Benzene VCCEP Tier 1 Submission

APPENDIX A

Exposure Appendices

APPENDIX A-1

This section contains a discussion of the exposure factors selected to calculate benzene dose based on the exposure concentrations developed in Section 7. It should be noted that separate exposure factors were not developed for boys and girls. The reason for this is that gender plays only a minor role in parameters such as body weight and inhalation rate for prepubescent children. In addition, gender did not have a significant effect on gross measures of activity such as time spent at home (LifeLine Group, 2002). Age of the individual has a much greater effect on both physiology and time-activity patterns than gender. In the case of individuals older than 18, data for men and women were separated.

Activity Patterns

Exposure times, exposure frequencies and exposure durations were determined for each of the age groups and exposure scenarios. The primary sources of activity pattern information were the Exposure Factors Handbook (EFH; EPA, 1997) and the Child-Specific Exposure Factors Handbook (CEFH; EPA, 2002). For activity patterns that are not as well documented (e.g., refueling), information was obtained from the peer-reviewed literature or determined using professional judgment.

The manner in which an individual spends his or her time can vary depending upon a variety of factors including, but not limited to, culture, location and personal preference (USEPA, 1997). Ideally, site-specific information would be used, however, for an exposure assessment evaluating a general US population, this is not feasible. The factors discussed below are based on average values, as recommended in Exposure Factors Handbook (USEPA, 1997) and Child-Specific Exposure Factors Handbook (USEPA, 2001).

Exposure Duration

The exposure durations for each scenario represent the number of years that an individual is potentially exposed. Thus for everyday activities, exposure durations are equal to the number of years an individual spends within each age group. A summary is provided in Table A-1.1.

Table A-1.1: Exposure Durations for Common Age Groups

Age Range	(years)
< 1 years	1
1 to < 2 years	1
2 to < 6 years	4
6 to < 16 years	10
16 to < 19 years	3
19 to < 35 years	17

Exposure Frequency

Exposure frequency can be described as the number of exposure events per year. It is typically, but not always, described in terms of days per year. For the ambient inhalation scenarios, the frequency of exposure to benzene is every day, or 365 days/year. However, as the exposure times spent in school and home vary (e.g. weekend vs. weekday; in-school vs. school break), ambient exposure frequencies vary somewhat. Children spend 180 days/year in school, and 185 days/year *not* in school. Adults (i.e., prospective parents) are assumed to work 250 days/year and not work the remaining 115 days/year. Infants (<1 year) have the same ambient exposure frequency year round, 365 days/year. In addition, exposure to benzene in in-vehicle air, in food, in water, and from tobacco smoke is assumed to occur 365 days/year.

The exposure frequencies for scenarios with non-daily exposures vary, and are discussed in more detail in those scenario-specific sections.

Exposure Time

Exposure time describes the number of hours per day that an individual spends doing a particular activity during which he or she may be exposed. A summary of the exposure times is presented in Table A-1.2 and discussed in more detail in this section.

Infant (< 1 year old)
An infant spends over 80% of his or her time indoors at home, or approximately 19.6 hours/day (EPA, 2002). Including time spent in other indoor environments, the average amount of time that an infant spends indoors on any given day is approximately 21.4 hours per day. Other environments in which an infant typically spends time are outdoors (1.4 hours/day; EPA, 2002) and in a vehicle (1.2 hours/day; EPA, 2002).

Infant (1 to < 2 year old)
The activity patterns of this age group are similar to the < 1 year old age group, spending 21.3 hours/day indoors (EPA, 2002). During school/day care days, 1.8 of these hours/day are spent at daycare. On non-school/non-work days, all of the indoor time is spent at home. Other environments in which a < 2 year old infant typically spends time are outdoors (1.6 hours/day; EPA, 2002) and in a vehicle (1.1 hours/day; EPA, 2002).

Child 2 to < 6 Years Old
A child between the ages of 2 and 6 years old spends the majority of his or her time at home. On a typical school day, this equates to approximately 17.4 hours/day (EPA, 2002). He or she exhibits similar activity patterns as the infant, likely because a child this age still spend much time with its parents. On a typical school (day care or pre-school) day, approximately 2.3 hours/day are spent outdoors, and 1.3 hours/day are spent traveling in a vehicle (EPA, 2002). The amount of time spent in day care or pre-school is 3.0 hours per day. EPA (2002) states that the average amount of time spent in school for this age range is 5.1 hours/day, however this value was adjusted to 3.0 hours/day, as this is the remaining time in a day that is not spent at home, in a vehicle or outdoors.

