Distributions And Probabilistic Analysis In Support Of The Model Toxics Control Act (MTCA) Cleanup Regulation Update

Science Panel Meeting
November 23, 2009

Memorandum

DATE: November 12, 2009

TO: MTCA Science Panel
Bruce Duncan, Ph.D., EPA Region – 10
Elaine Faustman, Ph.D., University of Washington
Rosaline Schoof, Ph.D., Integral Consulting, Inc
Teri Floyd, Ph.D., Floyd/Snider
Michael Riley, Ph.D., S.S. Papadopulos & Associates

From: Craig R. McCormack, Technical Policy Unit Staff and Miyoko Sasakura, University of Washington, Environmental & Occupational Health Sciences

Through: Martha Hankins, Unit Supervisor, Technical Policy Unit and Bruce Duncan, EPA Region 10

Subject: Selection of Final Distributions for Exposure Analysis

Background

At the final June 18, 2009 Science Advisory Board (SAB) meeting Ecology reviewed the proposed methodology to evaluate the contributions of different exposure parameters and exposure pathways to establish soil cleanup levels based on two and/or three concurrent exposure pathway models. The preliminary results from a one dimensional Monte Carlo analysis was presented to the SAB based on different exposure distributions. The SAB made several recommendations regarding the exposure distributions used to conduct the Monte Carlo simulations. The purpose of this memorandum is to follow-up on recommendations made to Ecology at the final June 18, 2009 SAB meeting.

Distributions

The SAB recommended Ecology re-evaluate the exposure distributions for the following parameters:

- Child and adult body weights;
- Child and adult soil ingestion rates;
- Soil volatilization factor; and
- Assumed correlation coefficient of one between body weight and body surface area exposed.

Additionally, the SAB recommended that:

- Ecology use information based on broad regulatory guidance as opposed to site-specific risk assessments;
- The basis for the soil volatilization factor (VFs) distribution should be re-evaluated; and
- Where possible, the exposure distributions should reflect populations for Washington State.

After the June 2009 SAB meeting Ecology staff met with Dr. Faustman and Bill Griffith (University of Washington biostatistician) to review the exposure distributions documentation and the development of the distributions used for the Monte Carlo simulations. The attached summary of revised exposure

distributions (**Attachment A**) reflects Ecology's response to the SAB recommendations, response from the meetings between Ecology staff and Dr. Griffith, and additional review of regulatory guidance and technical information. A more detailed description for the derivation of the chemical-specific soil volatilization factors is included as a separate attachment (**Attachment B**).

Unless there are technical deficiencies in Ecology's analysis or other regulatory guidance and technical documentation that demonstrate better alternative distributions, then Ecology will use the attached distributions for Monte Carlo simulations to evaluate contributions of exposure parameters and concurrent exposure pathways to establish soil cleanup levels.

Ecology believes that the information in the two attachments to this cover memorandum are responsive to the recommendations from the SAB. I will be contacting you to confirm that you agree that the distributions presented here are within the range of technical defensibility as discussed on June 18, 2009.

Cc: Peter Kmet, Dawn Hooper, David Bradley

Attachment A: Summary of Selected Exposure Distributions

Background and Context

The MTCA Cleanup Regulation Update is in progress and Ecology, Toxics Cleanup Program, is considering changing the risk-based equations to establish cleanup levels. The objective of the exposure analysis, using exposure distributions for the one dimensional Monte Carlo simulations, is to evaluate specific exposure parameters and pathways contributing to risk-based cleanup levels.

On June 18, 2009 Ecology presented to the MTCA Science Advisory Board descriptive statistics for distributions of selected exposure parameters, simulation models employed in the exposure analysis, and preliminary results. The MTCA Science Advisory Board members and invited scientific experts provided Ecology with the recommendations for re-evaluating selected distributions. This paper provides descriptive statistics for selected exposure distributions (based on the June 2009 MTCA Science Advisory Board meeting) for adult and child body weights, child and adult soil ingestion rates, soil volatilization factor (VFs), and additional rationale for the assumed correlation between body weight and body surface area exposed.

1. Adult and Child Body Weight Distributions

Background

The MTCA Science Advisory Board noted that Ecology should be able to identify Washington specific body weight data to develop the descriptive statistics for child and adult body weight distributions. EPA Region 10 guidance provides descriptive statistics for child and adult body weight distributions (below).

Child's Body Weight Distribution (kg)		
Child's Body Weight (Ages 0-6 yrs)		Defaults
Descriptive Statistic Normal Distribution	kg	
Mean	14.50	16 kg Default Average Body Weight MTCA Soil CULs Method B, MTCA Eqn's 740-1 & 2; and 740-4.
Std. Deviation	4.50	
Min	3.00	
Max	30.00	15 kg Default child body weight used by U.S. EPA

Interim Final guidance: Developing Risk-Based Cleanup Levels At Resource Conservation and Recovery Act Sites in Region 10. EPA 910/R-98-001. Page 6-23 and 6-24

Adult's Body Weight Distribution (kg)		
Adult's Body Weight		**Defaults**
Descriptive Statistic LogNormal Distribution	**kg**	
Mean	71.00	70 kg is the standard default adult body weight used by U.S. EPA and MTCA
Std. Deviation	15.30	
Min	30.00	
Max	136.00	
Interim Final guidance: Developing Risk-Based Cleanup Levels At Resource Conservation and Recovery Act Sites in Region 10. EPA 910/R-98-001. Page 6-23 and 6-24		

Ecology consulted with the Washington Department of Health regarding state-specific child and adult body weight information. Washington, as other states in Region 10, tracks trends in overweight and obesity based on self-reported body weight data for selected age groups. Because Washington Department of Health lacks population based body weight data (self reported or measured) and studies consistently show that people underreport their body weights, the Department of Health recommends that the distributions be based on the National Health and Nutrition Examination Survey (NHANES) data. U.S. EPA technical guidance for exposure factors relies on NHANES data, including body weight information.

Selection of Child and Adult Body Weight Distributions

Based on discussions with the Washington Department of Health, Ecology believes the above descriptive statistics for child and adult body weights reasonably estimates the body weights for children and adults in Washington State.[1]

Basis for the selection of child and adult body weight distributions

- Consistent with the Washington Department of Health recommendation, the Region 10 guidance relies on NHANES information for body weight data;
- Although the body weight information is derived from national exposure factors guidance, the child and adult body weight distributions are based on guidance dedicated for site evaluation in Region 10; and

[1] Juliet VanEenwyk, State Epidemiologist for Non-Infectious Conditions, Washington State Department of Health, June 29, 2009 e-mail correspondence.

- Ecology has consulted with the Washington Department of Health regarding the child and adult body weight distributions as reasonable approximations of the body weights for children and adults in Washington State.

2. Adult and Child Soil Ingestion Rate

Background

Child and adult soil ingestion rate distributions for the one dimensional Monte Carlo simulations for Ecology's exposure analysis were adapted from the U.S. Rocky Mountain Flats Human Health Risk Assessment, Task 3. At the June 2009 SAB meeting concerns were raised about Ecology using selected exposure distributions from site-specific U.S. EPA risk assessments. Subsequent to the June SAB meeting, Ecology determined that the EPA interpretation of the soil ingestion rate information presented in this document was based on the most current data available from a range of studies and not specific to the rocky Mountain Flats Colorado site. Ecology also met with Bill Griffith (University of Washington, Biostatistician) to review selected exposure distributions used by Ecology for the one dimensional Monte Carlo simulations. After reviewing the analysis conducted by EPA to derive the child and adult soil ingestion rate distributions, Dr. Griffith observed that the EPA analysis appeared to be thorough and was statistically sound or at least within a range of technical defensibility.

Based on the consultations with the University of Washington (Bill Griffith) and further review of Task 3 Report and Appendices of the U.S. Rocky Mountain Flats Human Health Risk Assessment, Ecology has changed the adult soil ingestion rate distribution from truncated LogNormal to a uniform distribution (noted in the table below). Although this change in the descriptive statistics for the adult soil ingestion rate does not substantially change the simulation results or sensitivity analysis, the change better reflects the statistical analysis performed to select a specific soil ingestion rate distribution and addresses more current interpretations of the Calabrese et al data.

