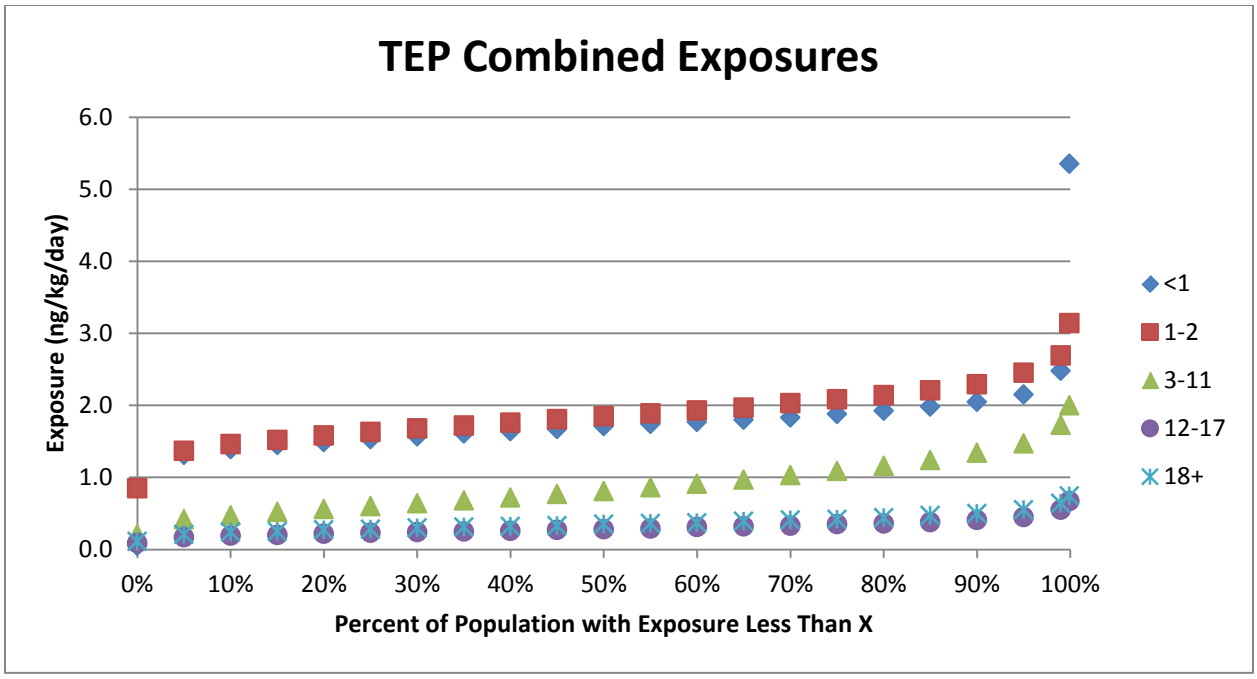

Figure 22. The full range of exposures across all percentiles of the population groups for TEP from all exposures.

3.4.1 Discussion of TEP Results

No data were available measuring concentrations of TEP in the dust of child care, offices, or car environments. Without these data, exposures were not considered for dermal contact with the dust on floors and other surfaces or for the exposures consequential to hand-to-mouth events when hands are loaded with TEP from the floors or other surfaces. Dust can be a notable source of children's exposures in child care environments. Thus, exposures presented for the combined environment scenario are likely underestimated for children, especially infants and children 1 to <3 years who may spend a large proportion of their day in a child care environment.

Infants and children aged 1 to <3 years experienced the highest exposures of all age groupings in the car and home environments. The car environment exposures may be slightly underestimated for all age groups because there were no data for TEP levels in car dust; however, the exposures in cars for children in this age group is higher compared to all other age groupings. Children's exposures from a given environment may be higher than adult's exposures, in part, because exposure is expressed in terms of mass of chemical per kg body weight per day. The exposures are likely to be higher for young children as their body weights are lower than older children and adults. The combined exposures are highest for infants and children 1 to <3 years, even without the likely additional exposures from the child care environment being considered. Children in this age group have frequent hand-to-mouth events and a relatively large proportion of their body surfaces are in contact with surfaces that could hold contaminated dust, so child care environment exposures could be an important contributor to overall exposure.

3.5 TPP Results

TPP concentration data (Table 36) were available for dust and air in the child care, home, and office environments. Concentrations in air, but not dust, were available for cars.

Table 36. TPP chemical concentration and type of value used for each media and environment for the exposure assessment. Note that units are in µg/area.

Study	Medium	Data from Study	Data Application
Child Care			
Bergh et al., 2011	Dust	Median 1.9 µg/g	Reported median value corrected for dust loading using EFH factors (all but front door mat) yielding mass over area of 1.4E-04 µg/cm^2,used as point value.
Bergh et al., 2011	Air	Mean 1.0E-04 µg/m^3	Mean value as reported used as point value with 10%/90% default for respired/ingested fractions.
Homes			
Fan et al., 2014	Dust	Median 1.6 µg/g	Reported median value corrected for dust loading using EFH factors (all but front door mat) yielding mass over area of 1.23E-04 µg/cm^2 , used as point value.
Bergh et al., 2011	Air	Mean 2E-04 µg/m^3	Mean value as reported used as point value with 10%/90% default for respired/ingested fractions.
Office			
Bergh et al., 2011	Dust	Mean 8.8 µg/g	Reported mean value corrected for dust loading using EFH factors (all but front door mat) yielding mass over area of 6.75E-04 µg/cm^2 , used as point value.
	Air	Mean 6E-04 µg/m^3	Mean value as reported used as point value with 10%/90% default for respired/ingested fractions.
Cars			
Staaf and Ostman, 2005	Air	Two samples: 3.0E-03 µg/m^3 and 1.0E-03 µg/m^3	Average value (2.0E-03 µg/m^3) of two reported values used as point value with 10%/90% default for respired/ingested fractions.

Tables 37-40 and Figures 23-26 present the results of the probabilistic modeling for TPP exposures for the modeled environments. These show the results of the full range of exposures across all percentiles of the population groups for the modeled environments.

Table 37. Results of probabilistic exposure assessment of TPP exposure by age group in the child care environment.

Age Group (years)	Child Care Percentile (ng/kg/day)		
	25th	50th	75th
<1	0.01	0.01	0.01
1 - <3	0.01	0.01	0.01
3 - <12	<0.01	<0.01	<0.01
12 - <18	<0.01	<0.01	<0.01
>= 18	<0.01	<0.01	<0.01

Table 38. Results of probabilistic exposure assessment of TPP exposure by age group in the home environment.

Age Group (years)	Home Percentile (ng/kg/day)		
	25th	50th	75th
<1	0.01	0.01	0.01
1 - <3	0.01	0.01	0.01
3 - <12	0.01	0.01	0.01
12 - <18	<0.01	<0.01	<0.01
>= 18	<0.01	<0.01	<0.01

Table 39. Results of probabilistic exposure assessment of TPP exposure by age group in the office environment.

Age Group (years)	Office Percentile (ng/kg/day)		
	25th	50th	75th
<1	NA	NA	NA
1 - <3	NA	NA	NA
3 - <12	NA	NA	NA
12 - <18	NA	NA	NA
>= 18	0.01	0.01	0.02

NA = Not Applicable

Table 40. Results of probabilistic exposure assessment of TPP exposure by age group in the car environment.

Age Group (years)	Car Percentile (ng/kg/day)		
	25th	50th	75th
<1	0.02	0.02	0.02
1 - <3	0.02	0.02	0.03
3 - <12	0.01	0.01	0.01
12 - <18	0.01	0.01	0.01
>= 18	0.01	0.01	0.01

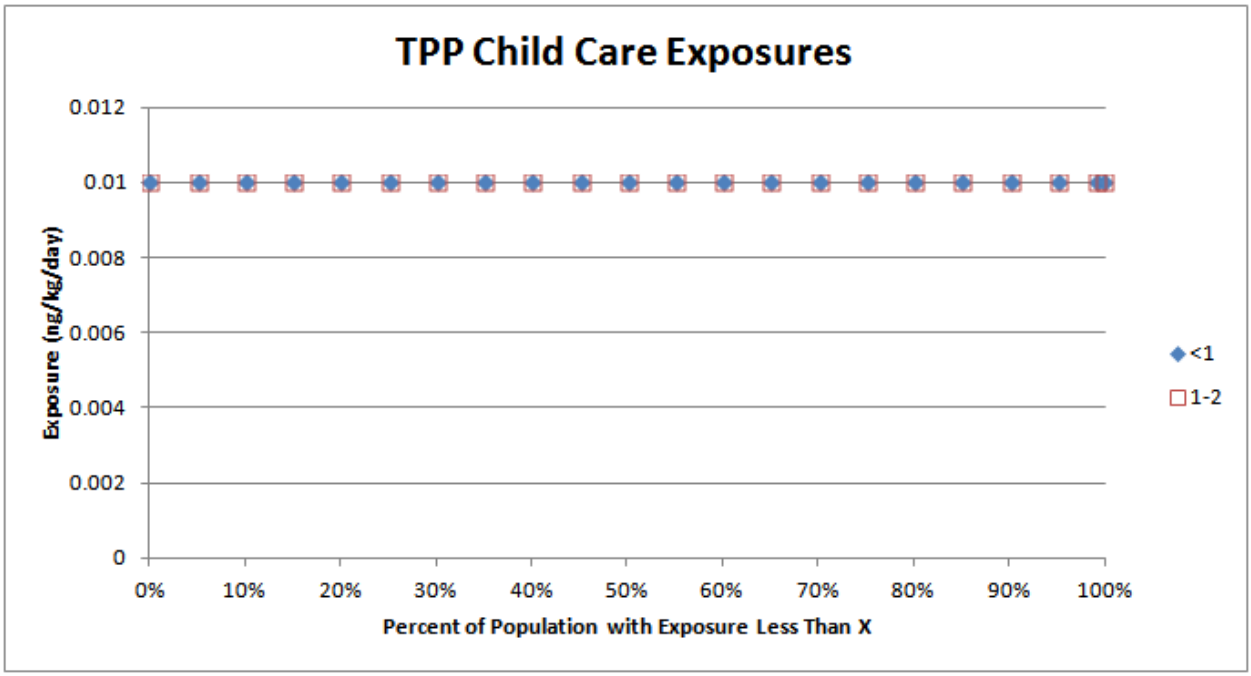

Figure 23. The full range of exposures across all percentiles of the population groups for TPP from child care center exposure.

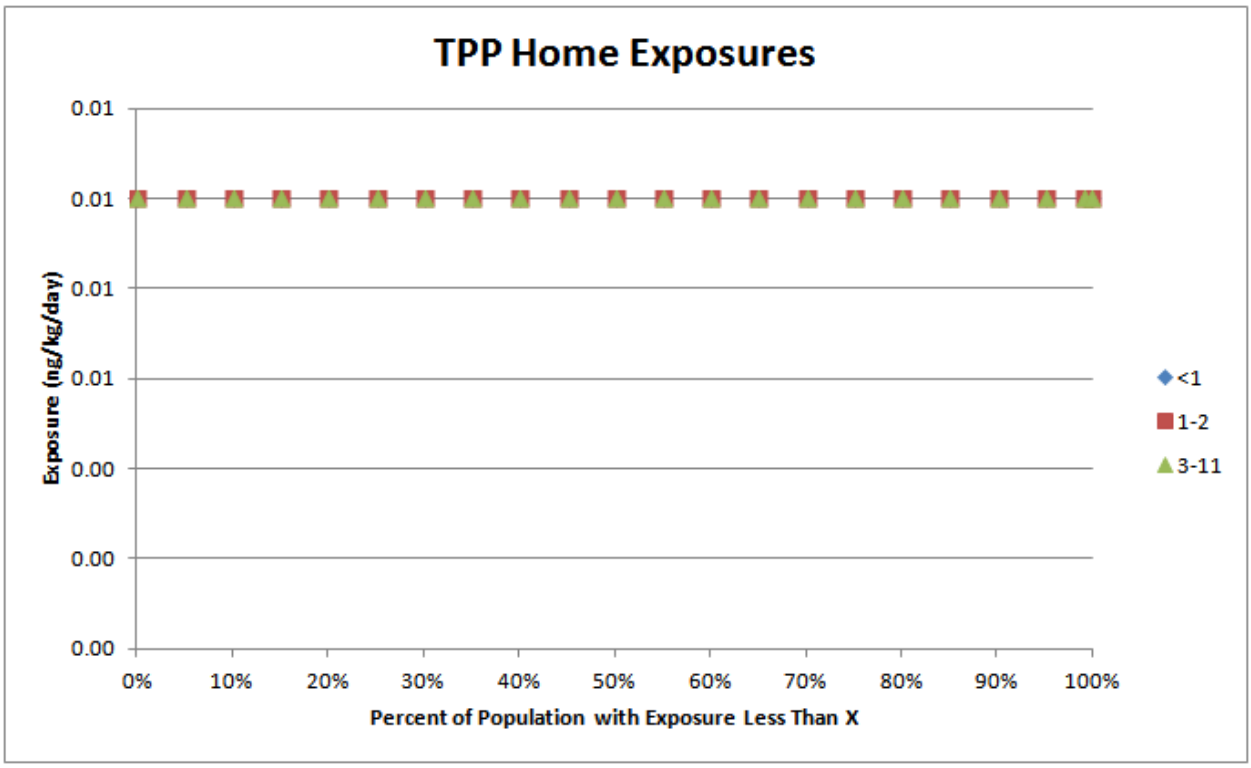

Figure 24. The full range of exposures across all percentiles of the population groups for TPP from home exposure.

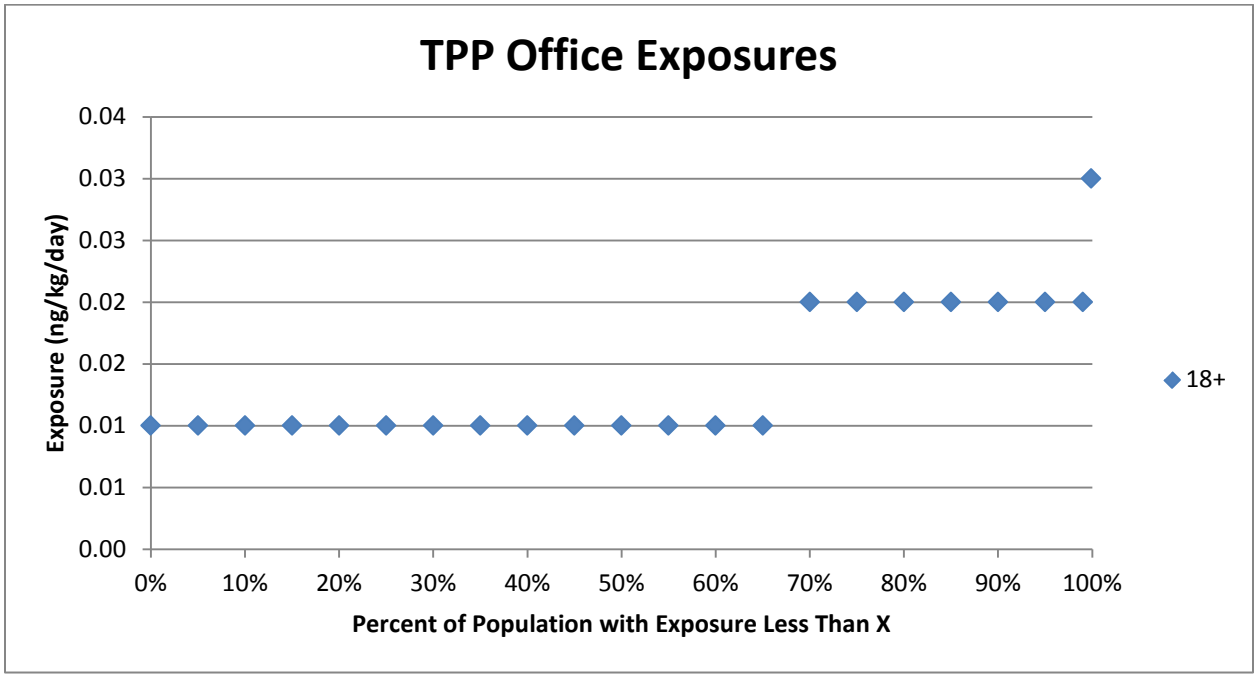

Figure 25. The full range of exposures across all percentiles of the adult population for TPP from office exposure.

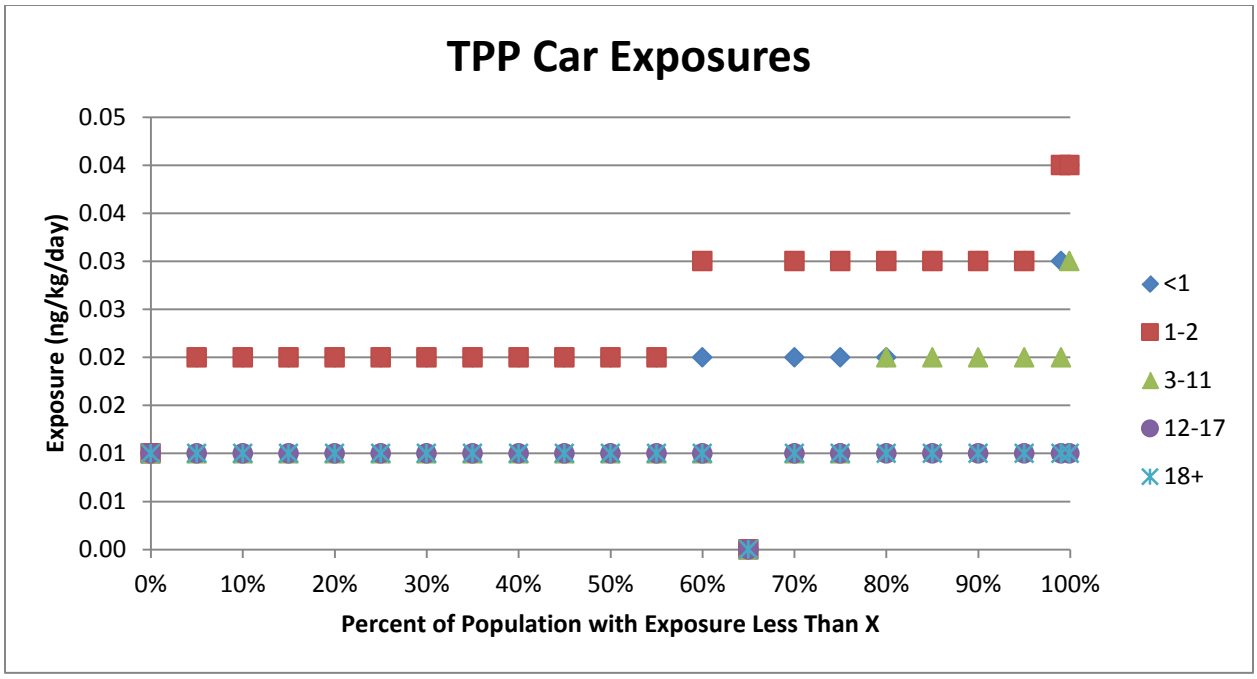

Figure 26. The full range of exposures across all percentiles of the population groups for TPP from car exposure.

Table 41 and Figure 27 show the results of the combination of all exposures from the modeled scenarios.

Table 41. TPP exposure estimates for combined exposures from the child care, home and office scenarios, by age group.

Age Group (years)	Combined Percentile (ng/kg/day)		
	25th	50th	75th
<1	0.03	0.03	0.03
1 - <3	0.03	0.03	0.04
3 - <12	0.01	0.01	0.02
12 - <18	0.01	0.01	0.01
>= 18	0.01	0.01	0.01

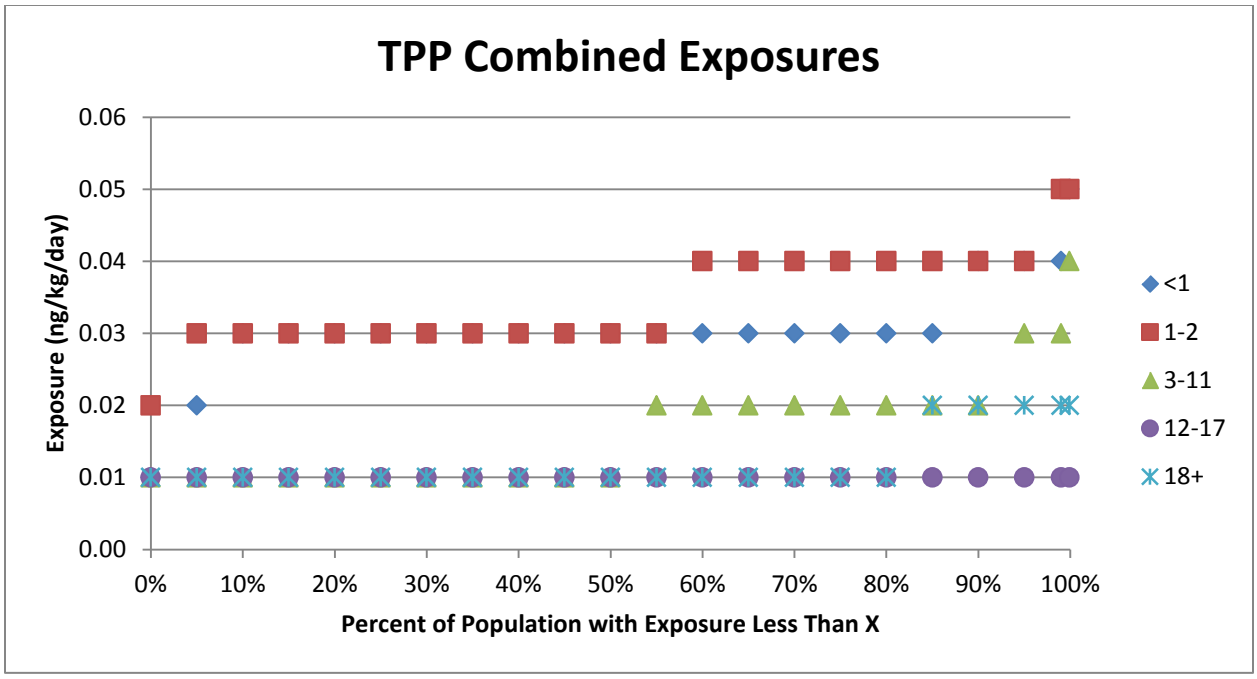

Figure 27. The full range of exposures across all percentiles of the population groups for TPP from all exposures.

3.5.1 Discussion of TPP results

Data were available for both dust and air concentrations for TPP in child care, home, and office environments. Only air data were available for cars. Exposures from all environments except the car environment were usually near or below 0.01 ng/kg/day for all population groups.

Infants and children experienced the highest exposures of all population groups in the car environment. The exposure for all population groups is likely to be underestimated for the car environment, as exposure from TPP in dust could not be considered. Since the exposure is expressed in terms of mass of chemical per kg body weight per day, the exposures are likely to be higher for young children as their body weights are lower than older children and adults.

The combined exposure assessment assumes a person will be in all of these environments (on an age-appropriate basis) where TPP concentrations exist in the dust and air of those environments. The highest exposures on a mg/kg BW/day for combined exposures are for infants and children. This is due, in part, to their low body weight and to the long durations each day in which they are in these indoor environments, especially at the home and child care settings.

3.6 TBB Results

TBB concentration data (Table 42) were available for dust and air in child care and home environments. Dust concentrations were available for office and car environments.

Table 42. TBB chemical concentration and type of value used for each media and environment for the exposure assessment. Note that units are in µg/area.

Study	Medium	Data from Study	Data Application
Child Care			
Bradman et al., 2012	Dust	Min 5.74E-06 µg/cm^2 25th 3.96E-05 µg/cm^2 50th 6.83E-05 µg/cm^2 75th 1.79E-04 µg/cm^2 90th 9.98E-04 µg/cm^2 95th 1.90E-03 µg/cm^2 max 8.60E-03 µg/cm^2	Data fit to lognormal distribution using Crystal Ball™ yielding mean 3.10E-04 µg/cm^2 and SD 1.40E-03 µg/cm^2. Distribution used for exposure assessment without correction for dust loading because study incorporated area distribution of chemical mass.
	Air	Mean (SD) 5.80E-04 (2.60E-03) µg/m^3	Mean and SD as reported by the authors used to create log normal distribution using Crystal Ball™. Derived distribution used for exposure assessment with 10%/90% default assumption for respired/ingested fractions.
Homes			
Brown et al., 2014	Dust	GM (GSD) 3.1E01 (8.59E-03) µg/g	GM and GSD corrected for dust loading using EFH factors (all but front door mat) yielding mass over area corrected GM and GSD of 2.38E-05 and 6.59E-07 µg/cm^2, which was used to create log normal distribution using Crystal Ball™. Derived distribution used for exposure assessment.
La Guardia et al., 2015	Air	Reported three values for respirable concentrations (1.42E-02, 1.62E-02, 5.52E-02) µg/m^3 and four values for inhalable but not respirable concentrations (5.54E-02, 1.69E-02, 1.30E-02, 2.60E-03) µg/m^3.	Values were used directly as reported for the risk assessment for the respirable air concentration and non-respirable air concentrations respectively.

Study	Medium	Data from Study	Data Application
Office			
Ali et al., 2011	Dust	5th %tile 1E-03 µg/g 50th %tile 7E-03 µg/g 95th %tile 3.0E-02 µg/g	Data fit to lognormal distribution using Crystal Ball™ yielding mean 1.02E-02 µg/g and SD 1.10E-02 µg/g. Mean and SD corrected for dust loading using EFH factors (all but front door mat) yielding mass over area corrected Mean of 7.78E-07 µg/cm^2 and SD of 8.43E-07 µg/cm^2. Derived distribution used for exposure assessment.
Cars			
Hassan and Shoeib, 2015	Dust	Median dust concentration from total dust collection from seats, roofs and dashboards of cars = 5.81E-03 µg/g	We corrected the reported median concentration value for dust loading, calculating dust loading on fabric areas is equivalent to EFH dust loading on untracked downstairs carpet and dust loading on dash board equivalent to dust loading on untracked linoleum. The fabric-related value of 3.37E-07 µg/cm^2 and dashboard-related value of 3.49E-08 µg/cm^2 were averaged, equaling 1.86E-07 µg/cm^2, which was used in the exposure assessment as a point value.

Tables 43-46 and Figures 28-29 present the results of the probabilistic modeling for TBB for the full range of exposures across all percentiles of the population groups for the modeled environments. No figures are presented for TBB from office exposures or car exposures because those exposures are low.