Table A-1.2: Time Activity Patterns

Age Group	Microenvironment	School/Work Day		Non-School/Non-Work Day	
		Time (hours/day)	Reference[a]	Time (hours/day)	Reference[a]
Infant (<1 year old)	Home (indoors)	--	--	21.4[a]	CEFH (9-52)
	Outdoors	--	--	1.4	CEFH (9-52)
	In car	--	--	1.2	CEFH (9-52)
1 to < 2 years old	Home (indoors)	19.5	CEFH (9-52)	21.3	CEFH (9-52)
	Preschool/Daycare	1.8[c]	CEFH (9-52)	-	
	Outdoors	1.6	CEFH (9-52)	1.6	CEFH (9-52)
	In car	1.1	CEFH (9-52)	1.1	CEFH (9-52)
2 to < 6 years old	Home (indoors)	17.4	CEFH (9-52)	19.6	CEFH (9-3)
	Preschool/Daycare	3.0[c]	CEFH (9-52)	-	
	Outdoors	2.3	CEFH (9-52)	3.1	CEFH (9-3)
	In car	1.3	CEFH (9-52)	1.3	CEFH (9-52)
6 to < 16 years old	Home (indoors)	15[c]	CEFH (9-52)	20.5	CEFH (9-3)
	School	6.1	CEFH (9-52)	-	
	Outdoors	1.6	CEFH (9-3)	2.2	CEFH (9-3)
	In car	1.3	CEFH (9-42)	1.3	CEFH (9-42)
16 to < 19 years old	Home (indoors)	14.2[c]	CEFH (9-41)	20.3	CEFH (9-3)
	School	6.5	CEFH (9-52)	-	
	Outdoors	1.9	CEFH (9-61)	2.3	CEFH (9-3)
	In car	1.4	CEFH (9-42)	1.4	CEFH (9-42)
19 to < 36 years old (male and female)	Home (indoors)	13.2[c]	EFH (15-6)	21.2[b]	EFH (15-6)
	Work	8	EFH (15-68)	-	
	Outdoors	1.5	EFH (15-176)	1.5	EFH (15-176)
	In car	1.3	EFH recommendation (p. 15-17)	1.3	EFH recommendation (p. 15-17)

-- Not applicable.
[a] CEFH = EPA, 2002; EFH = EPA, 1997
[b] Includes time spent in other indoor microenvironments.
[c] Calculated based on time remaining in day.

For the 2 to < 6 year old, on a typical non-school day, the average time spent at home is 18.9 hours/day (EPA, 2002). He or she spends approximately 3.1 hours/day outdoors and 1.3 hours/day traveling in a vehicle (EPA, 2002). The remaining time in the day (0.7 hours) is spent in a non-home indoor environment. This time was added to the time spent at home, and a value of 19.6 hours/day was used to represent the amount of time spent in the home/indoors.

Child 6 to < 16 Years Old

The activity patterns of this age group are similar to the younger child and the infant, with the added activity of attending school 180 days/year. During the school year, a child between the ages of 6 and 16 spends approximately 6 hours in school; which accounts for time spent both inside the school and outdoors during recess (EPA, 2002). Still, the majority of time for a child between the ages of 6 and 16 years is spent at home (approximately 15.5 hours/day; EPA, 2002). Approximately 2 hours/day are spent outdoors, and 1 hour/day is spent traveling in a vehicle (EPA, 2002). The number of hours spent at home on a typical school day was adjusted to 15.0 so that the total number of hours spent doing the various activities discussed above would equal 24 hours.

On a non-school day (i.e., weekend, summer), the activity pattern for the 6 to < 16 year old is slightly different. He or she spends an average of 2.2 hours outdoors and 1 hour in a vehicle (EPA, 2002). The amount of time spent at home is approximately 18.6 hours per day (USEPA, 2002). The remaining 2.2 hours of the day are spent in an indoor environment. This time was added to the time spent at home (2.2 hours + 18.6 hours) to determine the total amount of time spent indoors, 20.8 hours/day.

Teen 16 to < 19 Years Old

The time activity patterns of a teenager are similar to the child aged 6 to < 16 years for the major categories of school, home, outdoors and in-vehicle. On a typical school day, a teen spends 6.5 hours/day in school (EPA, 2002). Approximately 1.9 hours/day are spent outdoors, and 1.4 hours/day are spent traveling in a vehicle (EPA, 2002). The remainder of time is spent at home, 14.2 hours/day.

During the non-school portion of the year, a teenager spends approximately 2.3 hours/day outdoors, and 1.4 hours/day traveling in a vehicle. Approximately 17.9 hours/day are spent in the home, and the remaining hours in a day (2.4 hours) are spent in an indoor environment. The time in an indoor environment was added to the time spent at home to develop an in-home/indoor exposure time of 20.3 hours per day.

Adult Female 19 to < 36 Years Old

The exposure times for male and female prospective parents (i.e., adults) for the four major exposure categories are similar. Adults spend the majority of their day at home (13.2 hours/day; EPA, 1997). If employed, approximately 8 hours/day are spent at work. Adults spend approximately 1.5 hours/day outdoors and 1.3 hours/day in a vehicle (EPA, 1997). On a non-work day, the number of hours spent at work (8 hours) will be spent in some other indoor environment; thus this time was added to the in-home time to develop an in-home/indoor exposure time of 21.2 hours per day.