Selection of Child and Adult Soil Ingestion Rate Distributions

The selected child and adult soil distributions and point estimates are as follows:

Child's Soil Ingestion Rate, mg/day			
Child's Soil Ingestion Rate (Ages < 6 years)		**Soil Ingestion Rate Point Estimate for Children, < 6 years of age mg/day**	**Documentation Exposure Point Concentration**
Descriptive Statistic Truncated LogNormal	**Soil Ingestion Rate mg/day**		
Mean	44.6	200	EPA Exp. Factors Handbook, 1997
Std. Deviation	79.9		EPA Child Specific Exp. Factors Handbook, 2002
Min	0		Exposure point exposure est. for MTCA Eqn's 740-1 & 2; and 740-4.
Max	1000		
U.S. EPA Rocky Mountain Flats Human Health Risk Assessment, Task 3 Report & Appendices. Sept. 2002. Table A-8, page 152 & page 166.		200 mg/day RME point estimate recommended for children approximates 96th percentile of the defined distribution.	

Adult's Soil Ingestion Rate, mg/day			
Adult's Soil Ingestion Rate		**Soil Ingestion Rate Point Estimate for Adults mg/day**	**Documentation Exposure Point Concentration**
Descriptive Statistic Uniform distribution (0, 130)	**Soil Ingestion Rate mg/day**		
Min	0	50 Adult, Industrial 100 Adult, Residential	EPA Exp. Factors Handbook, 1997
Max	130		
U.S. EPA Rocky Mountain Flats Human Health Risk Assessment, Task 3 Report & Appendices. Sept. 2002. Figure A-5, page 139.		50 mg/day point estimate for MTCA Eqn's 740-1 & 2; and 740-4.	

Basis for the selection of the soil ingestion rate distributions

- The child and adult soil ingestion rate distributions were applied to similar residential reasonable maximum exposure scenarios used by MTCA to establish soil cleanup levels.
- The EPA interpretation of the soil ingestion rate information was based on the most current data available from a range of studies and not specific to the Rocky Mountain Flats Colorado site.
- Meta analysis was performed for the soil ingestion rate data across the different studies. Variability and uncertainty were accounted for in the statistical analysis.
- Ranking of the quality of information (confidence ratings) for the child and adult soil ingestion rate data were included in the analysis.

Basis for the adult soil ingestion rate uniform distribution (0, 130)

- Empirical adult soil ingestion rate data are available from two studies (Calabrese et al., 1990 and Calabrese et al. , 1997).[2&3] Although the purpose of these studies was to verify the tracer mass balance methodology for the child soil ingestion rate studies, as indicated by the authors, the studies offer an estimate of soil ingestion for adults.
- Selection of uniform distribution best accounts for inter-individual variability across the two Calabrese et al studies because a range of plausible ingestion rates for adults varies depending on which trace elements are examined.
- Uncertainty exists with Calabrese et al studies due to the small sample sizes and the prevalence of negative soil ingestion rates on many subject days.[4] The plausible minimum value of 0 mg/day was selected because negative ingestion rates are reasonable results given the uncertainty in the mass balance methodology but are unreasonable as input for an exposure model.
- The maximum of 130 mg/day is greater than 80% of the individual trace element results of the Calabrese et al 1990 and 1997 studies and is equal to the maximum value when trace element results are averaged for each individual.
- In consideration of the plausible range of soil ingestion rates and no information regarding the shape or spread of the distribution for adults (standard deviation and mean) a uniform distribution was selected.

---

[2] Calabrese, E.J., E.J. Stanek, C.E. Gilber, and R.M. Barnes. 1990 Preliminary Adult Soil Ingestion Estimates: Results of a Pilot Study. Regul. Toxicol. Pharmacol. 12:88-95.

[3] Calabrese, E. J., E.J. Stanek, P. Pekow, and R.M. Barnes. 1997. Soil Ingestion Estimates for Children Residing on a Superfund Site Ecotox. Environ. Safety. 36:258-268.

[4] Negative ingestion rates occur due to complexities of the tracer mass balance methodology used by Calebrese et al such as assumed GI tract transit time and non-soil sources of tracer elements.

Basis for the child soil ingestion rate truncated LogNormal distribution

- Data from the Calebrese et al 1997 study better accounts for similarities in potentially exposed populations from the West (Montana)
- Soil was sieved at 250 µm which is a more representative size fraction for particle adherence and the size fraction with the least uncertainty in trace element concentrations
- A larger database of subject day estimates for children exists to develop descriptive statistical summaries.
- Accounts for multiple sources of uncertainty and inter-individual variability in childhood soil ingestion rates:

  → Estimating gastrointestinal transit time from food to fecal samples;
  → Implementing exclusion criteria to remove unreliable daily estimates for certain tracer elements;
  → Inconsistency among tracer elements in daily estimates;
  → Assuming that intra-individual variability is characterized by a lognormal distribution and that all individuals exhibit the same intra-individual variability; and
  → Selecting a maximum value for truncating the probability density function that characterizes inter-individual variability.

Confidence ratings for soil ingestion rate for children

Considerations	Rationale	Rating
Study Elements		
• Level of peer review	Relevant analyses on data from two study populations are given in the peer review literature.	High
• Accessibility	Papers are available from peer review journals and are evaluated in *Exposure Factors Handbook* (U.S. EPA, 1997).	High
• Reproducibility	Methodology is presented in literature but without original survey data so results cannot be reproduced.	Medium
• Focus on factor of interest	Studies are designed to quantify incidental ingestion of soil by children, including soil transported indoors (dust).	High
• Representativeness of study population	Key study represents children of relevant ages (1 to 3 years), both male and female, including relevant geographic location (West). Difficult to assess representativeness of race and socio-economics, and potential bias (underestimation) introduced by selection of population near a smelter site who may have altered exposure patterns in response to educational outreach.	Medium
• Primary data	Analyses are based on primary data.	High
• Currency	Studies conducted within the past 10 years.	High
• Adequacy of data collection period	Data collected over seven consecutive days in September. Difficult to assess if conditions during period reflected a peak period of exposure to soil. Not adequate for estimating long-term average behavior because study period was short and did not include multiple time points. Insufficient data to generate reliable estimates of day-to-day variability.	Medium
• Validity of approach	Fecal tracer mass balance technique is generally considered to be the most reliable technique, despite difficulties in validation. Uncertainties include high inter-trace element variability and low precision of recovery for certain subject days, possibly due to absorption of trace elements and variability in GI transit times between subjects and within subjects.	Medium
• Study size	Both the number of subjects and duration of study period affect the quantity of subject-days of data. Sixty-four children were studied in two key studies, ranging from 5 to 8 days.	Medium
• Characterization of variability	High uncertainty in use of lognormal distribution to characterize intra-individual variability in order to extrapolate to long-term average ingestion rates. Method does not account for potential correlation between mean and SD on an individual basis (all children are assumed to exhibit the same short-term variability. Lognormal distribution fit to reported percentiles is adequate, but uncertainty in upper truncation limit (1000 mg/day).	Low
• Lack of bias in study design (high rating is desirable)	Key study population is from relevant geographic location, but potential bias from selection of population near a smelter site. Soil was sieved to yield a more representative size fraction of soil for exposure. Exclusion criteria remove daily estimates for selected trace elements thought to be unreliable, but cutoff is subjective.	Medium
• Measurement error	Potential for inaccurate mass balance calculation due to absorption of trace elements and variability in GI transit times.	Medium
Other Elements		
• Number of studies	Two key studies using same methodology on populations in different geographic areas.	Medium
• Agreement between researchers	General agreement that studies are the best available. Not much discussion yet on selection of probability distributions to characterize variability.	Medium
Overall Confidence Rating	Variability over one week period may overestimate variability extrapolated to one year. Uncertainty in mass balance methodology, and assumption associated with selection of probability distribution type and parameters. Recent, primary data from representative population, and moderate sample size.	Medium