Table 43. Results of probabilistic exposure assessment of TBB exposure by age group in the child care environment.

Age Group (years)	Child Care Percentile (ng/kg/day)		
	25th	50th	75th
<1	0.01	0.02	0.02
1 - <3	0.01	0.01	0.02
3 - <12	0.01	0.01	0.01
12 - <18	0.01	0.01	0.01
>= 18	0.01	0.01	0.01

Table 44. Results of probabilistic exposure assessment of TBB exposure by age group in the home environment.

Age Group (years)	Home Percentile (ng/kg/day)		
	25th	50th	75th
<1	0.73	0.79	0.85
1 - <3	0.89	0.99	1.11
3 - <12	0.28	0.39	0.55
12 - <18	0.15	0.18	0.21
>= 18	0.14	0.17	0.21

Table 45. Results of probabilistic exposure assessment of TBB exposure by age group in the office environment.

Age Group (years)	Office Percentile (ng/kg/day)		
	25th	50th	75th
<1	NA	NA	NA
1 - <3	NA	NA	NA
3 - <12	NA	NA	NA
12 - <18	NA	NA	NA
>= 18	<0.01	<0.01	<0.01

NA = not applicable

Table 46. Results of probabilistic exposure assessment of TBB exposure by age group in the car environment.

Age Group (years)	Car Percentile (ng/kg/day)		
	25th	50th	75th
<1	<0.01	<0.01	<0.01
1 - <3	<0.01	<0.01	<0.01
3 - <12	<0.01	<0.01	<0.01
12 - <18	<0.01	<0.01	<0.01
>= 18	<0.01	<0.01	<0.01

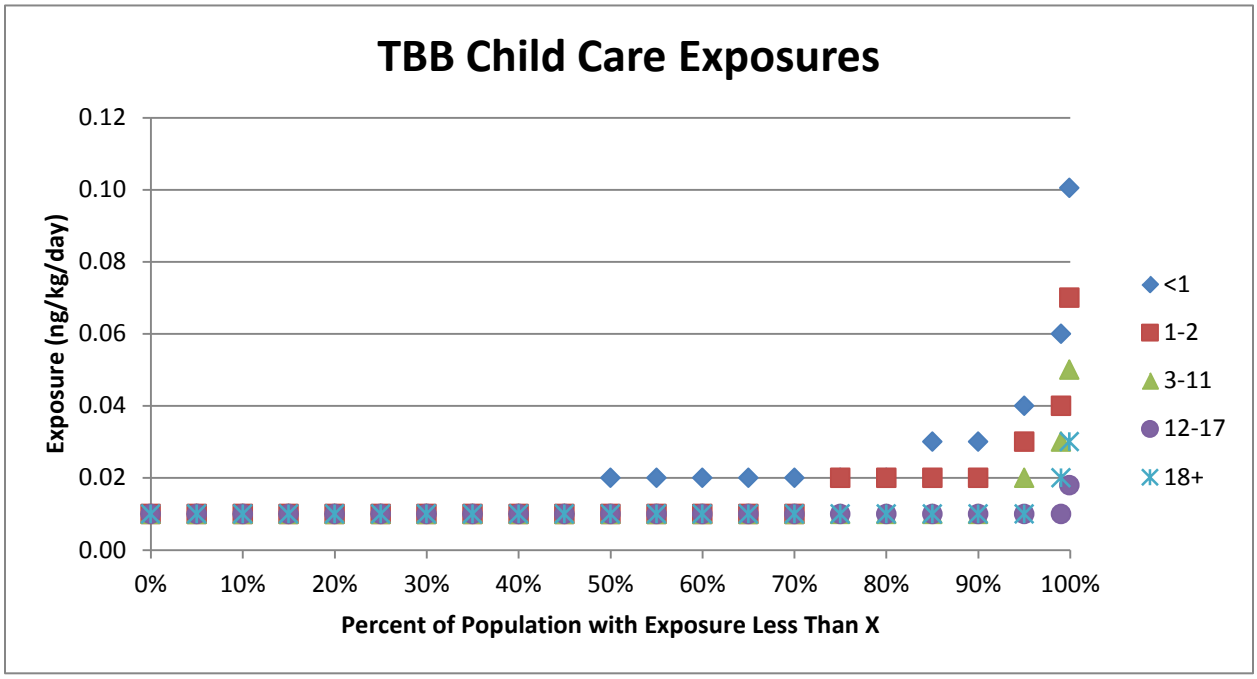

Figure 28. The full range of exposures across all percentiles of the population groups for TBB from the child care environment.

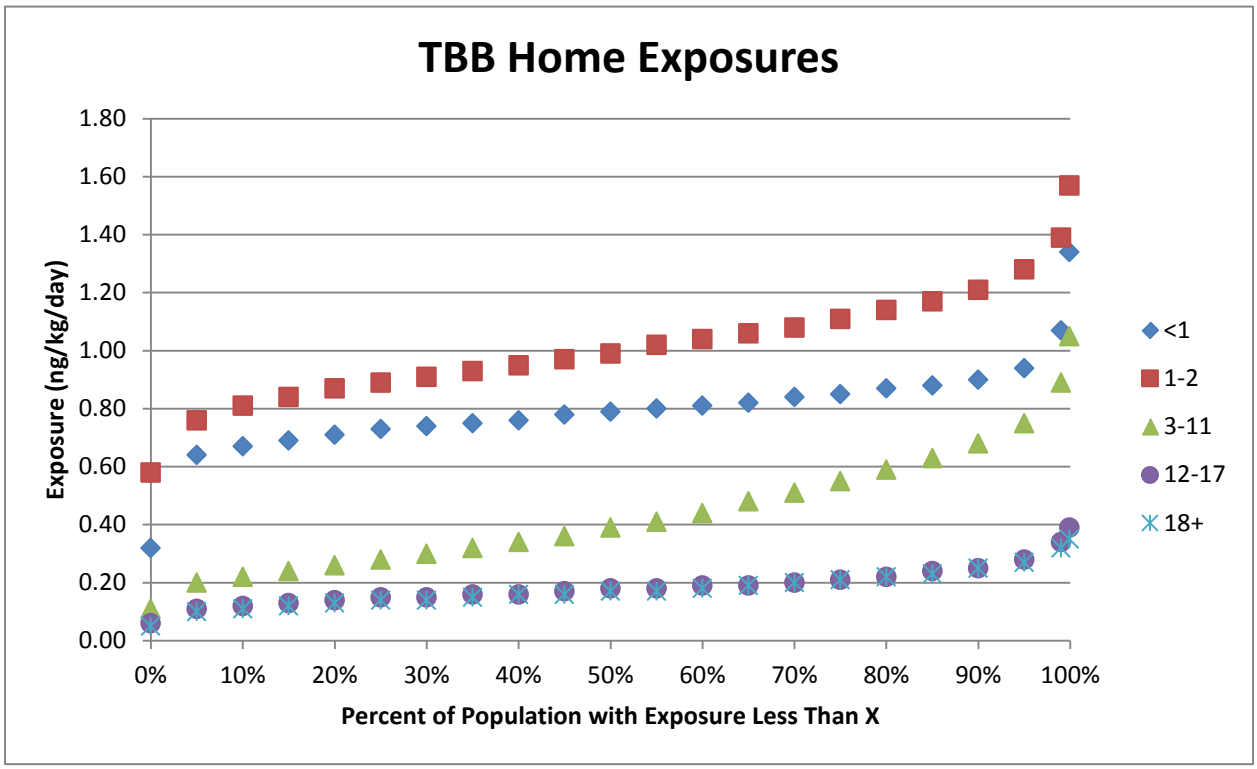

Figure 29. The full range of exposures across all percentiles of the population groups for TBB from the home environment.

Table 47 and Figure 30 show the results of the combination of all exposures from the modeled scenarios.

Table 47. TBB exposure estimates for combined exposures from the child care, home, office and car scenarios, by age group.

Age Group (years)	Combined Percentile (ng/kg/day)		
	25th	50th	75th
<1	0.74	0.80	0.85
1 - <3	0.90	1.00	1.12
3 - <12	0.28	0.38	0.56
12 - <18	0.14	0.17	0.21
>= 18	0.14	0.17	0.21

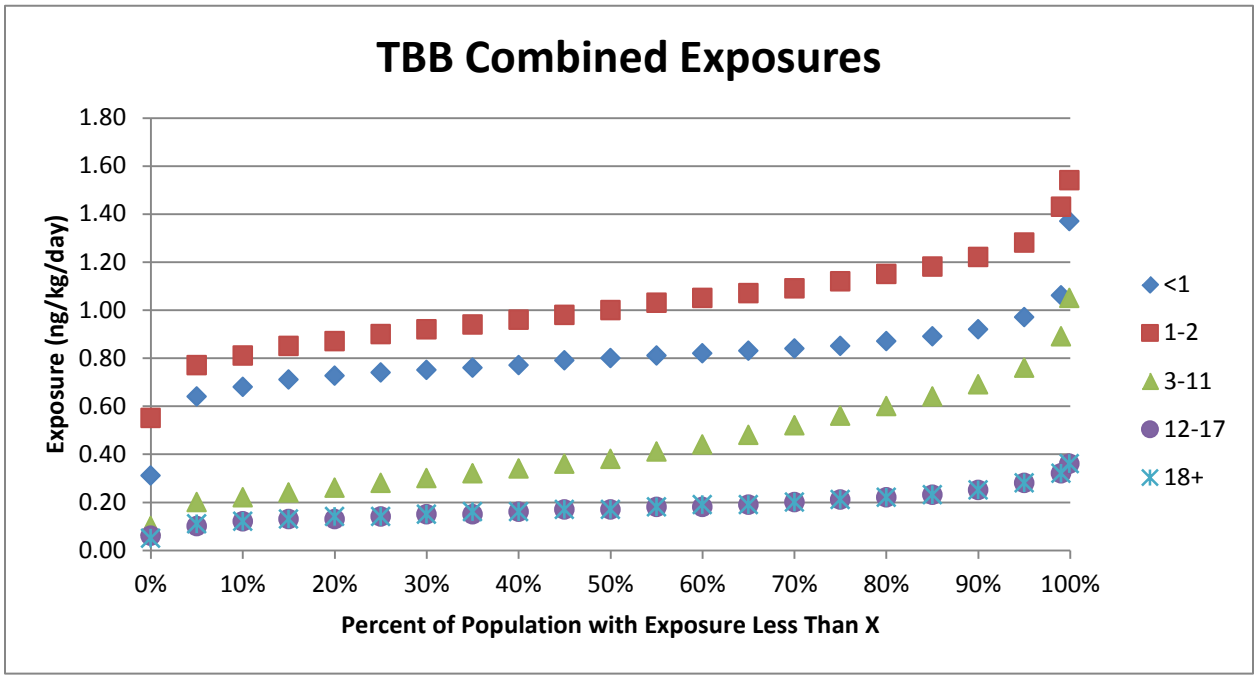

Figure 30. The full range of exposures across all percentiles of the population groups for TBB from all exposures.

3.6.1 Discussion of TBB Results

The highest exposures were experienced in the home environment for all age groups. This reflects the higher level of TBB concentrations in home dust as compared to dust concentrations in the child care, office and car environments. In addition, air concentrations of TBB were higher in the home than in the child care centers and no exposure contribution from TBB in air was considered for the office and car environments.

Infants and children aged 1 to <3 years experienced the highest exposures among the age groups for the child care and home environments. Children in these age groups have frequent hand-to-mouth events and a relatively large proportion of their body surfaces are in contact with surfaces that could bear contaminated dust. In addition, since the exposure is expressed in terms of mass of chemical per kg body weight per day, the exposures are likely to be higher for young children as their body weights are lower than older children and adults.

Exposures in office and car environments were usually <0.01 ng/kg body weight/day, although data for TBB concentrations in air particles in the air offices and cars were not available. This absence may have led to underestimation of exposure for adults in offices and for all age groups in cars.

3.7 TBPH Results

TBPH chemical concentration data (Table 48) were available for dust and air in child care, home and office environments. Dust concentration data for TBPH were available for cars.

Table 48. TBPH chemical concentration and type of value used for each media and environment for the exposure assessment. Note that units are in µg/area.

Study	Medium	Data from Study	Data Application
Child Care			
Bradman et al., 2012	Dust	min 3.24E-06 µg/cm^2 25th 1.22E-05 µg/cm^2 50th 2.82E-05 µg/cm^2 75th 7.43E-05 µg/cm^2 90th 5.60E-04 µg/cm^2 95th 9.58E-04 µg/cm^2 max 1.70E-03 µg/cm^2	Data fit to lognormal distribution using Crystal Ball™ yielding mean 8.25E-05 µg/cm^2 and SD 2.130E-04 µg/cm^2. Derived distribution used for exposure assessment. No dust mass/area correction needed because study incorporated area distribution of chemical mass.
	Air	Mean (SD) 2.30E-04 (8.70E-04) µg/m^3	Mean and SD as reported by the authors used to create log normal distribution using Crystal Ball™. Derived distribution used for exposure assessment with 10%/90% default assumption for inspired/ingested fractions.
Home			
Brown et al., 2014	Dust	GM (GSD) 1.4 E-01 (5.9 E-03) µg/g	Reported GM and GSD corrected for dust loading using EFH factors (all but front door mat) yielding mass over area of GM 1.1E-05 µg/cm^2 (GSD 4.6E-07 µg/cm^2). Corrected GM and GSD used to create log normal distribution with Crystal Ball™ and used in exposure assessment.
La Guardia and Hale, 2015	Respirable Air <4µm	Mean 6.93E-03 µg/m^3	Mean value as reported used as point value without correction as author directly measures respirable fraction's concentration.
La Guardia and Hale, 2015	Non-respirable air > 4µm	Mean 8.61E-03 µg/m^3	Mean value as reported used as point value without correction as author directly measures non-respirable fraction's concentration.
Office			
Ali et al., 2011	Dust	Mean (SD) 9.50E-02 (8.90E-02) µg/g	Reported Mean and SD corrected for dust loading using EFH factors (all but front door mat) yielding mass over area of 7.28E-06 (6.82E-06) µg/cm^2. Corrected Mean and SD used to create log normal distribution with Crystal Ball™ and used in exposure assessment.
Newton et al., 2015	Air	GM 4.2E-05 µg/m^3	Geometric Mean value as reported used as point value with 10%/90% default for inspired/ingested fractions.

Study	Medium	Data from Study	Data Application
Car			
Springer et al., 2012	Dust	Median 4.00E-01 µg/g for dust collected on seats	Median corrected for dust loading using EFH untracked area of downstairs carpet factor only, because only car seat fabric sampled in study. Corrected area over mass Mean of 2.32E-05 µg/cm^2 used as point value.

Tables 49-52 and Figures 31-32 present the results of the probabilistic modeling for TBPH exposures for the modeled environments. These show the results of the full range of exposures across all percentiles of the population groups for the modeled environments. No graphical representation is presented for TBPH from the office and car environments because the exposures were low (<0.01 ng/kg/day).

Table 49. Results of probabilistic exposure assessment of TBPH exposure by age group in the child care environment.

Age Group (years)	Child Care Percentile (ng/kg/day)		
	25th	50th	75th
<1	0.01	0.01	0.01
1 - <3	0.01	0.01	0.01
3 - <12	0.01	0.01	0.01
12 - <18	<0.01	<0.01	<0.01
>= 18	0.01	0.01	0.01

Table 50. Results of probabilistic exposure assessment of TBPH exposure by age group in the home environment.

Age Group (years)	Home Percentile (ng/kg/day)		
	25th	50th	75th
<1	0.18	0.19	0.20
1 - <3	0.22	0.24	0.27
3 - <12	0.07	0.09	0.13
12 - <18	0.04	0.04	0.05
>= 18	0.03	0.04	0.05

Table 51. Results of probabilistic exposure assessment of TBPH exposure by age group in the office environment.

Age Group (years)	Office Percentile (ng/kg/day)		
	25th	50th	75th
<1	NA	NA	NA
1 - <3	NA	NA	NA
3 - <12	NA	NA	NA
12 - <18	NA	NA	NA
>= 18	<0.01	<0.01	<0.01

NA = not applicable

Table 52. Results of probabilistic exposure assessment of TBPH exposure by age group in the car environment.

Age Group (years)	Car Percentile (ng/kg/day)		
	25th	50th	75th
<1	<0.01	<0.01	<0.01
1 - <3	<0.01	<0.01	<0.01
3 - <12	<0.01	<0.01	<0.01
12 - <18	<0.01	<0.01	<0.01
>= 18	<0.01	<0.01	<0.01

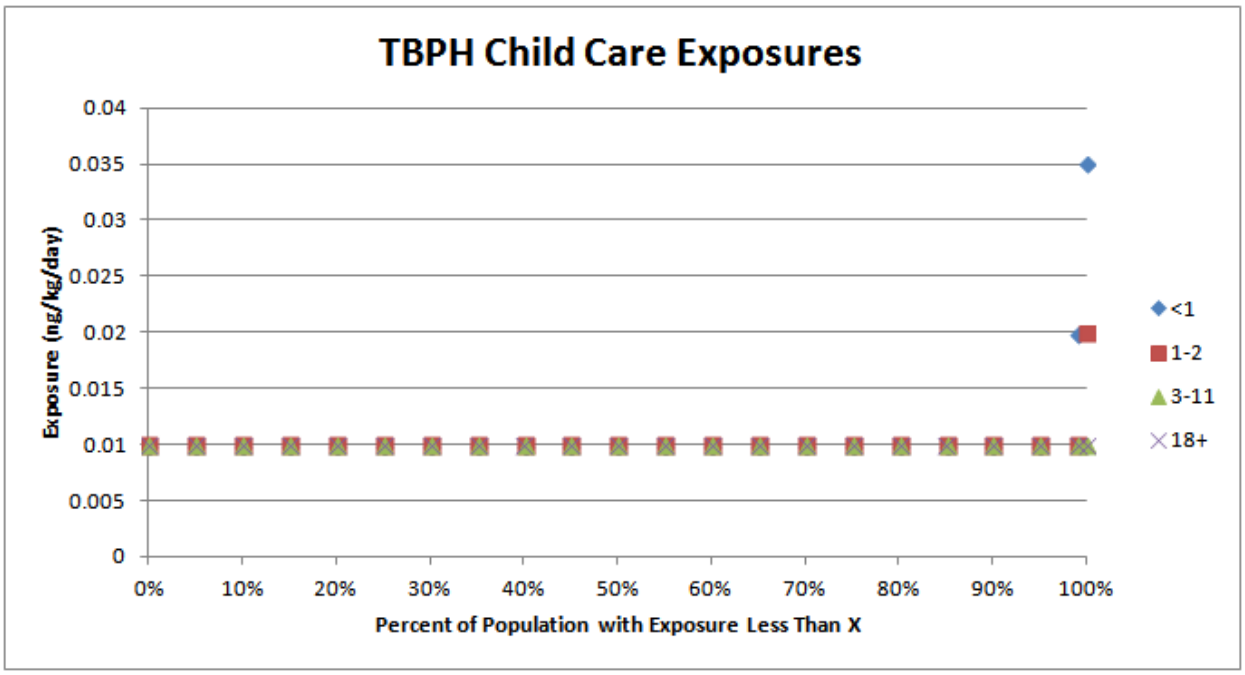

Figure 31. The full range of exposures across all percentiles of the population groups for TBPH from the child care environment.

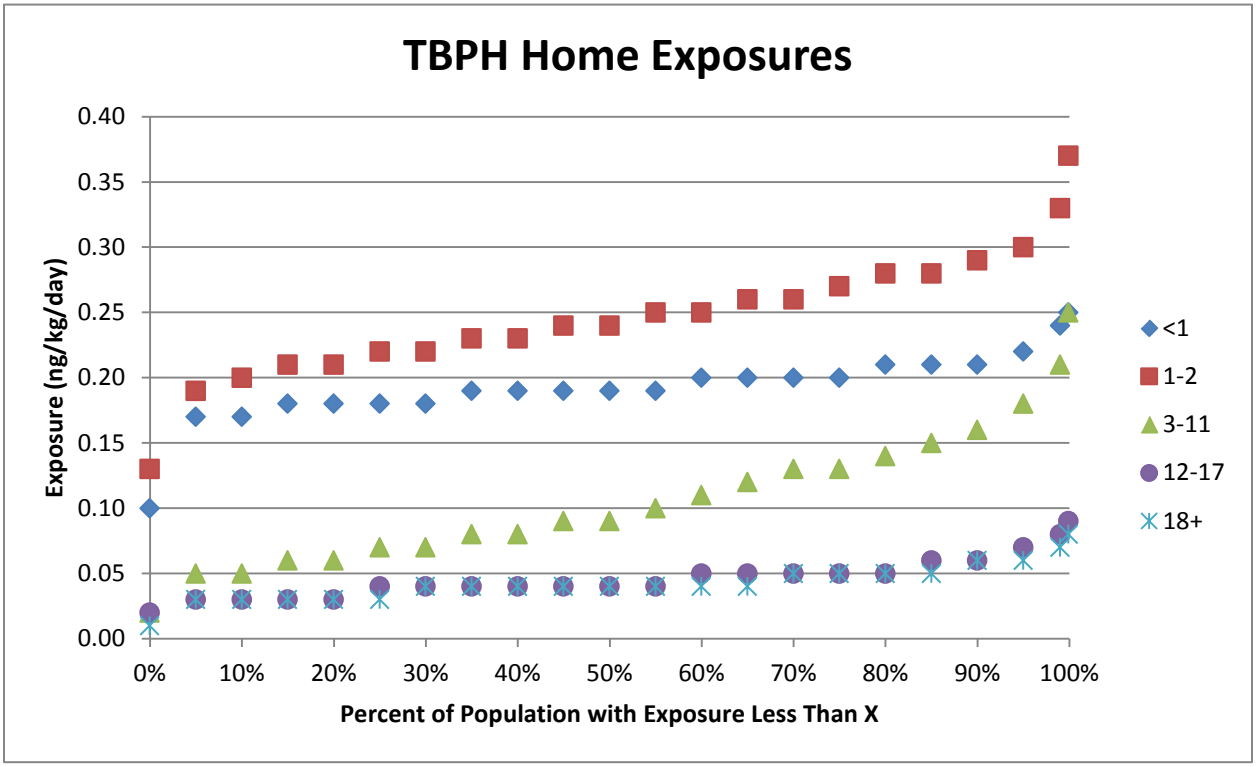

Figure 32. The full range of exposures across all percentiles of the population groups for TBPH from the home environment.

Table 53 and Figure 33 show the results of the combination of all exposures from the modeled scenarios.

Table 53. TBPH exposure estimates for combined exposures from the child care, home and office scenarios, by age group.

Age Group (years)	TBPH / Combined Percentile (ng/kg/day)		
	25th	50th	75th
<1	0.19	0.20	0.21
1 - <3	0.22	0.25	0.27
3 - <12	0.07	0.10	0.14
12 - <18	0.04	0.04	0.05
>= 18	0.04	0.04	0.05

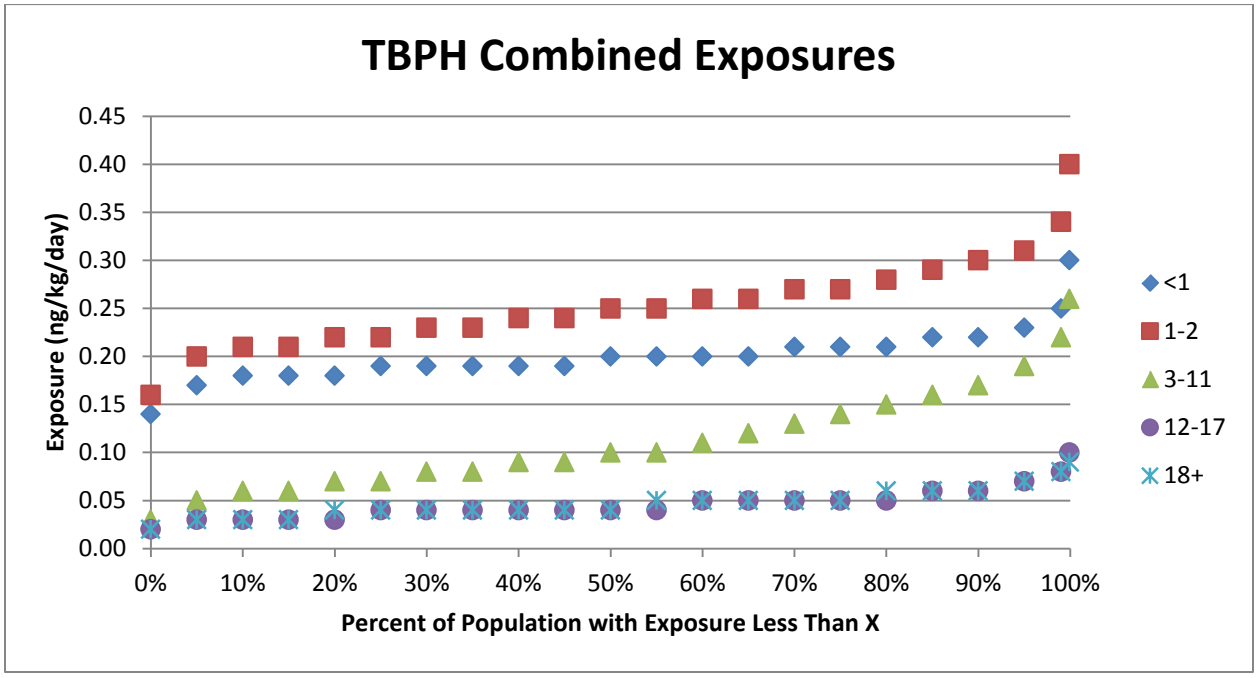

Figure 33. The full range of exposures across all percentiles of the population groups for TBPH from all exposures.

3.7.1 Discussion on TBPH Results

Data were available for dust and air for the child care, home and office environments. For the car environment, only TBPH dust concentrations were available. Because no air concentration data were

available for TBPH in cars, that exposure calculation may be an underestimate, as would also be the case for the combined environments scenario.

Exposures were low for all age groups for all environments except the home. Infants and children, relative to other age groups, experienced the highest exposures in the home. Infants and children 1 to <3 years have frequent hand-to-mouth events and a relatively large proportion of their body surfaces are in contact with surfaces in the home, car and child care centers that could have contaminated dust on the surfaces. Also, since the exposure is expressed in terms of mass of chemical per kg body weight per day, the exposures are likely to be higher for young children as their body weights are lower than older children and adults.