Physiological Parameters

Like activity factors, most physiological parameters are unique to each age group evaluated. In terms of estimating body dose, the physiological parameters to be considered include: benzene absorption, body weight, skin surface area, ingestion rates for food and water and inhalation rates. Each of these is further described below.

Absorption Factors

Inhaled benzene is not completely absorbed by the lungs. Therefore, the calculation of benzene dose via inhalation must incorporate an inhalation absorption factor (ABS). In controlled laboratory experiments, a significant amount of both human and animal data indicate that approximately 50% of inhaled benzene is absorbed into the body via the inhalation route of exposure (Iron and Gross, 2002, USEPA, 2001; ACGIH, 1998; ATSDR, 1997). Thus, 50% was used as the inhalation ABS for all age groups.

Studies indicate that oral absorption of benzene is nearly complete (i.e., ABS = 100%) and therefore use of an ABS was unnecessary for this route of exposure (EPA, 1999; IRIS, 2001).

Body Weight

Body weights for children up to 18 years old were obtained from CEFH for the various age groups, and represent an average of the mean male and female children body weights. Mean body weights for 18 to 35 year old males and females were obtained from EFH. Body weights are summarized on Table A-1.3.

Table A-1.3: Body Weight

Age Range	(kg)
< 1 year	7.2
1 to < 2 years	11.4
2 to < 6 years	16.1
6 to < 16 years	41.1
16 to < 19 years	66.8
19 to < 36 years	
female	62.4
male	76.3

Inhalation Rate

The inhalation rates used in the assessment are based on level of activity and the age of the individual. The value used was the mean value for the range reported in the EFH. The age specific inhalation rates for children under 18 are based on the average of the male and female inhalation rates. The adult rates for males and females are separate. With the exception of the small engine scenario, the inhalation rates were those predicted for “long term” activity (EPA, 1997). These inhalation rates are presented on Table A-1.4 below. The refueling scenario includes an age group of 16 to 18 year olds. Long term inhalation rates were used, except for refueling scenarios where the inhalation values for short term exposures were used.

Table A-1.4: Inhalation Rates for All Scenarios Except the Refueling Scenario

Age Range	(m^3/hr)
< 1 year	0.19
1 to < 2 years	0.28
2 to < 6 years	0.33
6 to < 16 years	0.52
16 to < 19 years	0.60
19 to < 36 years	
female	0.47
male	0.63

Food and Tapwater Ingestion Rates

Dietary exposures to benzene were evaluated using residue data reported in the FDA's Total Diet Study (FDA, 1999). This study involved monitoring of volatile organic compounds in prepared foods collected as part of the annual market basket surveys. Consumption rates of tapwater and the benzene containing foods in the FDA market basket and similar foods were evaluated using LifeLine™ Version 2.0.

Food and tapwater ingestion rates vary with season and age (LifeLine, 2002). In the LifeLine software, data on the consumption of tapwater and specific foods is taken from the 1994-6 and 1998 Continuing Survey of Food Intakes by Individuals (CSFII 1994-96, 1998). CSFII 1994-96, 1998 surveys were conducted by the Agricultural Research Service (ARS) of the U.S. Department of Agriculture (see http://www.barc.usda.gov/bhnrc/foodsurvey/pdf/Facts1.pdf; accessed 7/1/03.).

Appendix A-2
Indoor Air Trends Analysis: Derivation of Indoor Air Normalization Factor

A normalization factor was derived to adjust historical indoor air benzene concentrations in homes with attached garages to account for current day fleet improvements and benzene content in reformulated gasoline. Specifically, EPA's Mobile 6.2 model (released February 2004 and available at www.epa.gov.otaq/m6.htm) was used to model the emission rate change of benzene from vehicles due to improved evaporative emission controls and reduced benzene content in gasoline. The change in emission rates between the study year and 2003 was then used to calculate the normalization factor.

The Adgate et al 2004 study was used as the basis for the normalization factor. This study was conducted during the summer of 1997 in Minnesota. The Mobile6.2 model was run to produce "summer" emissions estimated for the fleet of vehicles in operation in 1997 and 2003. In order to characterize the relative effects of changes in fuel properties versus changes in fleet characteristics on benzene emissions over time, three runs of MOBILE6.2 were generated as follows:

Run 1 = 1997 fleet characteristics and 1997 fuel parameter values
Run 2 = 1997 fleet characteristics and 2003 fuel parameter values
Run 3 = 2003 fleet year characteristics and 2003 fuel parameter values.

National average default model parameters (age, vehicle miles traveled distribution by model year, and technology characteristics) were used to characterize the Minnesota fleet. Estimates of daily minimum and maximum summer average temperatures in Minnesota were drawn from National Weather service data. These data are summarized below.

Table A-2.1:
July Average Daily Temperature

Min Temp (^oF)	69.0
Max Temp (^oF)	85.0

These temperature inputs were held constant for MOBILE6.2 model runs in both 1997 and 2003.