Confidence ratings for soil ingestion rate for adults

Considerations	Rationale	Rating
Study Elements		
• Level of peer review	Relevant analyses on data from two study populations are given in the peer review literature.	High
• Accessibility	Papers are available from peer review journals. One study is evaluated in the *Exposure Factors Handbook* (U.S. EPA, 1997).	High
•Reproducibility	Methodology is presented in literature but not always at the level of the individual subject-day-trace element level. Therefore, the summary results cannot be reproduced from the original data.	Medium
• Focus on factor of interest	Studies are designed as pilot studies to validate the mass balance tracer methodology applied to children; adult subjects were fed capsules of soil, and trace element from capsule and food were subtracted from total excreted to yield estimates of incidental soil/dust ingestion.	Medium
• Representativeness of study population	Adults ages 22 to 45 years, both male and female, including relevant geographic location (West). Small sample sizes (n=6, n=10) and study duration (four weeks or less) plus uncertainty in activities and hobbies during study period.	Low
• Primary Data	Analyses are based on primary data, with emphasis on two studies (n=6 and n=10).	High
• Currency	Studies conducted within the past 15 years.	High
• Adequacy of data collection period	Data collected over seven consecutive days in September. Difficult to assess if conditions during period reflected a peak period of exposure to soil. Not adequate for estimating long-term average behavior because study period was short and did not include multiple time points. Insufficient data to generate reliable estimates of day-to-day variability.	Medium
• Validity of approach	Fecal tracer mass balance technique is generally considered to be the most reliable technique, despite difficulties in validation. Uncertainties include high inter-trace element variability and low precision of recovery for certain subject days, possibly due to absorption of trace elements and variability in GI transit times within subjects and between subjects. Best tracer methodology was developed to identify trace element(s) on each subject-day that had the lowest food/soil ratio.	Medium
• Study size	See representativeness above.	Low
• Characterization of variability	Use of uniform distribution reflects high uncertainty in interindividual variability due to small sample size and inconsistent results by trace elements. No attempt was made to quantify intraindividual variability in order to derive a distribution relevant to long-term average.	Low
• Lack of bias in study design (high rating is desirable)	Use of soil capsules ensures a higher quantity of trace elements excreted, but numerous days yielded negative mass balance results, especially for the study with n=10 for which nearly 50% of subject-days had negative estimates.	Low
Measurement error	Potential for inaccurate mass balance calculation due to absorption of trace elements and variability in GI transit times. See bias discussion above.	Low
Other Elements		
• Number of studies	Two studies using same methodology on populations in different geographic areas.	Medium
• Agreement between researchers	General agreement that studies are best available. Not much debate yet on selection of probability distributions to characterize variability.	Medium
Overall Confidence Rating	Primary data but small sample sizes. Repeat measurements over three to four week period, although no attempt to quantify intra-individual variability. Uncertainty in mass balance methodology given the number of days of negative ingestion rate estimates.	Low

3. Distribution for Soil Volatilization Factor (VFs)

Background

During the June SAB meeting Ecology noted that the distribution used for the soil volatilization factor (VFs) was derived from 130 volatile organic chemicals for which the soil volatilization factor has been empirically determined. The SAB felt that the VFs distribution was incorrect because the VFs is a chemical – specific determination and the distribution should be established using a well characterized volatile organic chemical acting as a surrogate for others. Ecology reviewed relevant technical guidance regarding the derivation of the VFs for volatile organic chemicals and agreed with the SAB's observation.[5] Ecology performed a separate statistical analysis and simulation to construct a new VFs distribution. A separate paper (attached) provides a detailed description of the analysis. Below is a brief summary of that analysis.

Soil volatilization factors are dependent on a soil dispersion factor for volatiles (Q/C_{vol}) and diffusivity (D_A). Soil dispersion depends on meteorological conditions (Q/C_{vol}) and chemical-specific information (D_A). In order to derive a chemical-specific VFs distribution, the best-fist distribution was determined for the dispersion modeling constants for specific climate zones. Crystal Ball®(Fusion Edition, Release 11.1.1.1.00) goodness of fit tests and professional judgment were used to determine the appropriate distribution for each constant. Consistent with EPA's Soil Screening Guidance, the areal extent of the site contamination was included in the model and uniformly distributed between 0.5 and 500 acres. The distribution of the areal extent of site contamination combined with the best-fit distributions for the soil dispersion constants for different climate zones provided a distribution of Q/C_{vol} outputs that can be used to determine the distribution of VFs. A distribution was fit to the VFs output for epichlorohydrin and trichloroethylene (TCE) for use in the model created to evaluate soil cleanup levels.

[5] Supplemental Guidance for Developing Soil Screening Levels For Superfund Sites. OSWER 9355.4-24. December 2002. Appendix D, Exhibit D-3.

Selection of the Soil Volatilization Factor (VFs) Distribution

Based on the simulation modeling described above, the VFs descriptive statistics for epichlorohydrin and TCE are provided in the table below:

Soil Volatilization Factor (VFs) Distributions for Trichloroethylene and Epichlorohydrin							
Chemical	**Distribution**	**Goodness of Fit Statistical Test**					
		A-D	A-D p-value	K-S	K-S p-value	Chi-Square	Chi-Square p-value
TCE	LogNormal	1.6375	0	0.0309	0	32.980	0.132
Epichlorohydrin	LogNormal	1.5629	0	0.0306	0	28.630	0.28

Descriptive Statistics		
Chemical	**Distribution**	**Descriptive Statistics (m^3/kg)**
TCE	LogNormal	μ (Mean) = 1.60E+03 (1578.87)
		σ (Std. Dev) = 3.70E+02 (366.66)
		Min = 7.40E+02 (744.08)
		Max = 3.40E+03 (3358.81)
Epichlorohydrin	LogNormal	μ (Mean) = 8.75E+03 (8749.83)
		σ (Std. Dev) = 2.17E+03 (2168.77)
		Min = 3.62+03 (3620.43)
		Max = 2.20+04 (22041.74)

A-D – Anderson Darling; **K-S** - Kolmogorov-Smirnov

While selecting a surrogate chemical was considered as a way to account for the VFs distribution, the distribution for TCE and epichlorohydrin were used to evaluate the exposure parameters and pathways to establish soil cleanup levels for TCE and epichlorohydin specifically.

The basis and derivation of the soil volatilization factor (VFs) is provided in Appendix B, page 13.

4. Correlation Between Body Weight and Body Surface Area

Background

For the one dimensional Monte Carlo simulations conducted for this analysis Ecology assumed that total body surface area was positively correlated with body weight, with an assumed rank correlation coefficient of 1. Federal technical guidance notes a strong positive correlation between body surface area and body weight. [6&7] Referencing Phillips et. al., 1993, EPA's Exposure Factors Handbook (page 6-3), notes a strong correlation (0.986) between body surface area and body weight.[8]

Some SAB members have noted the allometric scaling for body weight and body surface area. When extrapolating from animal data, the human dose equivalent to the dose in the animal study is based on the assumption that different species are equally sensitive to the biological effects of a chemical if they absorb approximately the same dose. The dose extrapolation is based on the body surface area being approximately proportional to the 2/3 power of body weight with the equivalent dose expressed in mg/body weight$^{2/3}$-day.[9]

$$\textbf{Surface area} = (\textbf{Constant, K}) \times (\textbf{Weight}^{2/3})$$

However, as an alternative, others have noted that an allometric interspecies scaling for carcinogenicity extrapolation between animals and humans is more appropriately based on ¾ power of the body weight.[10&11] The 2005 EPA Cancer Guidelines notes:

> *For oral exposures, administered doses should be scaled from animals to humans on the basis of equivalence of mg/kg$^{3/4}$-d (milligrams of the agent normalized by the 3/4 power of body weight per day) (U.S. EPA, 1992b). The 3/4 power is consistent with current science, including empirical data that allow comparison of potencies in humans and animals, and it is*

---

[6] U.S. Environmental Protection Agency. 1998. Interim Final Guidance: Developing Risk-Based Cleanup Levels at Resource Conservation and Recovery Act Site In Region 10. EPA 910/R-98-001. Page 6-19.

