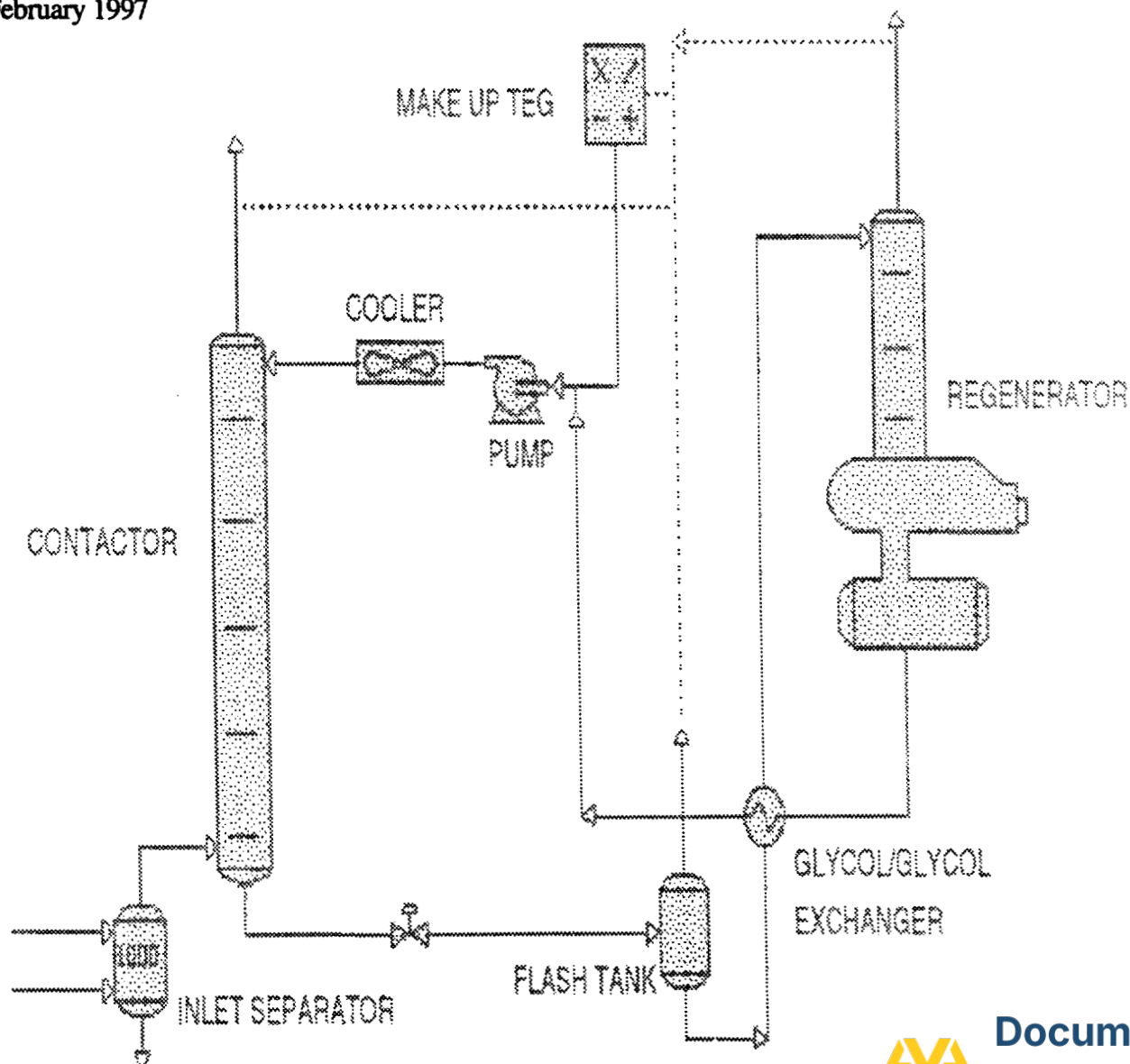


A METHODOLOGY FOR ESTIMATING INCREMENTAL BENZENE EXPOSURES AND RISKS ASSOCIATED WITH GLYCOL DEHYDRATORS

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EXECUTIVE SUMMARY

The U.S. Environmental Protection Agency (EPA) is currently evaluating potential applicability criteria for glycol dehydrator air emission controls. To assist this evaluation, the American Petroleum Institute (API) commissioned TRJ Environmental, Inc. (TRJ) to develop a methodology to estimate benzene exposures and associated risks under representative emission conditions.