The fuel parameter values were drawn from summer gasoline surveys performed by the Alliance of Automobile Manufactures for Minnesota. The survey indicated that in both 1997 and 2003, 'regular' grade gasoline had the largest percent of the market share. As such, average reported fuel parameter values for regular gasoline were used in each case. Key fuel property values used in the MOBILE6.2 runs are shown below in Tables A-2.2 and A-2.3:

Table A-2.2: Minnesota Summer 1997 Gasoline Properties

	Premium	Mid-Grade	Regular	Weighted Average
RVP	9.6	9.5	9.7	9.7
E200	52.9	58.7	69.5	66.9
E300	78	76.3	76.7	76.8
T50	194	182	160	165.3
T90	352	360	358	357.7
Arom	16.1	26.5	27.7	26.6
Olef	10.6	10.6	8.6	9.0
Bz	0.9	1.7	1.7	1.4
EtOH	9.5	9.5	9.3	9.3
S	60	90	60	63.5

Table A-2.3: Minnesota Summer 2003 Gasoline Properties

	Premium	Mid-Grade	Regular	Weighted Average
RVP	9.6	9.7	9.8	9.8
E200	42.8	51.4	57.5	55.9
E300	84.8	82.9	83.6	83.6
Arom	22.8	23.4	24.9	24.6
Olef	6.1	6.1	6.2	6.2
Bz	1	1.2	1.3	1.2
EtOH	7.3	9.6	9.5	9.4
S	50	80	80	78.0

It is important to note that these MOBILE6.2 runs incorporate the effects of changes in federal emissions standards on the vehicle fleet in operation. The effects of local and/or state vehicle-related emissions controls (such as vehicle Inspection/Maintenance programs and Stage II vapor recovery) are not included in the modeling runs.

The model was run to include light duty gasoline vehicles (LDGV) and light duty gasoline trucks (LDGT). The emissions rates modeled based on the three runs are presented below.

Table A-2.4: MOBILE 6.2 Runs for the Adgate et al (2004) study

				Weighted Average of LDGV and LDGT emission rates (mg/mi)		
Run No.	Fleet Year	H/L Temps (^{o}F)	Fuel benzene %	Hot Soak	Diurnal	Resting
1	1997	85/69	1.4	2.619	0.387	1.535
2	1997	85/69	1.2	2.181	0.318	1.249
3	2003	85/69	1.2	1.944	0.241	0.975

Using the benzene emission rates shown above, both historical and projected emission factors were calculated by summing the average emission rates across each type (i.e. hot soak, diurnal and resting) for each run. These emission factors are shown below.

Table A-2.5: Evaporative Emission Factors for Each MOBILE 6.2 Run

Run No.	Emission Rate mg/mi	Description
1	4.541	Historical - emission factor for study year (H)
2	3.748	Projection - emission factor after benzene content decrease (i.e hold fleet year constant)
3	3.160	Projection - emission factor for combined effect of benzene content decrease and fleet improvements
NA	3.953	Calculation - inferred emission factor after fleet improvements (i.e hold bz content constant)

The changes in emission factors were then calculated to determine the change attributable to fuel benzene content decrease and that which is attributable to fleet emissions improvement. The changes in emission factors are shown below.

Table A-2.6: Changes in Emission Factors

	Δ Emission Rate (mg/mi)	% of total reduction
Emission factor change attributable to bz ct decrease (dEb)	-0.7932151	57%
Emission factor change attributable to fleet improvment (dEf)	-0.588351962	43%
Total change in emission factor (dEt)	-1.381567062	100%

The indoor air normalization factor (NF) was derived by calculating a garage emissions factor as the ratio of the garage emissions in the study year to the projected 2003 year emissions. To do that, it was assumed that the fraction of emissions from the cars varied from 0 to 1, such that when only cars were parked in the garage, all of the benzene emissions would be due to the cars (100%). When both cars and small engine equipment were in the garage, it was assumed that the cars contributed 50% of the emissions and when only small engine equipment was in the garage, the cars contributed 0% of the emissions. The small engine equipment scenario allowed for the evaluation of the change in emission rates due solely to decreased benzene content in the fuel. The change in garage emission factors was calculated as follows:

$$dGEF = CF \times dEt + (1-CF) \times dEb$$

where;

dGEF = change in garage emission factor (mg/mi)
CF = car factor (varies from 0 to 1)
dEt = total change in emissions factor (mg/mi)
dEb = emission factor attributable to benzene content decrease

The garage factor was then calculated as:

$$GF = \frac{H}{H + dGEF}$$

Where;

GF = garage factor
H = Historical emissions factor (using 1997 fleet and fuel properties) (mg/mi)
dGEF = change in garage emission factor (mg/mi)

The garage factors are presented on the table below.

