RISK ASSESSMENT OF PROSPECTIVE CLEANUP LEVELS FOR 2,3,7,8-TCDD IN SURFACE SOILS AT THE VERTAC CHEMICAL CORPORATION SITE, JACKSONVILLE, ARKANSAS

REVISED REPORT

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I. INTRODUCTION

The Vertac Chemical Corporation site ("the Site") is a former chemical manufacturing facility in Jacksonville, Arkansas that has been identified as a National Priorities List (Superfund) site by the U.S. Environmental Protection Agency ("EPA"). The compound 2,3,7,8-tetrachlorodibenzo-p-dioxin ("TCDD") is the primary constituent of potential concern in on-site soils, although certain chloroaromatic compounds are also present in on-site soils. A draft Feasibility Study ("FS") report, describing and evaluating remedial action alternatives for on-site soils, has been prepared by Roy F. Weston, Inc. (Weston 1994).

Hercules Incorporated ("Hercules") retained ENVIRON Corporation ("ENVIRON") to evaluate prospective cleanup goals for TCDD and the chloroaromatic compounds detected in on-site surface soils. To perform its evaluation, ENVIRON completed risk assessment calculations, including Monte Carlo simulations of exposure variability to adult trespassers on the Site. This report summarizes the methods and results of these calculations, which were based upon standard concepts for quantitative health risk assessments, EPA's assessment of the carcinogenic potential of TCDD and the chloroaromatic compounds, upper-bound estimates of the concentrations of TCDD in on-site surface soil samples that were developed during the Remedial Investigation ("RI") of the Site, and a derivation of sub-chronic and acute Acceptable Daily Intakes ("ADIs") for TCDD consistent with EPA methods.

The main report consists of four sections and is supplemented by four appendices. The methods and results for TCDD are presented in the main body of this report. Appendix A presents the sampling results for TCDD in on-site surface soils. Appendix B summarizes the exposure factor distributions that were employed in the Monte Carlo simulations. Appendix C presents ENVIRON's derivation of the sub-chronic and acute ADIs for TCDD. Finally, the results for chloroaromatic compounds, which were obtained by the same methods as for TCDD, are presented in Appendix D.

II. EXPOSURE AND RISK ASSESSMENT

A. Potential TCDD Exposure Concentrations

Prior to and during the RI for on-site soils, 461 gridded areas were identified for sampling and analysis (see Figure 4-1 of the RI report; Weston 1992). Three composite samples were taken within each grid and were each analyzed for TCDD. Based upon these sample results, an upper-bound, statistical estimate of the average concentration; i.e., the 95th percentile upper confidence limit on the arithmetic mean ("95%-UCL") was calculated for each grid. The resulting upper-bound estimates are listed in rank order in Table 4-2 of the RI, which is reproduced for convenience in Appendix A of this report, and are plotted as a histogram in Figure 1. The upper-bound estimates range from non-detect (with an analytical limit of detection of 0.3 ng/g or lower) to 2,800 ng/g (or ppb, mass part per billion); they form a highly skewed data set with many of the sample concentrations near or below the analytical limit of detection (i.e., < 0.3 ng/g, which is the upper end of the range in detection limits). For the unremediated Site, the arithmetic mean of the 95%-UCL concentrations of TCDD in all of the grids is 22.5 ng/g, while the geometric mean is 1.4 ng/g. Figure 2 compares the 95%-UCL to the individual composite sample results for four of the grids to illustrate the variability of composite samples within a grid and the conservatism imparted by choosing the 95%-UCL to represent an entire grid.

Hercules has proposed that a fence be constructed on-site to separate clean areas on the north side of the Site from areas subject to future or on-going remedial actions (e.g., the former production area, the on-site landfill). The proposed location of the fence is shown in Figure 3. Areas within the fence that have already been remediated account for approximately 40% of the total area to be fenced (Hercules 1994). By definition, the 95%-UCL concentrations of TCDD tend to be higher in grids within the area proposed for fencing than in gridded areas outside the area proposed for fencing. The arithmetic mean of the 95%-UCL concentrations of TCDD in all grids within the proposed fenced area is 30.3 ng/g, while the geometric mean is 2.3 ng/g; this compares to 22.5 ng/g and 1.4 ng/g for the arithmetic mean and geometric mean of the 95% UCL concentrations over all 461 grids, as cited above.

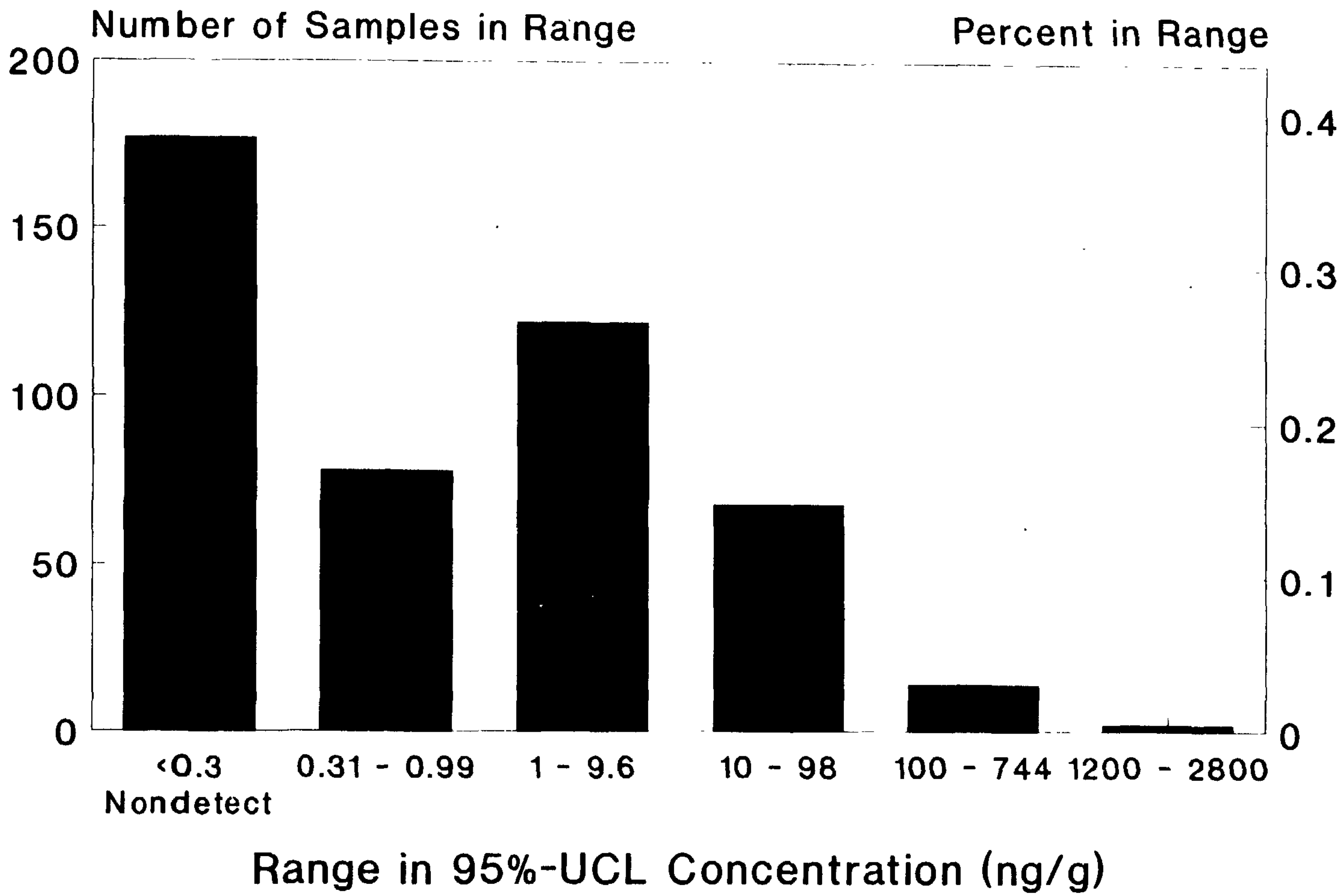

Figure 1: Distribution of Upper-bound 2,3,7,8-TCDD Concentrations in 461 Soil Grids at the Vertac Chemical Site, Jacksonville, Arkansas

This figure shows the distribution of the 95%-UCL concentrations of TCDD from the 461 soil grids established at the Site. For six ranges of the 95%-UCL concentrations, the number of grids and the percent of grids in that range are shown on the left-hand and right-hand ordinates (y-axes), respectively. Approximately 38% of the grids did not have detectable levels of TCDD. More than half (55%) of the grids have a 95%-UCL concentration less than 1 ng/g.

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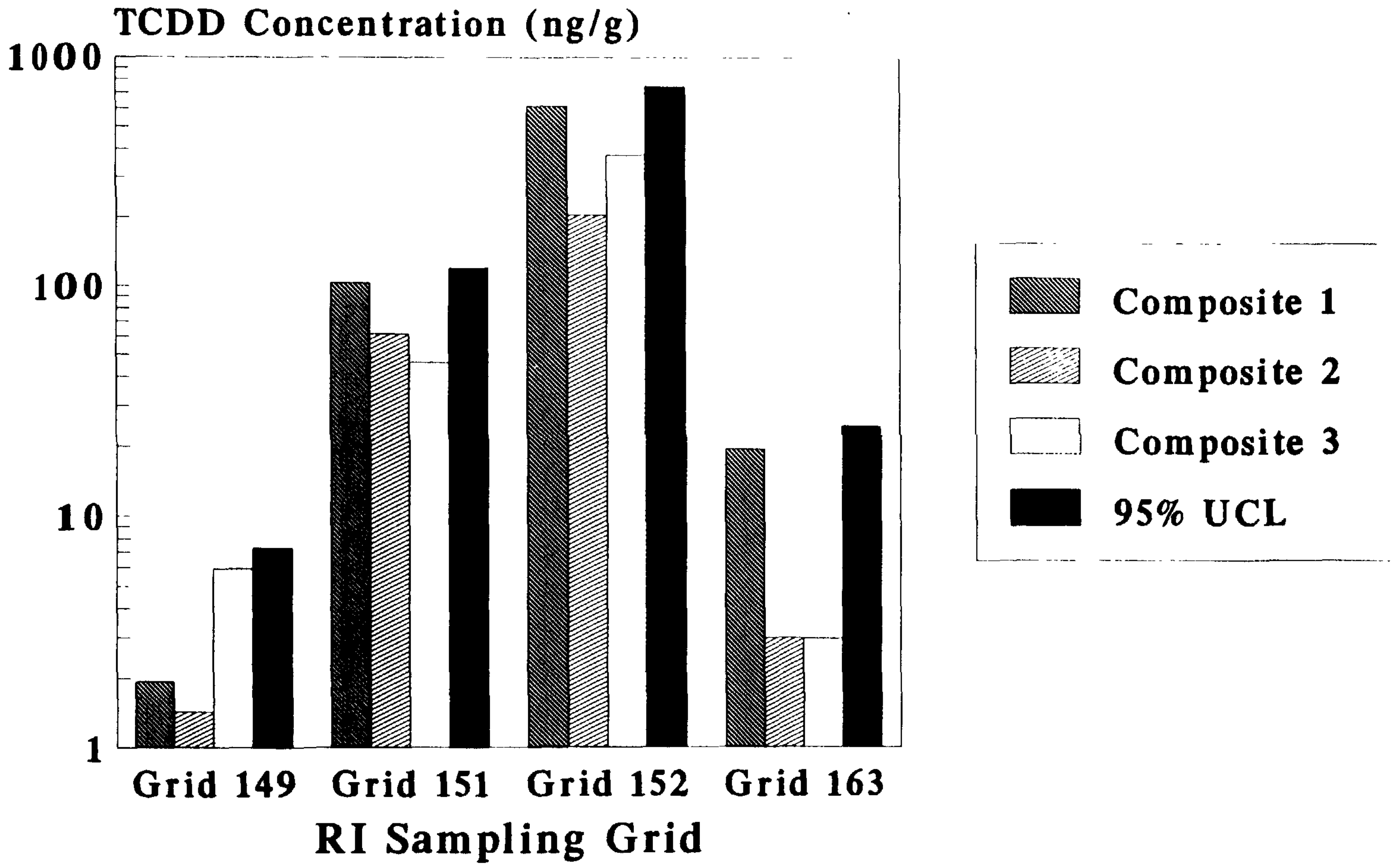

Figure 2: Comparison of Composite Sample Results and 95% Upper Confidence Limit Estimates for 2,3,7,8-TCDD at the Vertac Chemical Site, Jacksonville, Arkansas

This figure shows the concentrations of TCDD in three composite samples and the 95%-UCL concentration based upon the composite samples for four of the 461 grids established at the Site. The 95%-UCL concentrations, rather than the composite concentrations, were used to estimate exposure concentrations in this report. For each of the four grids, the 95%-UCL concentration exceeds the respective composite concentrations.

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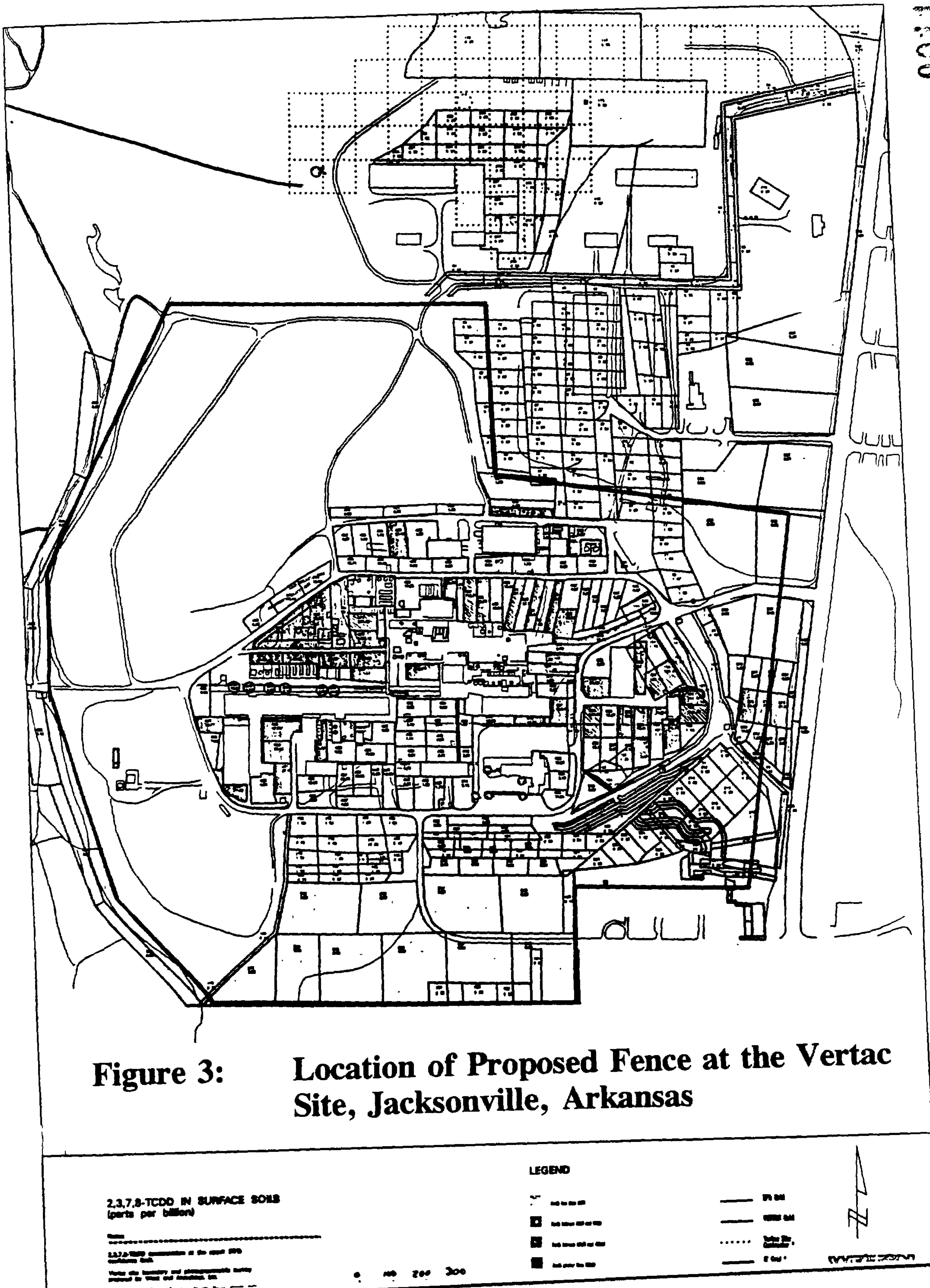

Figure 3: Location of Proposed Fence at the Vertac Site, Jacksonville, Arkansas

Using a range of prospective cleanup standards, ENVIRON calculated the arithmetic mean of the 95%-UCL concentrations of TCDD that would remain within the sampled (gridded) areas after remediation (i.e., capping or excavating soil in every grid that has a 95%-UCL concentration of TCDD greater than the stated not-to-exceed cleanup standard). Statistical calculations were performed using two different assumptions about the TCDD concentration that will remain in remediated areas of the Site:

1) a concentration of 0.3 ng/g (the upper end of the range in detection limits) was assumed to apply to the surface soil in remediated grids; and

2) a concentration equal to the not-to-exceed (NTE) standard was assumed to apply to the surface soil in remediated grids.