[7] Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A). December 1989. EPA/540/1-89/002. Page 6-39

[8] Phillips, L.J.; Fares, R.J.; Schweer, L.G. 1993. Distributions of Total Skin Surface Area to Body Weight Ratios For Use In Dermal Exposure Assessments. J. Exposure Anal. Environ. Epidemiol. 3(3):331-338.

[9] EPA's Approach for Assessing the Risks Associated With Chronic Exposure to Carcinogens. Background Document 2. January 17, 1992. (http://www.epa.gov/IRIS/carcino.htm)

[10] Thomas H. Slone. Body Surface Area Misconceptions. Letter to the Editor Risk analysis, Vol 13, No. 4, 1993, pages 375-377.

[11] Lorenz R. Rohomberg and Thomas A. Lewandowski. Methods for Identifying A Default Cross-Species Scaling Factor. Prepared for EPA's Risk Assessment Forum. April 2, 2004.

also supported by analysis of the allometric variation of key physiological parameters across mammalian species.[12]

Recommended Correlation

For this probabilistic exposure analysis, Ecology believes that the strong positive correlation between body surface area and body weight needs to be recognized. For the purposes of this evaluation, the allometric scaling factor of ¾ of the body weight to determine the human equivalent dose from animal studies is inappropriate because Ecology is not determining the human equivalent dose based on different animal studies. Ecology will continue to assume a correlation coefficient of 1 between body surface area and body weight for this one dimensional Monte Carlo exposure analysis. The rationale for this assumed correlation:

- Recognizes a strong positive correlation between body surface area and body weight;
- Is supported by regulatory guidance;
- Is consistent with current science and is within the range of technical defensibility.

[12] U.S. Environmental Protection Agency. Guidelines for Carcinogen Risk Assessment. March 2005. EPA/630/P-03/001F. Section 3.1.3.1, Page 3-6.

Adult versus Child Exposure Duration

The MTCA Cleanup Regulation defines the Reasonable Maximum Exposure (RME) as: "the highest exposure that is reasonably expected to occur at a site under current and potential future site use."[13] In establishing cleanup levels and standards, as policy, the MTCA Cleanup Regulation is based on and protective of the most sensitive populations, including pregnant women, unborn children, children and most sensitive wildlife and plant species.[14] Under the MTCA Cleanup Regulation, cleanup levels are based on estimates of the "reasonable maximum exposure" (RME). [15]

- The RME is designed to represent a high end (but not worst case) estimate of individual exposures. It provides a conservative estimate that falls within a realistic range of exposures.[16]
- The RME is defined as reasonable because it is a product of several factors that are an appropriate mix of average and upper-bound estimates. RME estimates typically fall between the 90th and 99.9 percentile of the exposure distribution.[17]
- The RME takes into account both current and reasonably foreseeable future conditions.

MTCA risk based soil cleanup levels are established based on the following reasonable maximum exposure scenarios:

- Unrestricted, Residential, Soil Cleanup Levels and Standards, WAC 173-340-740, defines the RME in terms of the incidental soil ingestion rate of 200 mg/day for a child; and
- Restricted, Industrial, Soil Cleanup Levels and Standards, WAC 173-340-740, defines the RME in terms of the incidental soil ingestion rate of 50 mg/day for an adult.

Exposure duration, or the period of exposure to a hazardous substance, is an exposure parameter used in the MTCA soil cleanup equations. The six year exposure duration used in MTCA to establish soil cleanup levels for unrestricted properties is based on the assumption that for children between the ages of 1-6 years they are expected to incur at least 50% of the total lifetime dose associated with direct soil contact.

---

[13] WAC 173-340-708 (3) (b)

[14] Washington State Department of Ecology, Concise Explanatory Statement, MTCA Cleanup Regulation, February 12, 2001, page 119.

[15] MTCA defines the RME as the "…the highest exposure that can be reasonably expected to occur for a human or other living organisms at a site under current and potential future site use." CERCLA provides a similar definition "…the highest exposure that is reasonably expected to occur at a Superfund site…"

[16] U.S. Environmental Protection Agency. An Examination of EPA Risk Assessment Principles and Practices. EPA/100/B-04/0001. March 2004.

[17] IBID.

This exposure analyses suggests that the 30 year exposure duration, not age adjusted and age adjusted to account for differences between children and adult patterns of exposure and body weight, plays an important role in establishing cleanup levels compared to the six year exposure duration currently used to establish soil cleanup level under MTCA. When deterministic models are used to establish risk based soil cleanup level using a six year exposure duration compared to a 30 year exposure duration the corresponding percentiles from a simulated exposure distribution shows that the deterministic risk based cleanup levels are not protective of human health for selected volatile chemicals.

For the deterministic exposure analysis, the soil cleanup level results using both exposure durations were evaluated and tabulated.

Attachment B: Derivation of Soil Volatilization Factor (VFs) Distribution

Introduction-Context for Evaluation

During the Science Advisory Board (SAB) meeting held on June 18, 2009, there was a concern that the descriptive statistics for soil volatilization factor (VFs) may have been inappropriately determined. Initially, the mean and standard deviation of VFs across all 130 chemicals catalogued by the EPA were determined to estimate the descriptive statistics for VFs. The resultant descriptive statistics were 6.49E+04 ± 2.72E+05 m^3/kg where the maximum and minimum VFs were 2.90E+06 m^3/kg and 9.00+02 m^3/kg respectively. As the only statistic used in the models where the standard deviation was an order of magnitude larger than the mean, the variability in VFs dominated the variance and ultimately dominated the sensitivity of the soil cleanup model. This result was questioned by the SAB and an alternative methodology to determine VFs distributions requested. Pursuant to a suggestion by the SAB, a surrogate chemical was chosen instead where its resulting VFs descriptive statistics were then applied to all models simulating soil cleanup levels.

Five chemicals were chosen to evaluate and model soil clean up levels. The five were: arsenic, benzo[a]pyrene, chlordane, epichlorohydrin and Trichloroethylene (TCE). Epichlorohydrin and TCE were specifically selected based on their soil volatility and their potential to influence the dominance of the exposure pathways (ingestion, dermal, or inhalation) to establish soil cleanup levels. As volatile chemicals, both epichlorohydrin and TCE were initially considered as a possible surrogate to estimate the VFs descriptive statistic.

Background

VFs is a function of dispersion factor (Q/C_{vol}), a climate specific term, and apparent diffusivity (D_A), a chemical specific term. VF is mathematically defined as:

$$VFs = \frac{\mathbf{Q/C} \times (3.14 \times D_A \times T)^{1/2} \times CF}{2 \times \rho_b \times \mathbf{D_A}} \qquad \textbf{Equation 1}$$

Where:

- VFs [m^3/kg]: volatilization factor
- Q/C_{vol} [g/m^2-s per kg/m^2]: dispersion factor for volatiles emitted from the soil; inverse of the ratio of the geometric mean air concentration to the emission flux at the center of the source
- D_A [cm^2/s]: apparent diffusivity
- CF [m^2/cm^2]: a 10^{-4} conversion factor
- ρ_b [g/cm^3]: dry soil bulk density

The following details the equations to determine Q/C_{vol} (climate-zone specific)[18] and D_A (chemical specific): [19]

$$Q/C_{vol} = A \times \exp\left[\frac{(\ln A_s - B)^2}{C}\right]$$ **Equation 2**

Where:

- Q/C_{vol} [g/m^2-s per kg/m^2]: dispersion factor for volatiles emitted from the soil; inverse of the ratio of the geometric mean air concentration to the emission flux at the center of the source
- A, B, C: values based on air dispersion modeling for specific climate zones
- A_s [acres]: areal extent of the site or contamination

$$D_A = \frac{[(\theta_a^{10/3} \times D_i \times H' + \theta_w^{10/3} \times D_w)/n^2]}{\rho_b \times K_d + \theta_w + \theta_a \times H'}$$ **Equation 3**

Where:

- D_A [cm^2/s]: apparent diffusivity
- θ_a [L_{air}/L_{soil}]: air-filled soil porosity
- D_i [cm^2/s]: diffusivity in air
- H': dimensionless Henry's law constant determined by H×41
  - H [atm-m^3/mol]: Henry's law constant
  - 41: units conversion factor
- D_w [cm^2/s]: diffusivity in water
- n [L_{pore}/L_{soil}]: total soil porosity
- ρ_b [g/cm^3]: dry soil bulk density
- K_d [cm^3/g]: soil-water partition coefficient determined by $K_{oc} \times f_{oc}$
  - K_{oc} [cm^3/g]: soil organic carbon partition coefficient
  - f_{oc} [g/g]: fraction organic carbon in soil
- θ_w [L_{water}/L_{soil}]: water-filled soil porosity

The dispersion factor (Q/C_{vol}) and apparent diffusivity (D_A) were derived first in order to determine VFs. [20] Additionally, as a parameter influenced by meteorological factors (e.g. temperature and pressure), it is difficult to identify and determine values to calculate chemical specific VFs without certain assumptions concerning climate conditions—namely temperature and pressure. Therefore, a temperature of 25°C and a pressure of 1atm were assumed.