The combined exposure scenario where all people are expected to be in all contaminated environments each day and in age appropriate patterns is dominated by the exposures from the home for all age groups. Again, the infants and young children (1 to <3 years) experienced the highest exposure levels.

3.8 TBBPA Results

TBBPA concentration data (Table 54) were available for dust in the child care environment and for both dust and air in home and office environments. No data were available for the car environment.

Table 54. TBBPA chemical concentration and type of value used for each media and environment for the exposure assessment. Note that units are in µg/area.

Study	Medium	Data from Study		Data Application
Child Care				
Harrad et al., 2010	Dust	min 5th median mean 95th max	1.70E-02 µg/g 2.00E-02 µg/g 1.10E-01 µg/g 2.00E-01 µg/g 4.60E-01 µg/g 1.40 µg/g	Study reported dust loading factors (low 0.025 g/m^2 and high 0.3 g/m^2). Each reported concentration was corrected for dust loading using first the low and then the high factors. These twelve mass over area calculations (µg/cm^2) were fitted to a lognormal distribution using Crystal Ball™. The distribution [Mean 4.84E-06 µg/cm^2 and SD 5.26E-06 µg/cm^2] was used for the exposure assessment.
Home				
Fromme et al., 2014	Dust	median	2.80E-02 µg/g	The reported values were fitted to a pareto distribution with Crystal Ball™ [Mean 3.87E-02 µg/g and SD 3.72E-02 µg/g]. The mean and SD were corrected for dust loading using EFH factors (all but front door mat) yielding mass over area of Mean 2.97E-06 µg/cm^2 and SD 2.85E-06 µg/cm^2. The mean and SD defined a log normal distribution in Crystal Ball™ which was used in the exposure assessment.
		95th	1.05E-01 µg/g	
Saito et al., 2007	Air	Saito measured TBBPA in home air, reporting no detectable amounts LOD 173 pg/m^3 and MDL 1.2 ng/m^3		
Office				
Geens et al., 2009	Dust	Median 7.50E-02 µg/g		Median corrected for dust loading using EFH factors (all but front door mat) yielding mass over area of 5.75E-06 µg/cm^2 used as point value.
Ni and Zheng et al., 2013	Air $PM_{2.5}$	Median 5.07E-04 µg/m^3		Median value used as a point value directly for inspired air concentration.
Ni and Zheng et al., 2013	Air PM_{10}	Median 2.4E-04 µg/m^3		Median value used as a point value directly for inhaled but not inspired (swallowed) air particle concentration.

Tables 55-58 present the results of the probabilistic modeling for TBBPA exposures for the modeled environments and all exposures combined. These show the results of the full range of exposures across all percentiles of the population groups for the modeled environments. Graphs were not provided for TBBPA exposures, as results are very low for all population groups and environments.

Table 55. Results of probabilistic exposure assessment of TBBPA exposure by age group in the child care environment.

Age Group (years)	Child Care Percentile (ng/kg/day)		
	25th	50th	75th
<1	<0.01	<0.01	<0.01
1 - <3	<0.01	<0.01	<0.01
3 - <12	<0.01	<0.01	<0.01
12 - <18	<0.01	<0.01	<0.01
>= 18	<0.01	<0.01	<0.01

Table 56. Results of probabilistic exposure assessment of TBBPA exposure by age group in the home environment.

Age Group (years)	Home Percentile (ng/kg/day)		
	25th	50th	75th
<1	<0.01	<0.01	<0.01
1 - <3	<0.01	<0.01	<0.01
3 - <12	<0.01	<0.01	<0.01
12 - <18	<0.01	<0.01	<0.01
>= 18	<0.01	<0.01	<0.01

Table 57. Results of probabilistic exposure assessment of TBBPA exposure by age group in the office environment.

Age Group (years)	Office Percentile (ng/kg/day)		
	25th	50th	75th
<1	NA	NA	NA
1 - <3	NA	NA	NA
3 - <12	NA	NA	NA
12 - <18	NA	NA	NA
>= 18	0.01	0.01	0.01

NA = Not Applicable

Table 58. TBBPA exposure estimates for combined exposures from the child care, home, and office scenarios, by age group.

Age Group (years)	Combined Percentile (ng/kg/day)		
	25th	50th	75th
<1	<0.01	<0.01	<0.01
1 - <3	<0.01	<0.01	<0.01
3 - <12	<0.01	<0.01	<0.01
12 - <18	<0.01	<0.01	<0.01
>= 18	0.01	0.01	0.01

3.8.1 Discussion of TBBPA Results

Given the available data, none of the environments presents an exposure greater than 0.01 ng/kg/day to any population group. There were no data available to represent air concentrations of TBBPA in the child care environment, and measurements of air from the home showed only non-detectable levels. This assessment may underestimate exposure from the child care environment because there are no available data for air concentrations of TBBPA, although the available data indicate very low concentrations of TBBPA in dust and air in all environments where measured. There were no data to represent air or dust concentrations in cars, yielding a possible underestimate for the exposure from all environments combined.

3.9 ATO Results

ATO concentration data (Table 59) were available only for air in child care centers and dust in homes.

Table 59. ATO chemical concentration and type of value used for each media and environment for the exposure assessment. Note that units are in µg/area.

Study	Medium	Data from Study	Data Application
Child Care			
Majestic et al., 2012	Air	Mean (SD) 1.70E-02 (7.00E-03) µg/m^3	Mean and SD as reported by the authors used to create log normal distribution using Crystal Ball™. All mass from PM_1 concentration measurements inspirable, none available for ingestion.
Home			
McDonald et al., 2010	Dust	50^{th} %ile of entry area mass over area value 5.0E-01 µg/m^2	Reported value used as point value in exposure assessment. No dust mass/area correction needed because study incorporated area distribution of chemical mass

Tables 60-61 and Figure 34 present the results of the probabilistic modeling for ATO exposures for the modeled environments. These show the results of the full range of exposures across all percentiles of the population groups for the modeled environments. A graph is not provided for ATO exposures in the home environment because all of the results for all age groups were low.

Table 60. Results of probabilistic exposure assessment of ATO exposure by age group in the child care environment.

Age Group (years)	Child Care Percentile (ng/kg/day)		
	25th	50th	75th
<1	0.42	0.46	0.51
1 - <3	0.29	0.33	0.37
3 - <12	0.07	0.10	0.16
12 - <18	0.04	0.04	0.06
>= 18	0.04	0.05	0.06

Table 61. Results of probabilistic exposure assessment of ATO exposure by age group in the home environment.

Age Group (years)	Home Percentile (ng/kg/day)		
	25th	50th	75th
<1	<0.01	<0.01	<0.01
1 - <3	<0.01	<0.01	<0.01
3 - <12	<0.01	<0.01	<0.01
12 - <18	<0.01	<0.01	<0.01
>= 18	<0.01	<0.01	<0.01

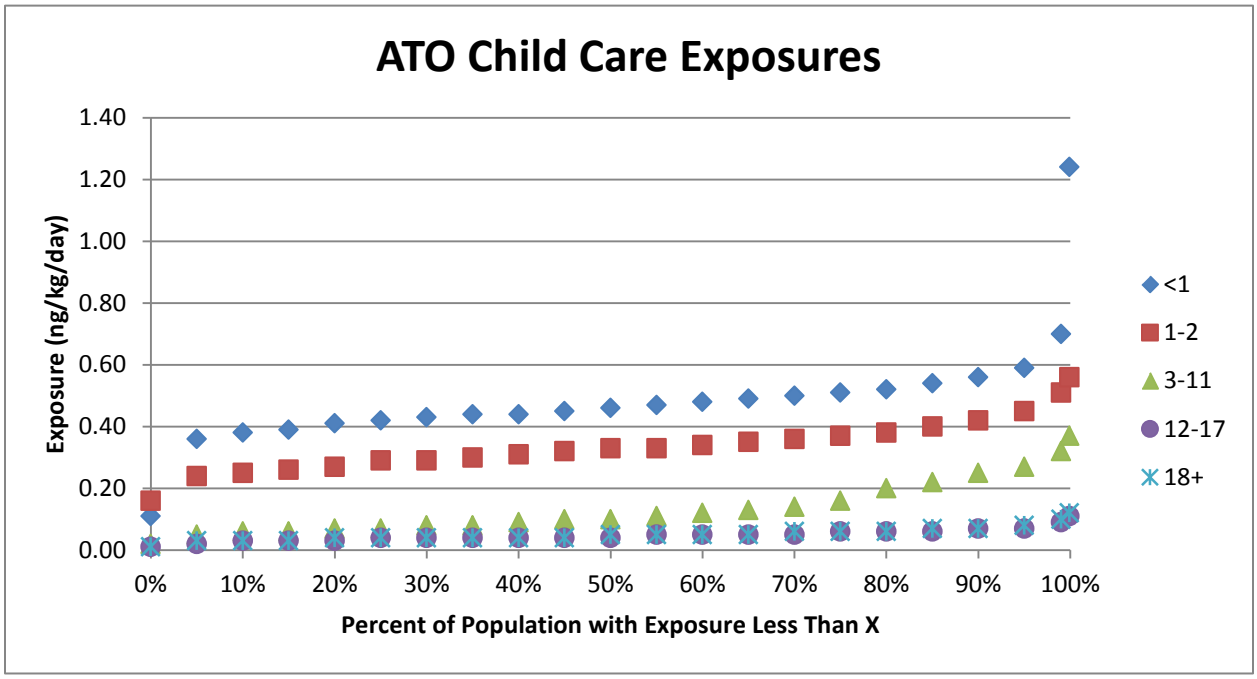

Figure 34. The full range of exposures across all percentiles of the population groups for ATO from the child care environment.

Table 62 and Figure 35 show the results of the combination of all exposures from the modeled scenarios.

Table 62. ATO exposure estimates for combined exposures from the child care and home scenarios, by age group.

Age Group (years)	Combined Percentile (ng/kg/day)		
	25th	50th	75th
<1	0.29	0.33	0.37
1 - <3	0.32	0.37	0.41
3 - <12	0.08	0.11	0.21
12 - <18	0.02	0.03	0.05
>= 18	0.06	0.08	0.10

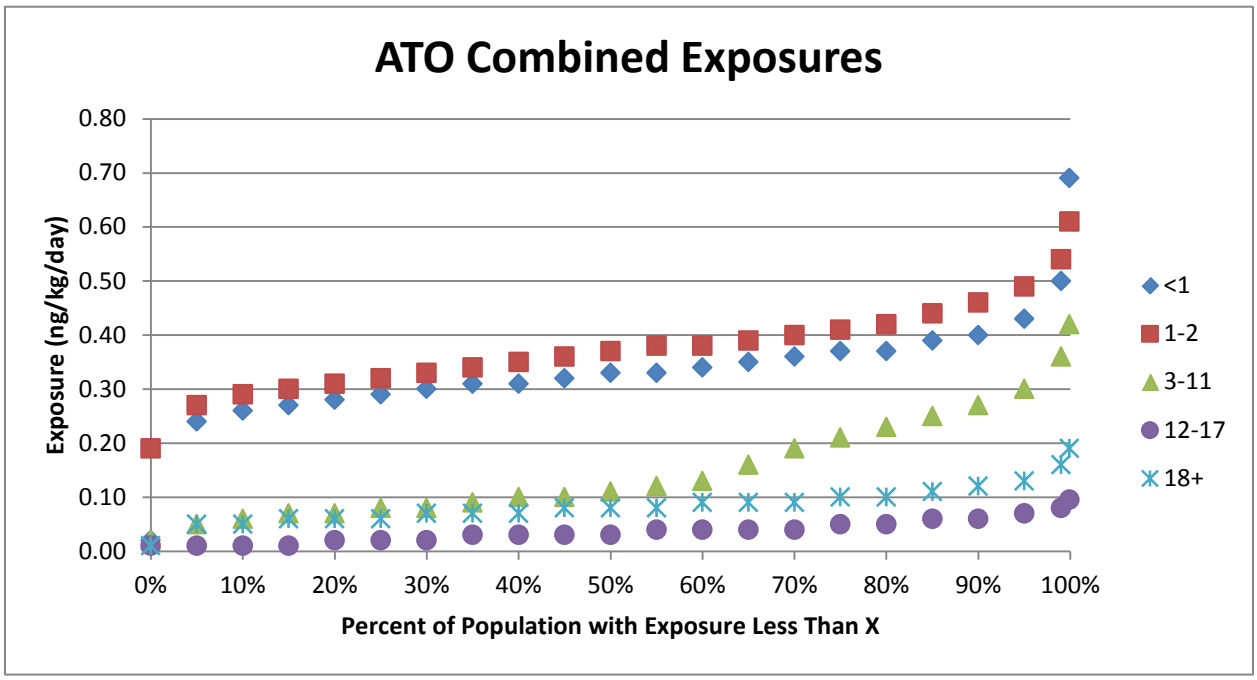

Figure 35. The full range of exposures across all percentiles of the population groups for ATO from all exposures.

3.9.1 Discussion of ATO Results

Analytical methodology reduces the collected ATO in air particulates or in dust to elemental antimony for quantification. This level can be converted, based on the relevant molecular weight, to the ATO equivalent, which would then assume all contributions of the elemental antimony would be from ATO rather than from environmental sources of elemental antimony. However, since the toxicology metrics to be used in a risk assessment for ATO are expressed in terms of elemental antimony, the exposure assessment will remain in elemental antimony units, not converted to ATO equivalents. This will provide the exposure metrics that are directly applicable to comparison with toxicology studies for the risk assessment considerations.

Contaminant concentrations of ATO in environments, such as child care, home, and office environments, have been inferred from the measurement of elemental antimony . However, elemental antimony is known to be in the environment also as a consequence of geological sources (mining, road dust, outside dirt), which are not related to flame retardant usage. Our goal was to select studies that are most likely to represent the antimony consequential from products containing ATO used as a flame retardant and that are representative of contemporary U.S. scenarios and studied and reported with acceptable quality.

Relevant antimony concentration data were available for air in child care centers and dust in homes. With such limited data available, few reliable conclusions can be made for exposure to ATO. This is in addition to the uncertainty regarding what portion of the antimony ion measured in these studies is actually from ATO use as a flame retardant. For purposes of this assessment, we assumed that all measured antimony in a study was from ATO.

In the home environment, only data from dust are available, yielding exposure contributions from dermal and oral (from hand-to-mouth events) exposures, but no contributions from inhalation or ingestion of air particulate matter are considered. No measurements of antimony in the dust or air of cars and offices are available.

The absence of air concentration data for homes results in an exposure assessment assuming no contribution from inhalation of dust particles, which results in a likely underestimate of exposure. Likewise, the absence of measurements of antimony in dust in the child care environment yields an exposure assessment that assumes no contribution from dermal or hand-to-mouth events in those environments. This also results in a likely underestimation of exposure.

Children experience the highest exposures per unit body weight to ATO in these assessments. Note, however, that exposure environments where adults could have exposures and children do not, such as offices, are not accounted for in this exposure assessment.

4 Discussion and Conclusions

This report uses a probabilistic approach and available published data to estimate human exposure to nine selected flame retardant chemicals. The focus is on indoor sources, such as indoor air and household dust, and exposure via multiple common routes of exposure, such as dermal, inhalation, and oral. Estimating a population's exposure to flame retardants is a challenge. Specific flame retardant uses are changing over time, new flame retardant chemicals are introduced, and old chemicals are replaced regularly. Flame retardant uses differ in different countries due to economics or consumer preferences, but prevalence of specific flame retardants also reflect regulatory decisions and the public and regulator's evolving understanding of potential risks. There is no single methodology for collecting or detecting and quantifying individual flame retardant concentrations in any given media. Reporting in the research publications varies in terms of detail of methodology, use of standard reference materials, and reporting of results. Flame retardants have been measured in many different media: products, surfaces of products, dust, particulates in air, indoor air, outdoor air, outdoor soils, indoor surfaces, water, and food. Below we discuss several key issues and uncertainties related to this exposure assessment.

4.1 An Assessment Approach Responsive to the Objective of Characterizing U.S. General Population Exposure

The focus of this exposure assessment is on contemporary indoor exposure to specific flame retardant chemicals for the general U.S. population. Relevant measurements of flame retardant concentrations in indoor air and dust were used to estimate exposures to children and adults from time spent in child care centers, homes, offices, and cars. The exposures are assumed to accrue because of the flame retardants' release from building materials, decorative and functional materials (carpeting, draperies, coverings), and other products used in those environments.

The flame retardant exposure data compiled from the literature for a previous TERA task order (0015) for CPSC (see Appendix A) was evaluated with this perspective. When considering the utility of the data in terms of relevance to our assessment objectives, the study dates were noted as an indicator of probable relevance to current chemical use. Given the differences in chemicals used in products over time, it is clear that there are era-related differences in the probability that a given chemical will exist in homes, products, workplaces, institutions, and public environments. By profiling the flame retardants that have been in these environments, or in older products, to provide exposure opportunity, the result may be a profile quite different from one focused on existing flame retardant exposure, and/or expected future use in consumer products.

A retrospective profile could provide data for consideration of potential contributions to biologically accrued flame retardant levels in people whose body burdens are consequential to past exposures over those past eras. That was not the scope of this exposure assessment project, but some chemical concentration data for those older eras are included in the Task Order 0015 Excel workbook.

The data as compiled in the Excel workbook includes, for many chemicals, measurements of flame retardants in products or measurements from wipe samples of products. In some studies, the product

composite materials (foam, plastic, fabric) were chemically analyzed to measure concentrations of the flame retardant in the product. Surface wipes of some products showed measureable amounts of flame retardant chemicals, presumably emanating from the surface of the product. Contaminated dust accrual could also account for some fraction of measureable amounts of the flame retardant collected on those wipes, and the source of that contamination could be from other products in the environment containing the flame retardant.

For this assessment, our approach was to use the dust and air particulate measurements as indicators of the overall contaminant levels of flame retardants in a particular environment. This approach has several advantages including the availability of a number of studies measuring flame retardant concentrations in dust and air particles in environments, such as homes, offices, outdoors, child care centers, cars, schools, gymnasiums, and airplanes. Where available, indoor/outdoor air measurement comparisons were used to confirm the expectation that the source of the flame retardants was from indoor objects or building materials (rather than manufacturing or mining activities outside of the indoor environment). Elemental antimony is used as a surrogate measurement for ATO. Antimony concentrations may also have contributions from elemental antimony from the Earth's crust. Some of this geologically sourced antimony may make its way indoors or into a car and be included in antimony concentrations but not be from ATO used as a flame retardant.

To represent the general U.S. population, four very common environments were chosen for this exposure assessment.—homes, child care centers, offices and cars. Industrial settings or outdoor settings are less likely to accrue the types of products relevant to the flame retardant uses. Within these categories, however, it is likely that there is great variability regarding the presence of flame retardant sources. For example, a number of studies describe "office" as an environment in which the study was conducted, but most lack details about the office contents, ages of the electronics and furnishings, or other important details about products in environment making direct comparison of the study results problematic, even for studies conducted within the U.S. This is an issue for all environments considering the variation in furnishings and cleaning of homes, cars, and child care centers. The following information was used to select the environments for this assessment:

- *Home* - Approximately 95% of the population lives in a household versus an institution or non-residential setting (U.S. Census Bureau, 2010).
- *Child Care Center* - Approximately 82% of preschool children attend some form of child care/preschool/play center for at least part of the week (Story et al., 2006). More than 60% of elementary level children attend some form of after-school care or summer child care or other similar center (Story et al., 2006). All of these facilities are likely to have electronics, foam mats, furniture, plastics, and other products that may contain flame retardants.

- *Office* - The office workspace is a key environment for flame retardant exposure, as contrasted to other working environments, because it is stocked with the kinds of products that could contain flame retardants, such as electronics, plastics, foam cushions, furniture, carpeting and other products made of fabric or plastics.
- *Car* - On any given day for the general public, there is greater than an 80% chance they will spend some time in a car (private car, taxi, or hired car) (Bueler and Hamre, 2014).

These environments align with CPSC priorities for consideration of population groups, emphasizing infant's and children's environments, while also representing the key environments in which most of the U.S. population will spend the majority of their time on any given day. This provides a good representation of the "general U.S. population" potential exposure profile. It does not necessarily represent less common exposure scenarios for subpopulations experiencing exposures from unique environments with potentially high concentrations of one or more flame retardants. An example unique environment might be the case of gymnasts and their coaches who frequently spending many hours per day in gym environments and come into contact with additional products with flame retardants (e.g., gymnastics foam pits). Another unique scenario not represented in the normative population and population environments would be people who frequently spend significant time on airplanes or other enclosed area with recycled air over densely furnished areas with flame retardant treated materials (e.g. airplane interiors). Those and other unique scenarios are not represented by this exposure assessment. Those scenarios and scenarios for any set of consumer products could be considered separately.

4.2 Key Limitations and Uncertainties

The principles of data selection are presented in the Methods section (Section 2). In selecting the studies from which values would be used for quantifying contaminant levels in a medium (dust or air) and an environment (child care, home, office, car), several important issues emerged that contribute to the overall uncertainty in the estimates and limitations to interpretation of results. These issues included using studies conducted outside the U.S., a preference for data that facilitated use of parametric distributions of values for exposure assessment parameters, and adjustments to chemical concentrations in dust to mass across the area of the surfaces (dust loading). In addition, the lack of data for one or both media in an environment contributes to uncertainty.

4.2.1 Domestic versus International Study Selection

Concentrations of flame retardants in the indoor air and on surfaces are a consequence of particulates contaminated with flame retardants escaping and or leaching from the products into that room space. Studies conducted in specific states or other countries may be generally representative for describing that potential.

In 1975, California adopted California's Technical Bulletin 117, requiring the use of flame retardants in upholstery in furniture sold in the state. The effect was an increased presence of flame retardants in furniture in California and possibly throughout the U.S. and in other countries. Since the furniture market is not focused solely on California, many manufacturers adopted the California standard for furniture destined for any market. International manufacturers often used the same chemicals in

furnishings to make them exportable to the U.S. and to comply with similar laws in other countries. Studies of dust and air concentrations of flame retardants in homes, child care centers, cars and offices provide very little information about the furnishings, electronics, or other features relevant to the possible sources of flame retardants. Nor do they detail cleaning and air filtering practices in these environments, which could reduce dust loads and air particulates. For our assessment, we assumed the California-based studies to be relevant to the general U.S. population, considering inherent unknowns and probable variations in the environment conditions in all of the available studies.

Products containing the originating flame retardants—the sources of the flame retardant treated products—are similar internationally – electronics, fabrics, and plastics in consumer products. Geography plays a lesser role for flame retardants than other environmental contaminant issues, although regional and socioeconomic factors do influence product availability. There could be a great deal of variability in how the home, office, or child care space is furnished between countries and even some variability within the U.S. Studies were very imprecise in terms of specificity for describing these environments. The international markets for many common consumer products and international use of the flame retardants provide a great blending of the consumer products within the spaces of these homes, offices and child care facilities. For these exposure assessments, preference was given to U.S. and Canadian studies when all other points of consideration were the same, but when a foreign study had an advantage for the assessment, it was not excluded simply because it was conducted outside of the U.S. An example of this is the use of Ni and Zeng (2013). In this study, the authors measured the concentrations of TBBPA on respirable particles ($PM_{2.5}$) and non-respirable particles (PM_{10}), demonstrating a significant preferential affinity of the flame retardant to the smaller, respirable particles. The offices sampled in this study could be somewhat different from offices in the U.S. However, the Ni and Zeng (2013) study strength was in its reporting of the significant concentration on the respirable particles in the air of these offices.

4.2.2 How Data are Reported in Studies

Ideally, the full reporting of all recorded data would accompany any publication, but the reality is that authors select the metrics to be reported in their publications. Data reduced to a single point, such as a mean, maximum, or median, provide an opportunity for introduction of bias in the presentation or interpretation of the results, and may mask issues important to consider in terms of study quality. There are advantages to having a description of the range and skew of the collected data. Such information may reveal researcher bias for a given outcome, or variability or skew could signal sample contamination or inadequate numbers of samples underlying an author's conclusion.

When the metrics provide enough information to construct a parametric distribution, a broad range of the population's potential exposure is considered. Rather than having just the "mean concentration" data, the range of contaminant levels experienced by the public—from low to high levels—can be described. This provides a more informative distribution of potential exposures that could be experienced by the general public (represented by exposures between 25^{th} and 75^{th} percentiles). While this assessment had a preference for studies that provided metrics that facilitate construction of

parametric distribution, the selected studies first had to pass a level of usability, quality and representativeness before this preference was considered.

4.2.3 Dust Loading

As discussed in Section 2, calculating exposure to dust presents some unique challenges that contribute to uncertainties in estimating human exposure. For most other media, exposure concentrations can be measured directly. For dust, adjustments must be made from chemical concentration in dust to mass across the area of the surfaces humans touch. Few studies report this "dust loading" and we had to employ standard assumptions provided in the EPA EFH to convert the concentration values for a collection of dust to an estimate of the mass of dust existing across a surface. These factors vary greatly (even an order of magnitude) depending on the type of surface and whether or not it is frequently disturbed. It is also known, as we discussed in Section 2, that collection methods can greatly influence the results. We had to assume that the collection methods employed in the research would comport to the conditions considered in the EPA EFH. Where little information was available about the surfaces, we applied an average of the surface factors from the EPA EFH. Again, this introduces further uncertainty, but these assumptions seemed reasonable and did not exaggerate the conversions from concentration to mass over area.

4.2.4 Impact of Data Gaps on Relative Contribution from Different Environments to Combined Daily Exposures

With the exception of TEP, the highest exposures (at the 50th percentile of the population's exposure) to flame retardants were experienced by infants or children ages 1 to <3 years. For most of the flame retardants, the environment contributing the most to the combined daily exposure for infants and young children ages 1 to <3 was the home environment (TDCPP, TCPP, TCEP, TBB, and TBPH). ATO is not considered in these comparisons because of the limited data and results for ATO. Infants and young children have frequent hand-to-mouth events and a relatively large proportion of their body surfaces are in contact with surfaces in the environments that could have contaminated dust on the surfaces. In addition, since the exposure is expressed in terms of mass of chemical per kg body weight per day, the exposures are likely to be higher for young children as their body weights are lower than older children and adults.

We made a number of observations by looking at the individual flame retardant results and making comparisons based on the values at and near the 50th percentile of the distribution of exposure for the age group cited.