These two assumptions cover the anticipated range of concentrations that would be expected to be present after remediation of surface soil. The first assumption would be appropriate for grids that are remediated by clean soil after, or in lieu of, excavation. The second assumption would be appropriate for grids that were remediated by soil removal, but did not receive a clean soil cover and had residual contamination equal to or below the not-to-exceed standard. The remedial action alternatives evaluated in the FS call for clean soil covers in all remediated grids (Weston 1994), suggesting that the first assumption is more appropriate for this Site.

Figure 4 shows the results of these calculations for the proposed fenced area of the Site. To illustrate the interpretation of Figure 4, consider a not-to-exceed cleanup standard of 100 ng/g. The calculations indicate that the arithmetic mean of the 95th-UCL concentrations of TCDD remaining within the gridded portion of the area that is proposed for fencing would be 12 ng/g once all grids with a 95%-UCL concentration greater than 100 ng/g have been remediated to a concentration of 100 ng/g; if all grids with a 95%-UCL concentration greater than 100 ng/g are remediated to a non-detectable concentration (i.e., 0.3 ng/g or less), then the arithmetic mean concentration is 7.9 ng/g within the gridded portion of the area that is to be fenced. For a not-to-exceed cleanup standard of 50 ng/g, the arithmetic means are 8.9 ng/g and 5.2 ng/g, respectively, for the two assumptions about TCDD concentration in remediated grids within the area that is to be fenced.

For the remainder of this report, ENVIRON used the arithmetic mean concentrations shown in Figure 4 to calculate the chronic risk measures (i.e., lifetime cancer risk estimates and non-cancer hazard quotient values for long-term exposures) associated with various

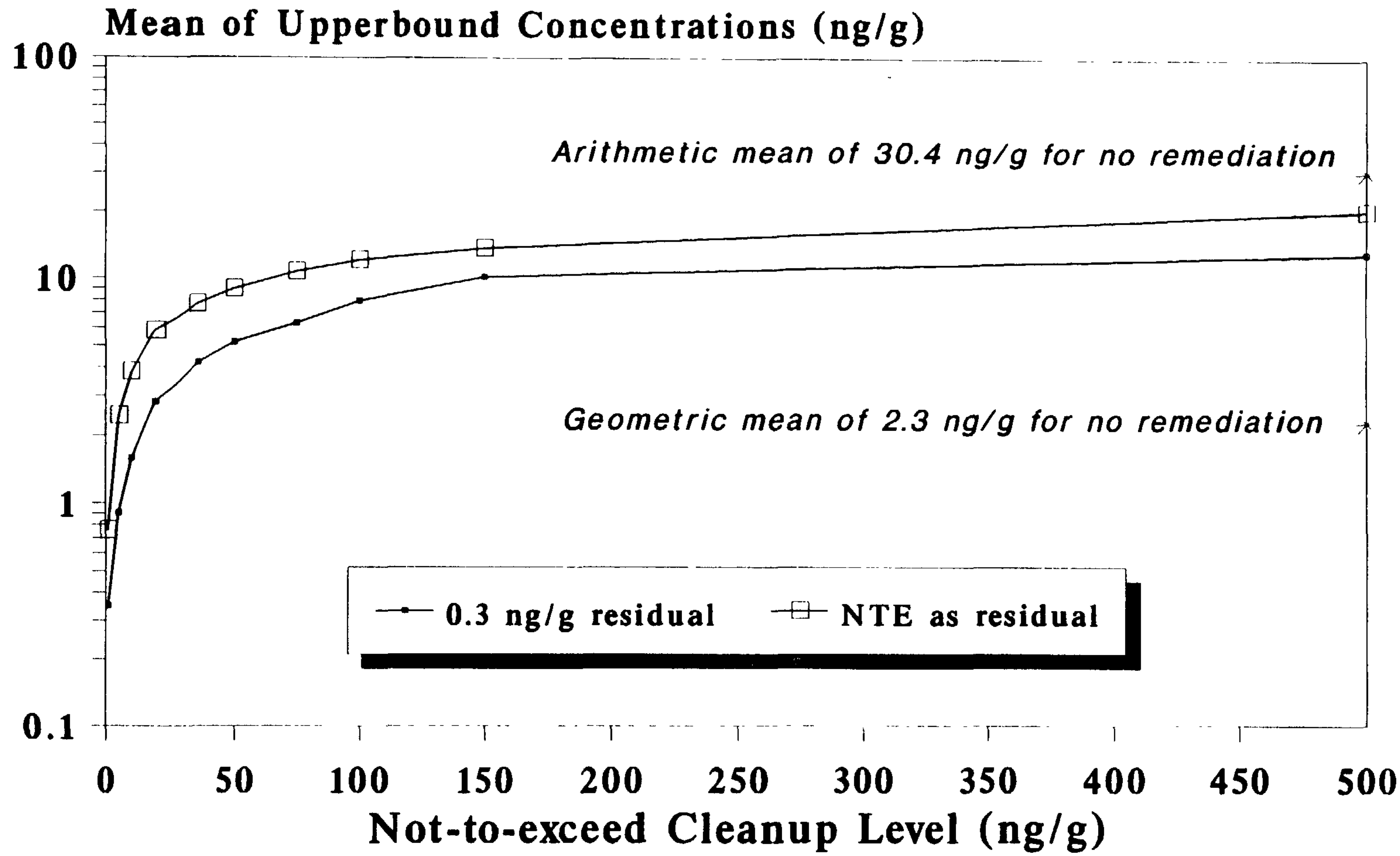

Figure 4: Average Concentration of 2,3,7,8-TCDD Remaining in Surface Soil within the Proposed Fenced Area at the Vertac Chemical Site

This figure shows the arithmetic mean of the upper-bound concentrations 2,3,7,8-TCDD in soil sampling grids within the proposed fenced area of the Site, assuming that all grids with an upper-bound concentration above the stated not-to-exceed level are remediated (e.g., by soil removal or capping) to reduce the concentration in surface soil to either 0.3 ng/g (the analytical detection limit for 2,3,7,8-TCDD) or the not-to-exceed (NTE) standard. Actual average concentrations within the proposed fenced area would be lower than shown here, because the non-gridded areas of the Site are believed not to contain elevated levels of 2,3,7,8-TCDD, as they were previously remediated with clean soil.

not-to-exceed cleanup standards for TCDD in surface soils at the Site. The grid-wide arithmetic mean is a <u>conservative</u> estimate of exposure concentration, because it is an average of the upper-bound (i.e., 95%-UCL) concentrations in each grid within the fenced area (see Appendix A and Figure 2); use of upper-bound concentrations are prescribed by EPA's *Risk Assessment Guidance for Superfund* (USEPA 1989). Portions of the area within the proposed fence (approximately 40%) were not grid-sampled and are believed not to have any soil contamination, because they were previously remediated and received a clean soil cover (Hercules 1993b, 1994). Consequently, the "grid-wide" arithmetic mean tends to overestimate the true arithmetic average concentration of TCDD in surface soils within the fenced area. For a given not-to-exceed standard, the actual average of the upper-bound concentrations of TCDD in surface soils within the fenced area is approximately 40% less than shown in Figure 4. Correspondingly, the chronic risk measures shown in the remainder of this report would be 40% less, if they were based upon the average concentrations for the entire fenced area rather than the grid-wide average concentrations.

B. Potential Exposure Scenarios

ENVIRON performed an exposure assessment for an adult trespasser. For the adult trespasser, this exposure assessment considers dermal contact with and incidental ingestion of surface soils. Comprehensive risk assessments (e.g., Paustenbach et al 1992) have generally found these pathways to be the primary contributors to on-site exposures in most situations of soil contamination.[1]

Because the Site is fenced and guarded, most individuals should be deterred from entering the Site. Site personnel recall only a few trespassers and no repeat trespassers over the past several years (Hercules 1993b).

Because chemical manufacturing is no longer conducted on-site, worker exposure should not be an issue. Remedial workers on the Site currently and maintenance workers in the future presumably will wear appropriate protective equipment during site activities. In any event, the remediation worker scenario is not a typical or appropriate basis for establishing cleanup standards.

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[1] Site-derived dust levels generally must exceed the ambient air quality standard for total suspended particulate for the inhalation route to approach the administered dose associated with direct contact to soil. Exceptions arise when a chemical substance is substantially more toxic via the inhalation route than by the oral or dermal route. This condition does not apply to TCDD, as EPA's risk assessment for dioxins assumes that TCDD is equally carcinogenic by the oral and inhalation routes (USEPA 1992c).

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C. Probability Distribution of Cancer Risks

Carcinogenic health risks were the primary focus of this analysis. As shown below, the total cancer risk to an on-site trespasser exposed to surface soils is assumed to be the sum of the risks from dermal contact and incidental ingestion.

$$LCR_{total} = LCR_{dermal} + LCR_{ingest} \qquad (1)$$

where:

where:	LCR_{total}	=	Incremental lifetime cancer risk, total from direct contact with surface soil
	LCR_{dermal}	=	Incremental lifetime cancer risk from dermal contact with soil
	LCR_{ingest}	=	Incremental lifetime cancer from incidental soil ingestion

The equations used to calculate these risks are as follows:

Dermal Contact:

$$LCR_{dermal} = \frac{C_s \, x \, SA \, x \, FS \, x \, AF \, x \, ABS_d \, x \, EF \, x \, ED}{BW \, x \, AT \, x \, 10^6} SF_{dermal} \qquad (2)$$

where:

C_s	=	Upper-bound TCDD concentration in surface soil (mg/kg)
SA	=	Total skin surface area (cm^2)
FS	=	Fraction of total skin area exposed (unitless)
AF	=	Soil-to-skin adherence factor (mg/cm^2-day)
ABS_d	=	Dermal bioavailability factor (unitless)
EF	=	Exposure frequency (days/year)
ED	=	Exposure duration (days)
BW	=	Body weight (kg)
AT	=	Averaging time (days)
SF_{dermal}	=	Cancer slope factor for the dermal route $(mg/kg\text{-}day)^{-1}$
10^6	=	Conversion factor (mg/kg)

Incidental Ingestion:

$$LCR_{ingest} = \frac{C_s \, x \, IR \, x \, FI \, x \, ABS_o \, x \, EF \, x \, ED}{BW \, x \, AT \, x \, 10^6} SF_{oral} \quad (3)$$

where:

IR	=	Incidental ingestion rate (mg/day)
FI	=	Fraction of daily soil intake ingested while on-site (unitless)
ABS_o	=	Oral bioavailability factor (unitless)
SF_{oral}	=	Cancer slope factor for the oral route $(mg/kg\text{-}day)^{-1}$

and all other factors are as described previously.

In calculating cancer risks with Equations 1-3, EPA typically uses upper-bound estimates of several of the exposure parameters described above. While EPA guidance on risk assessment for Superfund requires that a reasonable (emphasis added), maximum exposure (RME) be considered (USEPA 1989), the typical EPA practice frequently results in cancer risk estimates that are highly unlikely to occur (Burmaster and Harris 1993). In two recent guidance documents (USEPA 1992a,b), EPA recognizes that the RME approach in assessing risk is incomplete because it presents only a point estimate of risk with no information about where the RME estimate falls on the overall distribution of exposure and risk values. EPA suggests that quantitative uncertainty analyses (e.g., Monte Carlo simulation) be conducted to develop such distributions (USEPA 1990, 1992a, 1992b).

In Monte Carlo simulation, the input variables (e.g., amount of soil ingested daily, years of residence at any one location, etc.) can be set as a random variable each with its own probability distribution. Then, using a computer, a large number of risk calculations (e.g., using equations 1-3) are made. For each calculation, one random value from the appropriate probability distribution for each of the exposure variables in the model is selected, and a risk calculation is made and stored. This computation is repeated thousands of times (e.g., usually between 1,000 and 10,000). Upon completion of these computations, a risk probability distribution is derived (Burmaster and Harris 1993, Paustenbach et al 1992).

A Monte Carlo simulation of the variability in exposure to adult trespassers was conducted by ENVIRON for the Site for pathways involving direct contact with soil (i.e., incidental ingestion and dermal contact). The computer package @RISK (Palisade 1990) was employed. For each not-to-exceed standard considered for TCDD, 10,000 values each of dose and risk were calculated, stored, and statistically analyzed. The input parameters and distributions for the Monte Carlo analysis are summarized in Table 1. For three of the exposure variables, single values (i.e., point estimates) were used rather than a probability distribution of values. A discussion of each of the input parameters (point estimates or probability distributions) that were used in the Monte Carlo analysis is presented in Appendix B.

Figure 5 shows the cumulative distribution of the lifetime cancer risk for an adult trespasser in the proposed fenced area of the Site exposed to TCDD in surface soil after remediation to a not-to-exceed cleanup standard of 50 ng/g. Two curves are presented:

1) assuming a soil concentration (C_s, see Equations 1-3) of 8.9 ng/g, which is the arithmetic mean of the 95%-UCL concentrations of TCDD concentrations remaining in the fenced portion of the gridded areas of the Site after grids with 95%-UCL concentrations greater than 50 ng/g are remediated to 50 ng/g; and

2) assuming a soil concentration (C_s, see Equations 1-3) of 5.2 ng/g, which is the arithmetic mean of the 95%-UCL concentrations of TCDD concentrations remaining in the fenced portion of the gridded areas of the Site after grids with 95%-UCL concentrations greater than 50 ng/g are remediated to 0.3 ng/g (the upper end of detection limits for TCDD in site soils).

These exposure concentrations are taken from Figure 4. The EPA's cancer potency estimate for ingestion of TCDD (i.e., SF_{oral} = 156,000 kg-day/mg) was used to generate both curves in Figure 5.[2] For these assumptions, the Monte Carlo simulations indicate that 50 percent of individuals exposed to surface soil in the proposed fenced area of the Site (i.e., exposure concentration of 8.9 ng/g or less) would have a lifetime cancer risk of 2.8 per million (2.8×10^{-6}) or less. This is within the risk range (10^{-6} to 10^{-4}) that EPA typically deems acceptable in its Superfund remedy selection decisions (USEPA 1991). Actual risks may be much lower, because:

[2] A cancer potency estimate of 284,000 kg-day/mg was assumed for dermal exposure (i.e., SF_{dermal}), based upon EPA's assessment that 55% of the applied dose in feed was absorbed by test animals in the critical carcinogenicity study (USEPA 1992c, p. 4-4); i.e., $SF_{dermal} = SF_{oral} \div 0.55$.