The EPA assisted in this research effort by performing a series of dispersion model runs using emission parameters suggested by API and meteorological data representing 348 weather stations in the United States. TRJ performed a series of statistical analyses on the results of these runs which indicated that the distribution of ambient (outdoor) benzene concentrations produced by an operating glycol dehydrator unit could be estimated as a function of benzene emission rate, vent velocity, vent diameter, land use (urban or rural), and source-to-receptor distance. Equations based on the statistical analyses were incorporated into a spreadsheet model capable of plotting "outdoor concentration vs. distance" for specified emission scenarios and concentration percentiles.

In addition to the spreadsheet model, a Monte Carlo routine for estimating lifetime cancer risk as a function of the estimated benzene concentration distribution was also developed. The entire process (spreadsheet program and Monte Carlo routine) was incorporated into a PC-based model called SimRisk. SimRisk generates a lifetime risk distribution that accounts for four factors that affect benzene exposure (residential occupancy period, time spent indoors and outdoors at the home location, indoor/outdoor ratio for benzene concentration, and breathing rate). The lifetime risk distribution is specific to benzene emission rate, vent velocity, vent diameter, land use (urban or rural), and source-to-receptor distance.

A simplified version of SimRisk was developed that can be used to estimate the 50th and 95th percentile values of lifetime risk solely as a function of benzene emission rate, source-to-receptor distance, and land use. This simplified risk model could be incorporated into control applicability criteria for glycol dehydrator vent emissions. To determine the applicability of controls to a specific unit, the analyst would use a simple graph or lookup table obtained from the model to determine the minimum source-to-residence distance associated with a specified lifetime cancer risk. If the actual distance from the glycol dehydrator unit to the nearest residence exceeds this minimum distance, the analyst could assume that the glycol dehydrator unit requires no further emission controls. If, however, the actual distance from the glycol dehydrator unit to the nearest residence is equal to or less than this minimum distance, then the source may be subject to additional controls.

This model is applicable only to glycol dehydrators operating under a specific set of conditions and should not be used outside of the following ranges:

30 meters $\leq$ distance $\leq$ meters 2000 meters

2 inches $\leq$ vent diameter $\leq$ 4 inches

1 ton/year $\leq$ emission rate $\leq$ 7 tons/year

3.2 feet/sec $\leq$ vent velocity $\leq$ 20.3 feet/sec.

Section 1

INTRODUCTION

The U.S. Environmental Protection Agency (EPA) is currently evaluating potential applicability criteria for glycol dehydrator air emission controls. To assist this evaluation, the American Petroleum Institute (API) commissioned TRJ Environmental to develop a methodology to estimate benzene exposures and associated risks under representative emission conditions.

This report is divided into seven sections. Section 2 describes preliminary risk assessment analyses performed by EPA prior to the startup of this project. The analyses included dispersion model runs using 348 meteorological stations and the application of Monte Carlo modeling techniques to the dispersion model results. Section 2 also summarizes a series of exploratory analyses in which the SCREEN3 dispersion model was applied to eight emission scenarios identified as representative of typical operating conditions. The model produced an estimate of the maximum benzene concentration at each of 10 distances considered in the earlier EPA dispersion model runs.

Section 3 presents the results of a special analysis in which Version 2 of the Industrial Source Complex dispersion model (ISC2) was applied to 45 meteorological stations selected by API as representative of areas where glycol dehydrators were likely to be located. After completion of the special analysis, API and EPA jointly developed a set of 24 emission scenarios to be used in subsequent dispersion modeling runs. Section 4 describes the 24 emission scenarios and presents the results of applying the ISC2 model to 348 meteorological stations under each scenario. Researchers statistically analyzed these results and developed a spreadsheet model for estimating outdoor benzene concentrations as a function of

source-to-receptor distance and emission scenario. Section 4 describes the model and provides sample outputs.

Section 5 describes development of a PC-based model incorporating the spreadsheet and a Monte Carlo routine combining the outdoor benzene concentrations with randomly generated exposure factors to determine lifetime risk distributions. Section 6 presents a simplified method for estimating the 50th and 95th percentiles of these lifetime risk distributions. Section 7 discusses the limitations of the proposed modeling approach and provides recommendations for further research. Section 7 also describes a method by which model estimates can be used to determine whether or not a specific glycol dehydrator should be subject to controls for reducing benzene emissions.