- For TEP, the environment contributing the most to the combined daily exposure for all age groups was the car due to higher air concentrations in cars than the other environments.
- Office air concentrations of TCEP caused high exposures for adult office workers, presenting the highest exposures to this population of people above the age of 18 for any of these flame retardants.
- TDCPP and TCEP had data available on dust and air concentration for all four environments, minimizing the uncertainty in the combined exposure estimates caused by data gaps for any one

contributing source. For both of these chemicals, the home environment was the major contributor for infants and children 1-3 years (more than half of the combined exposures, considering all sources). For TCEP, exposure in the office environment was the key contributor for adult combined exposures.

- For TBB, the relative contribution to the combined exposures for young children (at the 50th percentile for children 1-3 years) was overwhelmingly from the home environment (>95%). All environments were informed with dust concentrations, while only the child care and home environments had data for both air and dust. The absence of air concentration data for the office environment and car environment may not impact this relative contribution comparison unless air concentrations in these environments are found to be very high.
- For TBBPA, available data indicate relatively low concentrations in dust and air in the environments for which data were available, and none of the environments presented an exposure greater than 0.01 ng/kg/day to any population group. However, lack of air measurements in the child care and car environments and lack of dust data in the car environment may lead to an underestimation of total exposure from the combined environments.
- The impact of data gaps appears to be potentially significant when considering the exposures from child care and home environments for ATO. The unique issues related to the analytical methodology measuring elemental antimony were discussed in this report. Antimony adherence to respirable dust particles presents an exposure for the child care environment, which is the dominant contributor to the combined exposures from these two environments. The absence of data for antimony in the home environment makes conclusions regarding relative contributions from particular environments difficult.

4.3 Conclusions

To consider the possible health threats posed by flame retardant chemicals, we must first understand what exposures to flame retardants may occur to different populations in their environments. Concentrations of flame retardants have been measured in air, dust, and other media from homes, vehicles, workplaces, schools and child care centers, and several other public spaces. The many flame retardant studies and publications referenced in this report presented substantial information on exposure concentrations but often lacked detailed information, which created complications that were challenging to address in the exposure assessments. This report discussed these complications and key issues are noted below.

- Industrial use of the flame retardants has changed over time; therefore the studies reflect a different era of use in consumer products.

- Descriptions of environments, consumer products, and potential flame retardant sources in the referenced publications were very limited.

- Different collection methods were employed in the publications; in particular, the particulate fractions in the collected air samples were poorly characterized in most studies.

- Different dust collection methods were employed, rarely with experimental designs that included dust dispersion analysis over the surfaces where dust was collected. Hence, general corrections were made for “dust loading.”

In spite of the challenges we had in conducting these exposure assessments, we were able to use a probabilistic approach to show a range of the possible exposures to the general population, which were calculated from available data and reasonable assumptions. We were able to put these exposures into perspective across populations and for several common environments. An additional limitation is that there are data on some specific environments that suggest concentrations of flame retardants may be higher in places other than the four environments we assessed (e.g. gymnastics centers); therefore, inclusion of these special environments for the relevant subpopulations may increase total exposure for these subpopulations.

The exposure assessment results presented in this document yield one of the two factors needed to assess the potential for human health risk from these flame retardants. Toxicity estimates are the second piece of the risk equation as risk is a function of exposure and toxicity. Lower exposures to more toxic chemicals may have greater health risk than larger exposures to less toxic chemicals.

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Appendix A
Flame Retardant Exposure Assessment Database, Report from CPSC Task Order 0015

Task Order 18
Contract Number
CPSC-D-12-0001

Final Report

September 28, 2016

Prepared by Toxicology Excellence for Risk Assessment and The LifeLine Group

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Appendix A: Flame Retardant Exposure Assessment Database, Report from CPSC Task Order 0015 (Contract CPSC-D-12-0001), prepared for CPSC by Toxicology Excellence for Risk Assessment (TERA), January 6, 2016.

TERA

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FOR PUBLIC HEALTH PROTECTION

Flame Retardant Exposure Assessment Database

Task Order 15
Contract Number
CPSC-D-12-0001

Final Report

December 17, 2015, rev. January 6, 2016

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Background

TERA, in conjunction with The LifeLine Group (LLG) organized previously collected exposure data on the flame retardant (FR) chemicals (listed in Table 1 below) into an Excel database. Exposure data collected and reported in previous work for CPSC was captured into a single Excel workbook. Emphasis was placed on data from the indoor environment. The purpose of creating the spreadsheet was to organize key information on data from each study that has potential relevance for assessing indoor exposure to the specified flame retardants. The spreadsheet is to provide a complete and accurate picture of the available data and evaluation of each study's quality and relevance for use in an exposure assessment.

Table 1: Selected FR chemicals for the database

FR Chemical	CASN
Trialkyl phosphates	
Tris(1,3-dichloro-2-propyl) phosphate (TDCPP)	13674-87-8
Tris(chloropropyl) phosphate, mixture of isomers (TCPP)	13674-84-5, 76649-15-5, 76025-08-6, 6145-73-9, 26248-87-3
Tris(2-chloroethyl) phosphate (TCEP)	115-96-8, 29716-44-7
Triethyl phosphate (TEP)	78-40-0
Aromatic phosphates	
Triphenyl phosphate (TPP)	1145-86-6
Brominated flame retardants	
2-Ethylhexyl 2,3,4,5-tetrabromobenzoate (TBB)	183658-27-7
Di(2-ethylhexyl) tetrabromophthalate (TBPH)	26040-51-7
Tetrabromobisphenol A (TBBPA)	79-94-7; 121839-52-9
Inorganic flame retardants	
Antimony trioxide (ATO)	1309-64-4

Approach

We designed a spreadsheet in consultation with the Contracting Officer's Representative (COR) that captures the key relevant data from the previous project reports on exposure information for nine flame retardants (see TERA reports for Tasks 0008 and 0010). As directed by the COR, we focused on indoor

exposures (primarily indoor air, particulates, household dust, and direct or inferred migration out of products) although outdoor air and some other media were captured to provide data for comparisons, as appropriate.

For the studies, relevant information from each study was captured using the column headings in Table 2. The database was initially populated with the information from relevant tables from the final reports of previous task orders. Studies were then reviewed to fill in any missing factual data. Following the data population step, each study was critically reviewed to complete the database entries, in particular evaluating the study quality with regard to relevance, representativeness, precision, and methodology. Qualitatively assessing the studies is important to provide context for the interpretation and use of the data. Table 3 describes the types of information captured for the individual quality descriptors.

Concentration data in other media, such as food and water, from the previous reports are copied into separate tabs for food and water. These studies did not undergo additional analysis or quality evaluation for the database. Similarly, the information from previous reports on biomonitoring studies were captured in separate tabs, with no additional analysis or quality evaluation. No additional literature searches were conducted for this project.

Table 2. List of database elements (column headings) and brief description of each.

Study Number	First digit is study number and main study entry. Each study is further numbered to represent each unique combination of study, FR, location, and media corresponding to a concentration measurement
Reference	Study short citation
Date Study Conducted	Date the study was conducted or the measurements were taken
Location (e.g., office, residence, room)	Where the measurement was taken
Chemical	Flame retardant name or abbreviation
Indoor air, outdoor air, dust	Media type
Suspected Source	Any products or conditions that are reported by the authors in the geographic area or space where the measurement was taken
Study Objective	Purpose or objectives of the study or hypothesis tested
Methods	For main study entry, a brief description of methods, for subrows, additional details for the particular media and/or location
Country (city/region)	Country and city or region(if reported) where the measurements were taken
n =	Number of items or locations sampled and number of replicates
n comments	Explanation for how “n” was determined
Average	Concentration labeled “average” by study authors

Mean	Concentration labeled “mean” by study authors
Median	Concentration labeled “median” by study authors
Lowest	Concentration labeled “lowest” by study authors
Highest	Concentration labeled “highest” by study authors
95th%	Concentration labeled “95th percentile” by study authors
Geometric Mean	Concentration labeled “geometric mean” by study authors
Units	Concentration units in nanograms (original study units in parentheses when not in nanograms)
Standard Deviation	Standard deviation, if given
Detection Frequency	As reported by the study authors
Limit of Detection	As indicated by author
Limit of Detection units	Units in nanograms (original study units in parentheses when not in nanograms)
Method Detection Limit	As indicated by author
Method Detection Limit units	Units in nanograms (original study units in parentheses when not in nanograms)
Quality – Relevance	See below
Quality – Representativeness	See below
Quality - Precision	See below
Quality – Methodology	See below
Comments	Highlight issues and unique features or related references for the publication.

Table 3. Quality descriptors used in the database.

A. Relevance: With CPSC’s assessment purpose—assessing human exposure in a residential setting—as the guiding principle, the information will be linked to its contribution in assessing the exposures to
- populations or special conditions experienced by the populations (socioeconomic, geographical, age, gender, etc.) with emphasis on life stages
- locale, as in home, day-care, office, etc.
- the physics of the product or media governing potential for release, transfer, binding, accumulation or uptake of the chemicals
- product type
- prospective relationship to biomonitoring data
- other

B. Representativeness: How can the information be applied in terms of
- chemicals to which it may be applied (all, presumably all, specific ones)
- relationship to pyrolytic forms of chemicals
- relationship to degradates or metabolites of parent chemical
- geographical, year data were collected, or other situation which favors the application of the information to US population assessment purposes
- utility in prospective assessments
- utility in relation to biomonitoring or other retrospective exposure profiles

	• other
C.	Precision: This relates to any situation in the publication that limits the data precision. For example, if data were summarized and original data not available or inadequately described for exposure assessment purposes, that precision issue will be pointed out. Issues related to number of measurements or duplicates or other methodology will be pointed out when suggestive of limitations or significant excellence.
D.	Methodology: This relates to any element of the methodology that constrains or limits the application of the information to the exposure assessment.

Results

The resulting database provides a standardized description of exposure data on nine flame retardants. As an Excel spreadsheet the entries can be sorted to be able to group data by media, location, chemical, or other relevant elements. The tab labeled "ALL CHEMS" presents the data from 108 studies in the database with 745 subrows. Food and water data (reported without additional analysis from previous tasks) can be located under their respective tabs in the same Excel file. Similarly, information on biomonitoring studies is captured in separate tabs for each FR (e.g., TCEP – bio). A list of all the studies cited in the Excel spreadsheet are found in the next section.

In capturing and reporting on these studies, we made the following observations:

- The use of individual flame retardants has changed with time and therefore human exposure and FR concentrations are changing
- Abundant information exists for many of the FRs to construct patterns of residue in multiple environments for the general US population and some subgroups for retrospective and prospective exposure assessments.
- Residue patterns expressed in the literature are derived from evolving methodologies for collection, separation and analysis of the matrices involved in the study. Different geographical and site conditions (rural, urban, proximity to transport lines or mines) and analytical processes make it necessary to consider these variables when constructing residue patterns from multiple studies.
- Abundance and quality of information differs for different FRs.
- Residue measurements for media in which ATO might exist are sometimes reported in the context of Sb residue. Depending on the methodology and subsequent statistical treatment of the data, these values may or may not represent ATO. Some may represent Sb as a consequence of ATO in the media or as a consequence of Sb uses not related to FR use. As data are extracted for use in exposure assessment, the assessor will need to examine each data source for this issue and apply the data accordingly.

Reference List for Database

The following is a list of references cited in the database.

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Appendix B
Exposure Assessment Algorithms

Task Order 18
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Final Report

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Prepared by Toxicology Excellence for Risk Assessment and The LifeLine Group

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This Appendix describes the numerous algorithms used in the LifeLine™ exposure modeling software. These algorithms reflect common exposure assessment practice for estimating exposures via inhalation, oral, and dermal routes of exposure. The information has been excerpted from the LifeLine development handbooks for the Community Based Assessment Software. Further details on the algorithms and software are freely available from The LifeLine Group (www.TheLifeLineGroup.org and CFChaisson@TheLifeLineGroup.org)

1 Inhalation Exposure

Treatment includes ONLY inhalation exposure to persons engaged in specific activities.

SCOPE AND APPROACH

The beginning point for these inhalation exposure models is the airborne concentration of the compound of interest within the breathing zone of the potentially exposed person (C_{avg}). C_{avg} will be operationally defined below and will be USER supplied. These critical inputs may be obtained from monitoring studies, obtained from other sub-models (*e.g.,* CONSEXPO 4.1, SWIMODEL 3.0 or WPEM 3.2) or provided by best professional estimates.

The average breathing zone concentration of toxicant (C_{avg}) provided by the USER will be that for the following forms of the substance mixed or suspended in air:

- Gaseous molecules
- Particulate – isomeric or fibrous material of varying sizes that are small enough to be dispersed in the air and remain there for the exposure duration of interest.

DEPENDENT VARIABLES

C_{avg} = time weighted average concentration of the toxicant in the breathing zone of the period during the duration (DUR) of the exposure (µg/m^3). It is the area under the C,t curve divided by the duration (DUR) of exposure. (USER supplied as a point value or distribution of concentrations)

INHALED = Estimated absorbed inhaled dose from breathing contaminated air per day of a specific person, and particular activity in micrograms per kg body weight per day (µg/kg/day).

$$\text{INHALED} = (C_{avg})(InhF)(InhR)(FREQ)(DUR)/BW$$

INDEPENDENT (PREDICTOR) VARIABLES

DUR = duration of exposure or the time the person is inhaling contamined air from the considered volume (hr) (USER input)

FREQ = frequency of inhalation exposure events per day (/day) (USER input – default 1)

InhF = inhaled factor or fraction of inhaled toxicant that is not immediately exhaled (0-1 unitless). (USER input or from rules presented to USER or Default=1)

InhR = rate of inhalation (age and activity-related) (m^3/hr) (Program Supplied)

2 DERMAL EXPOSURE

Dermal Exposure occurs when the substance under consideration comes in contact with some portion or all of a person's skin for some finite period of time during a 24 hour period.

The exposure results from a potentially transferable residue on a surface (DR) over a number of contacts with that surface per unit time.

Rate of exposure (µg/hr) = $(SA_{bodyzone})(CR_{bodyzone})(DR)(TE)$

$SA_{body\ zone}$ = Age and gender-specific surface area of the body zone under consideration. (cm^2).

$CR_{body\ zone}$ = Contact Rate: dermal exposure rate or **frequency** of contact for a specific body zone[1] (hr^{-1}) for the day of exposure – this basic rate is standardized for the activity level of young adults (Entered with STICKMAN – See Note 2 below)

DR = Dislodgeable (transferable) Residue (µg/cm^2): That part of the residue of a substance deposited on a solid material which may be transferred by direct contact to human skin or clothing (ASTM International, 2003).

TE = Transfer efficiency. The proportion (unitless 0 to 1) of the total available residue of the substance on the material (DR) that actually transfers per contact.

Substance could be anything such as a chemical, toxicant or microbe that can be deposited on the skin. It can be present as a neat substance (i.e., 100% of its mass is the substance of interest)

[1] STICK Person, which will include USER input for the frequency of contact ($CR_{body\ zone}$) of the body zone during the activity on that day. Example 1: touching reeds with an estimated 5 hand clasps or "regrips" per/min would be 300/hr for the hand. Example 2: walking through grass such that "new grass" passes over and contacts the lower leg and feet 30 times per min or 1800/hr.

or as a portion of another substance (e.g., a surface wax with 10% of the substance of interest or soil contaminated with 1% of a substance of interest.)

Material is the surface that the skin contacts. It includes surfaces such as floor, table, carpet, shower curtain, grass, pine cones, water, soil, air, etc.

TIME ELEMENT OF EXPOSURE (USER Supplied)

The model estimates the contact (applied) or absorbed dose from dermal exposure to a single agent during a single day (24 hour period). All of the exposure estimates in this document are on a per day basis. Thus, all are divided by t and t = 1 day.

2.1 Topical Exposure

This includes ONLY dermal exposure to clothed and unclothed body-zones. A separate analysis and exposure model is conducted and presented below for dermal and oral exposure for those portions of just the hand involved in hand-to-mouth activity. As such, the surface area of the hand in this analysis is corrected (reduced) to account for the hand-to-mouth activity not considered in this section.

DEPENDENT VARIABLES

CONTACT (APPLIED)$C_{bodyzone}$ = Estimated contact (applied) dermal dose per day to the skin surface after going through the clothing over the skin of a specific person for a particular operation in micrograms per kg body weight per day (µg/kg/day).

CONTACT (APPLIED)$C_{bodyzone}$ =

$$(SA_{bodyzone})(CR_{bodyzone})(FREQ)(DR)(TE)(prop)(SF)(DUR)(MFDA_{hand})(CP)(pClothed_{hand})(pExp_{hand})(MFAL)/BW$$

(see definitions below for other variables)

CONTACT (APPLIED)$B_{bodyzone}$ = Estimated contact (applied) dermal dose per day to the bared (unclothed) skin surface of a specific person for a particular operation in micrograms per kg body weight per day (µg/kg/day).

CONTACT (APPLIED)$B_{bodyzone}$=

$$(SA_{bodayzone})(CR_{bodyzone})(FREQ)(DR)(TE)(prop)(SF)(DUR)(DP)(MFDA_{hand})(1-pClothed_{hand})(pExp_{hand})(MFAL)/BW$$

(see definitions below for other variables)

C (A)$DD_{bodyzone}$ = contact **(**applied) dermal density or the amount of the substance of interest on the skin expressed in weight per unit area (µg/cm^2/day)

CONTACT (APPLIED)$DD_{bodyzone}$ = ($CR_{body\ zone}$)(MFAL)($MFDA_{bodyzone}$)(DUR)(FREQ)(DR)(TE)(prop)(SF)(CP_{matrix})

Note: The model considers that there is a limit to how much substance can be retained on the skin's surface.

C (A)$DL_{bodyzone}$ = Contact (applied) dermal loading of the actual amount of the substance (if it is not neat) on the skin

= ($CR_{body\ zone}$)(FREQ)(MFAL) ($MFDA_{bodyzone}$) (DUR)(DR)(TE) (SF)(CP_{matrix}) (µg/cm^2/day).

Notice that the only difference between C(A)DL and C(A)DD is that C(A)DL is for the entire substance while C(A)DD just considers the portion of the mass on the skin that is the substance of interest. For example, consider a pesticide which is 25% active ingredient in a nonvolatile vehicle. Assuming that it transferred with the same concentration, the total substance transferred on contact C(A)$DL_{bodyzone}$ would be 4 times as much as the active ingredient C (A)$DD_{bodyzone}$. The difference is the proportion of the substance (prop = 0.25 in this example) that is the substance of interest.

C (A)$DL_{bodyzone}$ is set by default within the program at 1000 µg/cm^2. The rationale for this default is given in Note 7

$DERMALC_{body\ zone}$ = Estimated systemic dermal dose per day for a substance that first penetrates through the <u>clothed</u> portion of skin and then the skin of a specific person for a particular operation in micrograms per kg body weight per day (µg/kg/day). It is the product of the contact (applied) dose and the dermal absorption (DA – see Note 6).

$$DERMALC_{body\ zone} = (APPLIED)C_{body\ zone}) (DA)$$

$DERMALB_{body\ zone}$ = Estimated systemic dermal dose per day for a substance that is absorbed through the <u>bare</u> (unclothed) portion of skin for a specific person for a particular operation in micrograms per kg body weight per day (µg/kg/day).

It is the product of the contact (applied) dose and the dermal absorption (DA).

$DERMALB_{body\ zone}$ = (CONTACT (**APPLIED)$B_{bodyzone}$) (DA)**

$$DERMAL\_SYSTEMIC\_TOTAL = \sum_0^i (DERMALB_{bodypart\_i} + DERMALC_{bodypart\_i})$$

$LOCAL\_SKIN_{bodyzone}$ = Estimated contact (applied) dose on any cm^2 on any particular body zone ($\mu g/cm^2/day$)

$$LOCAL\_SKIN_{bodyzone} = \max((CR_{bodyzone})(MFAL)(DUR)(DR)(CP)(MFDA_{bodyzone}))$$

(see Note 6b)

INDEPENDENT (PREDICTOR) VARIABLES

$BCA_{body\ zone}$ = Bared Contact Area : Age-specific bare (unclothed) surface area of a specific body zone that is subject to dermal exposure (cm^2) – (USER input to STICK PERSON – See Note 1)).

$$BCA_{body\ zone} = (SA_{body\ zone})\ (1- pClothed_{body\ zone})$$

BW = Age and gender-specific body weight of the exposed individual (kg) (Calculated by LifeLine software).

$CCA_{body\ zone}$ = Clothed Contact Area : Age-specific clothed surface area of a specific body zone that is subject to dermal exposure (cm^2) – (USER identified body zone on STICK PERSON – See Note 1)).

$$CCA_{body\ zone} = (SA_{body\ zone})\ (pClothed_{body\ zone})$$

CP_{matrix} = Clothing Penetration: the proportion of the substance that penetrates clothing to the bare skin (unitless 0 to 1). (Matrix 3 assigned) or USER supplied).

$CR_{body\ zone}$ = Contact Rate: dermal exposure rate or **frequency** of contact for a specific body zone[2] (hr^{-1}) for the day of exposure – this basic rate is STANDARDIZED for the activity level of young adults (Entered with STICKMAN – See Note 2)

DR = Dislodgeable (transferable)Residue ($\mu g/cm^2$): That part of the residue of a substance deposited on a solid material which may be transferred by direct contact to human skin or clothing (ASTM International, 2003). It is measured by shaking methodology (dislodgeable residues) or wipe(swipe) methodology (transferable residues). It is also called Surface Loading. (Cohen Hubal *et al* 2006)- (USER).

Note:
The proportion of the Dislodgeable Residue (substance) on the material that actually transfers per contact may vary dependent upon the characteristics of the material (eg carpet, tile, grass etc). This is called the transfer efficiency and is represented by a unitless value between 0 and 1. (TE – see below).

DL = Dermal Loading (ug/cm^2): The amount of the dislodgeable (transferable) residue (DR) on the contacted surface that transfers to the skin surface per contact. It is the product of the DR and the transfer efficiency represented by a value between 0 and 1 (TE –see below).

$$DL = (DR)(TE)$$

[2] STICK Person includes USER input for the frequency of contact ($CR_{body\ zone}$) of the body zone during the activity on that day.

Thus the quantify (DR)(TE) in all of the algorithms represents the dermal loading (DL).

DFR = Dislodgeable foliar residue (ng/cm^2). Used primarily in pesticides studies in which the following equation is used to estimate time dependent dermal exposure:

$$\text{Exposure (ng/day)} = \text{DFR (ng/cm}^2\text{)} \times \text{TC (cm}^2\text{/hr)} \times \text{DUR (hr/day)}$$

Note: That this calculation method does not use the discreet number of contacts but rather rate of contact (area/time) to estimate exposure. This resulting estimate, however, is completely analogous to the Contact (applied) dose calculated above in Eq.3 and Eq. 4. Indeed, TC can be thought of as the product of surface areas (SA) and contact rate (CR) to render the effected area of contact per hour. The dose equation for this approach is:

$$\text{Contact(applied)dose (µg/kg/day)} = (\text{DFR (ng/cm}^2\text{)} \times \text{TC (cm}^2\text{/hr)} \times \text{DUR (hr/day))/(1000*BW)}$$

See definition of TC below.

DA = Dermal Absorption: The proportion of the contact (applied) dose that penetrates the skin (unitless 0 to 1) this is STANDARDIZED for the permeability of the trunk skin of young adults. (USER over-ride or Skin Perm Default – See Note 6)

DUR = Duration: length of time of the activity during which dermal exposure occurred (hr) (USER)

FREQ = Frequency of dermal exposure event (/day). Note that this is different from the contact rate within the event. FREQ will typically be 1 event/day.

MDA = Estimated dermal absorption of the substance that occurs during the duration of the exposure based on transfer rate (PERM) (µg/cm^2). See Note 6.

MFAL = Modifying Factors for Age Related Activity (unitless with a minimum of 0 used to modify $CR_{body\ zone}$) - USER Supplied OR Accepted – See Matrix 4

$MFDA_{body\ zone}$ = Modifying factors for dermal absorption from differential penetration for body zones (unitless minimum 0) (USER over-ride or Accepted – See Note 5)

PERM (sometimes called J_{max}) = estimated amount of substance that penetrates or is absorbed through the skin per unit time (µg/cm^2/hr).

$pClothed_{body\ zone}$ = Proportion of the age-specific surface area of the body zone under consideration that is covered with clothing (unitless 0 to 1) (See Matrix 1)

$(1- pClothed_{body\ zone})$ = Proportion of the age-specific surface area under consideration that is NOT covered with clothing (unitless 0 to 1) (See Matrix 2).

$pExp_{body\ zone}$ = Proportion of specific body zone that is exposed during activity (unitless 0 to 1). (Enter with STICKMAN input – see Note 2).

prop = Proportion of the substance that is dislodgeable and is of interest. (0-1) For a pure substance it is1.0.

$pSA_{body\ zone}$ = Age and gender-specific proportion of the total dermal surface area for each specific body zone (0 to 1 unitless) that is exposed. See Note 4.

pSA_{hand_mouth} = Age and gender-specific proportion of the hand surface area (SAhand) that is mouthed. (unitless). USER.

SA = Age and gender-specific total dermal surface area (cm^2). (Calculated by LifeLine – See Note 3).

$SA_{body\ zone}$ = Age and gender-specific surface area of the body zone under consideration. (cm^2).

$$SA_{body\ zone} = (SA)\ (pSA_{body\ zone})$$

SA_{hand_mouth} = surface area of the hand that is mouthed (cm^2) (Note dermal and oral exposure from this part of the hand is calculated separately as explained in DERMAL_HAND, HAND-TO-MOUTH ORAL EXPOSURES* and INCIDENTAL ORAL

SA_{hand_dermal} = surface area of the hand that is not mouth (cm^2)

$$SA_{hand\_dermal} = SA_{hand}\ (1 - pSA_{hand\_mouth})$$

SF = surface factor. The proportion of the handled material (object) that actually touches the skin (unitless 0 – 1). Default = 1 Example, pine cones may only contact 10% of the area of the fingers when handled thus SF = 0.1. (USER).

TE = Transfer efficiency. The proportion of the total available residue of the substance on the material that actually transfers per contact. TE can be influenced by the surface characteristics of the material. For example, there will be differences between the transfer from carpet, wood or tile floor. A unitless value between 0 and 1.

TC = Transfer Coefficient (cm^2/hr) = Residue transfer rate to humans during the completion of specific activities (cm2/hr) (USEPA,1998)

Dermal-transfer coefficient TC) =dermal exposure (ng/hr)/DFL(ng/cm^2) .

t = Exposure averaging time (days).