TABLE 1
Distributions of Exposure Factor Values for Monte Carlo Simulations of Ingestion of and Dermal Contact with Surface Soils by an Adult Trespasser

Exposure Parameter	Assumed Inputs for Monte Carlo Simulations		
	Form of Parameter Distribution	**Distribution Statistics**	**Reference or Source**
Body weight (kg)	Cumulative (see Table B-1, Appendix B)	Minimum = 50 Maximum = 100 Expected value = 70.6	USEPA (1990)
Exposure duration (years)	Cumulative (see Table B-2, Appendix B)	Minimum = 0 Maximum = 64 Expected value = 13	USEPA (1990)
Exposure frequency (days/yr)	Exponential	Minimum = 0 Maximum = 365 Expected value = 17.6	ENVIRON (this project)
Daily soil ingestion rate (mg/day)	Lognormal	μ = 43 σ = 41	Thompson et al. (1992)
Fraction of daily intake acquired at site	Point estimate	0.5	ENVIRON (this project)
Oral bioavailability factor for 2,3,7,8-TCDD	Point estimate	0.1	Gallo and Meeker (1993)
Total skin surface area contacted (cm^2)	Cumulative (see Table B-3, Appendix B), correlated to body weight	Minimum = 15,000 Maximum = 25,000 Expected value = 18,400	USEPA (1990, Tables 4B-1 and 4B-2)
Fraction of skin surface exposed	Uniform	Minimum = 0.13 Maximum = 0.317 Expected value = 0.23	USEPA (1990, Table 4-2)
Soil/skin adherence factor (mg/cm^2-day)	Triangular	Minimum = 0.2 Most likely = 0.2 Maximum = 1.0	USEPA (1992d)
Dermal bioavailability factor for 2,3,7,8-TCDD	Uniform	Minimum = 0.001 Maximum = 0.03 Expected value = 0.015	USEPA (1992c)
Averaging time: carcinogens (days)	Point estimate	25,550	USEPA (1989)

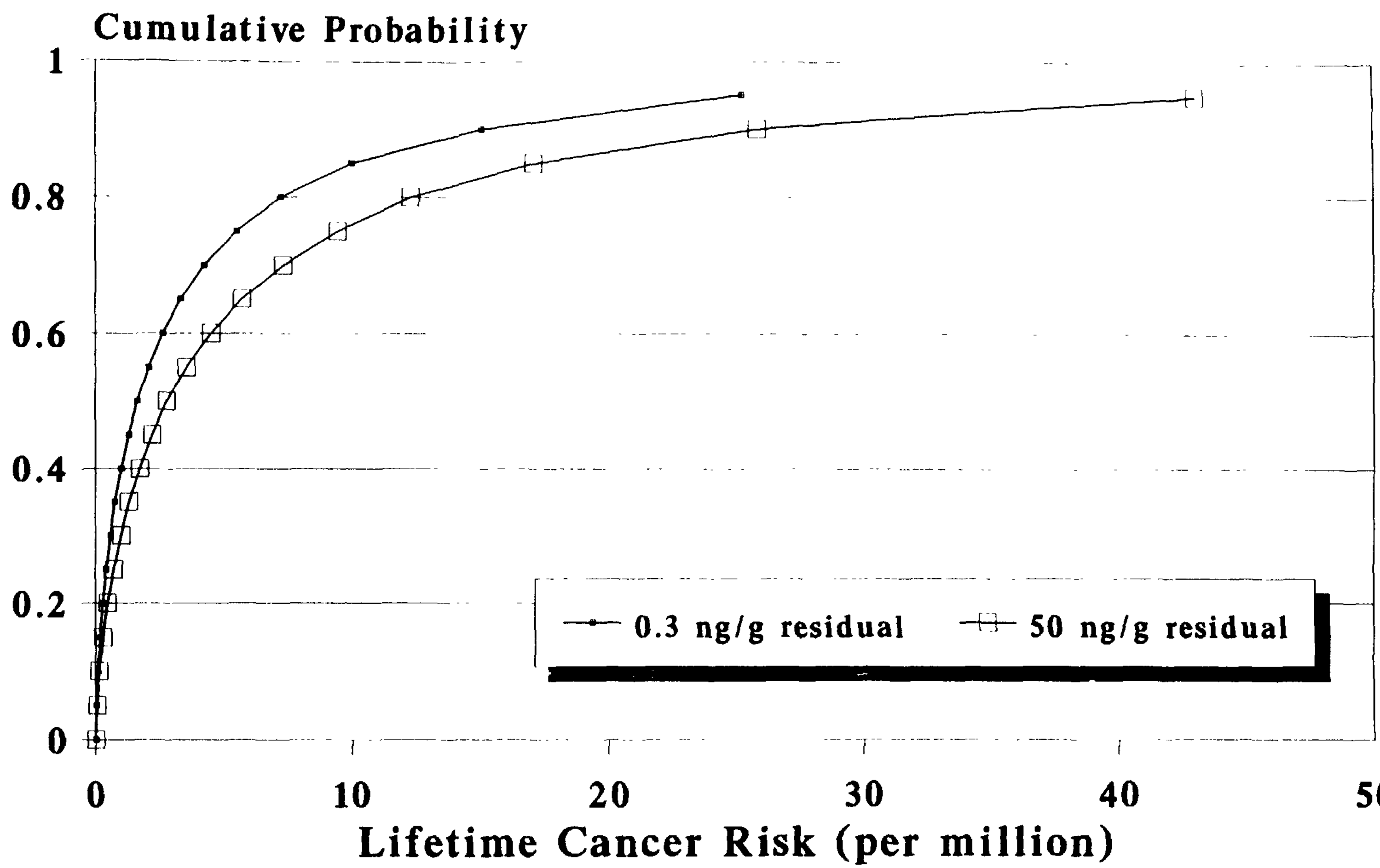

Figure 5: Cumulative Distribution of Cancer Risk to an Adult Trespasser in the Proposed Fenced Area at the Vertac Site after Remediation of Surface Soil to a Not-to-exceed Level of 50 ng/g TCDD

This figure shows the cumulative cancer risk distribution for direct contact with surface soil. Lifetime cancer risk (LCR) for an individual (determined by Equations 1 through 3) is plotted along the abscissa (x-axis). The ordinate (y-axis) shows the cumulative probability, as determined by the Monte Carlo simulations (see Appendix B). This figure indicates that the 95th percentile LCR value is 43 per million (4.3×10^{-5}) assuming an upper-bound exposure concentration of 8.9 ng/g (grids remediated to 50 ng/g; see Figure 4); 95% of trespassing individuals exposed to 2,3,7,8-TCDD in the gridded areas within the proposed fenced area after remediation would have an incremental LCR equal to or less than this value.

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1) the cancer potency of 2,3,7,8-TCDD may not be as high as previously estimated by EPA[3];

2) the risk calculations do not take into account any photolytic degradation of 2,3,7,8-TCDD at the soil surface; and

3) the risk calculations used conservative estimates of the TCDD exposure concentration (i.e., averages of upper-bound concentrations; see Figures 2 and 4) and do not take into account the fact that ungridded, previously remediated soil areas are believed not to contain TCDD.

Table 2 presents various values on the probability distribution of trespasser LCRs for not-to-exceed cleanup standards of 75 ng/g, 50 ng/g, 35 ng/g, and 20 ng/g. Table 2 shows the median (50th percentile) LCR values, as well as various upper-bound values (i.e., 90th and 95th percentile) that EPA guidance suggests as examples of "high end" risks that could be considered by the risk manager in setting cleanup levels (USEPA 1992b). The 95th-percentile LCR-values for these cases indicate that with a not-to-exceed cleanup standard as high as 75 ng/g, an adult trespasser with "high end" exposures would have a LCR-value of 51 per million, well within the risk range (10^{-6} to 10^{-4}) typically deemed acceptable by EPA. The 50th-percentile LCR-values for these cases indicate that with a not-to-exceed cleanup standard of as high as 75 ng/g, an adult trespasser with "typical" exposures would have a LCR-value of 3.3 per million, within the risk range (10^{-6} to 10^{-4}) typically deemed acceptable by EPA. Figure 6 shows the 95th- and 50th-percentile LCR values for a wider range of TCDD cleanup levels than are tabulated in Table 2. Figure 6 indicates that with a not-to-exceed cleanup standard as high as 500 ng/g an adult trespasser with "high end" exposures would have a LCR equal to or below the 100-per-million (1×10^{-4}) risk level typically deemed acceptable by EPA (USEPA 1991). Again, actual risks may be much lower than those listed in Table 2 and Figure 5, because:

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[3] Based on a recent conversation with Mr. Steve Bayard of the Office of Health and Environmental Assessment, it is our understanding that the cancer slope factor (SF) for 2,3,7,8-TCDD is currently under review by EPA. Mr. Bayard suggested a revised SF for 2,3,7,8-TCDD of 0.8×10^5 kg-day/mg, or one-half of the current value of 1.56×10^5 kg-day/mg, may be more appropriate. Using the lower slope factor, the LCR values shown in Figure 5 (and Figure 6) would be reduced by approximately one-half.

TABLE 2 Comparison of Residual Concentrations and Risk Measures Associated with Alternative Cleanup Standards for 2,3,7,8-TCDD Based Upon Trespasser Exposures at the Vertac Site				
Description of Residual Concentration or Risk Measure	**Value of Concentration or Risk Measure for Soil Removal or Capping Every Grid with an Upper-bound TCDD Concentration Greater than the Stated Cleanup Standard**			
	20 ng/g	**35 ng/g**	**50 ng/g**	**75 ng/g**
Concentration Statistics (ng/g TCDD) After Application of Stated, Not-to-exceed Cleanup Standard				
Maximum Upper-bound (95th Percent Confidence Limit for Mean) TCDD Concentration in any Unremediated Grid[1]	19	35	48	72
Arithmetic Mean Residual Concentration of TCDD Averaged over all Grids within the Proposed Fenced Area (with Remediated Grids at the Not-to-exceed Standard)[2]	5.8	7.7	8.9	10.7
Arithmetic Mean Residual Concentration of TCDD Averaged over all Grids within (the Proposed Fenced Area (with Remediated Grids at 0.3 ng/g)	2.8	4.2	5.2	6.3
Upper-bound Estimates of Lifetime Cancer Risk (LCR; per million) based upon Arithmetic Mean Residual TCDD Concentration after Remediation to Stated, Not-to-exceed Cleanup Standard				
Median (50th percentile) LCR Based Upon Monte Carlo Simulations	1.8	2.4	2.8	3.3
90th percentile LCR Based Upon Monte Carlo Simulations	17.	22.	26.	31.
95th percentile LCR Based Upon Monte Carlo Simulations	28.	37	43.	51.

TABLE 2 Comparison of Residual Concentrations and Risk Measures Associated with Alternative Cleanup Standards for 2,3,7,8-TCDD Based Upon Trespasser Exposures at the Vertac Site				
Description of Residual Concentration or Risk Measure	**Value of Concentration or Risk Measure for Soil Removal or Capping Every Grid with an Upper-bound TCDD Concentration Greater than the Stated Cleanup Standard**			
	20 ng/g	**35 ng/g**	**50 ng/g**	**75 ng/g**
Noncancer, Sub-chronic Hazard Quotient (HQ_{sc}) Estimates based upon Annualized Exposures to Arithmetic Mean Residual TCDD Concentrations after Remediation to Stated, Not-to-exceed Cleanup Standard				
Median (50th percentile) HQ Based Upon Monte Carlo Simulations	0.02	0.02	0.03	0.03
90th percentile HQ Based Upon Monte Carlo Simulations	0.09	0.11	0 13	0.16
95th percentile HQ Based Upon Monte Carlo Simulations	0.13	0.17	0.20	0.23
Noncancer, Acute Hazard Quotient (HQ_{ac}) Estimates based upon One-time Exposure to Maximum TCDD Concentration after Remediation to Stated, Not-to-exceed Cleanup Standard				
Median (50th percentile) HQ Based Upon Monte Carlo Simulations	0.13	0.24	0.32	0.49
90th percentile HQ Based Upon Monte Carlo Simulations	0.32	0.59	0.81	1.21
95th percentile HQ Based Upon Monte Carlo Simulations	0.40	0.73	1.00	1.50

FOOTNOTES:

1 Used to Calculate Tabulated Values of Acute Hazard Quotient.
2 Used to Calculate Tabulated Values of Lifetime Cancer Risk and Sub-chronic Hazard Quotient (taken from Figure 4).

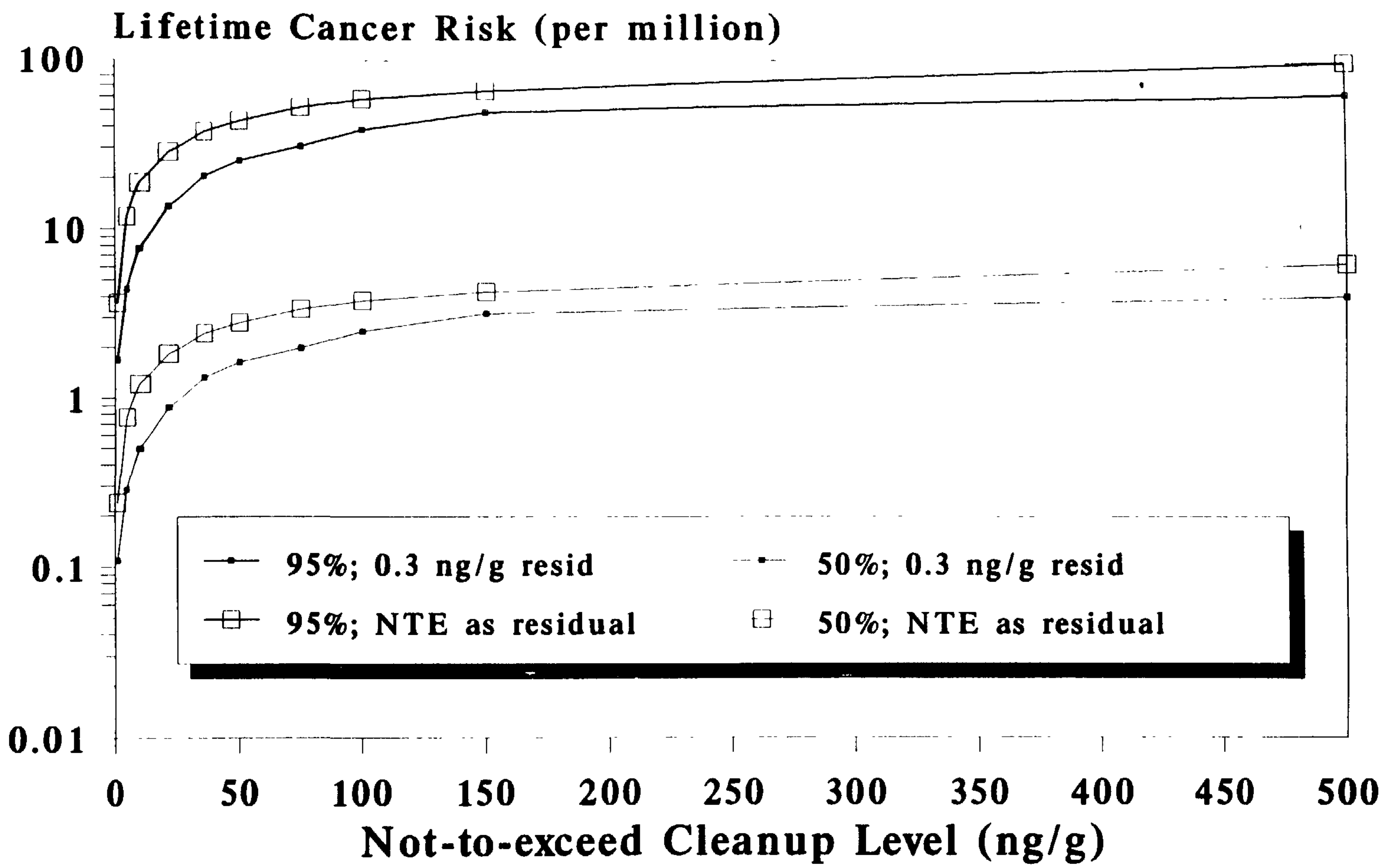

Figure 6: Lifetime Cancer Risks to an Adult Trespasser in the Proposed Fenced Area at the Vertac Site after Remediation of Surface Soil to Various Not-to-exceed Cleanup Levels for TCDD

This figure shows the 95th- and 50th-percentile values on the cumulative cancer risk distribution for direct contact with surface soil using the arithmetic mean concentrations shown in Figure 4 as the exposure concentrations (C_s). The not-to-exceed cleanup standard (ng/g TCDD) is plotted along the abscissa (x-axis). The ordinate (y-axis) shows the LCR value, as determined by the Monte Carlo simulations (see Appendix B). EPA guidance considers the 95th-percentile to be an indication of "high end" exposures; 95% of trespassing individuals exposed to 2,3,7,8-TCDD in the gridded areas after remediation would have an incremental LCR equal to or less than the 95th-percentile value. As shown in this figure, the 95th-percentile LCR value is 43 per million (4.3×10^{-5}) or less for a cleanup standard of 50 ng/g. The 50th-percentile (median) LCR value can be considered a typical exposure; 50% of adult trespassers exposed to gridded areas of the Site would have a LCR value equal to or less than the 50th-percentile value. As shown in this figure, the 50th-percentile LCR value is 2.8 per million (2.8×10^{-6}) or less for a cleanup standard of 50 ng/g.