Section 2

SCREENING ANALYSIS

The work in this report extends research conducted in 1995 by the Risk and Exposure Assessment Group (REAG) of EPA (Appendix A). Briefly, REAG acquired meteorological data for the 348 U.S. sites listed in Appendix B from the National Climatic Center in Asheville, North Carolina. The sites included all U.S. meteorological stations for which data were available at the time of the REAG analysis. REAG applied the ISC2-LT (long-term) dispersion model to each of the 348 sites and produced estimates of ambient (outdoor) benzene concentration at each of 160 points on a receptor grid surrounding a hypothetical glycol dehydrator unit. The receptor grid was laid out in a polar pattern with ten concentric rings at distances of 10, 20, 30, 50, 100, 200, 300, 500, 1000, and 2000 meters. These rings were intercepted by 16 equally spaced radial arms extending from the emission source to produce the 160 receptor points. The emission scenarios were defined according to the assumptions listed in Table A-1.

REAG applied Monte Carlo modeling techniques to the dispersion model estimates to determine lifetime cancer risk probabilities for people residing at various distances from the hypothetical glycol dehydrator unit. The modeling approach explicitly accounted for variability in breathing rate, time spent away from home, residential occupancy period, and indoor/outdoor ratio. REAG provided API with an informal summary of the input assumptions for the Monte Carlo analysis and examples of the model's output (personal communication, Mike Dusetzina, REAG, March 7, 1996). API reviewed these materials and directed TRJ to perform a series of screening analyses to determine the possible effects of varying the modeling assumptions concerning benzene emission rates, vent flow rates, and land use characteristics.

EPA's SCREEN3 dispersion model was applied to eight emission scenarios identified by API as representative of typical operating conditions. The model produced an

estimate of the maximum benzene concentration at each of 10 distances considered in the earlier EPA dispersion model runs. Table 2-1 lists the assumptions common to all runs. Table 2-2 presents the conditions specific to each run and lists the estimated concentrations at six selected distances.

Table 2-1. American Petroleum Institute specifications for SCREEN3.

Model specification	Value
Source type	Point
Stack height	10 feet
Stack diameter	2 inches
Stack gas exit temperature	225 degrees F.
Air temperature	293 degrees K. (default)
Receptor height	2 meters
Building downwash calculation?	No
Terrain	Flat
Fumigation calculation?	No
Modeled meteorological conditions	All stabilities and wind speeds

The results in Table 2-2 are grouped in pairs by benzene, toluene, ethylbenzene, and xylene (BTEX) concentration in natural gas and land use. Within each pair, the runs differ with respect to benzene emission rate and total gas exit velocity from the vent. When the values associated with a benzene emission rate of 7 tons/year are divided by the paired values associated with the 1 ton/year runs, the resulting ratios increase with distance. For example, the ratio under the assumption of BTEX concentration = 550 ppmv in the natural gas and land use = urban is 4.90 for the 10 m distance and 6.94 for the 2 km distance. These results suggest that the dispersion model estimates for maximum benzene concentration are not proportional to emission rate when distances are relatively small.

The results listed in Table 2-2 also show that dispersion model estimates for rural locations tend to be higher over longer distances than corresponding estimates for urban locations. Consider, for example, the results associated with BTEX concentration = 550 ppmv in natural gas and benzene emission rate = 7 tons/year. Under these conditions, the maximum concentrations at 100 m and 500 m are 493 and 40.84 $\mu\text{g}/\text{m}^3$, respectively, for urban locations and 1204 and 289.5 $\mu\text{g}/\text{m}^3$, respectively, for rural locations. This example demonstrates a projected 12-fold concentration decrease between 100 m and 500 m for urban locations with only a 4-fold decrease between 100 m and 500 m for rural locations. This difference in the "concentration vs. distance" patterns for urban and rural sites can be explained by the higher turbulence caused by the urban "heat island" effect. This turbulence tends to disperse airborne pollutants closer to the emission point, causing a more rapid decrease in concentration with distance.

In summary, results of the screening analyses suggest that (1) dispersion model estimates of maximum outdoor benzene concentration are not proportional to emission rate when distances are relatively small and (2) the dispersion model concentration estimates for rural locations tend to be higher over longer distances than corresponding estimates for urban locations.