USEFUL EQUATIONS

CONTACT (APPLIED) DOSE or amount of substance on the surface of the skin per unit time

$$(\mu g/cm^2) = (DR)(TE)(prop)(SF)(CR)(DUR)(CP)$$

ABSORBED DOSE or actual amount estimated to go through the skin for that body zone ($\mu g/cm^2$) =(CONTACT (APPLIED)DOSE)(DA)(MFDAbody zone)

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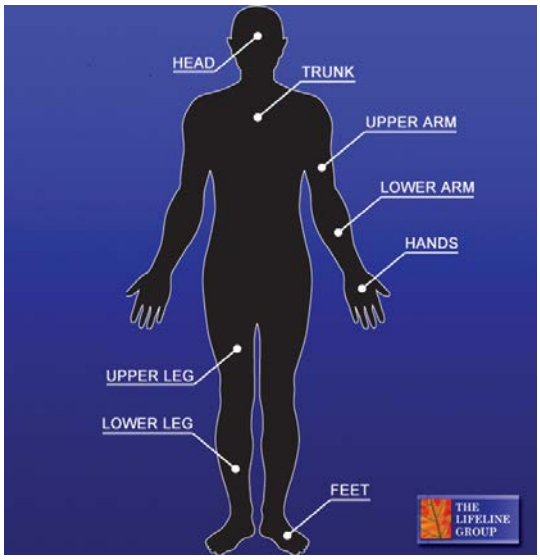
Whitmyre, G., J. Ross, M. Pandian, Evans,J., Lunchick,C. (2005). Development of Risk_Based Restricted Entry Levels, in *Occupational and Residential Exposure Assessment for Pesticides,* Franklin,C. and Worgan,J., (Eds),John Wiley and Sons Ltd. Chichester, West Sussex, England, pp 45-69.

3 Applications to Activity Record Generator Inputs

3.1 Note 1. Seasonal Clothing Check List (See Matrix 1, 2 and 3)

		S	F	W	Spr
Hat		☐	☐	☐	☐
Underwear					
Tee shirt	☐	☐	☐	☐	
Shorts	☐	☐	☐	☐	
Socks	☐	☐	☐	☐	
Shoes	☐	☐	☐	☐	
Pants					
Shorts		☐	☐	☐	☐
Long		☐	☐	☐	☐
Shirt					
Long Sleeved		☐	☐	☐	☐
Short Sleeved		☐	☐	☐	☐
Coat					
Vest	☐	☐	☐	☐	
Half Length		☐	☐	☐	☐
Full		☐	☐	☐	☐
Gloves		☐	☐	☐	☐

3.2 Note 2. Stick Person



USER Input for Activity Under Consideration:

For **TOPICAL** exposure:

1. Check all exposed body zones above (0 thru i).
2. For EACH Body Zone (0 thru i)
    a. Enter the Rate of Contact for this body zone ($CR_{body\ zone}$)
    b. Enter proportion of this body zone that is exposed ($pExp_{body\ zone}$) during this activity which the user enters (default =1). For example a collector walking through high grass might only have the front half (0.5) of their lower legs exposed at $CR_{body\ zone}$ rate of dermal contact with the remainder essentially nil.

Matrix 1
Proportion of Dermal Surface Area Covered or Clothed Values for various Body Zone/Clothing Combinations ($pClothed_{body\ zone}$)

	Hat	Tee Shirt	Under Shorts	Socks	Shoes	Short Pants	Long Pants	LSleeved Shirt	SSleeve Shirt	Vest Coat	Half Coat	Full Coat	Gloves
Head	**0.5**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Trunk	NA	**1**	**0.2**	NA	NA	**0.2**	**0.2**	**0.9**	**0.9**	**0.9**	**0.9**	**0.9**	NA
UArms	NA	**0.6**	NA	NA	NA	NA	NA	**1**	**0.6**	**0**	**1**	**1**	NA
LArms	NA	**0**	NA	NA	NA	NA	NA	**0.9**	NA	**0**	**0.9**	**0.9**	NA
Hands	NA	NA	NA	NA	NA	NA	NA	0	NA	NA	NA	NA	**1**
ULeg	NA	NA	**0.2**	NA	NA	**0.5**	**1**	NA	NA	NA	NA	NA	NA
LLeg	NA	NA	**0**	**0.2**	NA	**0**	**0.9**	NA	NA	NA	NA	NA	NA
Feet	NA	NA	NA	**1**	**1**	NA	NA	NA	NA	NA	NA	NA	NA

Matrix 2 (read across)
Proportion of Dermal Surface Area Uncovered or Unclothed for various Body Zone/Clothing Combinations
(1- $pClothed_{body\ zone}$)

	HAT	Tee Shirt	Under Shorts	Socks	Shoes	Short Pants	Long Pants	LSleeved Shirt	SSleeve Shirt	Vest Coat	Half Coat	Full Coat	Gloves
Head	**0.5**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**0**
Trunk	NA	**0**	**0.8**	NA	NA	**0.8**	**0.8**	**0.1**	**0.1**	**0.1**	**0.1**	**0.1**	NA
UArms	NA	**0.4**	NA	NA	NA	NA	NA	**0**	**0.4**	**1**	**0**	**0**	NA
LArms	NA	**1**	NA	NA	NA	NA	NA	**0.1**	NA	**1**	**0.1**	**0.1**	NA
Hands	NA	NA	NA	NA	NA	NA	NA	**1**	NA	NA	NA	NA	NA
ULeg	NA	NA	**0.8**	NA	NA	**0.5**	**0**	NA	NA	NA	NA	NA	NA
LLeg	NA	NA	**1**	**0.8**	NA	**1**	**0.1**	NA	NA	NA	NA	NA	NA
Feet	NA	NA	NA	**0**	**0**	NA	NA	NA	NA	NA	NA	NA	NA

Notes: These are default values that can be over written by USER. Highest Proportion for EACH body zone (read across) would be used in the calculation of dermal exposure through each clothed body zone for clothing actually worn (from check list). For example, person designated as wearing a tee shirt, undershorts, socks, shoes, short pants, s. sleeved shirt and a vest coat would have the following Proportion covered or **$pClothed_{body\ zone}$** profile: Head =0, Trunk = 0.9, U Arms = 0.6 , L Arms = 0, Hands = 0, Uleg = 0.5, LLeg =0.2 and Feet = 1. Proportion Bare or **$1\text{-}pClothed_{body\ zone}$**: Head =1, Trunk = 0.1, U Arms = 0.4 , L Arms = 1, Hands = 1, Uleg = 0.5, LLeg =0.8 and Feet = 0.

Matrix 3
Clothing Penetration (CP)
USER Supplied OR Accept Assignments Below

	HAT	Tee Shirt	Under Shorts	Socks	Shoes	Short Pants	Long Pants	LSleeved Shirt	SSleeve Shirt	Vest Coat	Half Coat	Full Coat	Gloves*
Head	**0.1**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Trunk	NA	**0.25**	**0.25**	NA	NA	**0.25**	**0.25**	**0.25**	**0.25**	**0.05**	**0.05**	**0.05**	NA
UArms	NA	**0.25**	NA	NA	NA	NA	NA	**0.25**	**0.25**	NA	NA	**0.05**	NA
LArms	NA	NA	NA	NA	NA	NA	NA	**0.25**	NA	NA	NA	**0.05**	NA
Hands	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**0.1**
ULeg	NA	NA	**0.25**	NA	NA	**0.25**	**0.25**	NA	NA	NA	NA	NA	NA
LLeg	NA	NA	NA	**0.25**	NA	NA	**0.25**	NA	NA	NA	NA	NA	NA
Feet	NA	NA	NA	**0.25**	**0.1**	NA	NA	NA	NA	NA	NA	NA	NA

*If gloves are worn – hand-to-mouth activity is considered nil

Notes: CP = 1 is complete penetration.

The Lowest Applicable Proportion for clothing penetration (CP) for EACH body zone (read across) would be used in the calculation of dermal exposure. Also worst case would be used for layered clothes. For example, person designated as wearing a tee shirt, undershorts, socks, shoes, short pants, s. sleeved shirt and a vest coat would have the following **CP** profile: Head =1, Trunk = 0.05, U Arms = 0.25 , L Arms = 1, Hands = 1, Uleg = 0.25, LLeg =0.25 and Feet = 0.1.

Note: These default estimates are professional judgment of the LifeLine scientists based on clothes made from standard natural fibers. An individual wearing a tighter weave water repelling fabric would tend to have a much lower penetration than the standard weave fabric considered and estimated herein.

Matrix 4
Modification Factor for Age Related Activity (MFAL)
USER Supplied OR Accept Assignment Below

AGE	MFAL
0-1	1
1-2	1
3-5	1
6-12	1
13-19	1
21-60	1
>60	1

Note: All values are currently set to 1 (no modification)

3.3 Note 3. Determination of Total Body Surface Area (SA) from Height and Weight

Gehan and George (1970) forward an equation that does NOT require height only weight to estimate total skin SA.

$$SA = KW^{\frac{2}{3}}$$

SA = surface area in m^2
W = body weight in kg
K = constant

More commonly used is an algorithm that was first published in 1916 (Dubois and Dubois):

$$SA = a_0 H^{a_1} W^{a_2}$$

SA = surface area in square meters
H = height in cm
W = weight in kg

Gehan and George (1970) used a least-squares method to identify the values of the constants. They used 401 observations to develop values for the parameters a_0, a_1 and a_2 to include different age groups. This has been determined by the EPA to be the formula of choice to estimate dermal surface area (SA) from height and weight. There estimated parameters are presented below:

		Values		
Age group	**N**	**a_0**	**a_1**	**a_2**
All ages	401	0.02350	0.42246	0.51456
< 5 years old	229	0.02667	0.38217	0.53937
≥ 5 – <20 years old	42	0.03050	0.35129	0.54375
≥ 20 years old	30	0.01545	0.54468	0.46336

Programming Note: Suggest that you test the age of the person first chose the appropriate age-specific equation from the 4 listed above to calculate their SA using their height and weight.

REFERENCES

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Gehan, E; George, GL. (1970) Estimation of human body surface area from height and weight. Cancer

Chemother Rep 54(4):225–235.

3.4 Note 4. EPA Data on the Percentage of the Total Dermal Surface Area (100 x pSAbody zone) for Adults and Children

Table 6-5. Percentage of Total Body Surface Area by Part for Adults

	Men						Women					
Body part	N[a]	Mean	(s.d.)[b]	Min.	-	Max.	N	Mean	(s.d.)	Min.	-	Max.
Head	32	7.8	(1.0)	6.1	-	10.6	57	7.1	(0.6)	5.6	-	8.1
Trunk	32	35.9	(2.1)	30.5	-	41.4	57	34.8	(1.9)	32.8	-	41.7
Upper extremities	48	18.8	(1.1)	16.4	-	21.0	57	17.9	(0.9)	15.6	-	19.9
Arms	32	14.1	(0.9)	12.5	-	15.5	13	14.0	(0.6)	12.4	-	14.8
Upper arms	6	7.4	(0.5)	6.7	-	8.1	-	-	-	-	-	-
Forearms	6	5.9	(0.3)	5.4	-	6.3	-	-	-	-		-
Hands	32	5.2	(0.5)	4.6	-	7.0	12	5.1	(0.3)	4.4		5.4
Lower extremities	48	37.5	(1.9)	33.3	-	41.2	57	40.3	(1.6)	36.0	-	43.2
Legs	32	31.2	(1.6)	26.1	-	33.4	13	32.4	(1.6)	29.8	-	35.3
Thighs	32	18.4	(1.2)	15.2	-	20.2	13	19.5	(1.1)	18.0	-	21.7
Lower legs	32	12.8	(1.0)	11.0	-	15.8	13	12.8	(1.0)	11.4	-	14.9
Feet	32	7.0	(0.5)	6.0	-	7.9	13	6.5	(0.3)	6.0	-	7.0

[a] Number of observations.
[b] Standard deviation.
Source: Adapted from U.S. EPA, 1985.

**The Surface AREA of Hands is that portion of the hands NOT involved in hand-to-mouth activity.

$$SA_{hand} = SA_{hand} - (SA_{hand})\ (pSA_{hand\_mouth})$$

Table 6-8. Percentage of Total Body Surface Area by Body Part for Children

Age (yr)	N M:F	Percent of Total											
		Head		Trunk		Arms		Hands		Legs		Feet	
		Mean	Min-Max	Mean	Min-Max	Mean	Min-Max	Mean	Min-Max	Mean	Min-Max	Mean	Min-Max
< 1	2:0	18.2	18.2-18.3	35.7	34.8-36.6	13.7	12.4-15.1	5.3	5.21-5.39	20.6	18.2-22.9	6.54	6.49-6.59
1 < 2	1:1	16.5	16.5-16.5	35.5	34.5-36.6	13.0	12.8-13.1	5.68	5.57-5.78	23.1	22.1-24.0	6.27	5.84-6.70
2 < 3	1:0	14.2		38.5		11.8		5.30		23.2		7.07	
3 < 4	0:5	13.6	13.3-14.0	31.9	29.9-32.8	14.4	14.2-14.7	6.07	5.83-6.32	26.8	26.0-28.6	7.21	6.80-7.88
4 < 5	1:3	13.8	12.1-15.3	31.5	30.5-32.4	14.0	13.0-15.5	5.70	5.15-6.62	27.8	26.0-29.3	7.29	6.91-8.10
5 < 6													
6 < 7	1:0	13.1		35.1		13.1		4.71		27.1		6.90	
7 < 8													
8 < 9													
9 < 10	0:2	12.0	11.6-12.5	34.2	33.4-34.9	12.3	11.7-12.8	5.30	5.15-5.44	28.7	28.5-28.8	7.58	7.38-7.77
10 < 11													
11 < 12													
12 < 13	1:0	8.74		34.7		13.7		5.39		30.5		7.03	
13 < 14	1:0	9.97		32.7		12.1		5.11		32.0		8.02	
14 < 15													
15 < 16													
16 < 17	1:0	7.96		32.7		13.1		5.68		33.6		6.93	
17 < 18	1:0	7.58		31.7		17.5		5.13		30.8		7.28	

N: Number of subjects, male to female ratios.

Source: U.S. EPA 1985.

Note: The Surface AREA of Hands is that portion of the hands NOT involved in hand-to-mouth activity.

$$SA_{hand} = SA_{hand} - (SA_{hand})\,(pSA_{hand\_mouth})$$

3.5 Note 5. Modifying factors (MFDAbody zone) for Dermal Penetration from Differential Penetration for Adult Skin for 8 Stick Man Body Zones*

	Relative Rates**	$MFDA_{body\ zone}$
Head	3.6[1]	1.4
Trunk	2.5[2]	1[2]
UArms	1.2[3]	0.5
LArms	1.2[3]	0.5
Hands	2.0[4]	0.8
ULeg	1.2[3]	0.5
LLeg	1.2[3]	0.5
Feet	1.8[5]	0.7

* Ross, J.H. et al. FACTORS INFLUENCING ESTIMATES OF REENTRY WORKER EXPOSURE TO PESTICIDES, California Department of Pesticide Regulation, Worker Health and Safety Branch, HS-1677, March 23, 1993 (presented at 32nd SOT National Meeting, Poster No. 1636, March 14-18, New Orleans, LA

** Absent better referenced data, these **Relative Rate** values will be used for all ages.

1. average of "scalp" (3.0), "forehead" (4.2), "behind ear" (3.5) and "jaw" (3.5)
2. reported for "abdomen" and used to normalize $MFDA_{body\ zone}$ (*i.e.,* relative rate of 2.5 was set to 1.0 and the others were proportioned accordingly)
3. reported for "forearm"
4. average of "top of hand" (2.5) and "palm of hand" (1.5)
5. reported for "ball of foot".

3.6 Note 6a. Documentation for Basic Dermal Absorption (DA) and Contact Exposure Values for Assessment of Dermal Toxicity

3.6.1 Dermal Absorption (DA) Value

This value is calculated to estimate the proportion of the contact (applied) dose (or the amount on the skin surface) that is absorbed into the systemic circulation. Thus, the amount deposited per unit area is estimated along with the amount that is absorbed through this same area in the time frame of interest (e.g., one day).

The ratio of the amount estimated to be absorbed **/**amount applied is DA – a unitless proportion from 0-1.

DA is calculated separately for every body zone under consideration (as identified by the Stick Person) and for the clothed and unclothed portion of that body zone.

For example, given a specific body zone that is partially clothed:

The Contact (Applied) Dose (C(A)DD) or calculated amount of µg of the substance *on* any cm^2 of clothed skin for the body zone under consideration is a result of the following calculation:

$$C(A)DD_{bodyzone} = (CR_{body\ zone})(MFAL)(MFDA_{bodyzone})(DUR)(FREQ)(DR)(TE)(prop)(SF)(CP_{matrix})$$

All of these values come from USER input to the Stick Person and elsewhere.

Estimate the amount that is absorbed through the skin per cm^2 and use that value to calculate DA using the scheme directly below:

1. Calculate $C(A)DD_{bodyzone}$ which is the amount of substance estimated as getting to the surface of any cm^2 of clothed skin on this particular body zone.

2. Calculate PERM or the amount *that permeates* through that cm^2 per hour of skin using a selected QSAR model. The selected QSAR model to be available in the program is discussed in detail in Note 8. (Note just because this specific QSAR model is available in the program do not mean that it has to be used. The USER can run any QSAR model separately using this basic methodology and input the resulting PERM value).

3. Multiplying the subsequent permeation rate by $MFDA_{bodyzone}$ and the DUR (hrs) of the event renders an estimate of the dermal absorption of the substance

during this duration ($MDA_{bodyzone}$). Note: MDA is considered to be normalized for the permeability of the trunk skin of young adults; that is, no further adjustment is done to gauge the specific permeation rate differences between specific body parts.

4. Dermal Absorption ($DA_{bodyzone}$) = Amount calculated #3/#1 or $MDA_{bodyzone}/C(A)DD_{bodyzone}$ from above

That is, the estimated maximum proportion that could have penetrated or been absorbed through the skin during this time (DUR) is the maximum estimated that permeated the skin (MDA from 3 above) divided by the amount that was on the skin (C(A)DD from 1 above).

In situations where the amount of substance on the skin (*i.e.,* the applied dose C(A)DD is very small) then this estimated worst case dermal absorption proportion (DA) could possibly exceed 1. This is, of course, impossible; thus, IF DA > 1 THEN DA = 1. Since this will only happen for relatively small applied doses the practical effect of overestimation should not be great.

It should be noted that use of this approach provides a crude estimate of the actual dermal absorption.

Stick Person INPUTS by USER:

Body Zones Identified: Hands and Upper Legs Checked
Windows Open Requesting the following Input that USER supplies

CR_{hands} = 720/hr (footnote [3])
$pExp_{hands}$ = 0.25 (25% of the hand SA is exposed during this operation)
CR_{ULEG} = 5/hr (footnote [4])
$pExp_{uleg}$ = 0.5 (50% of the ULEG SA is exposure during this operation)

Seasonal Clothing Checklist INPUT by USER:

Clothes Worn for every season for this operation: underpants, tee shirt, and shorts, socks and shoes.

[3] Grasping of the reeds occurs once every 5 seconds or 12/min or 720/hr
[4] Reeds remain on weavers lap until exhausted and replaced 5 times per hour.

PROGRAM OPERATION:

DERMAL_SYSTEMIC_TOTAL dose:

$$DERMALC_{hand} = (SA_{hand})(CR_{hand})(DR)(TE)(prop)(SF)(DUR)(DP)(MFDA_{hand})(CP)(pClothed_{hand})(pExp_{hand})(MFAL)/BW$$

Since $pClothed_{hand}$ = 0 (no gloves) then $DERMALC_{hand}$ is calculated by the program to be zero.

$$DERMALB_{hand} = (SA_{hand})(CR_{hand})(DR)(TE)(prop)(SF)(DUR)(DP)(MFDA_{hand})(1 - pClothed_{hand})(pExp_{hand})(MFAL)/BW$$

SA_{hand} : is calculated as an age and gender-specific value for the individual by the LifeLine software – see Note 3 and 4.
BW : is also calculated as an age and gender specific value for the individual by the LifeLine software
FREQ = 1 (default)
prop = 1 (pure substance not in a compositional matrix)
1-$pClothed_{hand}$ = 1 (no gloves)
CR_{hand} = 720/hr: DR = 1 µg/cm2: TE= 0.1: SF =1: DUR= 5 hr: $pExp_{hand}$ = 0.25 : USER.
$MFDA_{hand}$: is automatically taken by the program from a lookup table – see Note 5.

DA (the ratio of absorbed/applied exposure) as a normalized value that is specific to the substance. It is estimated by the LifeLine software by first calculating the applied dose per cm^2 to the hand:

$$ADD_{hand} = (CR_{hand})(DR)(TE)(prop)(DUR)(SF)(MFAL)$$

$C(A)DD_{hand}/prop = ADL_{hand} = (720/hr)(1\ \mu g/cm^2)(0.1)(5\ hr)(1)(1)/(1)$

$C(A)DL_{hand} = 360\ \mu g/cm^2$

Since $CADL_{hand} < 1000\ \mu g/cm^2$ then $CADL_{hand} = 360\ \mu g/cm^2$. If it had been > $1000\ \mu g/cm^2$ then $CADL_{hand} = 1000\ \mu g/cm^2$ (USER can over-ride this default)

Thus, the actual applied dose of substance should now be recalculated as:

$$\mathbf{CADD_{hand} = (CADL_{hand})(prop)}$$

Next the amount that penetrates or is absorbed through this cm^2 during the exposure (DUR) is calculated using PERM for the substance as shown above.

PERM = ESTIMATED by a QSAR algorithm (i.e., SKINPerm). (USER can over-ride this value)

PERM = (Kp)(Sb) = (0.0048) (765) = 3.7 ug/((cm^2)(hr))

$MPD_{hand} = (PERM)(DUR)(MFDA_{hand}) = (3.7)(5)(0.8)$

$MDA_{hand} = 14.8\ \mu g/cm^2$

DA is calculated by the LifeLine program as the ratio that is absorbed/applied amount for 1 cm^2.

$$\mathbf{DA_{hand} = MPD_{hand} / C(A)DD_{hand} = 14.8/360 = 0.04 = 4\%}$$

OR

USER ASSIGNS DA = 0 to 1.0 (0 to 100%)

Thus **$DERMALB_{hand}$** is calculated and stored in the program.

The calculation of **$DERMALC_{uleg}$** and **$DERMALB_{uleg}$** remain

$$DERMALC_{ULEG} = (SA_{ULEG})(CR_{ULEG})(DR)(TE)(SF)(DUR)(DA)(MFDA_{ULEG})(CP)(pClothed_{ULEG})(pExp_{ULEG})(MFAL)/BW$$

$$DERMALB_{ULEG} = (SA_{ULEG})(CR_{ULEG})(DR)(TE)(SF)(DUR)(DP)(MFDA_{ULEG})(1-pClothed_{ULEG})(pExp_{ULEG})(MFAL)/BW$$

SA_{ULEG} : is calculated as an age and gender-specific value for the individual by the LifeLine software – see Note 3 and 4.
BW : is also calculated as an age and gender specific value for the individual by the LifeLine software.
CP = 0.25 (short pants/ULEG – Matrix 3)
$pClothed_{ULEG}$ = 0.5 (short pants/ULEG– Matrix 1)
$1\text{-}pClothed_{ULEG}$ = 0.5
$MFDA_{ULEG}$ = 0.5 : (ULEG - Note 5).
CR_{ULEG} : DRxTE = DL : SF: DUR: $pExp_{ULEG}$: USER.
DA : calculated by program or USER assigned as described above

$DERMAL\_SYSTEMIC\_TOTAL = DERMALB_{hand} + DERMALC_{uleg} + DERMALB_{uleg}$

The program also calculates the maximum Applied Dose per cm2 to any body zone. This would typically occur on the unclothed portion of any particular body zone. In this example:

$LOCAL\_SKIN_{hands} = 360\ \mu g/cm^2$ (see above calculation)

The program would go through the same calculations using body zone specific ($CR_{bodyzone}$) to render the maximum $LOCAL\_SKIN_{ULEG}$ which in this example would be the Applied Dose calculated for the unclothed portion of the upper leg. Since the dose and effect are local a LOCAL_SKIN dose will be reported for each exposed body part – Upper Leg and Hands in this example.

3.7 Note 7. Rationalization for the Assumption Applied Dermal Loading (ADL) or the amount of substance applied to the skin expressed in weight per unit area (µg/cm2) will not exceed 1000 µg/cm2 during any Dermal Exposure Event

EPA work done with Versar indicates that placing one's hands in water will result in a "wet" hand with the retention of 3,000-4,000 µg/cm^2 (3000-4000 µg /cm^2) of water upon withdrawal. Light oil results in about 15,000 µg/cm^2 retention. As a practical matter it is assumed that any transferred material will reach a level on the skin where as much comes off with contact as goes on. Using data from three others, Sedman (1989) developed a maximum soil load that could occur to the skin. His rounded arithmetic mean was 500 µg /cm^2. Driver et al (1989) conducted soil adherence experiments using various soil types collected from sites in Virginia. This study reports 580 µg /cm^2 for unsieved soil.

It is uncertain whether and unlikely that the compounds of interest in this study will behave like soil; however, most are anticipated having significantly low density and thus deposit less weight on the skin per unit volume.

3.8 Note 8. Calculation of Dermal Penetration Rate

$$^{10}\log[Kp_{sk-water}] = {}^{10}\log[Klip + Kpol] \quad cm/hour$$

$$Klip = 10^{[b1 + b2*{}^{10}\log(Kow) + b3*Mw]} \qquad Kpol = b4/Mw^{b5}$$

$$Klip = \text{permeation coefficient lipid medium}$$

$$Kpol = \text{permeation coefficient corneocytes [proteins]}$$

$$Kow = \text{octanol/water partition coefficient}$$

$$Mw = \text{molecular weight}$$

$$b1, b2, b3, b4, b5 = \text{regression coefficients}$$

Residual variance	= 0.4686
Degrees of freedom	= 177
Fraction of regression explained	= 0.682

b 1 = -2.590E+00	(SD for b 1 = 1.337E-01)
b 2 = 7.318E-01	(SD for b 2 = 5.396E-02)
b 3 = -6.832E-03	(SD for b 3 = 5.470E-04)
b 4 = 4.300E-02	(SD for b 4 = 6.158E-02)
b 5 = 1.361E+00	(SD for b 5 = 3.034E-01)

The above regression coefficients are from these databases and show an $r^2 = 0.68$.