1) the cancer potency of 2,3,7,8-TCDD may not be as high as previously estimated by EPA;

2) the risk calculations do not take into account any photolytic degradation of 2,3,7,8-TCDD at the soil surface; and

3) the risk calculations used conservative estimates of the TCDD exposure concentration (i.e., averages of upper-bound concentrations; see Figures 2 and 4) and do not take into account the fact that ungridded, previously remediated soil areas are believed not to contain TCDD.

The Monte Carlo simulations attempt to characterize the variability of exposure (and, hence, risk) among a population of potentially exposed individuals. EPA risk characterization guidance states that the technical uncertainty in risk estimates should also be characterized (USEPA 1992b). Towards that end, ENVIRON conducted sensitivity analyses in which selected exposure factor values were varied one at a time and the change in cumulative distribution of the LCR values was noted. Based in part upon discussions with EPA personnel concerning an earlier version of this report, ENVIRON chose four variables to investigate:

- oral bioavailability factor (ABS_o; equation 3);

- dermal absorption factor (ABS_d; equation 2); and

- exposure frequency (EF; equations 2 and 3); and

- cancer slope factors (SF_{dermal} and SF_{oral}; equations 2 and 3, respectively).

Figure 7 shows the results of the sensitivity analyses concerning the oral bioavailability factor. Point estimates of 0.4 and 0.2 were tested, in addition to the baseline value of 0.1 as shown in Table 1. The rationale for these sensitivity analyses is that EPA's default value 0.4 or 40% (USEPA 1992c), is higher than the site-specific value obtained through the study by Gallo and Meeker (1993). The results show that the LCR to a trespasser is not greatly sensitive to the value chosen for oral absorption. This pattern occurs because the dermal exposure route is modeled in such a way that it yields a substantially higher predicted dose.

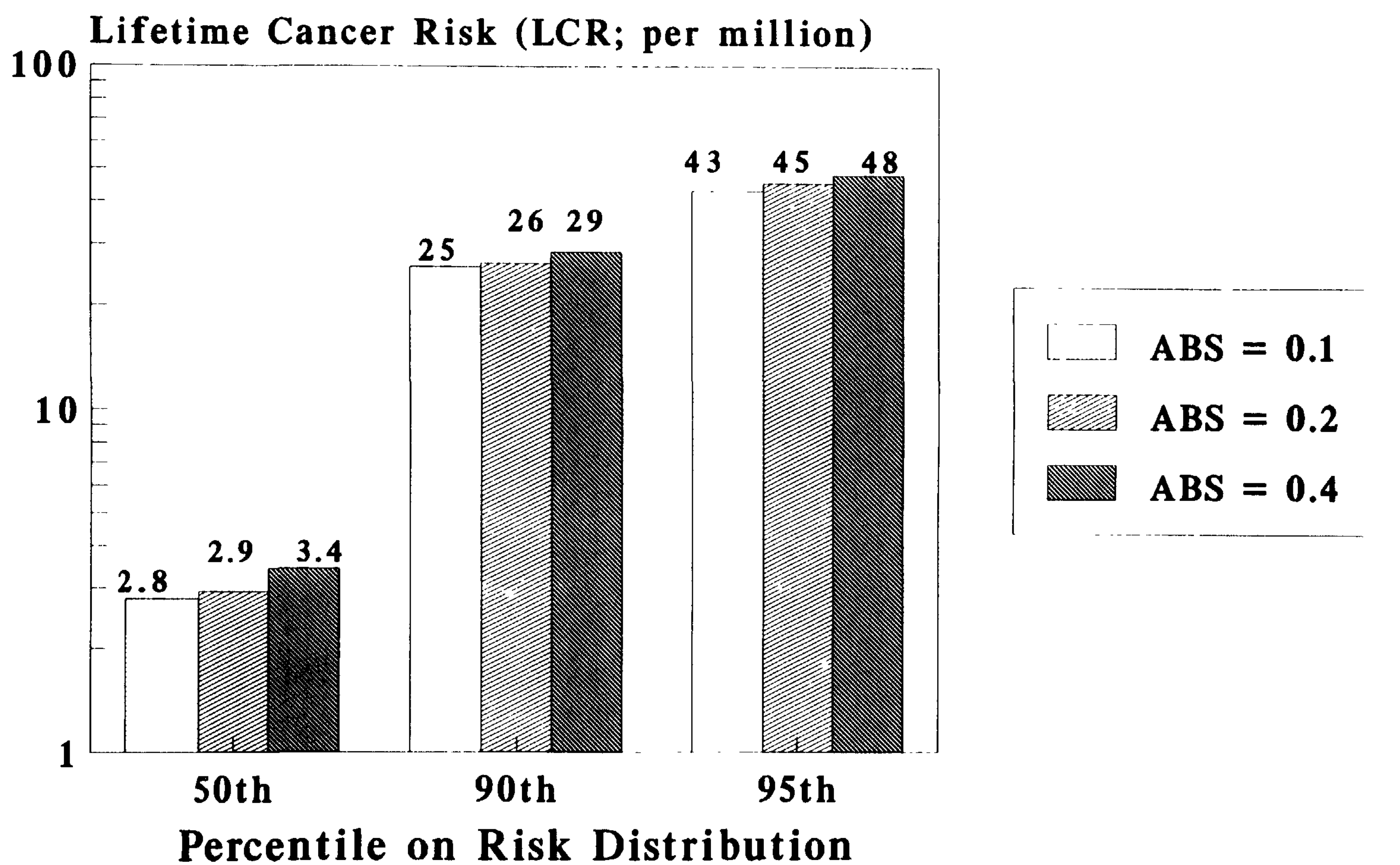

Figure 7: Sensitivity of Cancer Risk to an Adult Trespasser to the Oral Absorption Factor

This figure shows selected values on the cumulative distribution (i.e., 50th, 90th, and 95th percentiles) of LCRs for adult trespassers in the proposed fenced areas exposed to TCDD after remediation to a not-to-exceed cleanup standard of 50 ng/g, assuming an exposure concentration of 8.9 ng/g. Lifetime cancer risk, as determined by the Monte Carlo simulations, is plotted along the ordinate (y-axis). Exposure variables are as shown in Table 1, except that the oral absorption factor (ABS_o) was varied from the baseline case of 0.1 to include values of 0.2 and 0.4.

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relative to the ingested dose. Even at an assumed value of 0.4, the EPA default value (USEPA 1992c), the LCR associated with a not-to-exceed (NTE) TCDD standard of 50 ng/g (ppb) is below 100 per million (i.e., 48 per million).

Figure 8 shows the results of the sensitivity analyses concerning the dermal absorption factor. A uniform distribution between the EPA-recommended values of 0.001 and 0.03 was assumed for the baseline case, as shown in Table 1. These values are EPA's generic default assumptions (USEPA 1992d). Testing conducted by Gallo and Meeker (1993) suggests that TCDD in surface soils at the Site are not as bioavailable as was TCDD in the soil samples from other sites that formed the basis for EPA's generic default values.[4] Hence, the dermal bioavailability of TCDD in Site soils may be lower than was assumed in ENVIRON's baseline case. Alternatively, maximum values of 0.01 and 0.003 were assumed for the sensitivity runs. A uniform distribution with 0.001 as the miniumum value was assumed for each of the sensitivity runs. The results show that the LCR values for a trespasser are sensitive to the maximum value assumed for the dermal absorption factor. The LCR associated with a not-to-exceed (NTE) TCDD standard of 50 ng/g (ppb) decreased from 43 per million (maximum of 0.03) to 7 per million (maximum of 0.003).

Figure 9 shows the results of the sensitivity analyses concerning the exposure frequency. In each case, an exponential distribution was assumed for this exposure factor, but the curvature parameter (β) was varied from the baseline case of 17.6 days to values of 13.2 and 8.8 days. Lower values of β were evaluated because of the suggestion by EPA

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[4] In addition, actual absorption of TCDD into human skin from soil is likely to be less than has been observed experimentally, because animal testing has typically used dense coatings of contaminated soil on skin. The dense coatings enhance dermal permeation rates and exceed the amount of soil adherence that would be expected to occur naturally (USEPA 1992d).

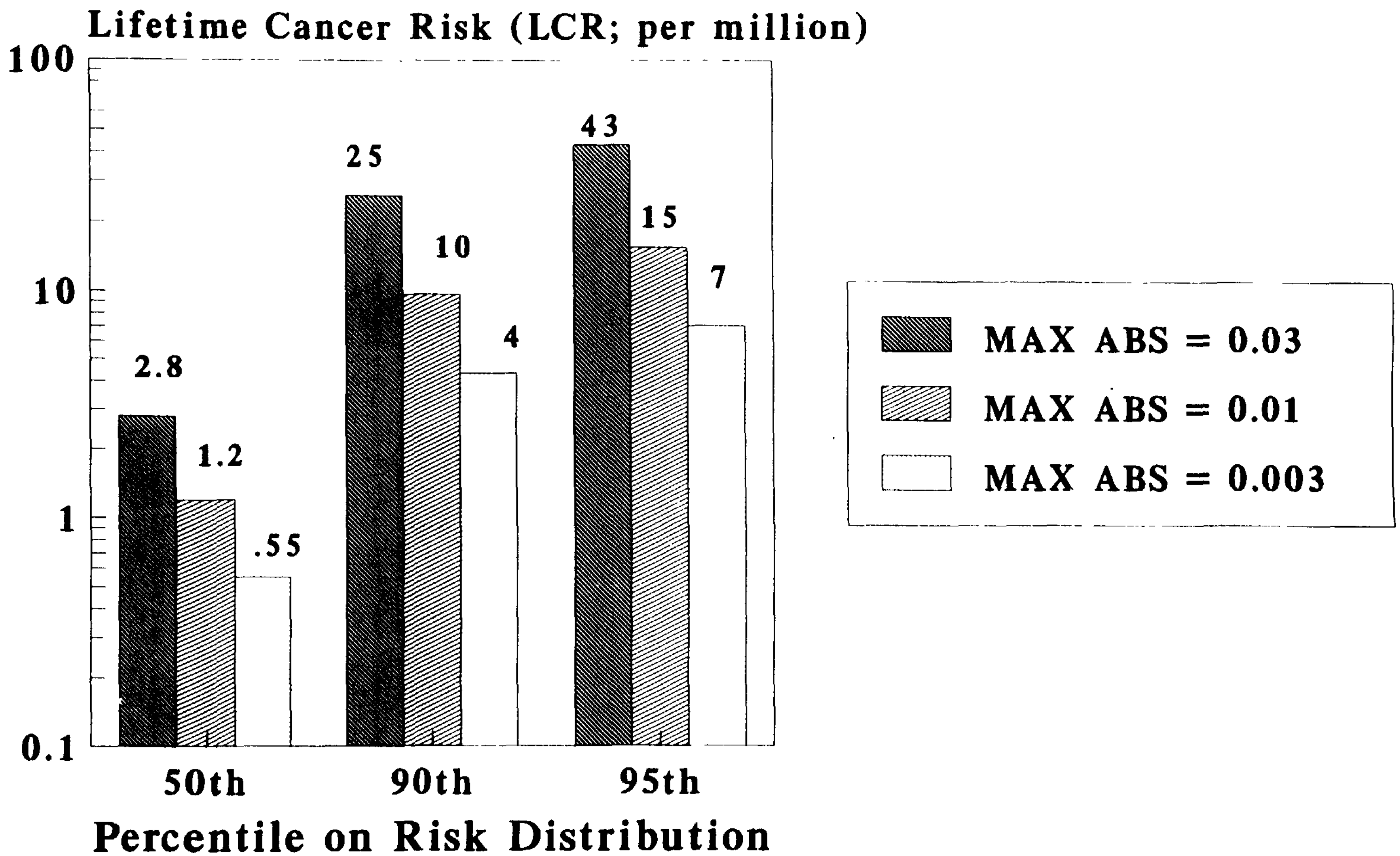

Figure 8: Sensitivity of Cancer Risk to an Adult Trespasser to the Dermal Absorption Factor

This figure shows selected values on the cumulative distribution (i.e., 50th, 90th, and 95th percentiles) of LCRs for adult trespassers in the proposed fenced areas exposed to TCDD after remediation to a not-to-exceed cleanup standard of 50 ng/g, assuming an exposure concentration of 8.9 ng/g. Lifetime cancer risk, as determined by the Monte Carlo simulations, is plotted along the ordinate (y-axis). Exposure variables are as shown in Table 1, except that the maximum value of the dermal absorption factor (ABS_d) was varied from the baseline case of 0.03 to include values of 0.01 and 0.003.

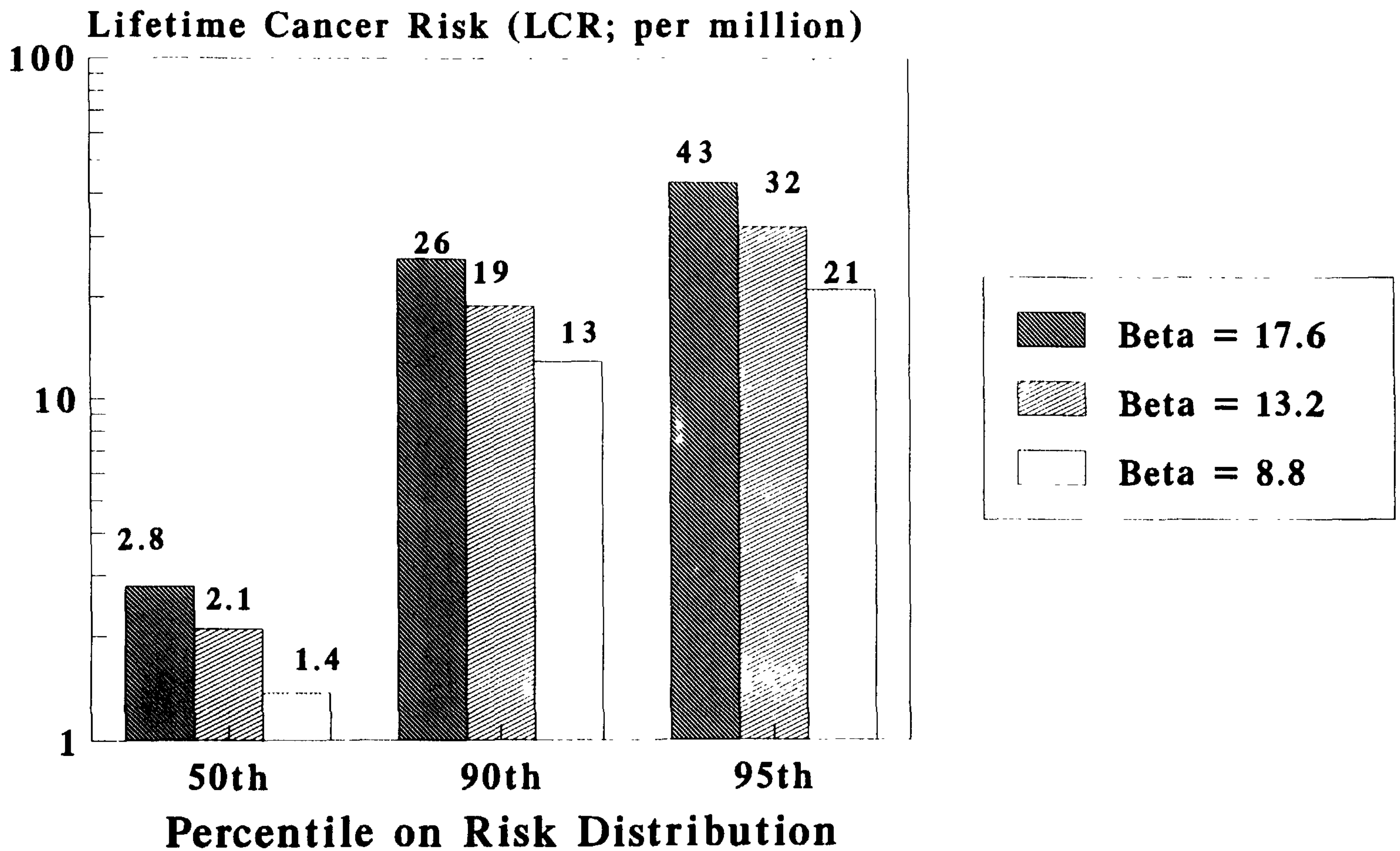

Figure 9: Sensitivity of Cancer Risk to an Adult Trespasser to the Exposure Frequency Distribution

This figure shows selected values on the cumulative distribution (i.e., 50th, 90th, and 95th percentiles) of LCRs for adult trespassers in the proposed fenced areas exposed to TCDD after remediation to a not-to-exceed cleanup standard of 50 ng/g, assuming an exposure concentration of 8.9 ng/g. Lifetime cancer risk, as determined by the Monte Carlo simulations, is plotted along the ordinate (y-axis). Exposure variables are as shown in Table 1, except that the exposure frequency (EF) distribution was varied by changing the curvature parameter (β, or Beta) from the baseline case of 17.6 days.