[18] United States Environmental Protection Agency. 1996. Soil Screening Guidance: User's Guide. Publication 9355.4-23. Office of Solid Waste and Emergency Response, Washington, D.C. Equation D-1; pD-2.
[19] United States Environmental Protection Agency. 1996. Soil Screening Guidance: User's Guide. Publication 9355.4-23. Office of Solid Waste and Emergency Response, Washington, D.C. Equation 4-8; p4-24.
[20] The Risk Assessment Information System: PRG Equations. http://rais.ornl.gov/prg/equations/vf.shtml

Dispersion Factor (Q/C_{vol})

The following table details the data used to determine Q/C_{vol}: [21]

Table 1: Table of A, B, C constants based on air dispersion modeling for specific climate zones

Meteorological Station	A	B	C
Salem, OR	12.3783	18.9683	218.2086
Seattle, WA	14.2253	18.8366	218.1845
Fresno, CA	10.2152	19.2654	220.0604
Los Angeles, CA	11.9110	18.4385	209.7845
San Francisco, CA	13.8139	20.1624	234.2869
Albuquerque, NM	14.9421	17.9869	205.1782
Las Vegas, NV	13.3093	19.8387	230.1652
Phoenix, AZ	10.2871	18.7124	212.2704
Boise, ID	11.3161	19.6437	224.8172
Casper, WY	17.6482	18.8138	217.0390
Denver, CO	11.3612	19.3324	221.2167
Salt Lake City, UT	13.2559	19.2978	221.3379
Winnemucca, NV	12.8784	17.9804	204.1028
Bismarck, ND	15.0235	18.2526	207.3387
Lincoln, NE	14.1901	18.5634	210.5281
Minneapolis, MN	16.2302	18.7762	216.1080
Atlanta, GA	14.8349	17.9259	204.1516
Charleston, SC	13.7674	18.0441	204.8689
Houston, TX	13.6482	18.1754	206.7273
Little Rock, AR	12.4964	18.4476	210.2128
Raleigh, NC	12.3675	18.6337	212.7284
Chicago, IL	16.8653	18.7848	215.0624
Cleveland, OH	12.8612	20.5164	237.2798
Harrisburg, PA	15.5169	18.4248	211.7679
Huntington, WV	9.9253	18.6636	211.8862
Hartford, CT	12.5907	18.8368	215.4377
Philadelphia, PA	14.0111	19.6154	225.3397
Portland, ME	10.4660	20.9077	238.0318
Miami, FL	12.1960	19.0645	215.3923

The values for A, B, and C in Table 1 for each of the 29 national sites were empirically derived using the Industrial Source Complex 3 (ISC3)[22] dispersion model to estimate the maximum annual average on-site

[21] United States Environmental Protection Agency. 1996. Soil Screening Guidance: User's Guide. Publication 9355.4-23. Office of Solid Waste and Emergency Response, Washington, D.C. Exhibit D-3; pD-7.

[22] ISC3: steady-state Gaussian plume model software provided by the EPA to assess air pollutant concentrations from a variety of sources associated with industrial complexes. United States Environmental Protection Agency. 2005. Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities. Publication EPA530-R-05-006. Office of Solid Waste and Emergency Response, Washington, D.C. p3-6.

air concentration. The estimations were conducted for a series of geographic areas ranging in size from 0.5 to 500 acres. [23]

To account for the varying climate conditions across the state of Washington, a distribution was separately fit to the data in columns A, B, and C using the Oracle Crystal Ball®, (Fusion Edition Release 11.1.1.1.00). Goodness-of-fit tests performed by the software—Anderson-Darling (A-D), Kolmogorov-Smirnov (K-S), and chi-square—and professional judgment helped evaluate the appropriate distribution for each variable. The best-fit distribution was used to describe the distribution of each data set in columns A, B, and C. The following table summarizes goodness-of-fit test results and descriptive statistics associated with the distributions for constants in columns A, B, and C.

Table 2: Summary of goodness-of-fit data and descriptive statistics associated with the chosen distribution for each constant

Constant	Distribution	Goodness of Fit						Descriptive Statistics
		A-D	A-D p-value	K-S	K-S p-value	Chi-square	Chi-square p-value	
A	Normal	0.1795	0.912	0.0964	0.784	0.5385	0.764	μ=13.46, σ=1.96
B	Lognormal	0.2154	0.717	0.0799	0.864	2.2414	0.326	μ=18.94, σ=0.81, Min=17.35, Max=∞
C	Lognormal	0.2319	0.651	0.0761	0.930	0.2222	0.637	μ=216.79, σ=11.47, Min=198.47, Max=∞

A uniform distribution was used to describe the variable A_s (the contaminated site area), to consider the range of square site areas to derive Q/C_{vol}.

[23] United States Environmental Protection Agency. 1996. Soil Screening Guidance: User's Guide. Publication 9355.4-23. Office of Solid Waste and Emergency Response, Washington, D.C. pD-1.

Deriving VFs Distributions

The following table summarizes the data used to determine VFs for TCE: [24]

Table 3: Summary of values used to determine VFs for TCE

Parameters	Values	Distribution	Assumption	Definition (units)
T	9.50E+08	N/A	N/A	exposure interval **(s)**
ρ_b	1.5	N/A	N/A	dry soil bulk density **(g/cm^3)**
θ_a	0.28	N/A	N/A	air-filled soil porosity **(L_{air}/L_{soil})**
n	0.43	N/A	N/A	total soil porosity **(L_{pore}/L_{soil})**
θ_w	0.15	N/A	N/A	water-filled soil porosity **(L-water/L-soil)**
ρ_s	2.65	N/A	N/A	soil particle density **(g/cm^3)**
D_i	0.079	N/A	N/A	diffusivity in air **(cm^2/s)**, chemical specific
H	0.0103	N/A	N/A	Henry's law constant **(atm-m^3/mol)**, chemical specific
H'	0.422	N/A	N/A	dimensionless Henry's law constant, chemical specific
D_w	9.10E-06	N/A	N/A	diffusivity in water **(cm^2/s)**, chemical specific
K_d	0.996	N/A	N/A	soil-water partition coefficient **(cm^3/g)**, chemical specific
K_{oc}	166	N/A	N/A	soil organic carbon partition coefficient **(cm^3/g)**, chemical specific
f_{oc}	0.006	N/A	N/A	fraction organic carbon in soil **(g/g)**
A	μ=13.46, σ=1.96	Normal	Variable	constants based on air dispersion modeling for specific climate zones
B	μ=18.94, σ=0.81, Min=17.35, Max=∞	Lognormal	Variable	constants based on air dispersion modeling for specific climate zones
C	μ=216.79, σ=11.47, Min=198.47, Max=∞	Lognormal	Variable	constants based on air dispersion modeling for specific climate zones
A_s	0.5-500	Uniform	Variable	contamination or site area extent **(acres)**