Table 2-2. Benzene concentration estimates ($\mu\text{g}/\text{m}^3$) from dispersion model runs which applied SCREEN3 to generic glycol reboiler vents.^a

BTEX concentration ^b , ppmv	Land use	Benzene emission rate, tons/yr	Exit velocity ^c , ft/sec	Distance, m					
				10	100	200	500	1000	2000
550	Urban	1	1.59	1573	88.45	28.76	5.98	1.95	0.70
		7	10.83	7715	493	186.5	40.84	13.45	4.86
	Rural	1	1.59	1957	204.5	140.3	49.72	18.06	6.49
		7	10.83	5644	1204	547.0	289.5	117.1	43.71
250	Urban	1	2.93	1490	84.14	28.33	5.96	1.95	0.70
		7	20.27	5209	435.4	179.4	40.49	13.41	4.85
	Rural	1	2.93	1589	183.3	122.6	47.78	17.79	6.45
		7	20.27	3124	1129	423.7	262.1	112.7	43.00

^aStack parameters common to all runs can be found in Table 2-1.

^bBTEX concentration (ppmv) of inlet natural gas to glycol dehydrator with an operating pressure of 855 psig, operating temperature of 100 degrees F, and glycol circulation rate of 3 gallons TEG per pound of water removed.

^cExit velocity is based on total volumetric flow rate of vent gas calculated using the GRI-Glycalc model.

Section 3

AN EPA TEST RUN OF ISC2 USING 45 SELECTED METEOROLOGICAL STATIONS

As discussed in Section 2, REAG applied the ISC2 dispersion model to data from 348 meteorological stations in an initial analysis of risks associated with benzene emitted by glycol dehydrators. These sites were selected to represent all areas of the United States. A second application of ISC2 was performed using a subset of 45 meteorological stations (Table 3-1) selected to represent areas where glycol dehydrators operating in oil and gas production fields were likely to be located. These stations are located in 17 states known to have operating glycol dehydrator units.

REAG assisted API by performing a test run of ISC2 based on the conditions listed in Table 3-2. The run assumed that the exit velocity was 1.59 ft/sec, the benzene emission rate was 1 ton/year, and the land use was rural. The remaining conditions were identical to those used in the SCREEN3 runs described in Section 2.

Table 3-3 provides descriptive statistics for the benzene concentration estimates according to distance from source. The statistics for each distance are based on 720 individual benzene concentration estimates, one for each combination of meteorological station (45 possibilities) and compass direction (16 possibilities). As expected, the value for each statistic decreases as distance increases. The distributions are positively skewed with relatively long upper tails. Plots on semi-log paper suggest that the empirical distribution of benzene concentrations at each distance can be well fit by a lognormal distribution. This finding is consistent with the results of subsequent analyses described in Section 4.

Table 3-1. Meteorological stations representing 45 geographical areas where glycol dehydrators are likely to be located.

State	Location	Site ID*
AK	Barter Island Airport	27401
AK	Barrow/W Post-W Rodgers	27502
AL	Mobile/WSO Airport	13894
CA	Fresno Air Terminal	93193
CA	Long Beach/WSO Airport	23129
CA	Los Angeles International Airport	23174
CA	Santa Barbara Airport	23190
CA	Redding/Aaf	24257
IL	Springfield/Capital Airport	93822
IN	Evansville Regional Airport	93817
KS	Wichita/Mid-Continent Airport	03928
KS	Concordia/Blosser Mun. Airport	13984
KY	Paducah/WSO Airport	03816
KY	Jackson/Julian Carroll Airport	03889
LA	Lake Charles/Municipal	03937
LA	New Orleans Int'l Airport	12916
LA	Shreveport/Regional Airport	13957
LA	Baton Rouge/Ryan Airport	13970
MS	Meriden/Key Field	13865
MO	Kansas City/Int'l Airport	03947
MO	Kansas City Airport	13988
MT	Cut Bank Airport	24137
ND	Williston/Sioux Falls Int'l Airport	94014
NM	Roswell	23009
OH	Toledo/Express Airport	94830
OK	Oklahoma City/Will Rodgers	13967
OK	Tulsa/International Airport	13968
PA	Pittsburgh/Macon Airport	94823
TX	Stephenville	03969
TX	Victoria/WSO Airport	12912
TX	Port Arthur/Jefferson City	12917
TX	Brownsville/International Airport	12919
TX	San Antonio	12921
TX	Corpus Christie/Int'l Airport	12924

(continued)

3-2

Table 3-1 (Continued)

State	Location	Site ID*
TX	Houston Intercontinental	12960
TX	Abilene/Municipal Airport	13962
TX	Wichita Falls/Municipal Airport	13966
TX	Midland/Regional Airport	23023
TX	San Angelo/WSO Airport	23034
TX	Lubbock/Regional Airport	23042
WV	Huntington/Tri-State Airport	03860
WV	Beckley/Raleigh Co. Memorial	03872
WV	Charleston/Kenawba Airport	13866
WY	Lander/Hunt Field	24021
WY	Rock Springs Airport	24027

*Site ID refers to the meteorological station STAR Site number (see complete listing of sites in Appendix B).