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personnel that the baseline case appeared to be conservative.[5] The results indicate that the LCR values are sensitive to the β-factor. The 95th percentile LCR for a not-to-exceed standard of 50 ng/g decreased from 43 per million (β = 17.6 days) to 21 per million (β = 8.8 days).

Figure 10 shows the results of the sensitivity analyses concerning the cancer slope factor. The rationale for these sensitivity analyses is that EPA is re-examining its cancer slope factor for TCDD, which is currently 156,000 $[mg/kg\text{-}day]^{-1}$. The alternative values considered (80,000 $[mg/kg\text{-}day]^{-1}$ and 9,700 $[mg/kg\text{-}day]^{-1}$) represent plausible interpretations of the available animal data. The results show that the LCR values are sensitive to the SF value. The 95th percentile LCR for a not-to-exceed standard of 50 ng/g decreased from 43 per million (SF_{oral} = 156,000 $[mg/kg\text{-}day]^{-1}$) to 3 per million (SF_{oral} = 9,700 $[mg/kg\text{-}day]^{-1}$).

D. Probability Distribution of Noncancer Risk Measures

The non-cancer Hazard Quotient (HQ) was also calculated in this analysis, using the exposure factor distributions shown in Table 1. As shown below, the total HQ for an on-site trespasser exposed to surface soils is assumed to be the sum of the HQs from dermal contact and incidental ingestion.

$$HQ_{total} = HQ_{dermal} + HQ_{ingest} \quad (4)$$

where:
- HQ_{total} = Total hazard quotient
- HQ_{dermal} = Hazard quotient from dermal contact with soil
- HQ_{ingest} = Hazard quotient from incidental soil ingestion

[5] The lower the β-factor, the lower is the average value of exposure frequency (EF, units days/yr), as indicated below:

β-factor	Expected (average) value of EF (days/yr)	Probability that EF is greater than 52 days/yr
17.6 days	17.6	0.050 (5%)
13.2 days	13.2	0.019 (1.9%)
8.8 days	8.8	0.003 (0.3%)

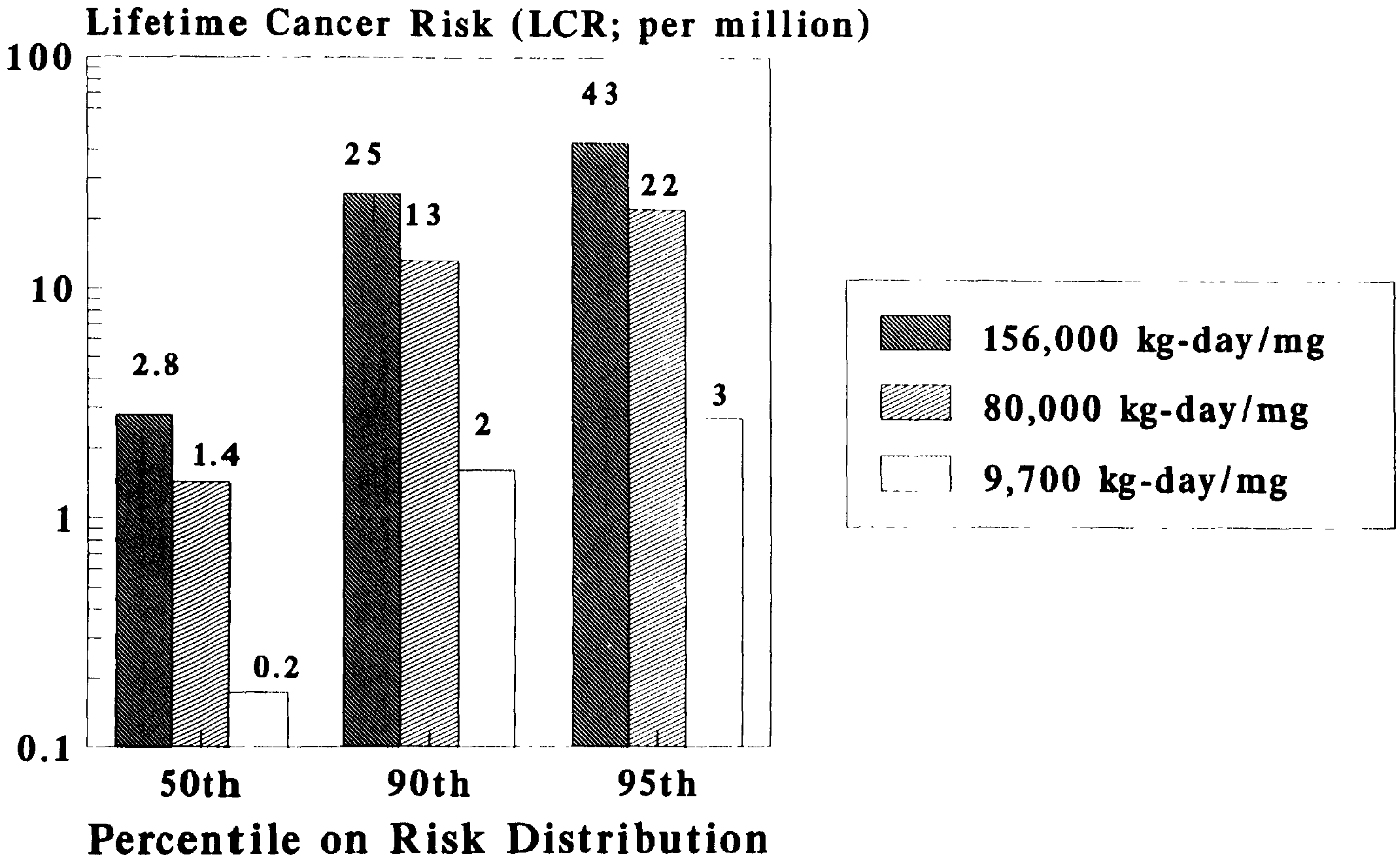

Figure 10: Sensitivity of Cancer Risk to an Adult Trespasser to the Cancer Slope Factor

This figure shows selected values on the cumulative distribution (i.e., 50th, 90th, and 95th percentiles) of LCRs for adult trespassers in the proposed fenced areas exposed to TCDD after remediation to a not-to-exceed cleanup standard of 50 ng/g, assuming an exposure concentration of 8.9 ng/g. Lifetime cancer risk, as determined by the Monte Carlo simulations, is plotted along the ordinate (y-axis). Exposure variables are as shown in Table 1. The cancer slope factor for TCDD ingestion was varied from the baseline case of 156,000 $[mg/kg\text{-}day]^{-1}$ to alternative plausible values and the dermal slope factor was adjusted according to EPA guidance (USEPA 1992c, p. 4-4); i.e., $SF_{dermal} = SF_{oral} \div 0.55$.

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The equations used to calculate the HQ-values for annualized exposures are as follows:

Dermal Contact:

$$HQ_{dermal,sc} = \frac{C_s \; x \; SA \; x \; FS \; x \; AF \; x \; ABS_d \; x \; EF}{BW \; x \; 365 \; x \; 10^6 \; x \; ADI_{dermal,sc}} \quad (5)$$

where:

$ADI_{dermal,sc}$	=	Subchronic acceptable daily intake for the dermal route (mg/kg-day)
365	=	Number of days per year (conversion factor to estimate an annualized exposure)

and all other factors are as described previously.

Incidental Ingestion:

$$HQ_{ingest,sc} = \frac{C_s \; x \; IR \; x \; FI \; x \; ABS_o \; x \; EF}{BW \; x \; 365 \; x \; 10^6 \; x \; ADI_{oral,sc}} \quad (6)$$

where:

$ADI_{oral,sc}$ = Subchronic acceptable daily intake for the oral route (mg/kg-day)

and all other factors are as described previously. Sub-chronic HQ values were developed using the sub-chronic Acceptable Daily Intake ($ADI_{oral,sc}$) derived by ENVIRON for ingestion of 2,3,7,8-TCDD (6.5 pg/kg-day, see Appendix C). USEPA risk assessment guidance indicates that the sub-chronic ADI applies to exposure durations of as much as 7 years, or one-tenth of a human lifetime. An ADI of 3.6 pg/kg-day was assumed for dermal exposure (i.e., $ADI_{dermal,sc}$), based upon EPA's assessment that 55% of the applied dose is absorbed by test animals in feeding studies (USEPA 1992c, p. 4-4); i.e., $ADI_{dermal,sc} = 0.55 * ADI_{oral,sc}$).

Figure 11 shows the cumulative distribution for the sub-chronic HQ for an adult trespasser in the proposed fenced area of the Site exposed to TCDD in surface soil after remediation to a not-to-exceed cleanup standard of 50 ng/g. Two curves are presented:

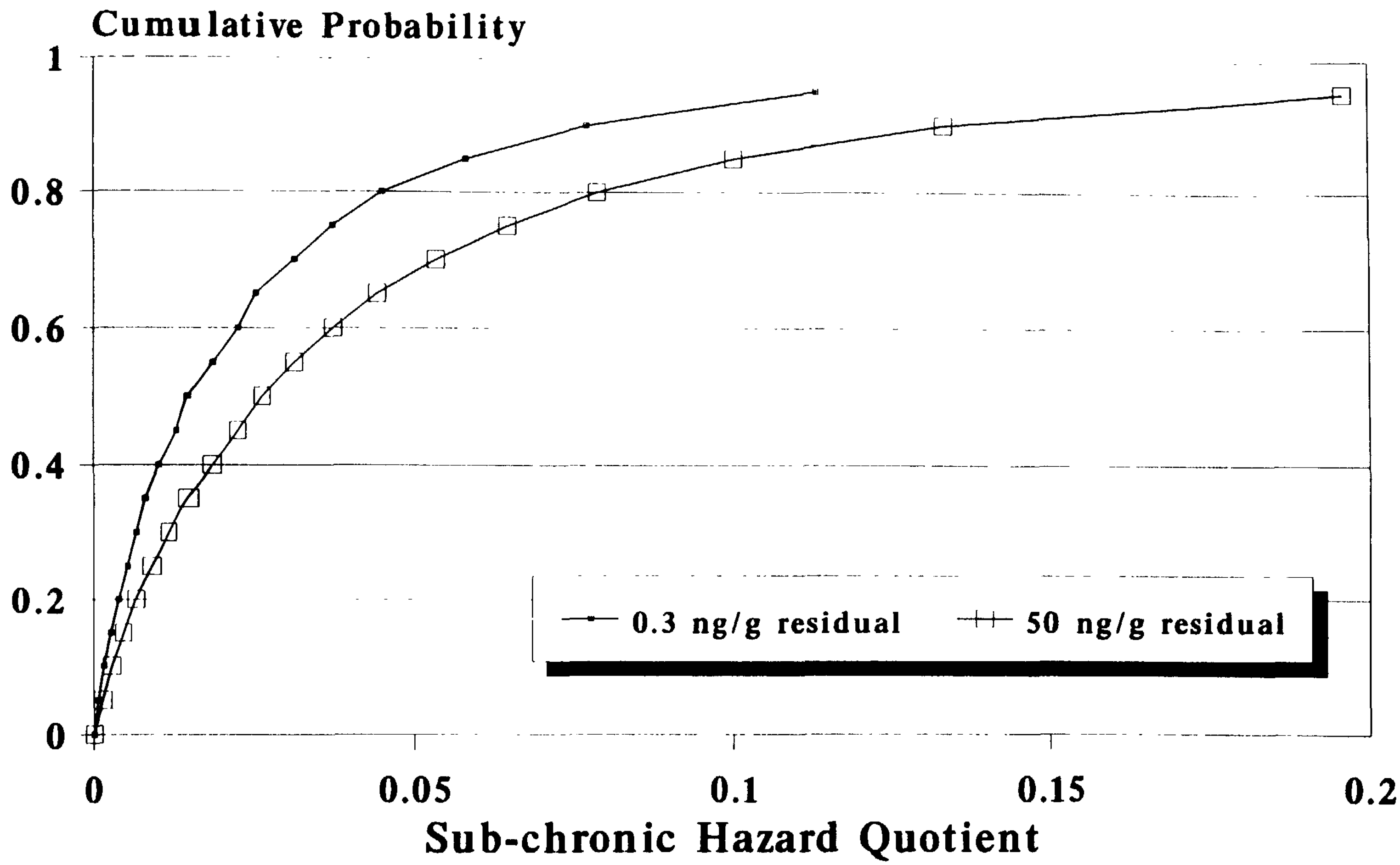

Figure 11: Cumulative Distribution of Sub-chronic Hazard Quotient for an Adult Trespasser in the Proposed Fenced Area at the Vertac Site after Remediation of Surface Soil to a Not-to-exceed Level of 50 ng/g TCDD

This figure shows the hazard quotient distribution for direct contact with surface soil. Sub-chronic hazard quotient (HQ_{sc}) for an individual (determined by Equations 4 through 6) is plotted along the abscissa (x-axis). The ordinate (y-axis) shows the cumulative probability, as determined by the Monte Carlo simulations (see Appendix B). This figure indicates that the 95th percentile HQ_{sc} value is 0.2, assuming an exposure concentration of 8.9 ng/g (grids remediated to 50 ng/g; see Figure 4); 95% of trespassing individuals exposed to 2,3,7-8-TCDD in the gridded areas within the proposed fenced area after remediation would have a HQ_{sc} equal to or less than this value.

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1) assuming a soil concentration (C_s, see Equations 4-6) of 8.9 ng/g, which is the arithmetic mean of the 95%-UCL concentrations of TCDD concentrations remaining in the fenced portion of the gridded areas of the Site after grids with 95%-UCL concentrations greater than 50 ng/g are remediated to 50 ng/g; and

2) assuming a soil concentration (C_s, see Equations 4-6) of 5.2 ng/g, which is the arithmetic mean of the 95%-UCL concentrations of TCDD concentrations remaining in the fenced portion of the gridded areas of the Site after grids with 95%-UCL concentrations greater than 50 ng/g are remediated to 0.3 ng/g (the upper end of detection limits for TCDD in site soils).

These exposure concentrations are taken from Figure 4. For these assumptions, the Monte Carlo simulations indicate that 50 percent of trespassing individuals exposed to surface soil in the proposed fenced area of the Site (i.e., exposure concentration of 8.9 ng/g or less) would have an HQ of 0.03 or less. The 95th-percentile sub-chronic HQ, an example of a "high end" exposure, is 0.20 or less. Both of these values are well below the value of 1 that EPA typically regards as acceptable (USEPA 1991). The actual HQ values may be lower, because these calculations:

1) do not take into account any photolytic degradation of 2,3,7,8-TCDD at the soil surface, and

2) used conservative estimates of the TCDD exposure concentration (i.e., averages of upper-bound concentrations; see Figures 2 and 4); and

3) do not take into account the fact that ungridded, previously remediated soil areas are believed not to contain TCDD.

Table 2 presents various subchronic HQ values on the probability distribution for adult trespassers for not-to-exceed cleanup standards of 75 ng/g, 50 ng/g, 35 ng/g, and 20 ng/g. The 95th-percentile HQ-values for these cases indicate that with a not-to-exceed cleanup standard of as high as 75 ng/g, an adult trespasser with "high end" exposures would have a sub-chronic HQ well below the value of unity typically deemed acceptable by EPA.

ENVIRON also considered a one-time (i.e., acute) exposure to the <u>maximum</u> upper-bound grid concentration remaining on-site after remediation at various cleanup standards.

In addition to equation 4, the equations used to calculate the acute HQ-values for one-time exposures are as follows: 0017 3

Dermal Contact:

$$HQ_{dermal,ac} = \frac{C_{s,max}\ x\ SA\ x\ FS\ x\ AF\ x\ ABS_d}{BW\ x\ 10^6\ x ADI_{dermal,ac}} \qquad (7)$$

where:

$C_{s,\ max}$ = Maximum TCDD concentration in any unremediated grid (mg/kg)

$ADI_{dermal,ac}$ = Acute acceptable daily intake for the dermal route (mg/kg-day)

and all other factors are as described previously.