Note: the above renders an estimate of Kp.

For immersion applications its use is relatively straightforward. The $K_{p\ sk\text{-}water}$ calculated above is the Kp in the variable list which is the permeation rate through skin from contact with an infinite source of liquid with the substance of interest at concentration (Cw with units of ug/cm3). The amount of substance that penetrates or is absorbed through the skin per unit area and unit time (ug/((cm2)(hr)) is called PERM.

PERM = (Kp)(Cw)

For topical applications one assumes that the applied amount of substance is very concentrated in the small amount of perspiration available on the surface of skin such that its concentration on the skin (in perspiration) is saturated. Thus Cw = saturation = solubility (Sb) of the substance in units of ug/cm^3.

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4 DERMAL_HAND, HAND-TO-MOUTH ORAL EXPOSURES

These exposures are for any person touching surfaces or objects with dislodgeable residue and then doing hand-to-mouth activity. This would include incidental dust ingestion from dermal pickup and subsequent hand-to-mouth activity.

4.1 TOPICAL DERMAL and Incidental Hand-to-Mouth Oral Exposure

This specific treatment isolates and only considers the DERMAL for the hand and ORAL (hand-to-mouth) topical exposure from that portion or surface area of the HANDS involved in hand-to-mouth activity. For the hand-to-mouth, this percentage of the total area of the hand (i.e., that involved in mouthing) is assumed to be age-related.

All of these calculations are on a **per cm^2 basis**. That is, the oral and dermal doses calculated herein are the contact(applied) dose density on one cm^2 of hand. These dose values (DermalDose and OralDose below) need to be multiplied by the estimated area of hand skin involved in the hand-to-mouth activity to get the total contact(applied) dose. See final dose calculations that occur later in the analysis.

It is assumed that no one engages in hand-to-mouth activity if they are wearing gloves.

Since this calculation set will happen separately for any one engaging in hand-to-mouth activity, the overall DERMAL EXPOSURE and the hand zone of the stick man figure within that assessment will be adjusted to subtract this area from its calculation of dermal exposure.

The Time Element considerations of these exposures are identical to that outlined in the DERMAL EXPOSURE.

Conceptual Definitions:

> Dermal_Hand: The topical dermal exposure that occurs on that portion of the hand that is also involved in hand-to-mouth activity.
>
> Oral_Hand: The incidental oral exposure that occurs from hand-to-mouth exposure for the Dermal_Hand part of the hand.
>
> IntDERMAL_HAND: The amount of substance that goes to skin of the hand during every interval between mouthing events. Sometimes this quantity is called loading or recharge.

Suppositions in the Dermal_Hand and Oral_Hand Model:

1. Initial Condition – clean/pristine skin on hands at the beginning of the day.
2. Maximum that can accumulate on skin of the hands before being "rubbed off" is 1000 $\mu g/cm^2$ (1 mg/cm^2 of a substance with unit density.
3. This analysis assumes that the dermal contact rate (CR) for hand to object with the transferred dry or splashed or contacted wet substance dermal loading (DL = (DR)(TE)) is always greater than or equal to the rate of hand-to-mouth activity (OCR).
4. One can enter the dislodgeable residue (DR) and transfer efficiency (TE) separately to calculate the dermal loading (DL) or DL can be entered directly.
    - Examples
        - 100 $\mu g/cm^2$ of dirt are transferred to the hand per contact (DL = 100 $\mu g/cm^2$) This is, DL the product of (DR)(TE) is entered directly = 100 $\mu g/cm^2$
        - The vinyl floor has 800 $\mu g/cm^2$ of a residue (DR = 800 $\mu g/cm^2$) of which 3% is transferred during every contact (TE =0.03). DL is calculated as the product of DR and TE = 240 $\mu g/cm^2$.
        - 2000 $\mu g/cm^2$ of a wet substance is transferred to the hand with every contact. DL = 2000 $\mu g/cm^2$ That is, DL the product of (DR)(TE) is entered directly = 2000 $\mu g/cm^2$.

5. The duration of each dermal exposure event to the hand is divided into discreet exposure periods between MOUTHING events.
6. The amount that accumulates on the skin during each of these intervals is the amount that came from the last interval plus the new contribution from dermal contact during that interval. At the end of each interval a mouthing event eliminates a certain portion (*e.g.,* given a 50% saliva extraction factor it would be 0.5) of the amount on the skin.
7. The amount on the skin of the hand for the beginning of the next period is the amount at the end of the previous period minus the amount that went to oral dosing.
8. Dermal_Hand and Oral_Hand (Hand-to-Mouth) dosing per cm^2 are calculated for every discreet exposure period and added up at the end of the exposure duration.

DEPENDENT VARIABLES

Contact (APPLIED) B_{hand_mouth}= Estimated contact (applied) dermal dose per day to the skin surface of the hand as a topical exposure from direct contact with the bared (unclothed) portion of skin of a specific person for a particular operation in micrograms per kg body weight per day (µg/kg/day).

Dermal_Hand$_n$ = the amount of substance that accumulates on the skin at the end of interval n before the nth mouthing event ($\mu g/cm^2$)

Oral_Hand$_n$ = amount of substance that goes to <u>oral</u> dosing per cm^2 of hand from the n^{th} mouthing event. That is, the first mouthing event happens at the end of the first interval of dermal exposure ($\mu g/cm^2$)

IntDERMAL_HAND = the constant amount of substance that goes to the hands during every interval (between mouthing events) ($\mu g/cm^2$)

n = number of mouthing events that occur between dermal contact events (dimensionless)

ORALDen = estimated oral dose from hand-to-mouth activity for one square centimeter of skin on the hand for the activity event under consideration. ($\mu g/cm^2$)

OralDose = estimated systemic oral dose from hand to mouth activity ($\mu g/kg/day$)

<u>INDEPENDENT VARIABLES</u>

CR = dermal contact rate or the number of times per hour dermal-hand contact with the substance occurs (/hr) (USER)

DR = Dislodgeable Residue: The amount of residue of the substance of interest available per surface area of object handled ($\mu g/cm^2$) - (USER). It is related to dislodgeable residue as shown below.

DR = Dislodgeable Residue: That part of the residue of a substance deposited on a solid material which may be transferred by direct contact to human skin or clothing (ASTM International, 2003). It is the amount of substance that goes to the skin per contact ($\mu g/cm^2$) - (USER). Note: Considered to be a constant in this treatment; however, it could be made more sophisticated by having it become a function of time since some residues tend to degrade. The
TE is a factor that takes into consideration the texture of the material.
Note:

Dermal Loading (DL) is the product of Dislodgeable Residue (DR) and Transfer Efficiency (TE – see below).

Dermal Loading (DL) = (DR)(TE) - calculated (using DR and TE) or input directly by USER.

If the residue is not the neat substance then the proportion of the residue that is the substance (prop) needs to be accounted for.

Examples:

1. 100 µg/cm^{2}of a dislodgeable residue (pesticide) available on the surface of a carpet (DR = 100) with 2% of it being transferred to the skin per contact (TE = 0.02), the dermal loading (DL) per contact would then be 2 µg/cm^2. Note that the dislodgeable residue is comprised of 100% of the residue (prop = 1.0).
    a. DR = 100 µg/cm^2, TE = 0.02, DL = 2 µg/cm^2 and prop = 1.0
2. 500 µg/cm^2 of a residue is transferred per contact with a wet clay contact (DR = 500). The transferred residue is mostly water with 5% of the substance of interest (prop = 0.05).
    a. DR = 500 µg/cm^2, TE = 1, DL = 500 µg/cm^2, prop = 0.05

Note: DR is considered to be a constant in this treatment; however, it could be made more sophisticated by having it become a function of time. (USER)

TE = transfer efficiency. The substance- and medium- specific proportion of the Dislodgeable residue (DR) (amount of substance per surface area of object touched) that actually transfers per contact. It is a unitless value between 0 and 1.

FREQ = frequency of dermal exposure events (/day). Note that this is different from the contract rate (CR) within the event. FREQ will typically be 1 event/day. (USER default = 1)

OCR = oral contact rate or amount of times per hour hand-to-mouth activity occurs (/hr). (USER)

Note: The model assumes that CR > OCR (Note to programmers need an error trap here)

SEF = saliva extraction factor or proportion of topical dermal amount that goes to oral per mouthing event (unitless proportion). (USER)

Note: All doses below are just for the mouth portion of the hands and are normalized per cm^2. They would need to be multiplied by the affected surface area of the hand that is mouthed. That is these dermal-hand and Oral-HAND(hand-to-mouth) doses are only for mouthed areas of the hands. This area would have to be subtracted from the non-mouth surface area to access the dermal dose to the remainder of the hands. This would be done automatically by the program given the appropriate inputs.

4.1.1 Applied Dermal and Oral Dose Model Derivation

1. Initial (*i.e.,* at the beginning of the day) Dermal_Hand and Oral_Hand (hand-to-mouth) dosing expressed in µg /cm^2 is zero (i.e., $Dermal\_Hand_0 = Oral\_Hand_0 = 0$)
2. Variables for Discreet exposure periods for Dermal Events.

a. OCR = oral contact rate or amount of times per hour hand-to-mouth activity occurs. Units = /hrs or hr^{-1}.
b. DUR is the total duration of exposure and for purposes of this analysis must be **both the same and concurrent for both Dermal_Hand and Oral-Hand dosing**. Units = hr.
c. (DUR)(OCR) = n = number of discreet MOUTHING events that occur within the duration of exposure. Unitless. For example: IF OCR = 10/hr AND DUR = 2 hours THEN n = 20 events of MOUTHING and 20 intervals for calculation.
d. CR = dermal contract rate or the number of times per hour of dermal-hand contact occurs. Units = 1/hr or hr^{-1}.
e. DL = (DR)(TE) = dermal loading (µg /cm^2)
f. The <u>constant</u> amount of residue that goes to skin of the hand during every interval (between mouthing events) is (CR) (DR) (TE) (DUR)/n) = IntDERMAL_HAND.
Since n = (DUR)(OCR) this can be simplified to:

$$IntDERMAL\_HAND = (CR)(DR)(TE)/OCR$$

3. Amount of residue that accumulates on the skin of the hand during the first interval <u>before</u> the first mouthing event (e.g., for interval 1 the contact(applied) dose to the skin is designated $DERMAL\_HAND_1$). It is the product of (CR)(DL)(TE)(DUR/n) or IntDERMAL_HAND thus:
    a. $DERMAL\_HAND_1 = DERMAL\_HAND_0 + IntDERMAL\_HAND$: Note: $DERMAL\_HAND_0$ = zero for clean skin. $DERMAL\_HAND_1$ is thus calculated and saved.
4. Amount that went to ORAL dosing at the <u>end</u> of interval 1 = $Oral\_Hand_1$: SEF = saliva extraction factor per event (unitless).
    a. $Oral\_Hand_1 = (SEF)(DERMAL\_HAND_1)$
5. Amount of residue on the skin at the <u>end</u> of the second interval is the amount left after the mouthing event of the first interval ($DERMAL\_HAND_1 – ORAL\_HAND_1$) + what goes to the skin in the second interval before the second mouthing event which is a <u>constant</u> for each interval (CR)(DL)(DUR/n) = IntDERMAL_HAND :
    a. $DERMAL\_HAND_2 = DERMAL\_HAND_1 - ORAL\_HAND_1 + IntDERMAL\_HAND$
6. Amount that went to ORAL dosing at the end of interval 2 = $ORAL\_HAND_2$: SEF = saliva extraction factor per event (unitless).
    a. $ORAL_2 = (SEF)(DERMAL\_HAND_2)$

$$DermalDen = \sum_{1}^{n} DERMAL\_HAND_{n-1} - ORAL\_HAND_{n-1} + IntDERMAL\_HAND$$

IF $DERMAL\_HAND_{n-1} > 1000$ µg /cm^2 **THEN** $DERMAL\_HAND_{n-1} = 1000$ µg /cm^2

This DermalDen is the contact(applied) dose to the skin expressed as the amount applied per square centimeter of skin during the duration (DUR) of exposure. When multiplied by the frequency per day (FREQ), surface area of the hand involved (SA_{hand_mouth}), the proportion of substance of concern in the transferred residue (prop) and divided by the body weight (BW) it is the same as **Contact(APPLIED)B$_{boby\ zone}$** (see DERMAL EXPOSURE MODEL) for the mouthed portion of the hand (i.e., **SA$_{hand_mouth}$**):

$$Contact(APPLIED)B_{hand\_mouth} = (DermalDen)(FREQ)(SA_{hand\_mouth})(prop) / BW$$

To estimate the dose that is absorbed through the skin (i.e., **DERMALB$_{hand_mouth}$**) one does the same calculation as is done in the DERMAL EXPOSURE MODEL; that is:

DERMALB$_{hand_mouth}$ = Estimated dermal dose per day that absorbs through the <u>bare</u> (unclothed) portion of skin for a specific person for a particular operation in micrograms per kg body weight per day (ug/kg/day).

It is the product of the contact(applied) dose and the unitless dermal absorption factor (DA). See DERMAL EXPOSURE MODEL for an explanation of DA.

DERMALB$_{hand_mouth}$ = **CONTACT(APPLIED)B$_{hand_mouth}$) (DA)**

Oral exposure is estimated as follows:

$$ORALDen = \sum_{1}^{n} (SEF)(DERMAL\_HAND_n)$$

$$ORALDose = (ORALDen)(SA_{hand\_mouth})(FREQ) / BW$$

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Appendix C
Selected Studies and Data

Task Order 18
Contract Number
CPSC-D-12-0001

Final Report

September 28, 2016

Prepared by Toxicology Excellence for Risk Assessment and The LifeLine Group

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1 Introduction

This appendix includes a detailed presentation of the studies considered, data selected, and statistical methods applied to set up the distribution of concentration values for each flame retardant in dust and/or air for the different environments. Section 2 of the main report (Methods) describes how the reported data were utilized in the assessments. In particular, Section 2.4 discusses how the dust data were corrected to account for dust loading on surfaces using factors from the U.S. Environmental Protection Agency (EPA) Exposure Factors Handbook (EFH) (U.S. EPA, 2011). Section 2.5 provides an example of how the concentration data were applied to the probabilistic model. In Sections 2.5.2 and 2.5.3, we discuss how we accounted for the portion of particulates in air that are inhaled and continue into the lungs (respired) and the portion of particulates that are captured in the nasopharyngeal area and assumed swallowed, respectively.

2 TDCPP - Selection of Studies and Data

We evaluated the available studies for Tris(1,3-dichloro-2-propyl) phosphate (TDCPP) and selected acceptable data to estimate exposure to dust and air in child care centers, homes, offices, and cars (Table C-1). These data were from six studies, which we thought to be the most relevant and representative of the exposure data. The studies provided enough data detail for utilization in a probabilistic exposure assessment and sufficiently described the methods to allow for a quality evaluation of the sampling and analytical methods used.

Table C-1. Data source summary: Studies containing data chosen for the TDCPP exposure assessment.

Study	Environment	Media
Bradman et al., 2012	Child Care Centers	Dust loading
		Indoor air
Fan et al., 2014	Homes	Dust
Bergh et al., 2011a		Indoor air
Carignan et al., 2013a	Offices	Dust
Yang et al., 2014		Indoor air
Carignan et al., 2013a	Cars	Dust
Staaf and Ostman, 2005a		Interior air

2.1 Child Care Environment

Bradman et al. (2012) investigated dust, as well as indoor and outdoor air, in 39 child care centers in California. This study assessed exposure to young children and provided extensive detail on all methodology aspects, including sampling, computational, and analytical methods. It provided comparisons to other studies and confirmed that the pattern of flame retardants in child care centers is similar to patterns in other indoor environments, such as schools and homes.

TDCPP concentrations in the dust samples provided values for the 25th, 50th, and 75th percentile measurements of TDCPP mass across surface area of 2.57 x 10^{-4}, 6 x 10^{-4}, and 1.1 x 10^{-3} µg/cm^2 respectively (Table 44 of Bradman et al. [2012]). Dust loading was accounted for in the study design and therefore, no dust loading correction was needed. These three values were used directly as three point values in the exposure assessment.

The Bradman et al. (2012) study also measured TDCPP in air particles in child care centers. A lognormal distribution was fit to the reported mean of 5.9 x 10^{-4} with a standard deviation (SD) of 3.6 x 10^{-4} µg/m^3. The mean and SD were used to create a log normal distribution using Crystal Ball™, and the derived distribution was used to represent the concentration of TDCPP on particles in air. Differentiation in concentrations by particle sizes was not reported, so as per standard assumption, 10% of the calculated inhaled mass was assumed to be respirable, and the remaining 90% of the calculated inhaled mass was assumed to be swallowed.

2.2 Home Environment

Fan et al. (2014) measured TDCPP in dust from Canadian urban homes as part of a comparative study on different dust sampling methods. Fresh dust (FD) samples were taken throughout the home by the study team using a vacuum sampler. Household dust (HD) was taken from the resident's vacuum cleaner. Both types of samples were analyzed and results reported separately. The median values for each of the two study designs were 2.7 and 2.0 µg/g, for HD and FD samples, respectively. From the data as presented, we used the average of the reported median values (2.35 µg/g) to represent the concentration of TDCPP in dust and corrected for dust loading using EFH factors (all but front door mat) yielding the point value of 1.8 x 10^{-4} µg/cm^2 for the mass over surface area for the exposure assessment. The results are assumed relevant for similar environments in the U.S.

Bergh et al. (2011a) measured TDCPP in the air of homes in Sweden. We assumed the study results are relevant to U.S. home scenarios as well. We used the mean value from the study showing TDCPP concentrations in air particles to be 3.1 ng/m^3 (3.1 x 10^{-3} µg/m^3). Differentiation in concentrations by particle sizes was not reported, so as per standard assumption, 10% of the calculated inhaled mass was assumed to be respirable, and the remaining 90% of the calculated inhaled mass was assumed to be swallowed.

2.3 Office Environment

Carignan et al. (2013a) measured TDCPP dust concentrations in offices in Boston. From the data as presented, we used the geometric mean value for the concentration of TDCPP in dust (6060 ng/g = 6.06 µg/g) and corrected for dust loading using EFH factors (all but front door mat), yielding the point value of 4.65 x 10^{-4} µg/cm^2 for the mass over surface area.

Yang et al. (2014) measured TDCPP in the air of offices in China. We assumed the study results are relevant to U.S. office scenarios. We used the median value from the study showing TDCPP concentrations in air particles of 6.3 x 10^{-4} µg/m^3. Differentiation in concentrations by particle sizes was

not reported, so as per standard assumption, 10% of the calculated inhaled mass was assumed to be respirable, and the remaining 90% of the calculated inhaled mass was assumed to be swallowed.

2.4 Car Environment

For cars, the geometric mean (GM) of 12.5 µg/g and geometric standard deviation (GSD) of 6.5 µg/g were used from the Carignan et al. (2013a) study. The surface area of the front and rear seats were vacuumed for 10 minutes and we assumed the dust loading on seats (assumed to be fabric) is equivalent to the EFH dust loading on untracked downstairs carpets. Applying this EFH factor (5.8×10^{-1} g/m^2) to the concentration yielded a GM mass over area of 7.25×10^{-4} µg/cm^2 (GSD 3.77×10^{-4} µg/cm^2) for calculation of exposure via car dust. The corrected GM (GSD) was used to create a log normal distribution using Crystal Ball™ for application to the exposure assessment.

Staaf and Ostman (2005a) measured TDCPP concentrations in car air. A point value of 5×10^{-3} µg/m^3 was reported from a single sample in the study. Differentiation in concentrations by particle sizes was not reported, so as per standard assumption, 10% of the calculated inhaled mass was assumed to be respirable, and the remaining 90% of the calculated inhaled mass was assumed to be swallowed.

2.5 Other Data Not Employed

Other studies were considered for this assessment on TDCPP. Stapleton et al. (2012, 2014), Saito et al. (2007), Marklund et al. (2005) and Dodson et al. (2012) are reputable studies, but the data reporting from the chosen studies was more useful for constructing the value distributions. Araki et al. (2014) and Kanazawa et al. (2010) study results may not be representative of U.S. scenarios. Schreder (2012) performed testing on specific products that are not applicable to this assessment approach. Note that many of Bradman's findings in the 2012 report to the California Air Resources Board were summarized in the more brief 2014 publication in Chemosphere (Bradman et al., 2014).

3 TCPP - Selection of Studies and Data

We evaluated the available studies for Tris(chloropropyl) phosphate, mixture of isomers (TCPP) and selected acceptable data to estimate exposure from dust and air in homes, and air in child care centers and offices (Table C-2). These data were from three studies, which we thought to be the most relevant and representative of the exposure data. The studies provided enough data detail for utilization in a probabilistic exposure assessment and sufficiently described the methods to allow for a quality evaluation of the sampling and analytical methods used.

Table C-2. Data source summary: Studies containing data chosen for the TCPP exposure assessment.

Study	Environment	Media
Marklund et al., 2005	Child Care Centers	Indoor air
Fan et al., 2014	Homes	Dust
Marklund et al., 2005	Homes	Indoor air
Yang et al., 2014	Offices	Indoor air

3.1 Child Care Environment

Marklund et al. (2005) measured TCPP in indoor air in several environments including child care centers in Sweden. The study results are assumed relevant to contemporary U.S. child care environments as well. From the reported data, we used the mean value for the air particle concentration of TCPP of 2.8 x 10^{-2} µg/m^3. Differentiation in concentrations by particle sizes was not reported, so as per standard assumption, 10% of the calculated inhaled mass was assumed to be respirable, and the remaining 90% of the calculated inhaled mass was assumed to be swallowed.

No data were available to represent child care dust.

3.2 Home Environment

Fan et al. (2014) measured TCPP in dust of Canadian urban homes and the results are assumed relevant to similar environments in the U.S. From the data as presented for the home dust samples collected from resident's vacuum cleaners (HD), we use the median value for the concentration of TCPP (1.1 µg/g) and corrected for dust loading using EFH factors (all but front door mat) yielding the point value of 8.43 x 10^{-5} µg/cm^2 for the mass over surface area. This was used as a point value in the exposure assessment.

Marklund et al. (2005) measured TCPP in air samples from bedrooms and living rooms. Two samples were taken in each room setting, and the averages were presented in the publication: 38 ng/m^3 (3.8 x 10^{-2} µg/m^3) from the bedroom and 210 ng/m^3 (2.1 x 10^{-1} µg/m^3) from the living room. We used an average of these averages to represent the entire home area (124 ng/m^3 = 1.24 x 10^{-1} µg/m^3). Differentiation in concentrations by particle sizes was not reported, so as per standard assumption, 10%

of the calculated inhaled mass was assumed to be respirable, and the remaining 90% of the calculated inhaled mass was assumed to be swallowed.

3.3 Office Environment

Yang et al. (2014) measured TCPP in indoor air of offices in China. We assumed the study results would be relevant to similar offices in the U.S., given that there may be similar electronic products and office furniture in such offices. From the available data, we used for the exposure assessment the reported median value of 7.76×10^{-3} µg/m^3 of which the standard assumption that 10% is available for inspiration and 90% available to swallow.

No data were available to represent office dust.

3.4 Car Environment

No data were available to represent any medium in cars.

3.5 Other Data Not Employed

Other studies were considered for this assessment on TCPP. Saito et al. (2007), Schreder (2012), and Haumann and Thumulla (2002) conducted testing on specific products that were not applicable to this assessment approach. Saito et al. (2007), Carlsson et al. (1997), and Dodson et al. (2012) conducted reputable studies, but the data from the above studies were more useful for constructing distributions. Carignan et al. (2013b) conducted testing on environments that were not applicable to this assessment.

4 TCEP - Selection of Studies and Data

We evaluated the available studies for Tris(2-chloroethyl) phosphate (TCEP) and selected acceptable data to estimate exposure from concentrations in dust and air in child care centers, homes, offices, and cars (Table C-3). These data were from seven studies that were the most relevant and representative of the exposure data. The studies provided enough data detail for utilization in a probabilistic exposure assessment and sufficiently described the methods to allow for a quality evaluation of the sampling and analytical methods used.

Table C-3. Data source summary: Studies containing data chosen for the TCEP assessment.

Study	Environment	Media
Bradman et al., 2012	Child Care Centers	Dust
		Indoor air
Ingerowski et al., 2001	Homes	Dust
Bergh et al., 2011a		Indoor air
Marklund et al., 2003	Offices	Dust
Marklund et al., 2005		Indoor air
Brandsma et al., 2014	Cars	Dust
Hartmann et al., 2004		Interior air

4.1 Child Care Environment

Bradman et al. (2012) investigated dust and indoor and outdoor air in 39 child care centers in California. This study assessed exposure to young children, the population of interest in child care facilities. The study provided extensive detail on all methodological aspects, including sampling, computational, and analytical methods. Bradman et al. (2012) provided comparisons to other studies and confirms that the pattern of flame retardants in child care centers is similar to patterns in other indoor environments, such as schools and homes.

Measurements of TCEP concentrations in the dust samples provided a median value of TCEP mass across surface area. Dust loading was accounted for in the study design, and no dust loading correction was needed. The median dust sample was reported as 838 ng/m^2, or 8.38 x 10^{-1} µg/m^2, and it was used directly as a point value in the exposure assessment.

Bradman et al. (2012) also measured TCEP in air particles in child care centers and reported a mean of 2.69 x 10^{-3} µg /m^3 with a SD of 3.89 x 10^{-3} µg /m^3. The mean and SD as reported by the authors were used to create a log normal distribution using Crystal Ball™ for application to the exposure assessment. Differentiation in concentrations by particle sizes was not reported, so as per standard assumption, 10% of the calculated inhaled mass was assumed to be respirable, and the remaining 90% of the calculated inhaled mass was assumed to be swallowed.

4.2 Home Environment

Ingerowski et al. (2001) measured TCEP in house dust from German homes as part of a study designed to investigate inter-laboratory comparisons of methodologies and results from pooled dust samples. We assumed the values measured for TCEP concentrations in this study would be relevant to U.S. homes. From the reported data, we used the median value for collected dust concentration (600 ng/g, or 6.0 x 10^{-1} µg/g, and corrected for dust loading using the EFH factors (except for front door mat), yielding a value of 4.6 x 10^{-5} µg/cm^2. This value is used in the exposure assessment.