The following table summarizes the data used to determine VFs for epichlorohydrin[25] :

Table 4: Summary of values used to determine VF for epichlorohydrin

Parameters	Values	Distribution	Assumption	Definition (units)
T	9.50E+08	N/A	N/A	exposure interval **(s)**
ρ_b	1.5	N/A	N/A	dry soil bulk density **(g/cm^3)**
θ_a	0.28	N/A	N/A	air-filled soil porosity **(L_{air}/L_{soil})**
n	0.43	N/A	N/A	total soil porosity **(L_{pore}/L_{soil})**
θ_w	0.15	N/A	N/A	water-filled soil porosity **(L-water/L-soil)**
ρ_s	2.65	N/A	N/A	soil particle density **(g/cm^3)**
D_i	0.0929	N/A	N/A	diffusivity in air **(cm^2/s)**, chemical specific
H	3.024E-05	N/A	N/A	Henry's law constant **(atm-m^3/mol)**, chemical specific
H'	0.00124	N/A	N/A	dimensionless Henry's law constant, chemical specific
D_w	1.09E-05	N/A	N/A	diffusivity in water **(cm^2/s)**, chemical specific
K_d	0.02694	N/A	N/A	soil-water partition coefficient **(cm^3/g)**, chemical specific
K_{oc}	4.49	N/A	N/A	soil organic carbon partition coefficient **(cm^3/g)**, chemical specific
f_{oc}	0.006	N/A	N/A	fraction organic carbon in soil **(g/g)**
A	μ=13.46, σ=1.96	Normal	Variable	constants based on air dispersion modeling for specific climate zones
B	μ=18.94, σ=0.81, Min=17.35, Max=∞	Lognormal	Variable	constants based on air dispersion modeling for specific climate zones
C	μ=216.79, σ=11.47, Min=198.47, Max=∞	Lognormal	Variable	constants based on air dispersion modeling for specific climate zones
A_s	0.5-500	Uniform	Variable	contamination or site area extent **(acres)**

Crystal Ball® generated Q/C_{vol} outputs when the A_s distribution and the distributions fit to the data in columns A, B, and C, were inserted into Equation 2. Crystal Ball ® inserted the constants listed in Table 3 or 4 and the Q/C_{vol} outputs into Equation 1 to generate VFs outputs. A distribution was fit to the VFs outputs generated by Crystal Ball® to determine a descriptive statistic for use in the soil cleanup model. Again, goodness-of-fit tests and professional judgment helped to evaluate the appropriate distribution

[24] United States Environmental Protection Agency. 2002. Soil Screening Guidance: User's Guide. Publication 9355.4-24. Office of Solid Waste and Emergency Response, Washington, D.C. Exhibit C-1, pC-4.

[25] The Risk Assessment Information System--Chemical Toxicity; http://rais.ornl.gov/cgi-bin/tox/TOX_select?select=nrad

for VFs. The table below summarizes goodness-of-fit test results and VFs descriptive statistics for TCE and epichlorohydrin.

Table 5: Summary of goodness-of-fit data and descriptive statistics associated with the VFs distribution for TCE and epichlorohydrin

Chemical	Distribution	Goodness of Fit						Descriptive Statistics
		A-D	A-D p-value	K-S	K-S p-value	Chi-square	Chi-square p-value	
TCE	Lognormal	1.6375	0	0.0309	0	32.9800	0.132	μ=1578.87, σ=366.66, Min=744.08, Max=3358.81
Epichlorohydrin	Lognormal	1.5629	0	0.0306	0	28.6300	0.28	μ=8749.83, σ=2168.77, Min=3620.43, Max=22041.74

The VFs distribution for TCE and epichlorohydrin were used to evaluate the exposure parameters and pathways to establish soil cleanup levels for TCE and epichlorohydin.

File: Distrib_Article_Construct + Miyoko's & MH Edits SciPanel 20091112

Probabilistic Analysis In Support Of The Model Toxics Control Act (MTCA) Cleanup Regulation Update

Washington State Department of Ecology
Toxics Cleanup Program

November 12, 2009

Acknowledgement: The Department of Ecology, Toxics Cleanup Program, acknowledges and appreciates the significant contribution made by Miyoko Sasakura (Graduate Student, Environmental & Occupational Health Sciences, University of Washington) in the analysis and writing of this document. Also, the Department of Ecology, Toxics Cleanup Program, acknowledges and appreciates the significant contribution made by Greg Pelletier in the development of the YASAIw simulation tool, and the numerous reviews and constructive comments to improve this document.

Contents

1.0 Background 3

2.0 Exposure Parameter and Scenarios 5

3.0 Objectives 6

4.0 Methodology 8

4.1 Models 8

4.2 Sensitivity Analysis 9

4.3 Variability 10

4.4 Distributions 11

5.0 Observations, Discussion, and Conclusions 18

1.0 Background

1.1 Model Toxics Control Act (MTCA) Cleanup Regulation

Washington State's hazardous waste cleanup law, the Model Toxics Control Act (MTCA) Cleanup Regulation (chapter 173-340 WAC), establishes the legal framework, policies, and procedures to cleanup hazardous waste sites protective of human health and the environment. The Model Toxics Control Act (chapter 70.105D RCW) was passed by the Washington State voters as Initiative 97 in November 1988. MTCA became effective March 1989 providing the Department of Ecology (Ecology) the statutory authority to establish cleanup standards and requirements for hazardous waste sites for Washington State. The rules to establish MTCA risk based cleanup standards and requirements were developed by Ecology in consultation with the Science Advisory Board (as established under MTCA), and in consultation with representatives from local government, citizens, environmental and business groups. The MTCA rules were first published in 1991, with additional rule amendments in January 1996, February 2001, and November 2007.

The Model Toxics Control Act (MTCA) Cleanup Regulation includes policies and procedures for establishing cleanup levels based on human health protection. Key features include:

- Cleanup levels are based on protecting sensitive population groups, including pregnant women, developing fetuses, and children.
- Cleanup levels are based on the "reasonable maximum exposure" that a person might encounter. The reasonable maximum exposure is designed to represent a high end (but not worst case) estimate of individual exposures.
- Cleanup levels are based on exposure parameters (e.g., soil ingestion rate) and toxicity factors (e.g. cancer slope factor) in EPA guidance and the scientific literature.

Ecology reviewed the available scientific literature and regulatory guidance when preparing the 2001 rule amendments. Based on that review, Ecology updated the methods used to establish soil cleanup levels. Specifically, Ecology revised the methods to require consideration of both soil ingestion and dermal contact. For most chemicals, dermal contact is evaluated only when changes to the standard equation results in site-specific cleanup levels that are "significantly higher" than values calculated using the default parameters.

Since the rule was revised in 2001, there have been several important scientific and regulatory developments relevant to establishing cleanup levels. This information raises several issues about the current MTCA procedures for establishing soil cleanup levels:

- Should Ecology revise the MTCA rule to provide clearer direction on when and how concurrent exposure pathways (e.g. soil ingestion, dermal contact and inhalation) are taken into account when establishing soil cleanup levels?

- Should Ecology revise the MTCA equations and exposure parameters based on current scientific information on age-related differences in exposure levels and susceptibility?
- Should Ecology consider other changes to the methods and policies for establishing soil cleanup levels based on current scientific information and/or regulatory guidance?
- Do the methods for establishing cleanup levels provide a reasonable level of conservatism given the uncertainty and variability in exposure and toxicity.

1.2 Introduction

As part of the MTCA 2009-2011 Cleanup Regulation Update Ecology is reexamining the methods, policies, and procedures to establish risk-based cleanup levels and standards protective of human health. This reexamination is based on new scientific information and regulatory guidance on human health risk assessment. The current deterministic risk-based cleanup levels and standards established under MTCA are based on scientific information and regulatory guidance available at the time the rule was amended in the late 1990's. Since the late 1990's significant advancements have been made in scientific information and regulatory guidance relevant to establishing risk-based cleanup levels protective of the health for Washington State's citizens.