Incidental Ingestion:

$$HQ_{ingest,ac} = \frac{C_{s,max} \; x \; IR \; x \; FI \; x \; ABS_o}{BW \; x \; 10^6 \; x \; ADI_{oral,ac}} \qquad (8)$$

where:

$ADI_{oral,ac}$ = Acute acceptable daily intake for the oral route (mg/kg-day)

and all other factors are as described previously. Based upon the toxicological evaluation presented in Appendix C, an acute oral ADI of 64 pg/kg-day (i.e., $ADI_{oral,ac}$) was established for these calculations. An ADI of 55 pg/kg-day was assumed for acute, dermal exposure (i.e., $ADI_{dermal,ac}$), based upon an assessment that 86% of the applied dose is absorbed by test animals that are fed TCDD in corn oil (USEPA 1992c, p. 4-3); i.e., $ADI_{dermal,ac}$ = 0.86 * $ADI_{oral,ac}$).

Table 2 presents various acute HQ values on the probability distribution for trespassers for not-to-exceed cleanup standards of 75 ng/g, 50 ng/g, 35 ng/g, and 20 ng/g. The 95th percentile HQ values indicate that an adult trespasser with "high end" exposures would have an acute HQ equal to 1 with a not-to-exceed cleanup standard of 50 ng/g.

As with the LCR values, ENVIRON conducted sensitivity analyses concerning the acute HQ to characterize technical uncertainties associated with exposure variables. Two exposure factors were evaluated:

- oral bioavailability factor (ABS_o; equation 8); and
- dermal absorption factor (ABS_d; equation 7).

The rationale for and approach to these sensitivity analyses are identical to the respective sensitivity analyses for LCR values.

Figure 12 shows the results of the sensitivity analyses concerning the oral bioavailability factor. Point estimates of 0.4 and 0.2 were tested, in addition to the baseline value of 0.1, as shown in Table 1. The rationale for these sensitivity analyses is that EPA's default value, 0.4 or 40% (USEPA 1992c), is higher than the site-specific value obtained through the study by Gallo and Meeker (1993). The results show that the acute HQ for a trespasser is not

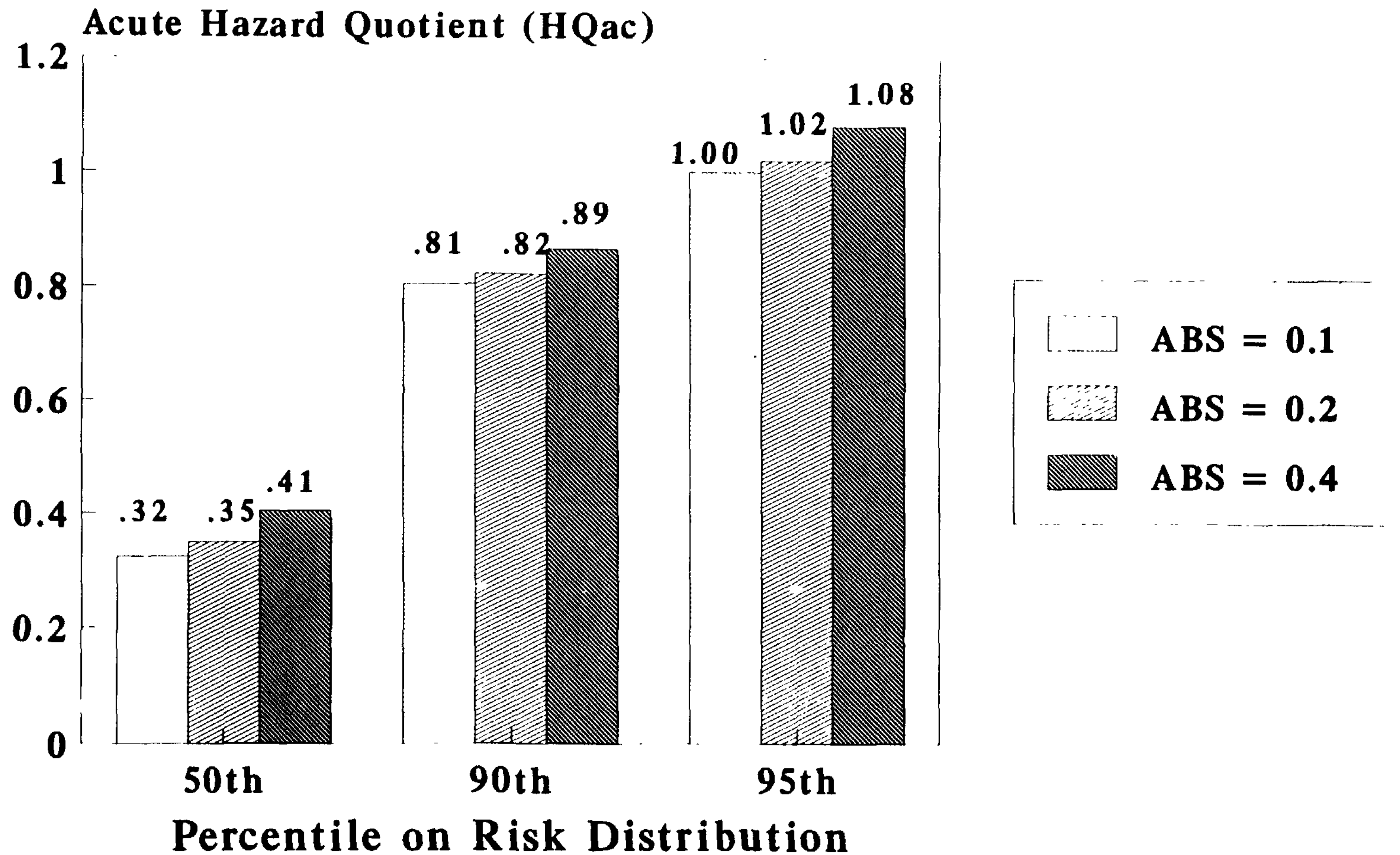

Figure 12: Sensitivity of the Acute Hazard Quotient for an Adult Trespasser to the Oral Absorption Factor

This figure shows selected values on the cumulative distribution (i.e., 50th, 90th, and 95th percentiles) of the acute Hazard Quotient (HQ_{ao}) for adult trespassers in the proposed fenced areas exposed to the maximum upper-bound concentration of TCDD after remediation to a not-to-exceed cleanup standard of 50 ng/g. Hazard quotient, as determined by the Monte Carlo simulations, is plotted along the ordinate (y-axis). Exposure variables are as shown in Table 1, except that the oral absorption factor (ABS_o) was varied from the baseline case of 0.1 to include values of 0.2 and 0.4.

greatly sensitive to the value chosen for oral absorption. This pattern occurs because the dermal exposure route is modeled in such a way that it yields a substantially higher predicted dose, relative to the ingested dose. The acute HQ associated with a not-to-exceed (NTE) TCDD standard of 50 ng/g (ppb) increased from 1.00 (oral aborption of 0.1) to only 1.08 (oral absorption of 0.4, the EPA default value (USEPA 1992c)).

Figure 13 shows the results of the sensitivity analyses concerning the dermal absorption factor. A uniform distribution between the EPA-recommended values of 0.03 and 0.001 was assumed for the baseline case, as shown in Table 1. These values are EPA's generic default assumptions (USEPA 1992d). Testing conducted by Gallo and Meeker (1993) and the test conditions used to develop EPA's default values collectively suggest that the dermal bioavailability of TCDD in Site soils may be lower than was assumed in ENVIRON's baseline case (see previous discussion on p. 20 of this report). Alternatively, maximum values of 0.01 and 0.003 were assumed for the sensitivity runs. A uniform distribution with 0.001 as the miniumum value was assumed each of the sensitivity runs. The results show that the acute HQ values for a trespasser are sensitive to the maximum value assumed for the dermal absorption factor. The acute HQ associated with a not-to-exceed (NTE) TCDD standard of 50 ng/g (ppb) decreased from 1.00 (maximum of 0.03) to 0.14 (maximum of 0.003).

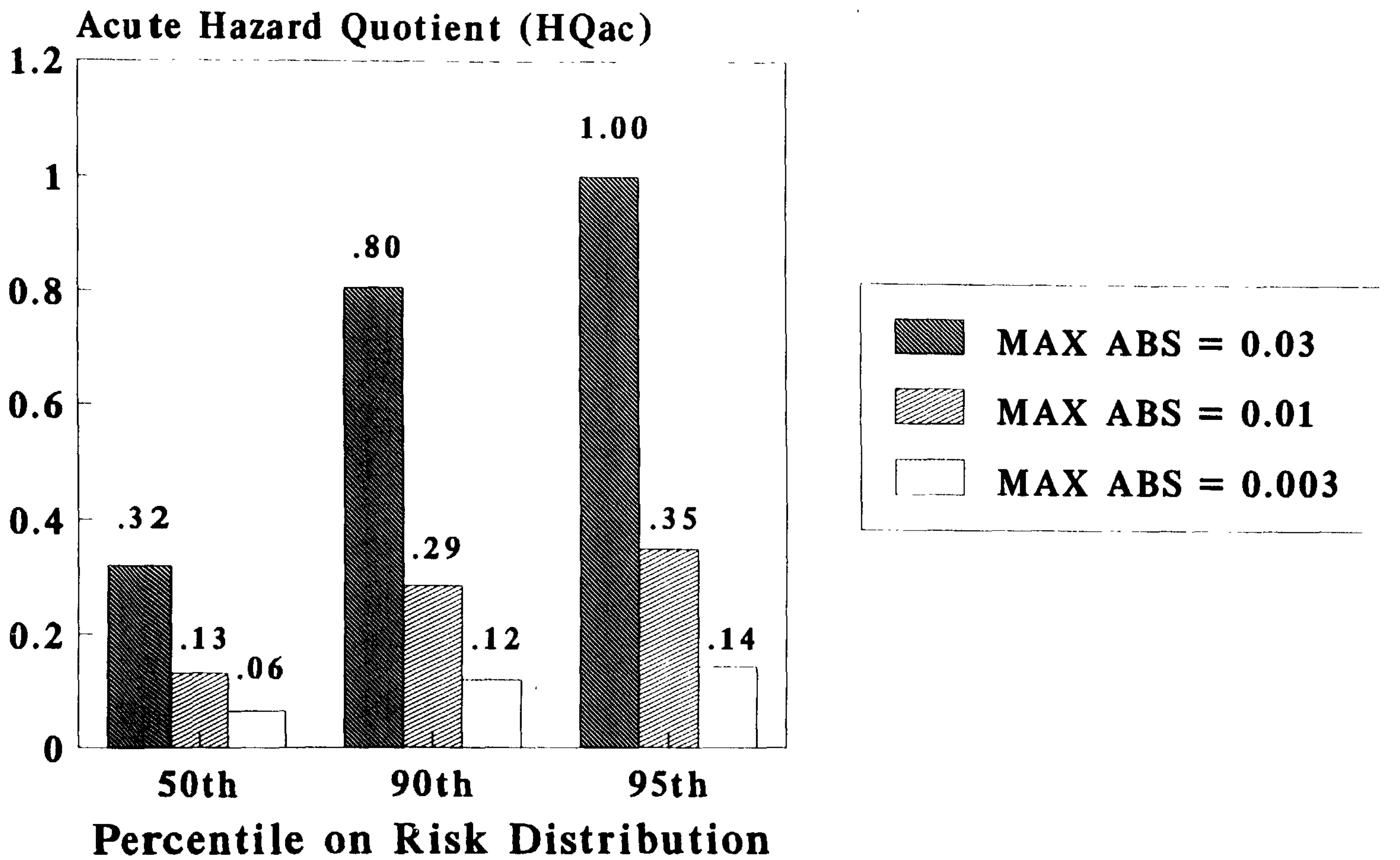

Figure 13: Sensitivity of the Acute Hazard Quotient for an Adult Trespasser to the Dermal Absorption Factor

This figure shows selected values on the cumulative distribution (i.e., 50th, 90th, and 95th percentiles) of the acute Hazard Quotient (HQ_{ac}) for adult trespassers in the proposed fenced areas exposed to the maximum upper-bound concentration of TCDD after remediation to a not-to-exceed cleanup standard of 50 ng/g. Hazard quotient, as determined by the Monte Carlo simulations, is plotted along the ordinate (y-axis). Exposure variables are as shown in Table 1, except that the maximum value of the dermal absorption factor (ABS_d) was varied from the baseline case of 0.03 to include values of 0.01 and 0.003.

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E. Prospective Cleanup Levels under a Soil Cap

On the basis of the results above, a not-to-exceed standard of 50 ng/g would satisfy USEPA's acceptable risk criteria for trespassing individuals with "high end" exposures. If adopted at this Site, gridded areas of the Site that have upper-bound TCDD concentrations less than 50 ng/g would not be remediated.

As part of the FS for on-site soils, Hercules evaluated remediation options for those gridded portions of the Site that have upper-bound TCDD concentrations greater than 50 ng/g, including containment in place (e.g., clean soil cover) and soil removal and treatment (Weston 1994). With these options exposures to TCDD concentrations greater than 50 ng/g (or other cleanup standard) are precluded by installing a barrier, in the case of containment in place, or removing the source material.

In the Times Beach Record of Decision (USEPA 1988, Attachment 1), EPA Region VII outlined a strategy for remedial action in which TCDD concentrations greater than a specified cleanup standard could be left in place underneath a barrier (e.g., clean soil cover or asphalt pavement). In a letter dated July 30, 1987 from Dr. Renata Kimbrough to Mr. David Wagoner, the Centers for Disease Control (CDC) proposed a quantitative approach to establishing concentration levels that are suitable for simple capping and are protective in the instance that the cap is somehow disturbed (USEPA 1988, Attachment 1). In that letter, it is suggested that a 12-inch cover of clean soil provides a 10-fold safety factor, such that if contaminated soil with a concentration of C_0 were contained underneath the soil cover, then the potential exposure concentration (C_e) would be $C_0 \div 10$ if the cover were somehow breached and the contaminated soil mixed with overlying cover material. This safety factor can be rationalized by assuming that 12 inches of clean soil are mixed by approximately 1 inch of contaminated soil at the soil/cover interface, or

$$C_e = C_0 \ x \ \frac{d_{surface}}{d_{cover}} \qquad (9)$$

where:

C_0	=	TCDD concentration in surface soil underneath the cap (ng/g)
d_{cover}	=	depth of clean soil cover (e.g., 12 inches)
$d_{surface}$	=	depth of contaminated soil assumed to be mixed with the overlying clean cover material (i.e., 1 inch), if the cover is breached

Under these assumptions, the ratio d_{cover} to $d_{surface}$ is 12 and becomes 10 when rounded to one significant figure. Given this quantitative approach, a 4-foot cap provides a safety factor of approximately 50 (48 inches divided by 1 inch, rounded to one significant figure).

In the case of trespasser exposures, a 50-ng/g cleanup standard yields acceptable risk measures for both long-term and short-term exposures. Setting C_e to be 50 ng/g, the analysis above (i.e., re-arranging Equation 9 to solve for C_0) indicates that TCDD concentrations up to 500 ng/g can be safely remediated by a 12-inch cover of clean soil and that TCDD concentrations up to 2,500 ng/g can be safely remediated by a 48-inch cap.

III. SUMMARY AND CONCLUSIONS

Monte Carlo simulations of exposure variability and an evaluation of site data for TCDD in surface soil indicate that application of a not-to-exceed standard of 50 ng/g TCDD at the Vertac Chemical site would result in:

- a "grid-wide" average concentration of TCDD of up to 6.7 ng/g over all grids site-wide, compared to 22.5 ng/g for the unremediated gridded area;

- an average concentration of TCDD of up to 8.9 ng/g over all grids within the area proposed for fencing, compared to 30.3 ng/g without remediation;

- acceptable risk measures (LCR < 100 per million, sub-chronic HQ < 1) for the 95th percentile individual exposed to the average of the 95% UCL concentrations of TCDD remaining in gridded portions of the Site; and

- acceptable acute HQ values (0.32 for the median and 1.00 for the 95th percentile) for an individual exposed once to the maximum concentration of 48 ng/g remaining in any unremediated grid.

On the basis of these results, a not-to-exceed standard of 50 ng/g would satisfy USEPA's acceptable risk criteria for trespassing individuals with "high end" exposures. Actual risks to adult trespassers associated with a 50 ng/g cleanup level may be much lower than those shown in Section II of this report, because:

1) the cancer potency for ingestion of 2,3,7,8-TCDD may not be as high as previously estimated by EPA;

2) the risk calculations do not take into account any photolytic degradation of 2,3,7,8-TCDD at the soil surface; and

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3) the risk calculations used conservative estimates of the TCDD exposure concentration (i.e., averages of upper-bound concentrations; see Figures 2 and 4) and do not take into account the fact that ungridded, previously remediated soil areas are believed not to contain TCDD.