Bergh et al. (2011a) measured air concentrations of TCEP in ten private homes in the Stockholm, Sweden area, sampling for eight hours in a central area of the home. Particle sizes in the collected air samples were not measured for differential concentrations of the chemical for different particle sizes. The mean value of 8.3 x 10^{-3} µg/m^3 as reported by the authors was used as a point value in the exposure assessment. Differentiation in concentrations by particle sizes was not reported, so as per standard assumption, 10% of the calculated inhaled mass was assumed to be respirable, and the remaining 90% of the calculated inhaled mass was assumed to be swallowed.

4.3 Office Environment

Marklund et al. (2003) measured TCEP in dust from offices in Belgium. We assumed the results are relevant to U.S. offices as well. The study report an average value of dust concentration from two samples from office linoleum, 48 mg/kg (4.8 x 10^{1} µg/g). This concentration value was converted to represent mass over area by applying both EFH factors involving linoleum surfaces (0.08 g/m^2 for tracked linoleum and 0.06 g/m^2 for untracked linoleum). This yielded two point values of 3.84 x 10^{-4} and 2.88 x 10^{-4} µg/cm^2. Both values were used as point values in the exposure assessment for dermal contact and hand-to-mouth events.

Marklund et al. (2005) measured TCEP in the indoor air of office environments in Sweden, which is assumed relevant to contemporary U.S. office environments as well. The authors reported the average concentration from duplicate air office samples, 730 ng/m^3 (7.30 x 10^{-1} µg/m^3), which was used in the exposure assessment to represent the air particle concentrations of TCEP. Differentiation in concentrations by particle sizes was not reported, so as per standard assumption, 10% of the calculated inhaled mass was assumed to be respirable, and the remaining 90% of the calculated inhaled mass was assumed to be swallowed.

4.4 Car Environment

Brandsma et al. (2014) measured TCEP in car dust in a study conducted in the Netherlands. The study focused on comparisons of analytical methods and presented measurements of TCEP in car upholstery and dashboard areas. From the study, we used the mean point value (2800 ng/g) to represent the concentration of TCEP in dust collected from the car dashboard. We used the median point value (600 ng/g) to represent the concentration of TCEP in dust collected from the car upholstery. We assumed the dust loading on upholstery is equivalent to the EFH dust loading on carpets (untracked down stairs

carpet factor of 0.58 g/m^2) and dust loading on the dashboard was equivalent to dust loading on untracked linoleum (factor of 0.6 g/m^2).

For the upholstery: 600 ng/g x 0.58 g/m^2 = 0.348 µg/m^2 = 3.48 x 10^{-5} µg/cm^2

For the dashboard: 2800 ng/g x 0.06 g/m^2 = 0.168 µg/m^2 =1.68 x 10^{-5} µg/cm^2

The average of these corrected means is used in the assessment = 258 µg/m^2, or 2.58 x 10^{-5} g/cm^2

Hartmann et al. (2004) developed analytical methods for air samples from the interior air of 12 cars in Zurich, Switzerland. (Note that some methodological issues exist with this 2004-era study including possible contamination of samples. Representation for modern U.S. cars may also be problematic because flame retardant use varies with the age and make of cars. We have assumed these study results are representative for at least some U.S. cars. The average value (7 x 10^{-3} µg/m^3) of the three reported individual values (4.3, 9.4, and 7.4 ng/m^3) was calculated to represent the probable concentration of TCEP in car air. Differentiation in concentrations by particle sizes was not reported, so as per standard assumption, 10% of the calculated inhaled mass was assumed to be respirable, and the remaining 90% of the calculated inhaled mass was assumed to be swallowed.

4.5 Other Data Not Employed

Other studies were considered for this assessment on TCEP. Saito et al. (2007), Fan et al. (2014), Stapleton et al. (2012, 2014), Fromme et al. (2014a), Ali et al. (2012a), Hutter et al. (2013), Bergh et al. (2011b) and Dodson et al. (2012) are all reputable studies, but the data reporting from the chosen studies were more useful for constructing the distribution values. Nagase et al. (2003), as cited by ATSDR (2012, Section 6.4.4), Carlsson et al. (1997), and Staaf and Ostman (2005b) had methodology issues. Kajiwara et al. (2011) and Kanazawa et al. (2010) study results may not be representative of U.S. scenarios. Fang et al. (2013) studied TCEP as a component of a new flame retardant product whose primary ingredient is not TCEP, but where TCEP was found as one of the chemicals resulting in dust from the product's use.

Wensing (1999) (as cited in Malmgren-Hansen et al. [2003]); Kim et al. (2013); Haumann and Thumulla (2002); Araki et al. (2014); Van den Eede et al. (2011); Cristale and Lacorte (2013); Abdallah and Covaci (2014); and Murray et al. (2013) (as cited in Fan et al. [2014]) all had methodology issues or the studies were not relevant to U.S. scenarios. Tonnig et al. (2008), Borling et al. (2006), Ionas et al. (2014), Schreder (2012), and Canada Gazette (2011) reported testing of specific products or media that were not applicable to this assessment approach. Note that many of Bradman's findings in the 2012 report to the California Air Resources Board were summarized in the more brief 2014 publication in Chemosphere (Bradman et al., 2014).

5 TEP - Selection of Studies and Data

We evaluated the available studies for Triethyl phosphate (TEP) and selected acceptable data to estimate exposure to dust and air in homes and indoor air of offices and cars (see Table C-4). These data were from three recent studies, which we thought to be the most relevant and representative of the exposure data. The studies provided enough data detail for utilization in a probabilistic exposure assessment and sufficiently described the methods to allow for a quality evaluation of the sampling and analytical methods used.

Table C-4 Data source summary: Studies containing data chosen for the TEP assessment.

Study	Environment	Media
Dodson et al., 2012	Home	Dust
Saito et al., 2007	Home	Indoor air
Saito et al., 2007	Office	Indoor air
Staaf and Ostman, 2005b	Cars	Interior air

5.1 Child Care Environment

No data were available to represent dust or air for the child care environment.

5.2 Home Environment

Dodson et al. (2012) measured TEP in house dust from homes in California. From the data as presented, we used the median value for the concentration of TEP in dust (28 ng/g, or 2.8 x 10^{-2} µg/g) and corrected for dust loading using EFH factors (all but front door mat) yielding the point value of 2.15 x 10^{-6} µg/cm^2 for the mass over surface area. This value was used in the exposure assessment for calculation of dermal exposure and oral exposure from hand-to-mouth activity.

Saito et al. (2007) measured TEP in the air of Japanese homes (apartments). We assumed the study results are relevant to U.S. home scenarios as well. We used a point value from the study showing TEP concentrations in air particles to be 2.4 x 10^{-3} µg/m^3. Differentiation in concentrations by particle sizes was not reported, so as per standard assumption, 10% of the calculated inhaled mass was assumed to be respirable, and the remaining 90% of the calculated inhaled mass was assumed to be swallowed.

5.3 Office Environment

Saito et al. (2007) also measured TEP in air in Japanese offices. We assumed the study results are relevant to U.S. office scenarios as well. We used the mean value from the study showing TEP concentrations in air particles to be 3.2 x 10^{-3} µg/m^3. Differentiation in concentrations by particle sizes

was not reported, so as per standard assumption, 10% of the calculated inhaled mass was assumed to be respirable, and the remaining 90% of the calculated inhaled mass was assumed to be swallowed.

No data were available to represent dust in the office environment.

5.4 Car Environment

Staaf and Ostman (2005a), reported TEP concentrations in interior air of three cars to be 220, 6, and 56 ng/m^3 (2.2 x 10^{-1}, 6.0 x 10^{-3} and 5.6 x 10^{-2} µg/m^3, respectively). The average of these measurements, 9.4 x 10^{-2} µg/m^3, was applied to the exposure assessment. Differentiation in concentrations by particle sizes was not reported, so as per standard assumption, 10% of the calculated inhaled mass was assumed to be respirable, and the remaining 90% of the calculated inhaled mass was assumed to be swallowed.

No data were available to represent dust in the car environment.

5.5 Other Data Not Employed

Other studies were considered for this assessment on TEP. Bergh et al. (2011b) is a reputable study, but the data reporting from these other studies were more useful for constructing the distributions. The study results from Araki et al. (2014) and Kanazawa et al. (2010) may not be representative of U.S. scenarios.

6 TPP - Selection of Studies and Data

We evaluated the available studies for Triphenyl phosphate (TPP) and selected acceptable data to estimate exposure to dust and air in child care centers, homes, and offices and in the air of cars. These data were from three studies that we thought to be the most relevant and representative of the exposure data (see Table C-5). The studies provided enough data detail for utilization in a probabilistic exposure assessment and sufficiently described the methods to allow for a quality evaluation of the sampling and analytical methods used.

Table C-5. Data source summary: Studies containing data chosen for the TPP assessment.

Study	Environment	Media
Bergh et al., 2011a	Child Care Centers	Dust
		Indoor air
Fan et al. 2014	Homes	Dust
Bergh et al. 2011a	Homes	Indoor air
Bergh et al. 2011a	Office	Dust
		Indoor air
Staaf and Ostman, 2005a	Cars	Interior air

6.1 Child Care Environment

Bergh et al. (2011a) measured TPP concentrations in dust collected from Swedish child care centers. From the data as presented, we used the median value of 1900 ng/g (1.9 µg/g) for the concentration of TPP in dust and corrected for dust loading using EFH factors (all but front door mat), yielding a point value of 1.46×10^{-4} µg/cm^2 for the mass over surface area.

Bergh et al. (2011a) also measured TPP in the air of Swedish child care centers. We assumed the study results are relevant to U.S. child care scenarios as well. We used the mean value from the study showing TPP concentrations in air particles to be 1×10^{-4} µg/m^3. Differentiation in concentrations by particle sizes was not reported, so as per standard assumption, 10% of the calculated inhaled mass was assumed to be respirable, and the remaining 90% of the calculated inhaled mass was assumed to be swallowed.

6.2 Home Environment

Fan et al. (2014) measured TPP in the dust of Canadian urban homes as part of a comparative study on different dust sampling methods. The results are assumed relevant to similar environments in the U.S. From the data as presented, we used the median value for the concentration of TPP in dust (1.6 µg/g) and corrected for dust loading using EFH factors (all but front door mat), yielding a point value of 1.23×10^{-4} µg/cm^2 for the mass over surface area. This was applied to the assessment for calculation of dermal exposure and exposure from hand-to-mouth activity.

Bergh et al. (2011a) measured TPP in the air of Swedish homes. We assumed the study results are relevant to U.S. home scenarios as well. We used the mean value of TPP concentrations in air particles from this study (2 x 10^{-4} µg/m^3). Differentiation in concentrations by particle sizes was not reported, so as per standard assumption, 10% of the calculated inhaled mass was assumed to be respirable, and the remaining 90% of the calculated inhaled mass was assumed to be swallowed.

6.3 Office Environment

Bergh et al. (2011a) measured TPP concentrations in dust collected from Swedish offices. From the data as presented we used the mean value for the concentration of TPP in dust (8.8 µg/g) and corrected for dust loading using EFH factors (all but front door mat), yielding a point value of 6.75 x 10^{-4} µg/cm^2 for the mass over surface area. This was used as a point value in the assessment for calculation of dermal exposure and exposure from hand-to-mouth activity.

Bergh et al. (2011a) also measured TPP in air in Swedish offices. We assumed the study results are relevant to U.S. office scenarios as well. We used the mean value from the study of TPP concentrations in air particles (6 x 10^{-4} µg/m^3). Differentiation in concentrations by particle sizes was not reported, so as per standard assumption, 10% of the calculated inhaled mass was assumed to be respirable, and the remaining 90% of the calculated inhaled mass was assumed to be swallowed.

6.4 Car Environment

Staaf and Ostman (2005a) reported TPP concentrations from the interior air of two cars to be 3 and 1 ng/m^3 (3.0 x 10^{-3} µg/m^3 and 1.0 x 10^{-3} µg/m^3, respectively). The average of these two measurements, 2 x 10^{-3} µg/m^3 was applied to the exposure assessment. Differentiation in concentrations by particle sizes was not reported, so as per standard assumption, 10% of the calculated inhaled mass was assumed to be respirable, and the remaining 90% of the calculated inhaled mass was assumed to be swallowed.

No data were available to represent dust in the car environment.

6.5 Other Data Not Employed

Other studies were considered for this assessment on TPP. Data reporting from the chosen studies were more useful for constructing distributions than the data from Saito et al. (2007), Marklund et al. (2005), Carlsson et al. 1997), and Dodson et al. (2012). The study results from Yang et al. (2014), Kanazawa et al. (2010), Kim et al. (2013), and Araki et al. (2014) may not be representative of U.S. scenarios. Stapleton et al. (2012) performed testing on specific products that were not applicable to this assessment. Carignan et al. (2013b) performed testing on environments that were not applicable to this assessment.

7 TBB - Selection of Studies and Data

We evaluated the available studies for 2-Ethylhexyl 2,3,4,5-tetrabromobenzoate (TBB) and selected acceptable data to estimate exposure to dust and air in child care centers and homes and dust in offices and cars (Table C-6). These data were from five studies, which we thought to be the most relevant and representative of the exposure data. The studies provided enough data detail for utilization in a probabilistic exposure assessment and sufficiently described the methods to allow for a quality evaluation of the sampling and analytical methods used.

Table C-6. Data source summary: Studies containing data chosen for the TBB assessment.

Study	Environment	Media
Bradman et al., 2012	Child Care Centers	Dust
		Indoor air
Brown et al., 2014	Homes	Dust
La Guardia and Hale, 2015	Homes	Indoor air respirable <4µm
		Indoor air inhalable >4µm
Ali et al., 2011	Offices	Dust
Hassan and Shoeib, 2015	Cars	Dust

7.1 Child Care Environment

Bradman et al. (2012) investigated dust and indoor and outdoor air in 39 child care centers in California to assess exposure to young children. The study provided extensive detail on all methodological aspects, including sampling, computational, and analytical methods. It provided comparisons to other studies and confirmed that the pattern of flame retardants in child care centers is similar to patterns in other indoor environments, such as schools and homes.

Bradman et al. (2012, Table 44) reported values representing a distribution of the mass of TBB found in dust collected over a measured surface area (noted as mass over surface area or µg/cm^2). These mass/unit area values are shown for "EHTBB" in Table 44.

- Min -5.74E-06 µg/cm^2
- 25th - 3.96E-05 µg/cm^2
- 50th - 6.83E-05 µg/cm^2
- 75th - 1.79E-04 µg/cm^2
- 90th - 9.98E-04 µg/cm^2
- 95th - 1.90E-03 µg/cm^2
- Max - 8.60E-03 µg/cm^2

We used these values to fit to a lognormal distribution using Crystal Ball™, yielding a mean of 3.10 x 10^{-4} µg/cm^2 and SD of 1.40 x 10^{-3} µg/cm^2. This distribution was used in the exposure assessment without

correction for dust loading because the study incorporated surface area measurements for collected dust.

For the air concentrations of TBB[1], Bradman et al. (2012, Table 40) reported a mean of 0.58 ng/m^3 and a SD of 2.6 ng/m^3 (5.8 x 10^{-4} [2.6 x 10^{-3}]) µg/m^3, which we applied to the assessment. Differentiation in concentrations by particle sizes was not reported, so as per standard assumption, 10% of the calculated inhaled mass was assumed to be respirable, and the remaining 90% of the calculated inhaled mass was assumed to be swallowed.

7.2 Home Environment

Brown et al. (2014) investigated dust (collected from vacuum cleaners) in 59 homes of participants in the Northern California Childhood Leukemia Study; dust was collected from vacuum cleaners. This study assessed exposure to the general population including children to flame retardants. Data from homes were used to estimate U.S. general population exposure. We used the reported GM of 3.1 x 10^1 µg/g and GSD of 8.59 x 10^{-3} µg/g and corrected with the EFH factors (all except front door mat). This yielded a GM of 2.38 x 10^{-5} µg/cm^2 and a GSD of 6.59 x 10^{-7} µg/cm^2. These values were used to create a log normal distribution using Crystal Ball™ for use in the exposure assessment.

La Guardia and Hale (2015) investigated dust, indoor air, and foam blocks for flame retardants in a gymnastic facility and also coaches' homes. Indoor air measurements (respirable and inhalable fractions) from the coaches' homes were used for this exposure assessment. The authors defined respirable particles to be less than four (4) microns in diameter (<PM_4) and larger particles (>PM_4) to be non-respirable. This study illustrated a preferential affinity of different analytes to different size particulates, which is an important consideration that makes this study particularly valuable.

The study reported three concentrations of TBB measured on respirable particles (<PM_4) as 14.2, 16.2, and 55.2 ng/m^3 (1.42 x 10^{-2}, 1.62 x 10^{-2} and 5.52 x 10^{-2} µg/m^3, respectively). These were used as three individual point values in the probabilistic analysis for the inhalation exposure. Four concentrations of TBB were reported for inhalable, but not respirable, particles (>PM_4) as 55.4, 16.9, 13, and 2.6 ng/m^3 (5.54 x 10^{-2}, 1.69 x 10^{-2}, 1.30 x 10^{-2}, and 2.60 x 10^{-3} µg/m^3, respectively). These were used as individual point values in the probabilistic analysis for oral ingestion by swallowing of those particles.

7.3 Office Environment

Ali et al. (2011) investigated dust in homes, offices, child care centers, and primary elementary schools in Belgium. TBB dust concentration measurements from the six offices sampled were used in this exposure assessment. This study used contemporary methods for vacuum collection and analysis by gas chromatography–mass spectrometry (GC-MS) with electron capture negative ionization (ECNI). The authors presented the 5th, 50th, and 95th percentiles, which were used to derive a lognormal distribution

[1] TBB is defined as "EH-TBB" in the Bradman (2012) report.

using Crystal Ball™, defined by a mean of 10.15 ng/g and a SD of 10.99 ng/g. These dust concentration values were corrected with the area factors from the EFH (all except front door mat), yielding the mass over area mean of 7.78 x 10^{-7} µg/cm^2 and SD of 8.43 x 10^{-7} µg/cm^2.

No data were available to represent air for the office environment.

7.4 Car Environment

For cars, the reported median value from the Hassan and Shoeib (2015) study was used to represent the concentration of TBB from total dust collection from seats, roofs, and dashboards of cars. This study was conducted in Egypt and may have limited representation for American cars. However, in the absence of other relevant data, the reported median point value of 5.81 ng/g (5.81 x 10^{-3} µg/g) was used to represent the possible concentration of TBB in dust from all surfaces in cars. This median concentration was corrected for surface area deposition using the EFH factor for untracked area of downstairs carpet to represent the seats and carpeting in the car, and the EFH factor for untracked area of linoleum to represent hard surfaces in the car. The average (1.9 x 10^{-7} µg/cm^2) of these two corrections (3.37 x10^{-7} µg/cm^2 and 3.49 x 10^{-8} µg/cm^2, respectively) were used to yield mass over area values.

For the fabric: 5.81 x 10^{-3} µg/g x 0.58 g/m^2 = 337 x 10^{-3} µg/m^2 = 3.37 x 10^{-7} µg/cm^2

For hard surfaces: 5.81 x 10^{-3} µg/g x 0.06 g/m^2 = 3.49 x 10^{-4} µg/m^2 =3.49 x 10^{-8} µg/cm^2

The average of these corrected means is used in the assessment = 1.86 x 10^{-7} µg/cm^2

No data were available to represent air for the car environment.

7.5 Other Data Not Employed

Other studies were considered for this assessment on TBB. The Newton et al. (2015), Johnson et al. (2013), Stapleton et al. (2009), and Shoeib et al. (2012) studies had issues with methodologies or sampling strategies. Fromme et al. (2014b); Dodson et al. (2012); Stapleton et al. (2008, 2014); Ali et al. (2012a, for house dust); Schreder and La Guardia (2014); and Hoffman et al. (2014) were good studies by reputable researchers but the chosen reports provided better options for metrics to create parametric distribution of values. Notably, Dodson et al. (2012) was a reputable study and used National Institute of Science and Technology (NIST) standard reference material (SRM) 2585. However, the authors did not provide metrics that allowed for good parametric distribution.

Stapleton et al. (2012), Schreder (2012), Carignan et al. (2013b), Ma et al. (2012), Schreder and La Guardia (2014), Allen et al. (2013), and Ali et al. (2012a, 2014) performed research on products or environments that were not the focus of this assessment.

Ali et al. (2012b) conducted studies on house dust in locations not relevant to the U.S. general population. For the home and child care environments, Bradman et al. (2012) presents a better option because their experimental method included direct measurement of the dust loading factor, making it unnecessary to make generalized corrections with the EFH factors. Note that many of Bradman's

findings in the 2012 report to the California Air Resources Board were summarized in the more brief 2014 publication in Chemosphere (Bradman et al., 2014). Ali and colleague's work (Ali et al., 2011) was used for the office environment, since Bradman and colleagues did not study the office environment.

8 TBPH - Selection of Studies and Data

The available studies for Di(2-ethylhexyl) tetrabromophthalate (TBPH) were evaluated and acceptable data were selected to estimate exposures from dust and air in child care centers, homes, and offices, and dust in cars (Table C-7). These data were from six studies, which were thought to be the most relevant and representative of the exposure data. The studies provided enough data detail for utilization in a probabilistic exposure assessment and sufficiently described the methods to allow for a quality evaluation of the sampling and analytical methods used.

Table C-7. Data source summary: Studies containing data chosen for the TBPH assessment.

Study	Location	Media
Bradman et al., 2012	Child Care Centers	Dust
		Indoor air
Brown et al., 2014	Homes	Dust
La Guardia and Hale, 2015	Homes	Indoor air
Ali et al., 2011	Offices	Dust
Newton et al., 2015	Offices	Indoor Air
Springer et al., 2012	Cars	Dust

8.1 Child Care Environment

Bradman et al. (2012) investigated dust, as well as indoor and outdoor air in 39 child care centers in California. This study assessed exposure to young children, the population of interest in child care environments. The study provided extensive detail on all methodology aspects, including sampling, computational, and analytical methods. It provided comparisons to other studies and confirms that the pattern of flame retardants in child care centers is similar to patterns in other indoor environments such as schools and homes.

Bradman et al. (2012, Table 44) presented data representing a distribution of the TBPH mass over area measurements. TBPH is represented by analyte “BEHTBP” in the table.

- Min - 3.24E-06 µg/cm^2
- 25th - 1.22E-05 µg/cm^2
- 50th - 2.82E-05 µg/cm^2
- 75th - 7.43E-05 µg/cm^2
- 90th - 5.60E-04 µg/cm^2
- 95th - 9.58E-04 µg/cm^2
- Max - 1.70E-03 µg/cm^2

These values were fit to a lognormal distribution using Crystal Ball™, defined by a mean 8.25 x 10^{-5} µg/cm^2 and SD 2.13 x 10^{-4} µg/cm. The derived distribution was used for the exposure assessment. No dust mass/area correction was needed because the study incorporated area distribution of chemical mass.

Bradman et al. (2012) also measured TBPH in air particles in child care centers and reported a mean of 2.3 x 10^{-4} with a SD of 8.7 x 10^{-4} µg/m^3. Differentiation in concentrations by particle sizes was not reported, so as per standard assumption, 10% of the calculated inhaled mass was assumed to be respirable, and the remaining 90% of the calculated inhaled mass was assumed to be swallowed.

8.2 Home Environments

Brown et al. (2014) investigated dust in 59 homes from participants in the Northern California Childhood Leukemia Study (and 27 fire station living quarters); dust was collected from vacuum cleaners. This study assessed exposure to the general population including children to flame retardant concentrations. Data from homes were used to estimate U.S. general population exposure. Brown et al. (2014) reported a geometric mean for the dust concentration of 144 ng/g and GSD of 5.94 ng/g. We corrected for dust loading using EFH factors (all except front door mat), yielding a TBPH dust mass per surface area of 1.1 x 10^{-5} µg/cm^2 with a SD = 4.6 x 10^{-7} µg/cm^2. This was used to create a log normal distribution with Crystal Ball™ for use in the exposure assessment to calculate exposures via dermal contact and hand-to-mouth events.

La Guardia and Hale (2015) investigated dust, indoor air, and foam blocks for flame retardants in a gymnastic facility and also coaches' homes. Indoor air measurements (respirable and inhalable fractions reported by the author, meaning particles that can be inspired versus those inhaled and ingested) from the coaches' homes were used for the home environment. This study illustrated a preferential affinity of different analytes to different size particulates. The authors reported a mean TBPH concentration for inhalable but non-respirable particles of 8.61 ng/m^3 (8.61 x 10^{-3} µg/m^3), which was used as a point value to represent the mass ingested from inhaled but not respirable particles. A mean TBPH concentration of respirable particles was reported as 6.93 ng/m^3 (6.93 x 10^{-3} µg/m^3), and it was used as point value without correction for exposure by inhalation.

8.3 Office Environment

Ali et al. (2011) investigated dust in child care centers, homes, offices, and primary elementary schools in Belgium. Dust concentration measurements from the six offices sampled were used for the office environment. This study is relevant to exposure for the general population. It used contemporary methods for vacuum collection and analysis by GC/MS with ECNI. The authors presented the needed information for construction of parametric distributions.

Ali et al. (2011) reported a distribution of values for TBPH on dust, defined by a mean of 9.5 x 10-2 µg/g with a SD of 8.9 x 10^{-2} µg/g. We corrected for dust loading with EFH factors (all except front door mat), yielding a distribution of TBPH mass per unit surface area of 7.28 x 10^{-6} µg/cm^2 and a SD of 6.82 x 10^{-6} µg/cm^2.

Newton et al. (2015) measured TBPH in office air particles in buildings in Stockholm, Sweden. We assume the study results are relevant to contemporary U.S. office scenarios. From the reported data, we used the reported geometric mean value of 4.2×10^{-5} µg/m^3 for the TBPH air particle concentration. Differentiation in concentrations by particle sizes was not reported, so as per standard assumption, 10% of the calculated inhaled mass was assumed to be respirable, and the remaining 90% of the calculated inhaled mass was assumed to be swallowed.

8.4 Car Environment

Springer et al. (2012) measured TBPH concentrations in dust samples from 20 cars in Boston during the winter of 2009. The dust was collected from vacuuming the entire surfaces of the front and back seats (which we assumed to be fabric) for 10 minutes. Dashboard, floor, and other surfaces were not vacuumed. In converting the reported dust concentration (median of 400 ng/g) to a mass per unit area, the EFH factor for "untracked area of downstairs carpet" condition was applied (0.58 g/m^2). The linoleum factors were not applied, as the experimental method did not sample hard surfaces within the car, only the seat surfaces. Applying the data yielded a TBPH mass per unit surface area of 2.3×10^{-5} µg/cm^2, which was used as a point value in the exposure assessment for dermal exposure and exposure via hand-to-mouth activity.