Table A-2.7: Derivation of Garage Factor

Garage Factor (i.e. ratio of garage emissions in study year to projected 2003 emissions)	Garage - cars only	Garage - mix of cars and small engines.	Garage - small engines only
Fraction of garage emissions from cars (CF): varies from 0 to 1	1	0.5	0
Change in garage emission factor (mg/mi): dGEF = CF*dEt+(1-CF)*dEb	-1.381567063	-1.087391082	-0.7932151
Garage factor: GF = H/(H + dGEF)	1.44	1.31	1.21

The indoor air NF was then calculated using information from the Adgate et al. (2004) study and the following equation:

$$NF = \frac{Sb}{Bb + Ib / GF}$$

Where;

NF = Normalization Factor
Sb = Study benzene concentration in homes <u>with</u> attached garages ($\mu g/m^3$)
Bb = Baseline benzene concentration in homes <u>without</u> attached garages ($\mu g/m^3$)
Ib= Incremental benzene concentration due to garage: Sb – Bb ($\mu g/m^3$)
GF = Garage Factor

The NFs are presented in Table A-2.8 below.

Table A-2.8: Derivation of Indoor Air Normalization Factor

Indoor Air Normalization Factor (i.e. ratio of study year to projected indoor air concentrations)	**Garage - cars only**	**Garage - mix of cars and sm eng.**	**Garage - small engines only**
Study benzene concentration in homes **with** attached garages (ug/m^3) (Sb)	11.79	15.66	6.93
Baseline benzene concentration in homes **without** attached garages (µg/m^3) (Bb)	4.25	4.25	4.25
Incremental benzene concentration due to garage (ug/m^3): Ib = Sb - Bb	7.54	11.41	2.68
Adjustment factor for indoor air: IAF = Sb / (Bb + Ib/GF)	1.24	1.21	1.07

The historical indoor air values can therefore be normalized to current conditions by dividing the reported indoor air concentrations by the NF. When this is done, the indoor air concentrations of benzene reported by Adgate et al, would range from 6.5 µg/m^3 to 12.9 µg/m^3. Based on this analysis, one would expect to observe a 7 to 19% reduction in indoor benzene concentrations due to changes in vehicle emission controls and benzene fuel content.

APPENDIX A-3

Exposure concentrations for food were derived from FDA's Total Diet Survey (FDA, 2003). In the Total Diet Survey, FDA personnel purchase foods from supermarkets or grocery stores four times per year from each of the four U.S. geographic regions. Each collection, referred to as a Market Basket, is a composite of similar foods purchased in three cities in each of the four regions (12 cities). Foods are prepared for consumption (i.e., as they will be eaten) and analyzed.

One Market Basket per quarter from the third quarter of 1995 through the first quarter of 1999 was available for analysis (totaling 14 applicable Market Baskets). The analytical results for benzene in the various foods are presented on Table A-3.1 and range up to 190 ppb. The FDA only presents the number of times benzene was detected in a food item (N) and the mean benzene concentration for that food item for those times it was detected (detect mean) and the maximum and minimum measured values.

Table A-3.1: Reported Levels of Benzene in Selected Foods as Measured by 14 FDA Market Basket Surveys

Samples with Detect Levels (based on 14 samples per food item)									
Food Item	**Detects**	**Mean**	**Min**	**Max**	**Food Item**	**Detects**	**Mean**	**Min**	**Max**
coleslaw with dressing	**14**	**0.0341**	**0.011**	**0.102**	**radish, raw**	**1**	**0.023**	**0.023**	**0.023**
banana, raw	13	0.0752	0.016	0.136	jelly, any flavor	1	0.023	0.023	0.023
beef chuck roast, baked	10	0.0428	0.016	0.099	popcorn, popped in oil	1	0.022	0.022	0.022
low-calorie cola carbonated	10	0.0307	0.014	0.055	cornbread, homemade	1	0.022	0.022	0.022
ground beef, pan-cooked	9	0.0338	0.01	0.19	tomato sauce, bottled	1	0.022	0.022	0.022
hamburger, fast-food	9	0.0219	0.011	0.047	fish sticks, frozen, heated	1	0.021	0.021	0.021
avocado, raw	7	0.0196	0.01	0.034	rye bread	1	0.021	0.021	0.021
cheeseburger, fast-food	6	0.03	0.01	0.054	Swiss cheese	1	0.02	0.02	0.02
raisins, dried	4	0.0358	0.014	0.097	grapefruit juice, from conc.	1	0.019	0.019	0.019
meatloaf, homemade	4	0.0285	0.01	0.056	sauerkraut, canned	1	0.019	0.019	0.019
bologna, sliced	4	0.022	0.007	0.05	lasagna with meat	1	0.019	0.019	0.019
tuna, canned in oil	4	0.0108	0.005	0.013	sandwich cookies cream fill	1	0.019	0.019	0.019
fruit-flavored cereal	3	0.04	0.011	0.088	corn grits, regular, cooked	1	0.018	0.018	0.018
olive or safflower oil	3	0.023	0.011	0.046	pear, raw	1	0.018	0.018	0.018
salami, sliced	3	0.0183	0.018	0.019	sweet cherries, raw	1	0.016	0.016	0.016
chicken nuggets, fast-food	2	0.0575	0.015	0.1	apple juice, bottled	1	0.016	0.016	0.016
fruit flavor sherbet	2	0.0415	0.022	0.061	beef, strained/junior	1	0.016	0.016	0.016
pork roast, baked	2	0.039	0.03	0.048	summer squash, boiled	1	0.014	0.014	0.014
eggs, scrambled	2	0.028	0.016	0.04	white potato, baked, skin	1	0.014	0.014	0.014
white bread	2	0.0245	0.024	0.025	chicken, fried fast-food	1	0.014	0.014	0.014
apple, red, raw	2	0.02	0.012	0.028	cantaloupe, raw	1	0.013	0.013	0.013
corn chips	2	0.019	0.013	0.025	plums, raw	1	0.013	0.013	0.013
pepperoni pizza, carry-out	2	0.019	0.01	0.028	cucumber, raw	1	0.013	0.013	0.013
sweet cucumber pickles	2	0.0185	0.011	0.026	clam chowder, canned	1	0.013	0.013	0.013
apple juice, strained	2	0.018	0.012	0.024	fruit-flavored carbonated	1	0.013	0.013	0.013
spaghetti and meatballs	2	0.0175	0.013	0.022	corn flakes	1	0.012	0.012	0.012
butter, regular (salted)	2	0.017	0.012	0.022	turkey and rice, strained/junior	1	0.012	0.012	0.012