Using an approach developed by CDC (see Equation 9), it was determined that TCDD concentrations up to 500 ng/g can be safely remediated by a 12-inch cover of clean soil and that TCDD concentrations up to 2,500 ng/g can be safely remediated by a 48-inch cap, since a 50-ng/g cleanup standard yields acceptable risk measures for adult trespassers.

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APPENDIX A
UPPER-BOUND TCDD CONCENTRATIONS IN SURFACE SOIL GRIDS

Reprinted from *Phase I Remedial Investigation Report for O.U. II, On-site Areas, Vertac Site Jacksonville, Arkansas, Volume I*, prepared by Roy F. Weston, Inc. December 1992.

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Table 4-2

Rank Order of 2,3,7,8-TCDD at Upper 95% Confidence Limit by Grid (a)
Vertac Site, Jacksonville, Arkansas

Rank Order	Grid Number	Upper 95% Confidence Limit (ng/g)	Rank Order	Grid Number	Confidence Limit (ng/g)
1	419	2800	41	400	28
2	470	1200	42	485	27
3	152	744	43	464	26
4	417	660	44	466	25
5	418	510	45	163	24
6	558	430 (b)	46	425	24
7	188	291	47	467	24
8	471	261	48	207	23 (R)
9	164	146	49	428	23
10	153	130	50	452	23
11	427	120	51	433	23
12	151	120	52	468	22
13	189	117	53	536	20
14	192	109	54	474	20
15	431	100	55	199	19
16	534	100	56	429	19
17	575	98	57	448	18
18	420	88	58	424	18
19	162	84 (R)	59	454	18
20	545	77	60	426	18
21	436	72	61	535	17
22	546	70	62	579	17
23	416	68	63	415	17
24	532	62	64	473	16
25	573	61	65	173	16
26	460	57	66	430	16
27	459	48	67	475	16
28	435	45	68	580	15
29	158	44	69	432	15
30	537	42	70	548	15 (b)
31	422	42	71	157	14
32	458	38	72	197	14 (b)(R)
33	461	37	73	563	14 (b)
34	421	37	74	444	14
35	184	35	75	538	13
36	574	34	76	495	11
37	161	33	77	445	11
38	446	32	78	493	11
39	469	29	79	456	11
40	542	28	80	476	10

Table 4-2

Rank Order of 2,3,7,8-TCDD at Upper 95% Confidence Limit by Grid (a)
Vertac Site, Jacksonville, Arkansas

Rank Order	Grid Number		Upper 95% Confidence Limit (ng/g)	
81	451		10	
82	450		10	
83	549		10	(b)
84	401		10	
85	208		9.6	(R)
86	463		9.5	
87	478		9.0	
88	477		8.9	
89	186		8.6	
90	480		8.5	
91	406		8.1	
92	578		7.9	
93	465		7.6	
94	434		7.3	
95	149		7.3	
96	453		7.2	
97	229		7.0	(R)
98	440		7.0	
99	533		6.9	
100	457		6.8	
101	202	grab	6.7	(b)(R)
102	438		6.6	
103	198		6.4	(b)(R)
104	529		6.3	(b)
105	499		6.0	
106	203		5.5	(c)
107	449		5.5	
108	174		5.5	
109	271		5.4	(c)
110	577		5.3	
111	572		5.2	
112	585		5.2	
113	559		4.9	(b)
114	462		4.8	
115	437		4.8	
116	482		4.8	
117	150		4.7	
118	547		4.5	
119	442		4.5	
120	172		4.4	

Rank Order	Grid Number		Confidence Limit (ng/g)	
121	441		4.3	
122	187		4.3	
123	412		4 2	
124	802		4.1	
125	211		4.1	
126	447		4.0	
127	819		3.9	
128	455		3.9	
129	439		3.5	
130	541		3.5	
131	820		3.3	
132	488		3.3	
133	402		3.3	
134	272		3.2	(c)
135	414		3.1	
136	561		3.1	(b)
137	947		3.1	(b)
138	281		3.0	(c)
139	562		3.0	(b)
140	144		3.0	
141	490		2.9	
142	803		2.9	
143	550		2.8	(b)
144	201	grab	2.8	(b)
145	282		2.8	(c)
146	491		2.7	
147	551		2.7	
148	544		2.7	
149	498		2.6	
150	487		2.5	
151	539		2.4	
152	543		2.3	
153	410		2.3	
154	155		2.3	
155	180		2.2	
156	407		2.2	
157	159		2.2	(c)
158	494		2.2	
159	576		2.0	
160	443		2.0	

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Table 4-2

Rank Order of 2,3,7,8-TCDD at Upper 95% Confidence Limit by Grid (a)
Vertac Site, Jacksonville, Arkansas

Rank Order	Grid Number	Upper 95% Confidence Limit (ng/g)	Rank Order	Grid Number	Confidence Limit (ng/g)
161	501	2.0 (b)	201	408	1.1
162	179	2.0	202	268	1.1 (c)
163	21	1.9	203	273	1.1 (c)
164	190	1.9	204	22	1.1
165	220	1.9 (R)	205	817	1.1
166	175	1.9	206	166	1.0
167	177	1.9	207	571	0.99
168	411	1.9	208	815	0.97
169	481	1.8	209	489	0.94
170	492	1.8	210	405	0.91
171	154	1.8	211	565	0.89
172	191	1.7	212	274	0.89 (c)
173	423	1.7	213	500	0.89 (b)
174	219	1.7	214	145	0.87
175	156	1.7	215	200 grab	0.87 (b)
176	8	1.7	216	185	0.86
177	176	1.6	217	213	0.86
178	17	1.6	218	583	0.84
179	108	1.6	219	182	0.83
180	160	1.6 (c)	220	805	0.80
181	147	1.6	221	568	0.78
182	404	1.5	222	169	0.77
183	486	1.5	223	584	0.77
184	564	1.5 (b)	224	801	0.76
185	483	1.5	225	181	0.74
186	221	1.4	226	85	0.72
187	413	1.3	227	129	0.71
188	7	1.3	228	227	0.69 (c)(R)
189	170	1.3	229	265	0.68 (c)
190	178	1.3	230	526	0.66 (b)
191	512	1.3 (b)	231	581	0.65
192	557	1.3 (b)	232	212	0.65
193	146	1.3	233	139	0.63
194	403	1.3	234	570	0.63
195	196	1.3	235	230	0.62 (c)
196	270	1.2 (c)	236	195	0.56
197	804	1.2	237	525	0.56 (b)
198	148	1.2	238	528	0.56 (b)
199	484	1.2	239	128	0.55
200	540	1.2	240	210	0.55

Table 4-2

Rank Order of 2,3,7,8-TCDD at Upper 95% Confidence Limit by Grid (a)
Vertac Site, Jacksonville, Arkansas

Rank Order	Grid Number	Upper 95% Confidence Limit (ng/g)	
241	280	0.55	(c)
242	409	0.51	
243	126	0.51	
244	194	0.51	
245	522	0.51	(b)
246	906	0.50	(b)
247	908	0.50	(b)
248	910	0.50	(b)
249	919	0.50	(b)
250	926	0.50	(b)
251	927	0.50	(b)
252	939	0.50	(b)
253	940	0.50	(b)
254	941	0.50	(b)
255	942	0.50	(b)
256	943	0.50	(b)
257	949	0.50	(b)
258	926A	0.50	(b)
259	567	0.50	
260	20	0.49	
261	130	0.48	
262	193	0.48	
263	506	0.48	(b)
264	816	0.47	
265	171	0.45	
266	807	0.45	
267	813	0.44	
268	818	0.44	
269	269	0.43	(c)
270	267	0.41	(c)
271	558	0.40	(b)
272	183	0.39	
273	810	0.39	
274	275	0.38	(c)
275	566	0.38	
276	569	0.38	
277	80	0.37	
278	254	0.37	(c)
279	250	0.35	(c)
280	123	0.34	

Rank Order	Grid Number	Confidence Limit (ng/g)	
281	125	0.33	
282	510	0.33	(b)
283	127	0.31	
284	504	0.31	(b)
285	1	0.30	
286	2	0.30	
287	3	0.30	
288	4	0.30	
289	5	0.30	
290	6	0.30	
291	9	0.30	
292	10	0.30	
293	11	0.30	
294	12	0.30	
295	13	0.30	
296	14	0.30	
297	15	0.30	
298	16	0.30	
299	18	0.30	
300	19	0.30	
301	23	0.30	
302	24	0.30	
303	25	0.30	
304	26	0.30	
305	27	0.30	
306	28	0.30	
307	29	0.30	
308	30	0.30	
309	31	0.30	
310	32	0.30	
311	33	0.30	
312	34	0.30	
313	35	0.30	
314	36	0.30	
315	37	0.30	
316	38	0.30	
317	39	0.30	
318	40	0.30	
319	41	0.30	
320	42	0.30	

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Table 4-2

Rank Order of 2,3,7,8-TCDD at Upper 95% Confidence Limit by Grid (a)
Vertac Site, Jacksonville, Arkansas

Rank Order	Grid Number	Upper 95% Confidence Limit (ng/g)
321	43	0.30
322	44	0.30
323	45	0.30
324	46	0.30
325	47	0.30
326	48	0.30
327	49	0.30
328	50	0.30
329	52	0.30
330	53	0.30
331	54	0.30
332	55	0.30
333	56	0.30
334	57	0.30
335	58	0.30
336	62	0.30
337	63	0.30
338	64	0.30
339	65	0.30
340	66	0.30
341	67	0.30
342	68	0.30
343	69	0.30
344	70	0.30
345	71	0.30
346	72	0.30
347	73	0.30
348	74	0.30
349	75	0.30
350	76	0.30
351	77	0.30
352	78	0.30
353	79	0.30
354	81	0.30
355	82	0.30
356	83	0.30
357	84	0.30
358	86	0.30
359	87	0.30
360	88	0.30

Rank Order	Grid Number	Confidence Limit (ng/g)
361	89	0.30
362	90	0.30
363	91	0.30
364	92	0.30
365	93	0.30
366	94	0.30
367	95	0.30
368	96	0.30
369	97	0.30
370	98	0.30
371	99	0.30
372	100	0.30
373	101	0.30
374	102	0.30
375	103	0.30
376	104	0.30
377	105	0.30
378	106	0.30
379	107	0.30
380	109	0.30
381	110	0.30
382	111	0.30
383	112	0.30 (b)
384	113	0.30 (b)
385	114	0.30 (b)
386	115 grab	0.30 (b)
387	120	0.30
388	121	0.30
389	122	0.30
390	124	0.30
391	131	0.30
392	132	0.30
393	133	0.30
394	134	0.30
395	140	0.30
396	167	0.30
397	168	0.30
398	209	0.30 (R)
399	214	0.30
400	215	0.30

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Table 4-2

Rank Order of 2,3,7,8-TCDD at Upper 95% Confidence Limit by Grid (a)
Vertac Site, Jacksonville, Arkansas

Rank Order	Grid Number		Upper 95% Confidence Limit (ng/g)	
401	216		0.30	
402	217		0.30	(R)
403	218		0.30	(R)
404	222		0.30	
405	223		0.30	
406	224		0.30	
407	225		0.30	
408	226		0.30	(c)
409	228		0.30	
410	248		0.30	(c)
411	249		0.30	(c)
412	251		0.30	(c)
413	252		0.30	(c)
414	253		0.30	(c)
415	255		0.30	
416	256		0.30	(c)
417	257		0.30	(c)
418	258		0.30	(c)
419	259		0.30	(c)
420	260		0.30	(c)
421	262		0.30	(c)
422	264		0.30	(c)
423	266		0.30	(c)
424	276		0.30	(b)
425	278	grab	0.30	(b)
426	524		0.30	(b)
427	806		0.30	
428	808		0.30	
429	809		0.30	
430	811		0.30	

Rank Order	Grid Number	Confidence Limit (ng/g)	
431	812	0.30	
432	814	0.30	
433	523	0.29	(b)
434	497	0.29	
435	496	0.29	
436	472	0.28	
437	505	0.27	(b)
438	513	0.27	(b)
439	560	0.25	(b)
440	514	0.23	(b)
441	511	0.22	(b)
442	521	0.19	(b)
443	515	0.18	(b)
444	517	0.17	(b)
445	519	0.17	(b)
446	502	0.16	(b)
447	527	0.16	(b)
448	263	0.14	(c)
449	509	0.12	(b)
450	520	0.12	(b)
451	552	0.11	
452	553	0.06	
453	503	0.06	(b)
454	479	0.06	
455	582	0.06	
456	507	0.04	(b)
457	508	0.04	(b)
458	516	0.04	(b)
459	518	0.04	(b)
460	555	0.04	
461	554	0.02	

Notes:

a = This table includes all surface soil grids and grab samples, except where they were subdivided during the RI.

b = Only one sample was obtained from the grid. The result of that sample is reported as the upper 95% confidence limit.

c = Upper 95% confidence limit from U.S. EPA data maps. Individual sample data were not available.

R = Presumed to have been wholly or partially remediated.

APPENDIX B
DOCUMENTATION OF ASSUMPTIONS USED IN THE MONTE CARLO SIMULATIONS FOR SOIL EXPOSURE PATHWAYS

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APPENDIX B
DOCUMENTATION OF ASSUMPTIONS USED IN THE MONTE CARLO SIMULATION FOR SOIL EXPOSURE PATHWAYS

The exposure factor values used in the Monte Carlo simulations of exposure variability are shown in Table 1 in the main report. This Appendix provides additional information about these exposure factors for adult trespassers.

A. Body Weight

Body weight was varied using information provided in the *Exposure Factors Handbook* (USEPA 1990). The cumulative distribution of body weights for adults is shown in Table B-1.

B. Duration of Exposure

Using Bureau of the Census data, the *Exposure Factors Handbook* (USEPA 1990) presents a summary of population mobility statistics as a discrete probability distribution. The distribution of residential duration time is shown in Table B-2.

This distribution was used to represent exposure duration for trespassers, as any trespassers would most likely come from nearby residences. This distribution conservatively assumes that an individual might trespass for his/her entire period of residency. Superfund risk assessments more commonly assume that an individual trespasses only during his/her teenage years, or for some other limited portion of a lifetime.

C. Exposure Frequency

There are no standard exposure assumptions for trespassers. For any given trespasser, the exposure frequency could presumably range from 0 (zero) days per year to 365 days per year with the minimum value being indicative of normal adult behavior and the maximum value being highly atypical.[1] For purposes of the Monte Carlo simulation, an exponential distribution was assumed, because it provides a decreasing probability with increases in exposure frequency. The cumulative probability function for an exponential distribution is:

$$F(X) = Pr[x \leq X] = 1 - e^{-X/\beta}$$

where, in this case:

x	=	the random variable for exposure frequency (days/year);
X	=	particular value of exposure frequency (days/year); and
β	=	the curvature parameter (days/year).

The lower the curvature parameter (β), the lower is the average value of exposure frequency (EF; units days/yr), as indicated below:

β-factor (days/year)	Expected (average) value of EF (days/yr)	Probability that EF is greater than 52 days/yr
17.6	17.6	0.050 (5%)
13.2	13.2	0.019 (1.9%)
8.8	8.8	0.003 (0.3%)

The exponential distribution is a continuous distribution that permits values greater than 365 days/year. To mitigate the influence that this impossible outcome could have on the Monte Carlo simulations, the β-parameter was set to minimize such extreme outcomes to a cumulative probability of 1 per billion (10^{-9}) or less; on this basis, β was set at 17.6 days per year.

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[1] Because the Site is fenced and guarded, most individuals should be deterred from entering the Site. Site personnel recall only a few trespassers and no repeat trespassers over the past several years (Hercules 1993b).

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D. Daily Soil Ingestion Rate

Ingestion rates were based on information developed for dust and soil ingestion by children (Binder et al 1986). The distribution of incidental ingestion rates of soil by adults was represented as a lognormal distribution with a mean and standard deviation of 43 and 41 mg/day, respectively (Thompson et al. 1992). Because it is impossible to distinguish between ingested outdoor soil and indoor dust, this distribution was conservatively assumed to reflect outdoor soil ingestion only.