No data were available to represent air for the car environment.

8.5 Other Data Not Employed

Other studies were considered for this assessment on TBPH. Fromme et al. (2014b) had methodology issues limiting its use for home dust scenarios. Dodson et al. (2012), Ali et al. (2012a), Stapleton et al.(2014), Ma et al. (2012), Schreder and La Guardia (2014), and Springer et al. (2012) were reputable studies, but the data reporting from the chosen studies for these analyses were more useful for constructing distributions. Stapleton et al. (2012) and Schreder (2012) tested specific products that were not applicable to this assessment approach. Hoffman et al. (2014) and Peng et al. (2015) performed testing on new flame retardant product formulations with new methodology. Although TBPH was detected, the scenarios were not representative for the generalized media and environments considered in these analyses. Carignan et al. (2013b), Allen et al. (2013), and Brown et al. (2014) tested environments that were not applicable to this assessment. Johnson et al. (2013) and Shoeib et al. (2012; as cited by Brown et al. [2014]) have methodology issues. Note that many of Bradman's findings in the 2012 report to the California Air Resources Board were summarized in the more brief 2014 publication in Chemosphere (Bradman et al., 2014).

9 TBBPA - Selection of Studies and Data

We evaluated the available studies for Tetrabromobisphenol A (TBBPA) and selected acceptable data to estimate exposure to dust in the child care and home environments and dust and air in the office environment (Table C-8). These data were from four studies, which we thought to be the most relevant and representative of the exposure data. The studies provided enough data detail for utilization in a probabilistic exposure assessment and sufficiently described the methods to allow for a quality evaluation of the sampling and analytical methods used. No data were available for estimating exposure from TBBPA in cars.

Table C-8. Data source summary: Studies containing data chosen for the TBBPA assessment.

Study	Environment	Media
Harrad et al., 2010	Child Care Centers	Dust
Fromme et al., 2014b	Homes	Dust
Geens et al., 2009	Offices	Dust
Ni and Zeng, 2013	Offices	Indoor air PM_{10}
Ni and Zeng, 2013	Offices	Indoor air $PM_{2.5}$

9.1 Child Care Environment

Harrad et al. (2010) measured levels of TBBPA in the dust in child care centers and primary schools in England's West Midlands. The study is likely reasonably representative of contemporary TBBPA concentrations in the U.S. child care environment and provides the advantage of presenting concentration data as collected across surface floor areas. The high and low mass over area data (0.025 g/m^2 and 0.3 g/m^2 respectively) were fitted to each of the reported values for dust concentrations (ng/g) (Table C-9). This was used to create a lognormal distribution, defined by a mean of 4.84 x 10^{-6} $\mu g/cm^2$ with SD of 5.26 x 10^{-6} $\mu g/cm^2$, which was used in the exposure assessment.

Table C-9. Conversion calculations for TBBPA Dust Concentration to Mass over Area Values.

Reported dust concentrations µg/g	Dust loading correction using low factor µg/cm²	Dust loading correction using high factor µg/cm²
1.70E-02	4.25E-08	5.10E-07
2.00E-02	5.00E-08	6.00E-07
1.10E-01	2.75E-07	3.30E-06
2.00E-01	5.00E-07	6.00E-06
4.60E-01	1.15E-06	1.38E-05
1.40E+00	3.50E-06	4.20E-05

No data were available for measurements of TBBPA in air at child care centers.

9.2 Home Environment

Fromme et al. (2014b) measured TBBPA concentrations in house dust collected from vacuum cleaner bags regularly used in homes in Germany. We assumed these measurements would be reasonably representative of contemporary scenarios in U.S. homes. The data presented for dust concentrations collected from floor vacuuming best fit a pareto distribution yielding a mean of 38.7 ng/g and SD of 37.2 ng/g. This mean concentration was corrected for dust loading using EFH factors (all except front door mat) yielding a TBBPA surface mass distribution defined by a mean of 2.97 x 10^{-6} µg/cm^2 and a SD of 2.85 x 10^{-6} µg/cm^2, which was used in the exposure assessment.

Saito et al. (2007) sampled air from eight Japanese homes for TBBPA. No TBBPA was detected in any sample (level of detection 173 pg/m^3, and method detection limit 1.2 ng/m^3). Air concentrations of TBBPA were thus not included in the exposure assessment for home environments. No other studies with measurements above the detection limit were found.

9.3 Office Environment

Geens et al. (2009) measured TBBPA concentrations in office dust collected from vacuum cleaner bags regularly used in Belgium. We assumed these measurements would be reasonably representative of contemporary scenarios in U.S. offices. The study of dust concentrations collected from floor vacuuming presented a median concentration of 7.5 x 10^{-2} µg/g, which was corrected for dust loading using EFH factors (all except front door mat), yielding a point value for TBBPA surface mass of 5.75 x 10^{-6} µg/cm^2 for estimation of exposure via dermal contact and hand-to-mouth events.

Ni and Zeng (2013) measured TBBPA concentrations in indoor air particles, separating respirable portions ($PM_{2.5}$) and larger particles (PM_{10}). Point values were available from the data reported in the study. We used the median $PM_{2.5}$ concentration of 5 x 10^{-4} µg/m^3 for the respirable air particle concentration and the PM_{10} concentration of 2.4 x 10^{-4} µg/m^3 as the concentration of TBBPA on particles that would be swallowed (oral exposure route). This research was conducted in an office building in China and the collection methodology utilized dusts from filters in central air conditioners. We assume the results are representative of U.S. office scenarios. The strength of this study is its separate measurements of the respirable versus non-respirable particles, suggesting that TBBPA may have a greater affinity for smaller particles.

9.4 Car Environment

No data were available for TBBPA in car dust or air.

9.5 Other Data Not Employed

Other studies were considered for this assessment on TBBPA. For the Saito et al. (2007) study, TBBPA was not detected in home or office air. The data reporting in the chosen Fromme et al. (2014b) study was better than in the Dodson et al. (2012), Stapleton et al. (2014), and Harrad et al. (2010) studies

because they could be fit to a distribution. The environments studied in the Deng et al. (2014), Napoli-Davis and Owens (2013), and Makinen et al. (2009) studies were not applicable to this assessment.

The Takigami et al. (2009) and Abb et al. (2011) studies had issues with their methodology, which were not useful for U.S. population. The chosen Fromme et al. (2014b) study was more representative for this assessment than the Wanner et al. (2008; as cited in Abb et al. [2011]) and the Abdallah et al. (2008, as cited in Abb et al. [2011]) studies. D'Hollander et al. (2010) showed limited representativeness and data reporting compared to the chosen studies. The Toms et al. (2009; as cited in Abb et al. [2011]) and Cunha et al. (2010; as cited in Abb et al. [2011]) studies showed limited representativeness and limited methodology descriptions. The scenarios chosen in Gallen et al. (2014), Choi et al. (2009), Takigami et al. (2008), and Rani et al. (2014) were not applicable to this assessment.

10 ATO - Selection of Studies and Data

Analytical methodology reduces the collected Diantimony Trioxide (ATO) in air particulates or in dust to elemental antimony for quantification. This level can be converted, based on the relevant molecular weight, to the ATO equivalent, which would then assume all contributions of the elemental antimony would be from ATO rather than from environmental sources of elemental antimony. However, since the toxicology metrics to be used in a risk assessment for ATO are expressed in terms of elemental antimony, the exposure assessment will remain in elemental antimony units, not converted to ATO equivalents. This will provide the exposure metrics that are directly applicable to comparison with toxicology studies for the risk assessment considerations.

Contaminant concentrations of ATO in environments, such as homes, child care centers and office environments, have been inferred from the measurement of elemental antimony. However, elemental antimony is known to be in the environment also as a consequence of geological sources (mining, road dust, outside dirt) not related to flame retardant usage. Our goal was to select studies that are most likely to represent the antimony consequential from products containing ATO used as a flame retardant and that are studied and reported with acceptable quality and representative of contemporary U.S. scenarios. We reviewed the available data for those studies that best represent concentrations of ATO in dust in child care, home, office, or car environments (Table C-10).

Table C-10. Data source summary: Studies containing data chosen for the ATO assessment.

Study	Environment	Media
Majestic et al. , 2012	Child Care Centers	Indoor air
McDonald et al., 2011	Homes	Dust

10.1 Child Care Environment

Majestic et al. (2012) studied antimony adherence to different size fractions of air particulate matter (PM) collected in an Arizona elementary school. Results show measurements from PM_1 to be most indicative of antimony adsorption consequential to fire retardant sources within the school, as compared to outdoor sources of antimony. The authors report the mean (SD) concentration of antimony as 1.7×10^{-2} µg/m^3 (7.0×10^{-3} µg/m^3). This mean and SD were used to create a log normal distribution using Crystal Ball™ which was applied to the exposure assessment. The inhaled mass from PM_1 would be completely inspired, with none resulting in oral exposure. This study is valuable because it provides measurements of PM_1, which is more representative of antimony air concentrations relevant to flame retardant usage

No data were available to represent dust for the child care environment.

10.2 Home Environment

McDonald et al. (2011) measured concentrations of elemental antimony collected by surface wipe methods in Canadian homes. The authors reported concentrations (in $\mu g/m^2$) for the 50^{th} and 95^{th} percentiles as well as a maximum value. The 50^{th} percentile of 5×10^{-1} $\mu g/m^2$ was used in the exposure assessment. No dust loading corrections are needed as the wipe methods already account for surface distribution. Data from this study were selected because the collection methods reflect direct accounting for mass over area and may be more representative of U.S. home scenarios than other studies.

No data were available to represent air for the home environment.

10.3 Office Environment

No relevant studies are available to estimate exposure to ATO in the office environment.

10.4 Car Environment

No relevant studies are available to estimate exposure to ATO in the office environment.

10.5 Other Data Not Employed

Rasmussen et al. (2001) measured concentrations of elemental antimony in vacuumed house dust collected from 50 homes in Ottawa, Ontario, Canada. Results were (mg/kg sample): Mean 7.28, GM 5.54, Median 5.12, Range 1.16-57.41, 90^{th} %ile 12.5, 95^{th} %ile 15.38. Dust loading corrections would be required to use these data for a mass per unit surface area estimate, although such corrections may be inefficient given the uncertainty of collection methods for the vacuumed dust samples.

Glorennec et al. (2012) reported on settled dust in French homes using surface wipes. Antimony contamination at levels above the level of quantification were noted only in about 10% of the samples at levels ranging from 1.4 to 8.8 $\mu g/m^2$. These are roughly comparable to findings by McDonald et al. (2011). The McDonald work was more refined as reported.

Turner and Hefzi et al. (2010) sampled indoor house dust from vacuumed areas of houses in Saudi Arabia for elemental antimony. Results are complicated by an arid and sandy environment and results must be corrected for dust loading. Wipe sample studies in Canadian and French homes by the McDonald et al. (2011) and Glorennec et al. (2012) studies are likely to be more representative of U.S. homes than Turner and Hefzi et al. (2010).

Rivas et al. (2014) focused on finding elemental indicators of traffic pollution on $PM_{2.5}$ size air particles collected in various geographical areas in and around schools in urban Barcelona, Spain. Air concentrations of elemental antimony in the schools (as a function of adherence to particulate matter ($PM_{2.5}$) were reported as mean 0.83 ng/m^3, range 0.13-1.6 ng/m^3, median 0.83 ng/m^3, and SD 0.35 ng/m^3. Notably, the lower contaminant concentrations reported by Rivas and colleagues may reflect the findings by Majestic et al. (2012) that antimony adheres preferentially to small particulates, PM_1. Rivas'

lower values measured in $PM_{2.5}$ particulates in Spain may reflect the differential adherence, or may reflect other country differences, such as use of ATO treated consumer products. Data from Majestic et al. (2012) was preferred for the exposure assessment.

Other studies such as Kawamura et al. (2006), Huang et al. (2014), Gonzales et al. (2004), Fergusson et al. (1986), Davis and Gulson, (2005), Barbieri et al. (2014), Fontúrbel et al. (2011), Yoshinaga et al. (2014), and Bi et al., (2011) were not considered relevant or useable.

11 References

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Appendix D

Activity Factors for Each Environment

Task Order 18

Contract Number CPSC-D-12-0001

Final Report

September 28, 2016

Prepared by Toxicology Excellence for Risk Assessment and The LifeLine Group

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Table of Contents

This appendix lists the activity factors used in the probabilistic assessment for each of the four environments: child care, home, office, and car.

1 Activity/ Environment: Activities While Being in Child Care

Location: inside for all seasons

Hand-to mouth event activity factors: see Table D-1

Table D-1. Hand-to-mouth event activity factors. Except where noted activity factors are from Table 4-1 EFH (EPA, 2011, p. 4-3)

Age	Events/hour	Proportion of hand in or on mouth (ARG defaults)[1]
<1 month	30[1]	0.5
1 to < 3 months	30[1]	0.5
3 to < 6 months	28	0.5
6 to < 12 months	19	0.5
1 to < 2 years	20	0.2
2 to < 3 years	13	0.2
3 to < 6 years	15	0.2
6 to < 11 years	7	0.2/0.05[2]
11 to < 16 years	1[1]	0.05
16 to < 21 years	1[1]	0.05
>=21years	1[1]	0.05

[1] Default values estimated by professional judgement for the LifeLine exposure models' exposure factors values (The LifeLine Group)

[2] Proportion of hand represented by a normal distribution with the mean of 20% and Std. Dev. of 5%. This default value estimated by professional judgement for the LifeLine exposure models' exposure factors values (The LifeLine Group).

Activity Exertion Level: Three levels of activity are considered for the time spent in the child care environment: passive, light and moderate

Inhalation Rate: See Table D-2, for all seasons

Table D-2. Inhalation rate (m^3/hour) for all seasons, from EFH (EPA, 2011)

Age	Resting (m^3/hour)	Light Activity (m^3/hour)	Moderate (m^3/hour)
<1 month	0.19	0.46	0.84
1 to < 3 months	0.19	0.46	0.84
3 to < 6 months	0.19	0.46	0.84
6 to < 12 months	0.19	0.46	0.84
1 to < 2 years	0.28	0.72	1.3
2 to < 3 years	0.29	0.72	1.3
3 to < 6 years	0.27	0.66	1.3
6 to < 11 years	0.29	0.66	1.3
11 to < 16 years	0.32	0.78	1.5
16 to < 21 years	0.32	0.72	1.6
21<31	0.25	0.72	1.6
31<41	0.26	0.72	1.6
41<51	0.29	0.78	1.7
51<61	0.30	0.78	1.7
61<71	0.29	0.72	1.6
71<81	0.30	0.72	1.5
>=81	0.29	0.72	1.5

Probability on a given day of activity existing and exertion level:

0 – 4 years	82%
5-14 years	30 %
15-20 years	0
21-65 years	0
66-85 years	0

60% of the time in the environment = passive exertion level
20% of the time in the environment = light exertion level
20% of the time in the environment = moderate exertion level

Activity Duration: type of distribution and minutes

0-4 years	Distribution: Triangular: Low = 60, Most Likely Value = 420, High = 480
5-14 years	Duration: Single Value = 252

15-20 years	Duration: Single Value = 0
21-65 years	Duration: Single Value = 0
65-85 years	Duration: Single Value = 0

Activity Frequency:

0 – 4 years	1
5-14 years	1
15-20 years	0
21-65 years	0
66-85 years	0

Clothing: For all age groups: See Table D-3

Table D-3. Types of clothing for all age groups*

Season	Clothing Type	Clothing Items Selected
Winter	Default	Long pants, long sleeved shirt, socks, shoes, half-length coat
Spring	Default	Long pants, long sleeved shirt, socks, shoes
Summer	Default	Long pants, short sleeved shirt, socks, shoes
Fall	Default	Long pants, long sleeved shirt, socks, shoes

*Descriptions estimated by professional judgement for the LifeLine exposure models' exposure factors values (The LifeLine Group)

Hourly Boundary Governor: Whole Day

2 Activity: Daily Living in Home Environment

Location: inside for all seasons

Hand-to-mouth events: See Table D-4

Table D-4. Hand-to-mouth event activity factors. Except where noted, events/hour are from Table 4-1 EFH (EPA, 2011, p. 4-3)

Age	Events/hour	Proportion of hand in or on mouth (ARG defaults)[1]
<1 month	30[1]	0.5
1 to < 3 months	30[1]	0.5
3 to < 6 months	28	0.5
6 to < 12 months	19	0.5
1 to < 2 years	20	0.2
2 to < 3 years	13	0.2
3 to < 6 years	15	0.2
6 to < 11 years	7	0.2/0.05[2]
11 to < 16 years	1[1]	0.05
16 to < 21 years	1[1]	0.05
>=21years	1[1]	0.05

[1] Default values estimated by professional judgement for the LifeLine exposure models' exposure factors values (The LifeLine Group)
[2] Proportion of hand represented by a normal distribution with the mean of 20% and Std. Dev. of 5%. This default value estimated by professional judgement for the LifeLine exposure models' exposure factors values (The LifeLine Group).

Inhalation Rate: See Table D-5, for all seasons

Table D-5. Inhalation rate (m^3/hour) for all seasons, from EFH (EPA, 2011)

Age	Resting (m^3/hour)	Light Activity (m^3/hour)	Moderate Activity (m^3/hour)
<1 month	0.19	0.46	0.84
1 to < 3 months	0.19	0.46	0.84
3 to < 6 months	0.19	0.46	0.84
6 to < 12 months	0.19	0.46	0.84
1 to < 2 years	0.28	0.72	1.3
2 to < 3 years	0.29	0.72	1.3
3 to < 6 years	0.27	0.66	1.3
6 to < 11 years	0.29	0.66	1.3
11 to < 16 years	0.32	0.78	1.5

Age	Resting (m^3/hour)	Light Activity (m^3/hour)	Moderate Activity (m^3/hour)
16 to < 21 years	0.32	0.72	1.6
21<31	0.25	0.72	1.6
31<41	0.26	0.72	1.6
41<51	0.29	0.78	1.7
51<61	0.30	0.78	1.7
61<71	0.29	0.72	1.6
71<81	0.30	0.72	1.5
>=81	0.29	0.72	1.5

Probability on a given day of activity existing and exertion level: 95%, for all ages

Activity Exertion Level: Three levels of activity are considered for the time spent in the home environment: passive, light and moderate

Activity Duration: (minutes) passive

0 to 1 years	605
1 through 2 years	733
3 through 5 years	656
6 through 11 years	575
12 through 17 years	567
18 through 65 years	508
66 through 85 years	759

Activity Duration: (minutes) light

0 to 1 years	236
1 through 2 years	282
3 through 5 years	297
6 through 11 years	312
12 through 17 years	304
18 through 65 years	242
66 through 85 years	268

Activity Duration: (minutes) moderate

0 to 1 years	158
1 through 2 years	733
3 through 5 years	656
6 through 11 years	575
12 through 17 years	567

18 through 65 years	508
66 through 85 years	759

Activity Frequency: for all age groups: 1 time per day

Clothing: For all age groups: See Table D-6

Table D-6. Types of clothing for all age groups*

Season	Clothing Type	Clothing Items Selected
Winter	Default	Long pants, long sleeved shirt, socks, shoes
Spring	Default	Long pants, long sleeved shirt, socks, shoes
Summer	Default	Long pants, short sleeved shirt, socks, shoes
Fall	Default	Long pants, long sleeved shirt, socks, shoes

*Descriptions estimated by professional judgement for the LifeLine exposure models' exposure factors values (The LifeLine Group)

Hourly Boundary Governor: Whole Day

3 Activity: Working in Office Environment

Location: inside for all seasons

Hand-to mouth event activity factors: see Table D-7

Table D-7. Hand-to-mouth event activity factors. Except where noted, events/hour are from Table 4-1 EFH (EPA, 2011, p. 4-3).

Age	Events/hour	Proportion of hand in or on mouth (ARG defaults)[1]
<1 month	30[1]	0.5
1 to < 3 months	30[1]	0.5
3 to < 6 months	28	0.5
6 to < 12 months	19	0.5
1 to < 2 years	20	0.2
2 to < 3 years	13	0.2
3 to < 6 years	15	0.2
6 to < 11 years	7	0.2/0.05[2]
11 to < 16 years	1[1]	0.05
16 to < 21 years	1[1]	0.05
>=21years	1[1]	0.05

[1] Default values estimated by professional judgement for the LifeLine exposure models' exposure factors values (The LifeLine Group)

[2] Proportion of hand represented by a normal distribution with the mean of 20% and Std. Dev. of 5%. This default value estimated by professional judgement for the LifeLine exposure models' exposure factors values (The LifeLine Group).

Activity Exertion Level: Two levels of activity are considered for the time spent in the office environment: passive and light

Inhalation Rate: See Table D-8, for all seasons

Table D-8. Inhalation rate (m^3/hour) for all seasons, from EFH (U.S. EPA, 2011)

Age	Resting (m^3/hour)	Light Activity (m^3/hour)
<1 month	0.19	0.46
1 to < 3 months	0.19	0.46
3 to < 6 months	0.19	0.46
6 to < 12 months	0.19	0.46
1 to < 2 years	0.28	0.72
2 to < 3 years	0.29	0.72
3 to < 6 years	0.27	0.66

Age	Resting (m^3/hour)	Light Activity (m^3/hour)
6 to < 11 years	0.29	0.66
11 to < 16 years	0.32	0.78
16 to < 21 years	0.32	0.72
21<31	0.25	0.72
31<41	0.26	0.72
41<51	0.29	0.78
51<61	0.30	0.78
61<71	0.29	0.72
71<81	0.30	0.72
>=81	0.29	0.72

Probability of Activity Existing:

0 to 17 years	Single value 0
18 to 65 years	Single value 71%
65 to 85 years	Single value 0

Activity Duration: type of distribution and minutes, passive and light

0 to 17 years	Single value 0
18 to 65 years	Distribution: Normal, Mean=484.8, Std Dev 173.1, Upper Bound 1440
65 to 85 years	Single value 0

Activity Frequency:

0 to 17 years	Single value 0
18 to 65 years	Single value 1
65 to 85 years	Single value 0

Clothing for 18 to 65 years during passive and light activities: See Table D-9

Table D-9. Types of clothing worn during passive and light activities*

Season	Clothing Type	Clothing Items Selected
Winter	Default	Long pants, long sleeved shirt, socks, shoes
Spring	Default	Long pants, long sleeved shirt, socks, shoes
Summer	Default	Long pants, short sleeved shirt, socks, shoes
Fall	Default	Long pants, long sleeved shirt, socks, shoes

*Descriptions estimated by professional judgement for the LifeLine exposure models' exposure factors values (The LifeLine Group)

Hourly Boundary Governor: Whole Day

4 Activity/Environment: Daily Transportation in Cars

Location: inside for all seasons

Hand-to mouth event activity factors: see Table D-10

Table D-10. Hand-to-mouth event activity factors. Except where noted, events/hour are from Table 4-1 EFH (EPA, 2011, p. 4-3)

Age	Events/hour	Proportion of hand in or on mouth (ARG defaults)[1]
<1 month	30[1]	0.5
1 to < 3 months	30[1]	0.5
3 to < 6 months	28	0.5
6 to < 12 months	19	0.5
1 to < 2 years	20	0.2
2 to < 3 years	13	0.2
3 to < 6 years	15	0.2
6 to < 11 years	7	0.2/0.05[2]
11 to < 16 years	1[1]	0.05
16 to < 21 years	1[1]	0.05
>=21years	1[1]	0.05

[1] Default values estimated by professional judgement for the LifeLine exposure models' exposure factors values (The LifeLine Group)
[2] Proportion of hand represented by a normal distribution with the mean of 20% and Std. Dev. of 5%. This default value estimated by professional judgement for the LifeLine exposure models' exposure factors values (The LifeLine Group).

Activity Exertion Level: light for all seasons

Inhalation Rate: See Table D-11, for all seasons

Table D-11. Inhalation rate (m^3/hour) for all seasons, from EFH (U.S. EPA, 2011)

Age	Light Activity
<1 month	0.46
1 to < 3 months	0.46
3 to < 6 months	0.46
6 to < 12 months	0.46
1 to < 2 years	0.72
2 to < 3 years	0.72
3 to < 6 years	0.66
6 to < 11 years	0.66
11 to < 16 years	0.78

Age	Light Activity
16 to < 21 years	0.72
21<31	0.72
31<41	0.72
41<51	0.78
51<61	0.78
61<71	0.72
71<81	0.72
>=81	0.72

Probability on a given day of activity existing

0-1 year	87%
1-2 years	87%
3-5 years	87%
6-10 years	87%
11-15 years	87%
16-20 years	87%
21-85 years	87%

Activity Duration: type of distribution and minutes

0-1 year	Distribution: Log Normal, Mean=94, Std Dev=90.2, Upper Bound=593
1-2 years	Distribution: Log Normal, Mean=94, Std Dev=90.2, Upper Bound=593
3-5 years	Distribution: Log Normal, Mean=94, Std Dev=90.2, Upper Bound=593
6-10 years	Distribution: Log Normal, Mean=94, Std Dev=90.2, Upper Bound=593
11-15 years	Distribution: Log Normal, Mean=64.8, Std Dev=71, Upper Bound=630
16-20 years	Distribution: Log Normal, Mean=64.8, Std Dev=71, Upper Bound=630
21-85 years	Distribution: Log Normal, Mean=93.8, Std Dev=92.3, Upper Bound=1280

Activity Frequency: for all age groups: 1 time per day

Clothing: For all age groups: See Table D-12

Table D-12. Types of clothing for all age groups*

Season	Clothing Type	Clothing Items Selected
Winter	Default	Long pants, long sleeved shirt, socks, shoes, half-length coat
Spring	Default	Long pants, long sleeved shirt, socks, shoes
Summer	Default	Long pants, short sleeved shirt, socks, shoes
Fall	Default	Long pants, long sleeved shirt, socks, shoes

*Descriptions estimated by professional judgement for the LifeLine exposure models' exposure factors values (The LifeLine Group)

Hourly Boundary Governor: Whole Day

5 References

U.S. Environmental Protection Agency (EPA), 2011. Exposure Factors Handbook: 2011 Edition. National Center for Environmental Assessment, Washington, DC; EPA/600/R-09/052F. Available at: https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=236252