The current MTCA Cleanup Regulation defines two steps to establish cleanup requirements for individual hazardous waste sites in Washington State; establishing cleanup standards and selecting cleanup actions. Cleanup standards established under MTCA includes risk-based cleanup levels and points of compliance for each hazardous waste site. Additionally, the MTCA risk-based cleanup levels are established for each medium (ground water, surface water, soil, and air) at a hazardous waste site. Under the MTCA Cleanup Regulation, cleanup levels are based on estimates of the "reasonable maximum exposure" (RME). [1]

The MTCA Cleanup Regulation defines the Reasonable Maximum Exposure (RME) as: "the highest exposure that is reasonably expected to occur at a site under current and potential future site use."[2] In establishing cleanup levels and standards, as policy, the MTCA Cleanup Regulation is based on and protective of the most sensitive populations, including pregnant women, unborn children, children and most sensitive wildlife and plant speciesThe RME is designed to represent a high end (but not worst case) estimate of individual exposures. In fact, it provides a conservative estimate that falls within a realistic range of exposures.[3]

---

[1] MTCA defines the RME as the "…the highest exposure that can be reasonably expected to occur for a human or other living organisms at a site under current and potential future site use." CERCLA provides a similar definition "…the highest exposure that is reasonably expected to occur at a Superfund site…"

[2] WAC 173-340-708 (3) (b)

[3] U.S. Environmental Protection Agency. An Examination of EPA Risk Assessment Principles and Practices. EPA/100/B-04/0001. March 2004.

- The RME is defined as reasonable because it is a product of several factors that are an appropriate mix of average and upper-bound estimates. RME estimates typically fall between the 90th and 99.9 percentile of the exposure distribution.[4]
- The RME takes into account both current and reasonably foreseeable future conditions.

Regardless of the site use conditions (unrestricted, residential, or restricted soils, industrial), cleanup levels and standards are based on a reasonable maximum exposure expected to occur at the site that accounts for both current and potential future uses.[5] Different sections of the MTCA Cleanup Regulation define media - specific reasonable maximum exposures:

- Unrestricted, Residential, Soil Cleanup Levels and Standards, WAC 173-340-740, defines the RME in terms of the incidental soil ingestion rate of 200 mg/day for a child;
- Restricted, Industrial, Soil Cleanup Levels and Standards, WAC 173-340-740, defines the RME in terms of the incidental soil ingestion rate of 50 mg/day for an adult;
- Air Cleanup Levels and Standards, WAC 173-340-750, defines the RME in terms of a breathing rate of $10m^3$/day for a child and $20m^3$/day for an adult.

In defining the different RME's and exposure parameters to establish cleanup levels and standards Ecology has made policy choices that provide a reasonable balance between central tendency and upper bound estimates. In combination these exposure estimates provide a reasonable maximum exposure estimate for the different media.

2.0 Exposure Parameters and Scenarios

Risk management decisions for the MTCA Cleanup Regulation Update are based on a variety of factors. In addition to new technical information to support the MTCA update, consideration of divergent views from environmental and business communities, Tribal governments, risk-based methods and policies of federal and state environmental and public health agencies, and incremental benefits outweigh the incremental costs of complying with the revised cleanup standards and requirements. A risk management priority is to evaluate the methods for establishing risk-based soil cleanup levels under MTCA. Consistent with the MTCA's reasonable maximum exposure, current soil risk based cleanup levels are based on direct contact, single exposure, soil ingestion pathway. New technical information and regulatory guidance indicates consideration of age adjusted concurrent exposure pathways to derive soil risk-based cleanup levels. A risk management probabilistic decision model was developed to help evaluate the different exposure parameters and pathways that may influence the model outputs. The overall objective is to provide risk managers with sufficient information to make an informed decision as to whether, if at all, to change the current MTCA single exposure pathway deterministic risk based model to a concurrent (ingestion, dermal, inhalation) exposure pathway deterministic risk based model.

[4] IBID.
[5] Washington State Department of Ecology, 1991 Responsiveness Summary to the MTCA Cleanup Regulation

Four risk management probabilistic decision models were used to explore the influence of different exposure parameters and pathways using different combinations of age adjustments, exposure parameters, and exposure pathways. The four exposure models included:

- Ingestion and dermal concurrent exposure pathways with age and without age adjustments;
- Ingestion, dermal, and inhalation concurrent exposure pathways with and without age adjustments

3.0 Objectives

The overall objective/goal of this probabilistic exposure analysis is to provide risk managers with the tools to make better risk management decisions regarding the use of single or concurrent exposure models with and without age adjustments to calculate soil cleanup levels for Washington State. Three specific objective to this analysis include:

#1/ Compare single not age adjusted, with age and not age adjusted two and three concurrent exposure pathway models.

#2/ Using the YASAIw simulation tool with defined exposure distributions, evaluate different exposure parameters to estimate per cent contribution to variance to indicate the importance/influence of a particular exposure parameter and pathway on the predicted risk-based cleanup level.

#3/ Provide risk managers with an assessment of which exposure pathway model is reasonably protective based on the defined exposure distributions and the respective exposure simulations.

Table 1: Exposure Parameter Definitions/Abbreviations

Parameter	Definition
ABW	Average body weight
BWc	Body weight of child
BWa	Body weight of adult
SIR	Soil ingestion rate
$SIR_{<6}$	Child soil ingestion rate
$SIR_{7\text{-}31}$	Adult soil ingestion rate
SA	Dermal surface area exposed
$SA_{<6}$	Child dermal surface area exposed
$SA_{7\text{-}31}$	Adult dermal surface area exposed
AF	Soil adherence factor
$AF_{<6}$	Child soil adherence factor
$AF_{7\text{-}31}$	Adult soil adherence factor
VFs	Volatilization factor
ED	Exposure duration
$ED_{<6}$	Child exposure duration
$ED_{7\text{-}31}$	Adult exposure duration

4.0 Methodology

4.1 Models

Series of simulations were conducted using YASAIw and compared with the commercial software package Crystal Ball[R] (Fusion Edition Release 11.1.1.1.00) using four different concurrent exposure models. The simulation outputs were expressed as sensitivity analysis with contribution to variance (Spearman's Rho Rank Correlation) for different exposure parameters and per centiles, mean, and standard deviation for simulation outputs for cleanup levels and exposure parameters. The simulated sensitivity analysis, expressed as percent contribution to variance, provided information regarding the influence/prominence different exposure parameters had on risk based cleanup levels. The simulation results for-cleanup levels based on the four exposure models were compared to the current deterministic risk based cleanup levels to provide information regarding the level of protection afforded by single and concurrent, age adjusted and not age adjusted, exposure models.

In addition to comparison of probabilistic versus deterministic soil cleanup level estimates, the variations in soil cleanup level across the four different probabilistic based models were evaluated. The models were: two age and not age adjusted models for concurrent ingestion and dermal pathways and two age and not age adjusted models for concurrent ingestion, dermal, and inhalation pathways.

The probabilistic exposure models are provided in Equations 1 through 4 and the deterministic exposure models are provided in Equation 1 and 5. The age adjustment methodologies for the soil ingestion and dermal exposure pathways are provided by Equations 6 and 7.