pork bacon, pan-cooked	2	0.014	0.011	0.017	suckers, any flavor	1	0.012	0.012	0.012
peanut butter, smooth	2	0.011	0.003	0.019	pancake from mix	1	0.011	0.011	0.011
fruit drink, from powder	1	0.095	0.095	0.095	prune juice, bottled	1	0.011	0.011	0.011
chicken breast, roasted	1	0.036	0.036	0.036	potato chips	1	0.011	0.011	0.011
turkey breast, roasted	1	0.034	0.034	0.034	sweet roll or Danish	1	0.011	0.011	0.011
margarine, stick (salted)	1	0.03	0.03	0.03	frankfurters, beef, boiled	1	0.01	0.01	0.01
mayonnaise	1	0.028	0.028	0.028	grapes, seedless, raw	1	0.01	0.01	0.01
peach, raw	1	0.027	0.027	0.027	French fries, frozen, heated	1	0.01	0.01	0.01
beef stroganoff	1	0.026	0.026	0.026	cream cheese	1	0.01	0.01	0.01
brownies, commercial	1	0.025	0.025	0.025	tomato, stewed, canned	1	0.01	0.01	0.01
tomato, red, raw	1	0.024	0.024	0.024	chocolate snack cake	1	0.01	0.01	0.01
split peas with veg ham	1	0.024	0.024	0.024	French salad dressing	1	0.01	0.01	0.01

The sources of the benzene residues are unclear, but are not likely to be a function of the commercial use of the chemical. Benzene is not used in food processing and is not approved as a direct or indirect food additive. McNeal et al. (1993) speculated that the added benzoates might be reduced by ascorbates present in certain foods to form benzene. A second source of exposure could be the concentration of benzene in fatty foods by absorption from air. This may explain the levels reported in oils and fatty materials such as cheese and salad dressings. Finally, benzene was consistently found in a variety of cooked meats. Because of its volatility, solubility and the ability of mammals to metabolize benzene, bioaccumulation in animals is not believed to occur. This suggests that cooking processes may cause the formation of benzene in meat.

The residue data from market basket surveys were entered into LifeLine™ Version 2.0 in accordance with the protocol described below. Foods with no detectable levels of benzene in the 14 studies were assumed to have no benzene residues. Non-detect samples for foods where benzene was detected in at least one study were assigned a level of ½ the detection limit, or 0.5 ppb. The residues are entered as a range of 14 values. The 14 values are estimated based on the number of detects, and the minimum, maximum, and mean of the reported concentration. These inputs reflect a single sample of a composite of each food prepared from samples collected from three cities per region. Since these are composites, they are likely to underestimate the actual variance in residues in the individual food items.

Certain of the foods identified in Table A-3.1 were assumed to reflect levels in the raw agricultural commodities (RACs) or the food, as it is typically prepared (e.g. cooked meat). Data on commodities, such as oils or cooked meats, which are used as ingredients in other foods (canned stews, spaghetti sauces) were used to predict the range in those products taking into account the fraction of the final product represented by the commodities. These RACs were entered in the Lifeline “Food Residue Translator” module as identified on Table A-3.2.