Table 3-2. Specifications for the Test Run of ISC2 applied to 45 meteorological stations.

Parameter	Specification
Number of meteorological stations	45 (selected by API)
Exit velocity	1.59 feet/sec
Benzene emission rate	1 ton/year
Land use	Rural
Source type	Point
Stack height	10 feet
Stack diameter	2 inches
Stack gas exit temperature	225 degrees F.
Air temperature	293 degrees K. (default)
Receptor height	2 meters
Building downwash calculation?	No
Terrain	Flat
Fumigation calculation?	No
Modeled meteorological conditions	All stabilities and wind speeds

Table 3-3. Descriptive statistics for estimated benzene concentrations ($\mu\text{g}/\text{m}^3$) at specified distances from 45 hypothetical emission sources.^a

Ring	Distance, meters	n	Benzene concentration, $\mu\text{g}/\text{m}^3$						
			Arith. mean	Arith. S. D.	Minimum	25%	50%	75%	Maximum
1	10	720	19.68	11.97	1.75	11.75	16.73	24.33	92.44
2	20	720	11.27	6.76	1.03	6.76	9.62	13.97	52.39
3	30	720	7.43	4.35	0.82	4.51	6.40	9.16	33.64
4	50	720	4.12	2.44	0.44	2.49	3.55	5.09	18.91
5	100	720	1.66	1.01	0.17	0.98	1.41	2.07	7.92
6	200	720	0.60	0.38	0.05	0.35	0.51	0.75	2.99
7	300	720	0.32	0.21	0.03	0.18	0.27	0.41	1.63
8	500	720	0.140	0.091	0.011	0.078	0.112	0.179	0.724
9	1000	720	0.046	0.030	0.003	0.025	0.038	0.058	0.242
10	2000	720	0.015	0.010	0.001	0.008	0.013	0.019	0.080

^aThese data were obtained from an ISC2 dispersion model run performed by the Risk and Exposure Assessment Group, U.S. Environmental Protection Agency. Table 3-1 lists the 45 meteorological stations used in the runs. Emission conditions are described in Table 3-2. Each of the 45 sites produced 16 concentration values for each of the 10 rings listed in the table above (45 sites x 16 values/ring = 720 values/ring for all sites).

Following the completion of the test run, API conferred with EPA concerning the use of the 45 stations in an analysis to estimate lifetime cancer risks associated with benzene emitted by glycol dehydrators. EPA recommended using the complete set of 348 meteorological stations that were used in the initial EPA risk assessment (Appendix A). These stations were considered to provide a more complete range of potential exposure conditions. Section 4 describes model development using the 348 meteorological stations.

Section 4

INITIAL MODEL DEVELOPMENT

After completion of the test run described in Section 3, API and EPA jointly developed a set of 24 emission scenarios to be used in subsequent dispersion modeling runs. These scenarios are listed in Table 4-1. Each scenario specifies benzene emission rate (1 or 7 tons/year), vent velocity (3.21, 10.9, or 20.3 feet/sec), vent diameter (2 or 4 inches), and a land use (urban or rural). Conditions common to all scenarios are listed below:

release height = 12 feet

release temperature = 225 degrees F

For each scenario, EPA ran the ISC2 dispersion model for each of the 348 meteorological stations. The far-left column in Table 4-1 lists the names of the 24 data files produced by these runs. Each data file contained 55,680 values of annual average outdoor benzene concentration: one for each combination of meteorological station (348 possibilities), distance from source (10 possibilities), and compass direction (16 possibilities).

Each of the EPA data files was reformatted into a new file suitable for statistical analyses. Tables C-1 through C-12 in Appendix C provide descriptive statistics calculated from these files. Each table provides results for one combination of vent velocity, vent diameter, and land use. The results within each table are further stratified by distance and emission rate. The statistics in each table row are based on 5,568 outdoor benzene concentrations (348 stations times 16 compass points). Each set of 5,568 values was referred to as a "scenario-distance data set" (SDDS).