E. Fraction Ingested that Represents Contaminated Soil

There are no standard values of this factor for a trespasser. It is reasonable to assume, however, that a trespasser will not spend his/her entire waking day on-site, so that on days when trespassing only a fraction of the daily soil ingestion rate will be experienced while on-site. In this assessment, a point estimate of 0.5 (one half) was assumed for the fraction ingested that represents contaminated soil.

For comparison, EPA has recommended that half of an individual's daily water intake be assumed to occur while at work (USEPA 1991). On this basis, a value of one half (FI = 0.5) appears to be a conservative "high end" value for the fraction of soil and dust that is ingested while trespassing.

F. Total Skin Surface Area

For adult trespassers, the total surface area is an average of the surface areas for adult males and females provided in the *Exposure Factors Handbook* (USEPA 1990). This distribution is shown in Table B-3. Because there is an implicit correlation between body weight and total body surface area, ENVIRON assumed a positive correlation factor of 0.7.

G. Oral Bioavailability Factor

According to EPA's exposure assessment for dioxins, gut absorption of 2,3,7,8-TCDD in humans is approximately 20-40% of the administered dose when the vehicle is soil (USEPA 1992b, Chapter 8). The available literature indicates, however, that order-of-magnitude differences can be observed between soils from different sites and values less than 20% have been reported (Umbreit et al 1986). Therefore, a site-specific value seems most appropriate for this factor.

Gallo and Meeker (1993) conducted an oral bioavailability study on five soil samples taken from the Vertac Chemical site. Estimated factors ranged from 0.5 to 8.6% with an arithmetic mean value of 2.3%. For this risk assessment, the oral bioavailability factor value was assumed to be 10%, which is higher than any of the five measured values in the bioavailability study.

H. Fraction of Skin Area Exposed

There are no standard exposure assumptions concerning the amount of skin exposed for trespassers. As an upper-bound estimate, EPA often assumes that the head, hands, forearms, and lower legs are exposed. For adult males, this represents an average of 31.7% of the total body area, according to the *Exposure Factors Handbook* (USEPA 1990, Table 4-2). As a lower-bound estimate, the head and hands could be used; this represents an average of 13% of the total body area of adult males, according to the *Exposure Factors Handbook* (USEPA 1990, Table 4-2). For the Monte Carlo simulations, an uniform distribution was assumed with the minimum and maximum values described above.

I. Soil/Skin Adherence Factor

Soil adherence was assumed to range from 0.2 to 1 mg/cm^2 based on EPA's dermal exposure assessment guidance document (1992a). A uniform distribution was assumed.

J. Dermal Bioavailability Factor

USEPA (1992b) indicates that the dermal bioavailability factor for 2,3,7,8-TCDD is in the range of 0.1% to 3%. For the Monte Carlo simulations, a uniform distribution was assumed with these stated values for the minimum and maximum.

K. Averaging Time

An averaging time of 25,550 days (70 years x 365 days/year) was used to estimate the lifetime cancer risks, per EPA guidance (USEPA 1989).

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TABLE B-1
Cumulative Probability Distribution of Adult Body Weights[a]

Body Weight (kg)	Percentile
50[b]	0
52.3	5
55.3	10
57.6	15
61.1	25
68.7	50
77.9	75
84.4	85
89.1	90
97.0	95
100.0[b]	100

[a] Calculated as an average of male and female body weights at each respective percentile, based upon data in Tables 5A-1 and 5A-2 of the *Exposure Factors Handbook* (USEPA 1990).

[b] The 0 and 100th percentile values were estimated for purposes of the Monte Carlo simulations.

TABLE B-2
Discrete Probability Distribution of Number of Years in Current Residence[a]

Years Lived in Current Home	Percent of Total Householders
0 - 1	7.5
1 - 3	16.9
3 - 13	40.2
13 - 18	11.0
18 - 23	7.9
23 - 33	9.5
>33	7.0

[a] From the *Exposure Factors Handbook* (USEPA 1990). This distribution was used to represent trespassers under the assumption that trespassers would most likely come from nearby residences. This conservatively assumes that an individual might trespass for his/her entire period of residency.

TABLE B-3 Total Adult Body Surface Area	
Percentile	**Surface Area (m^2)**
0	1.50
5	1.56
10	1.61
15	1.64
25	1.70
50	1.82
75	1.95
85	2.03
90	2.09
95	2.19
100	2.50

Source: Total body surface area is adapted from *Exposure Factors Handbook* (USEPA 1990), by taking the average of total body surface areas for male and female populations for each respective percentile.

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APPENDIX C
DERIVATION OF A SUBCHRONIC ACCEPTABLE DAILY INTAKE FOR 2,3,7,8-TCDD

APPENDIX C
DERIVATION OF A SUBCHRONIC ACCEPTABLE DAILY INTAKE FOR 2,3,7,8-TCDD

The acute and subchronic toxicity of 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) has been studied extensively in a variety of mammalian species with examination of a wide range of potential adverse effects. As early as 1976, Kociba et al. (1976) reported the results of a study in which TCDD was administered by gavage in corn oil at dose levels of 0, 0.001, 0.01, 0.1, or 1 μg/kg body weight, 5 days/week for 13 weeks. Adverse effects on growth and on the liver and thymus were reported at the two highest dose levels. No significant adverse effects were reported at the 0.01 μg/kg dose level.

Also in rats, Goldstein et al. (1982) administered TCDD by gavage at dose levels of 0, 0.01, 0.1, 1.0, and 10 μg/kg once per week for 16 weeks. Animals in the high dose group died or became moribund within eight to twelve weeks of dosing and signs of porphyria were seen at the next two lower dose levels. The only effect seen at the lowest dose level was increased liver enzyme activity (a three-fold increase in aryl hydrocarbon hydroxylase (AHH) activity). This is not considered to represent a truly adverse effect, so the lowest dose can be considered a no-observed-adverse-effect level (NOAEL). Adjusting for equivalent daily dosing, the daily NOAEL is approximately 1.4 ng/kg·day.

More recently, DeCaprio et al. (1986) fed TCDD to Hartley guinea pigs at dietary concentrations of 0, 2, 10, 76, or 430 μg/kg of diet (ppt) for up to 90 days. Animals in the high dose group showed body weight loss, thymic atrophy, liver enlargement, and 60% mortality within 60 days when the remaining survivors were killed. Animals receiving TCDD at 76 ppt showed decreased body weight gain and increased relative liver weight. Males also showed reduced relative thymus weights and elevated serum triglyceride concentrations, while females showed hepatocellular cytoplasmic inclusion bodies and lowered serum alanine aminotransferase activity. No adverse effects were reported at the two lowest dose levels. Based on body weight and food consumption data from this study, the dietary NOAEL (10 ppt) corresponds to a daily dose level of approximately 0.65 ng/kg·day.

Recent studies have also shown that reproductive/developmental and immunologic endpoints are sensitive to acute or subchronic administration of TCDD. In a study in which pregnant rats were given single oral doses of 0, 0.064, 0.16, 0.4, or 1 μg/kg, adverse effects on the reproductive status of male offspring were seen at all dose levels. At the lowest dose level, male offspring showed reduced weight of the ventral prostate, epididymis, and cauda epididymis, reduced sperm number per cauda epididymis, reduced daily sperm production, and reduced seminiferous tubule diameter (Mably et al. 1992a,b,c). Thus, the acute LOAEL is 64 ng/kg.[1]

In studies of the immunotoxic effects of TCDD, reductions in delayed-type hypersensitivity responses to tuberculin were reported in guinea pigs given oral doses of TCDD as low as 0.04 μg/kg weekly for 8 weeks (Vos et al. 1973). This corresponds approximately to a daily LOAEL of 5.7 ng/kg·day. Immunologic effects have been reported at lower dose levels when TCDD is administered intraperitoneally (Clark et al. 1983) or subcutaneously (Neubert et al. 1990), but the relevance to human health of these routes of exposure and of the endpoints examined is questionable.

The most appropriate basis for a subchronic ADI for protection of human health appears to be the dietary study by DeCaprio et al (1986), which showed a NOAEL of 0.65 ng/kg·day. This dose level is 100-times lower than the acute LOAEL for reproductive effects from the work of Mably et al. (1992a,b,c), and is 10-times lower than the subchronic oral LOAEL for immunotoxic effects reported by Vos et al. (1973). Hence, it is likely to be protective for these effects also.

Derivation of a subchronic ADI from the NOAEL involves dividing the NOAEL by an appropriate safety factor. The standard safety factor for deriving a human ADI from a high quality animal NOAEL is 100, comprised of a factor of ten to allow for potentially greater sensitivity of humans than animals, and another factor of ten to allow for potentially greater variability in sensitivity among the outbred human population than the generally inbred experimental animal population (Dourson and Stara 1983). Use of the 100-fold safety factor yields a subchronic ADI of 6.5 pg/kg·day {= (0.65/100) ng/kg·day}.

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[1] Using a 1,000-fold safety factor, an acute ADI of 64 pg/kg-day can be derived.

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APPENDIX D
DEVELOPMENT OF PROSPECTIVE CLEANUP GOALS FOR SELECTED CHLOROAROMATIC COMPOUNDS

Cleanup goals based on monte carlo simulation are consistent & risk based standard.

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APPENDIX D
DEVELOPMENT OF PROSPECTIVE CLEANUP GOALS FOR SELECTED CHLROAROMATIC COMPOUNDS

As described in Section II.A of the main report, 461 soil grids were established at the Vertac Chemical Site and were sampled and analyzed for 2,3,7,8-tetrachlorodibenzo-p-dioxin ("TCDD"). Soil samples from many of these grids were also analyzed for volatile organic compounds, semi-volatile organic compounds, and pesticides, as described in the Remedial Investigation ("RI") report (Weston 1992). Based upon concentration data for these substances and the results of the draft baseline risk assessment for the Site (Weston 1992), several chloroaromatic compounds (principally semi-volatile organic compounds and pesticides) were identified by Roy F. Weston, Inc., RI consultants to Hercules Incorporated ("Hercules"), as warranting further investigation. Specifically, ENVIRON was retained by Hercules to develop risk-based soil cleanup goals for the following 11 substances:

- 2-chlorophenol
- 4-chlorophenol
- 2,4-dichlorophenol
- 2,4-dichlorophenoxyacetic acid
- 2,6-dichlorophenol
- silvex (2,4,5-trichlorophenoxypropionic acid)
- tetrachlorobenzene
- 2,3,6-trichlorophenol
- 2,4,5-trichlorophenol
- 2,4,6-trichlorophenol
- 2,4,5-trichlorophenoxyacetic acid

Prospective soil cleanup goals for these substances were developed using Monte Carlo simulations of exposure variability among adult trespassers and assuming that soil ingestion and dermal contact are the primary exposure routes of potential concern. Exposure factors for the Monte Carlo simulations were those provided in Appendix B of this report, except for the chemical-specific oral and dermal absorption factors, which were taken without modification from the draft baseline risk assessment report (Weston 1992).

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The toxicity parameters for the chloroaromatic substances were also taken from the draft baseline risk assessment report (Weston 1992). EPA Reference Doses ("RfDs") were not available for several of the substances (i.e., 4-chlorophenol, 2,6-dichlorophenol, and 2,3,6-trichlorophenol). Per the suggestion of EPA toxicologists in Region VI, it was assumed that these substances were similar in toxicity to their closest homolog that had a published RfD; this assumption was previously adopted in the draft baseline risk assessment (Weston 1992).

Equations 1 through 3 from the main report were employed for 2,4,6-trichlorophenol, which was treated as a carcinogen per EPA's carcinogenicity assessment of this substance. Equations 4 through 6 were employed for the other chloroaromatic compounds, which were treated as non-carcinogens. As written, equations 1 through 6 allow for the calculation of risk measures (lifetime cancer risk and non-cancer hazard quotient). They can also be used to calculate soil cleanup goals through a combination and re-arrangement that expresses the total risk equation (dermal plus ingestion components) in terms of the soil concentration. In estimating prospective cleanup goals, a target lifetime cancer risk of 10^{-4} was assumed for carcinogens (i.e., 2,4,6-trichlorophenol). A target hazard quotient of 1 is assumed for the other chloroaromatic compounds.

The cleanup goals that result from the Monte Carlo simulations are summarized in Table D-1 along with concentration statistics developed by ENVIRON using the RI soil concentration data. Calculated soil cleanup goals are based upon chronic exposures. As such, the risk-based goal should be interpreted as an average residual concentration ("AVG" goal) to be attained after remediation. When the average concentration in soil, based upon the RI data, is less than the stated average concentration goal ("AVG" goal), then "no remediation is indicated" for that substance.[1] For substances for which the average concentration in soil, based upon the RI data, is greater than the stated average concentration goal ("AVG" goal), then remediation is warranted and a not-to-exceed ("NTE") concentration goal can be

[1] For those substances for which an average concentration in soil was not calculated, based upon the RI data, a conclusion of "no remediation indicated" can also be reached by comparing the maximum detected concentration to the residual concentration goal. If the maximum detected is less than the residual "AVG" goal, then no remediation should be necessary.

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calculated, as was done for 2,3,7,8-TCDD.[2] On this basis, only tetrachlorobenzene was identified as requiring remediation.

References

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[2] The interpretation of the NTE and AVG concentrations is as follows: when grids with concentrations greater than the not-to-exceed ("NTE") level are remediated, then the stated average concentration goal ("AVG") should be attained within the gridded portion of the proposed fenced area (see Figure 4 of the main report).

TABLE D-1
Prospective Cleanup Goals for Surface Soil, Based Upon Trespasser Exposures, for the Vertac Chemical Corporation Site, Jacksonville, Arkansas

Substance of Potential Concern	Prospective Cleanup Goals and Concentration Statistics for Selected Substances (mg/kg)			
	Average Soil Cleanup Goals Based Upon Monte Carlo Simulations of Trespasser Exposures		Concentration Statistics for Soil Samples	
	95th percentile Adult	50th percentile Adult	Maximum Detected	Arithmetic Average
CHLOROPHENOLS				
2-chlorophenol	2,000	10,000	3	1.9
4-chlorophenol	Assumed to be same as 2-chlorophenol per concurrence by EPA		0.12	not computed
2,4-dichlorophenol	1,000	65,000	360	6.9
2,6-dichlorophenol	Assumed to be same as 2,4-dichlorophenol per concurrence by EPA		15	0.54
2,3,6-trichlorophenol	Assumed to be same as 2,4,5-trichlorophenol per concurrence by EPA		0.73	not computed
2,4,5-trichlorophenol	20,000	100,000	270	2
2,4,6-trichlorophenol	9,000	100,000	79	3.5
CHLOROBENZENES				
Tetrachlorobenzene	500	3,000	17,000	not computed
CHLOROPHENOXYACIDS				
2,4-dichlorophenoxyacetic acid	2,000	10,000	5,500	191
silvex	1,000	10,000	290	12.4
2,4,5-trichlorophenoxyacetic acid	2,000	10,000	710	23.1

TABLE D-1
Prospective Cleanup Goals for Surface Soil, Based Upon Trespasser Exposures, for the Vertac Chemical Corporation Site, Jacksonville, Arkansas

Substance of Potential Concern	Prospective Cleanup Goals and Concentration Statistics for Selected Substances (mg/kg)	
	Average Soil Cleanup Goals Based Upon Monte Carlo Simulations of Trespasser Exposures	Concentration Statistics for Soil Samples

FOOTNOTES:

Soil cleanup goals were estimated using Monte Carlo simulations of exposure variability (columns #2 and #3; rounded to one significant figure) and assuming that soil ingestion and dermal contact are the primary exposure routes of potential concern. Exposure factors for the Monte Carlo simulations were those provided in Appendix B of this report, except for the chemical-specific oral and dermal absorption factors, which were taken without modification from the baseline risk assessment report for the Site (Weston 1992). Toxicity parameters (Reference Doses and cancer Slope Factors) for these substances were also adopted from the baseline risk assessment report for the Site (Weston 1992).

A target lifetime cancer risk of 10^{-4} was assumed for 2,4,6-trichlorophenol, which was treated as a carcinogen. A target hazard quotient of 1 is ~~assumed for the other substances~~, which are treated as non-carcinogens. The prospective soil cleanup goals are ~~proportional to the target values~~ of the lifetime cancer risk and the hazard quotient, so that alternative goals can be readily calculated from the listed values (e.g., an average goal of 700 mg/kg can be derived for 2,4,6-trichlorophenol, on the basis of a 95th percentile exposure, if a target cancer risk of 10^{-5} is chosen).

Concentration statistics shown in columns #4 and #5 were calculated by ENVIRON using the RI database for soil samples.

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