Table A-3.2: Data Entered into Lifeline as Raw Agricultural Commodities

FDA Raw Data – Total Diet Study	Raw Agricultural Commodity
Banana, raw	Banana
Raisins, dried	Raisins
Avocado, raw	Avocado
Peach, raw	Peach
Apple, red, raw	Apple (not juice)
Apple juice, strained and apple juice, bottled	Apple juice
Tomato, red, raw	Tomato
Radish, raw	Radish
Pear, raw	Pear
Sweet cherries, raw	Cherries
Summer squash, boiled	Squash
Grapefruit juice, from conc.	Grapefruit
Sauerkraut, canned	Cabbage;
	Cabbage, Chinese, napa
	Cabbage, Chinese, mustard
	Cabbage, Chinese, bok choy
Eggs, scrambled	Eggs
Olive or safflower oil	All oils
Butter	Milk, fat
Cantaloupe, raw	Cantaloupe
Plums, raw	Plums
Cucumber, raw	Cucumber
Prune juice, bottled	Prunes
Grapes, seedless, raw	Grapes
Peanut, butter	Peanut, butter
Beef chuck roast, baked	Beef (not baby)
Beef, strained/junior	Beef, meat- babyfood
	Beef, meat byproducts- babyfood
	Beef, fat- babyfood

A number of prepared foods in Table A-3.1 could not be entered as RACs and were manually entered into the Food Residue Translator output file. Due to the large number of foods (i.e. greater than 8,000) identified in the Food Residue Translator output file as containing trace benzene based on the ingredient file and RAC benzene content, data was manually entered for only those foods that had an average residue level 10 times higher than the assumed non-detect level and were not otherwise entered as a RACs. The prepared foods data meeting the criteria for inclusion are identified in Table A-3.3. The residues in foods were assumed to apply for the specific foods analyzed and for similar foods that were not sampled in the survey (e.g. data on hamburgers with and without cheese). Exclusion of the data for foods with average residue levels less than 5 ppb is not expected to appreciably change the average dose estimate because these data are simply a refinement to the residue levels that the Food Residue Translator calculates based on the raw commodity inputs.

Table A-3.3: Data Entered into Lifeline as Prepared Foods[a]

TDS Food Item No.	Food Item	Average (mg/kg)
111	Coleslaw with dressing	0.034
13	Ground beef, pan-cooked	0.022
147	Hamburger, fast-food	0.014
275	Cheeseburger, fast-food	0.013
72	Fruit-flavored cereal	0.009
241	Chicken nuggets, fast-food	0.009
148	Meatloaf, homemade	0.009
193	Fruit drink, from powder	0.007
29	Bologna, sliced	0.007
287	Fruit flavor sherbet	0.006

[a] Low calorie cola, carbonated (average of 0.022 mg/kg) could not be entered into Lifeline because the CSFII 1994-96, 1998 translation file does not contain ingredient information for this food item.

Appendix A-4

Public water systems are used in most urban areas. The USEPA Safe Drinking Water Act (SDWA) requires that public water suppliers sample and verify that benzene levels are less than the maximum contaminant level (MCL) of 5 µg/L. In November 1999, the USEPA published a report containing data reflective of the occurrence of contaminants in public water systems that are regulated under the SDWA (USEPA, 1999). The database compiled numerous state monitoring databases into the National Drinking Water Contaminant Occurrence Database (NCOD). The data comes from nearly 26,000 public water systems and includes 10.7 million analytical results. In most cases, the data represents finished drinking water after treatment, although some sampling points may be at various places within a water system.

The NCOD data was handled in the following manner to determine drinking water exposure point concentrations. First, data collected prior to 1987 was eliminated because treatment methods have since been modernized, therefore any significant benzene concentrations in drinking water supplies prior to 1987 have most likely been reduced through treatment. Second, data reported as “not detected” at a concentration of 0 were eliminated; this is information that is inaccurate and cannot be quantitatively analyzed. Third, the maximum benzene concentration of 43,213 µg/L was determined to be an outlier and eliminated, as the second highest benzene concentration was 1,100 µg/L. Fourth, if a public water supply system at one time detected benzene at a concentration over the MCL of 5 µg/L, only the latest sample results from that system was utilized. Thus, the database reflects any improvements that public water supply systems may have implemented after identifying a potential problem. Therefore the maximum concentration of 1,100 µg/L was eliminated and the most recent maximum identified. The resulting database included 40,880 benzene drinking water data records from 24 states. The following table identifies the summary statistics for benzene in public drinking water based on the NCOD database. Samples collected between May 1987 and December 2000 were included in this analysis.

Table A-4.1: Public Water Supply Summary Statistics (May 1987 through December 2000)[a]

Statistic	Public Water Supply Concentration (N= 40,880) (µg/L)
Maximum	355
Mean	0.27
Median	0.25
95th Percentile (by rank)	0.5

[a] The mean, median, and 95th percentile values were calculated using half the detection limit for non-detects.