Table 4-1. Dispersion model output files received from the Risk and Exposure Assessment Group (Jan. 26 and Feb. 1, 1996).^a

REAG file name	Benzene emission rate, tons/year	Vent diameter, inches	Vent velocity, ft/sec	Land use
723.21r	7	2	3.21	rural
723.21u	7	2	3.21	urban
7210.9r	7	2	10.9	rural
7210.9u	7	2	10.9	urban
7220.3r	7	2	20.3	rural
7220.3u	7	2	20.3	urban
743.21r	7	4	3.21	rural
743.21u	7	4	3.21	urban
7410.9r	7	4	10.9	rural
7410.9u	7	4	10.9	urban
7420.3r	7	4	20.3	rural
7420.3u	7	4	20.3	urban
123.21r	1	2	3.21	rural
123.21u	1	2	3.21	urban
1210.9r	1	2	10.9	rural
1210.9u	1	2	10.9	urban
1220.3r	1	2	20.3	rural
1220.3u	1	2	20.3	urban
143.21r	1	4	3.21	rural
143.21u	1	4	3.21	urban
1410.9r	1	4	10.9	rural
1410.9u	1	4	10.9	urban
1420.3r	1	4	20.3	rural
1420.3u	1	4	20.3	urban

^aAll runs used 348 meteorological stations. Stack height = 12 feet. Release temperature = 225 degrees F.

Analyses of the SDDS revealed that the lognormal distribution usually provided a good fit to the data. A lognormal distribution can be completely specified by its geometric mean (GM) and geometric standard deviation (GSD). If data are well fit by a lognormal distribution, the GM will closely match the median (i.e., the 50th percentile value). Each pair of GM and median values listed in Appendix C match within 2 percent.

The GM and GSD values listed for a particular SDDS can be used to estimate any percentile in the distribution of outdoor benzene concentrations associated with the SDDS. To estimate the benzene concentration corresponding to the P percentile [$C_{out}(P)$], calculate the quantity

$$C_{out}(P) = (GM)(GSD)^z \quad (1)$$

where the area under the unit normal curve from zero to z is equal to P expressed as a fraction. Values of z for selected percentiles are listed below:

<u>percentile</u>	<u>z value</u>
5	-1.645
10	-1.282
25	-0.6745
50	0
75	0.6745
90	1.282
95	1.645
99	2.326

For example, the GM and GSD of the first SDDS listed in Table C-1 of Appendix C are $10.1 \mu\text{g}/\text{m}^3$ and 1.768, respectively. The 95th percentile can be estimated by the expression

$$C_{out}(95\%) = (10.1)(1.768)^{1.645} = 25.8 \mu\text{g}/\text{m}^3. \quad (2)$$

The actual 95th percentile is $26.0 \mu\text{g}/\text{m}^3$, a difference of less than 1 percent.

A series of exploratory stepwise linear regression (SLR) analyses was performed to determine whether the geometric means and geometric standard deviations listed in

Appendix C could be estimated directly from the parameters defining the scenario (emission rate, vent velocity, vent diameter, and land use). The SLR analyses indicated that the geometric means could be estimated well at all distances between 10 and 2000 meters, whereas the geometric standard deviations could be estimated well for distances between 30 and 2000 meters.

The geometric means in Appendix C were found to be proportional to emission rate when other parameters were held constant. Researchers subsequently performed a series of followup SLR analyses on the quantity

$$\text{LNRATIO} = \ln[(\text{geometric mean benzene conc.})/(\text{benzene emission rate})] \quad (3)$$

and found that LNRATIO could be estimated well at all distances between 10 and 2000 meters. Regression results based on separate analyses of the urban and rural data are included in Table 4-2.

The geometric standard deviation (a dimensionless quantity) was found to be independent of benzene emission rate. Regression results for geometric standard deviation based on separate analyses of the urban and rural data are included in Table 4-3. Note that these regression analyses omitted dispersion modeling results for distances of 10 and 20 meters. TRJ did not find a regression equation that could provide a good fit to dispersion model estimates for all distances when these two distances were included. Consequently, the regression analyses were applied to data for distances of 30 to 2000 meters. TRJ found that the following equations could be used to estimate the geometric standard deviations for 10 and 20 meters as a function of the geometric standard deviation estimated for 30 meters:

$$\text{Urban:} \quad \text{GSD}(10 \text{ meters}) = (1.020)[\text{GSD}(30 \text{ meters})] \quad (4)$$

$$\text{GSD}(20 \text{ meters}) = (1.014)[\text{GSD}(30 \text{ meters})] \quad (5)$$

$$\text{Rural:} \quad \text{GSD}(10 \text{ meters}) = (1.008)[\text{GSD}(30 \text{ meters})] \quad (6)$$

$$\text{GSD}(20 \text{ meters}) = (1.004)[\text{GSD}(30 \text{ meters})] \quad (7)$$