Determination of Exposure Concentrations - Non-Public Water Supply

Non-public drinking water is mainly utilized in rural areas. Approximately 10%, or 16 million households, obtain their drinking water from non-public supplies. This includes approximately 15-million households obtaining their drinking water as groundwater from private drilled or dug wells, and approximately 1 million households obtaining their drinking water from untreated surface water sources (such as springs, lakes, and rivers).

Because monitoring of non-public water supplies is not required by federal regulations, there is no national database containing this data.

However, starting in 1991, the U.S. Geological Survey (USGS) began its National Water Quality Assessment (NAWQA) program, which collects water quality data from various study basins across the United States. Although this water quality data does not necessarily represent drinking water, it does present a generalization of water quality for ambient groundwater and surface water that could be used as non-public drinking water sources. Benzene data from the NAWQA database was prepared for analysis in this exposure assessment and treated in the manner described below. Samples collected between July 1986 and September 2000 were included in this analysis.

The data was first reduced so as to most likely represent water that may be used for domestic consumption. For example, all groundwater and surface water sources in urban areas were eliminated, as people living in these areas typically obtain their drinking water from public supply systems.

The table below identifies the levels of benzene in non-public groundwater supplies.

Table A-4.2: Summary Statistics for Benzene Analyses from Ambient Groundwater and Surface Water (July 1986 through September 2000)[a]

Statistic	Groundwater (N = 3,759) (µg/L)	Surface Water (N = 586) (µg/L)	All (N = 4,345) (µg/L)
Maximum Detect	100	24	100
Mean	0.32	0.48	0.34
Median	0.05	0.03	0.05
95th Percentile (by rank)	0.10	0.20	0.10

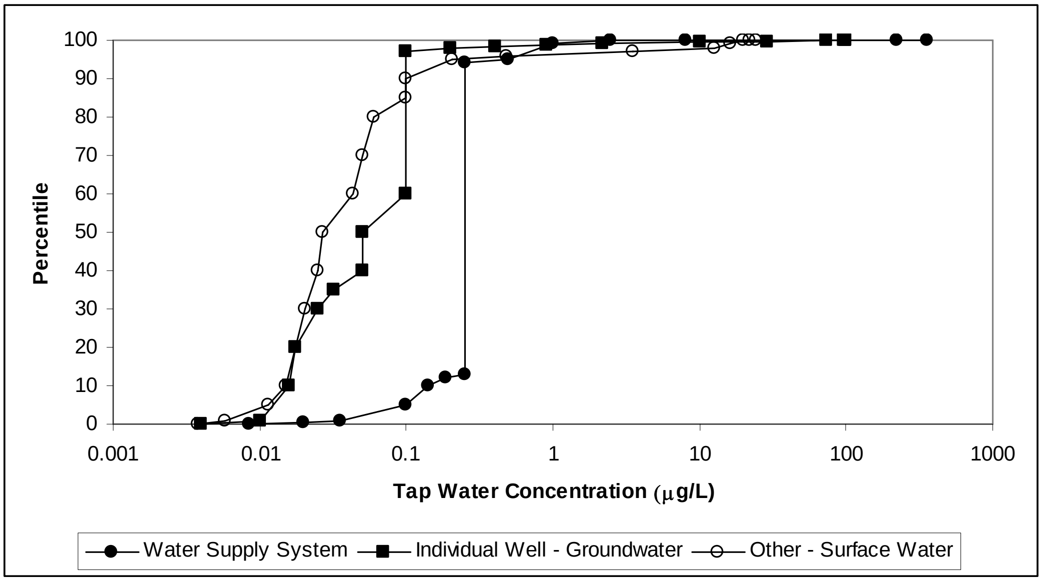
[a] The mean, median, and 95th percentile values were calculated using half the detection limit for non-detects.

LifeLine™ Version 2.0 requires that distributions of residues are entered for different water types. The following assumptions were used in the assessment:

- An empirical cumulative distribution function based on the modified NCOD data described above was input into LifeLine™ as representative of a typical water distribution system;
- An empirical cumulative distribution function based on the modified USGS groundwater data described above was input into LifeLine™ as representative of a residential groundwater well; and
- An empirical cumulative distribution function based on the modified USGS surface water data described above was input into LifeLine™ for the ‘other’ tap water sources input category.

These input distributions are presented graphically Figure A-4.1

Figure A-4.1: Empirical Distributions for Benzene levels in Tap Water



LifeLine™ Version 2.0 uses the data on concentrations to determine the oral exposure using the tap water intake rates measured in he 1994-6 and 1998 Continuing Survey of Food Intakes by Individuals (CSFII 1994-96, 1998). Because benzene is lipophylic, exposure to benzene during showering can result in exposure by dermal absorption. In addition, benzene can volatilize during showering and result in inhalation exposures. Dermal exposures to benzene are predicted based the individual's surface area and the duration of the shower along with the concentration of benzene in the water. The inhalation exposure to benzene during showering was quantified using the Andelman shower volatilization model. The software model also assumes that no ventilation occurs in a well-mixed bathroom (LifeLine, 2002).