Equation 1. Concurrent Exposure Pathway Model, No Age Adjustment (MTCA Method B, Equation 740-5)

$$\text{Soil Cleanup Level (mg/kg)} = \underbrace{\frac{\text{Risk} \cdot \text{AT} \cdot \text{ABW} \cdot \text{UCF1}}{\text{CPFo} \cdot \text{AB1} \cdot \text{EF} \cdot \text{ED} \cdot \text{SIR}}}_{\text{(Ingestion Component)}} + \underbrace{\frac{\text{Risk} \cdot \text{AT} \cdot \text{ABW} \cdot \text{UCF1}}{\text{CPFd} \cdot \text{ABSd} \cdot \text{EF} \cdot \text{ED} \cdot \text{SA} \cdot \text{AF}}}_{\text{(Dermal Component)}}$$

Equation 2. Two Concurrent Exposure Pathway Model, Age Adjustment

$$\text{Soil Cleanup Level (mg/kg)} = \underbrace{\frac{\text{Risk} \cdot \text{AT}}{\text{CPFo} \cdot \text{AB1} \cdot \text{EF} \cdot \text{IFSadj} \cdot \text{UCF1}}}_{\text{(Ingestion Component)}} + \underbrace{\frac{\text{Risk} \cdot \text{AT}}{\text{CPFd} \cdot \text{ABSd} \cdot \text{EF} \cdot \text{SFSadj} \cdot \text{UCF1}}}_{\text{(Dermal Component)}}$$

Equation 3. Three Concurrent Exposure Pathway Model, No Age Adjustment

$$\text{Soil Cleanup Level (mg/kg)} = \underbrace{\frac{\text{Risk} \cdot \text{AT} \cdot \text{ABW} \cdot \text{UCF1}}{\text{CPFo} \cdot \text{AB1} \cdot \text{EF} \cdot \text{ED} \cdot \text{SIR}}}_{\text{(Ingestion Component)}} + \underbrace{\frac{\text{Risk} \cdot \text{AT} \cdot \text{ABW} \cdot \text{UCF1}}{\text{CPFd} \cdot \text{ABSd} \cdot \text{EF} \cdot \text{ED} \cdot \text{SA} \cdot \text{AF}}}_{\text{(Dermal Component)}} + \underbrace{\frac{\text{Risk} \cdot \text{AT}}{\text{InhUR} \cdot (1/\text{VFs} + 1/\text{PEF}) \cdot \text{EF} \cdot \text{ED} \cdot \text{UCF2}}}_{\text{(Inhalation Component)}}$$

Equation 4. Three Concurrent Exposure Pathway Model, Age Adjustment

$$\text{Soil Cleanup Level (mg/kg)} = \underbrace{\frac{\text{Risk} \cdot \text{AT}}{\text{CPFo} \cdot \text{AB1} \cdot \text{EF} \cdot \text{IFSadj} \cdot \text{UCF1}}}_{\text{(Ingestion Component)}} + \underbrace{\frac{\text{Risk} \cdot \text{AT}}{\text{CPFd} \cdot \text{ABSd} \cdot \text{EF} \cdot \text{SFSadj} \cdot \text{UCF1}}}_{\text{(Dermal Component)}} + \underbrace{\frac{\text{Risk} \cdot \text{AT}}{\text{InhUR} \cdot (1/\text{VFs} + 1/\text{PEF}) \cdot \text{EF} \cdot \text{ED} \cdot \text{UCF2}}}_{\text{(Inhalation Component)}}$$

Equation 5. Single Ingestion Exposure Pathway Model (MTCA Method B Equation 740-2)

$$\text{Soil Cleanup Level (mg/kg)} = \frac{\text{Risk} \bullet \text{AT} \bullet \text{ABW} \bullet \text{UCF1}}{\text{CPFo} \bullet \text{AB1} \bullet \text{EF} \bullet \text{ED} \bullet \text{SIR}}$$

(Ingestion Component)

Equation 6. Age Adjustment Equations for the Soil Ingestion Exposure Pathway

$$\text{IFSadj (mg-year/kg-day)} = \frac{ED_{<6} \bullet SIR_{<6}}{BWc} + \frac{(ED_{7\text{-}31} - ED_{<6}) \bullet SIR_{7\text{-}31}}{BWa}$$

Equation 7. Age Adjustment Equation for the Dermal Exposure Pathway

$$\text{SFSadj (mg-year/kg-day)} = \frac{SA_{<6} \bullet AF_{<6} \bullet ED_{<6}}{BWc} + \frac{SA_{7\text{-}31} \bullet AF_{7\text{-}31} \bullet (ED_{7\text{-}31} - ED_{<6})}{BWa}$$

4.2 Sensitivity Analysis

Using Spearman's Rho Rank Correlation, the sensitivity analyses were expressed as percent contribution to variance to determine an exposure model's sensitivity to individual exposure parameters. Combinations of inputs and simulated exposure model outputs were plotted to illustrate the rank influence of exposure parameters on output values.The exposure parameters significantly influence model output when the Spearman's Rho Rank Correlation approaches unity (e.g., 1 or -1).

The exposure parameters, units of measure, and values are provided in Table 2, below:

Table 2: Defined Exposure Parameters

Parameter	Definition	Units	Values
Risk	Target Cancer Risk	unitless	1.00×10^{-6}
ABW	Average body weight	kg	Distribution or Point Estimate
BWc	Body weight of child	kg	Distribution or Point Estimate
BWa	Body weight of adult	kg	Distribution or Point Estimate
AT	Averaging time, years	years	75
UCF1	Unit conversion factor	kg/mg	1.00×10^{6}
UCF2	Unit conversion factor	µg/mg	1.00×10^{3}
CPFo	Oral cancer potency factor	kg-day/mg	Chemical-specific
AB1	Gastrointestinal absorption fraction, unitless	unitless	1
CPFd	Dermal cancer potency factor, (CPFo/AB1)	kg-day/mg	Chemical-specific
ABS	Dermal absorption fraction	unitless	Chemical-specific
EF	Exposure Frequency, unitless	unitless	1
SIR	Soil ingestion rate	mg/day	Distribution or Point Estimate
$SIR_{<6}$	Child soil ingestion rate	mg/day	Distribution or Point Estimate
$SIR_{7\text{-}31}$	Adult soil ingestion rate	mg/day	Distribution or Point Estimate
IFSadj	Age adjusted ingestion factor for soil	mg-year/kg-day	Calculated
SFSadj	Age adjusted dermal exposure factor for soil	mg-year/kg-day	Calculated
SA	Dermal surface area exposed	cm^2	Distribution or Point Estimate
$SA_{<6}$	Child dermal surface area exposed	cm^2	Distribution or Point Estimate
$SA_{7\text{-}31}$	Adult dermal surface area exposed	cm^2	Distribution or Point Estimate
AF	Soil adherence factor	mg/cm^2-day	Distribution or Point Estimate
$AF_{<6}$	Child soil adherence factor	mg/cm^2-day	Distribution or Point Estimate
$AF_{7\text{-}31}$	Adult soil adherence factor	mg/cm^2-day	Distribution or Point Estimate
InhUR	Inhalation unit risk	$m^3/\mu g$	Chemical-specific
VFs	Volatilization factor	m^3/kg	Chemical-specific distribution
PEF	Particulate emission factor	m^3/kg	1.32×10^{9}
ED	Exposure duration	years	Distribution or Point Estimate
$ED_{<6}$	Child exposure duration	years	Distribution or Point Estimate
$ED_{7\text{-}31}$	Adult exposure duration	years	Distribution or Point Estimate

4.3 Variability

The outputs using the probabilistic exposure models were compared with outputs using the deterministic exposure models for concurrent ingestion, dermal, and inhalation to assess the variability of risk-based cleanup levels. The four different deterministic risk based models were used with two permutations: two age and not age adjusted deterministic exposure models for concurrent ingestion and dermal pathways, and two age and not age adjusted deterministic exposure models for concurrent ingestion, dermal, and inhalation pathways. A 6 year and 30 year exposure duration was used for each of these deterministic models.

4.4 Distributions

All exposure distributions were based on review of the technical literature, state and federal regulatory guidance, and federal probabilistic risk assessments conducted at various facilities throughout the United States.[6]

4.4.1 Soil Volatilization Factor (VFs)

The distributions assigned to the soil volatilization factors (VFs) for epichlorohydrin and trichloroethylene were derived based on the application of the commercial software package Oracle's Crystal Ball[R] using goodness-of-fit tests to empirically determine soil dispersion factors for 29 national sites conducted with a 0-500 acres size range of geographic areas.

VFs is a function of dispersion factor (Q/C_{vol}), a climate specific term, and apparent diffusivity (D_A), a chemical specific term. VF is mathematically defined as:

Equation 8. Soil Volatilization Factor (VFs) Equation

$$VFs = \frac{\mathbf{Q/C} \times (3.14 \times D_A \times T)^{1/2} \times CF}{2 \times \rho_b \times \mathbf{D_A}}$$

Where:

- VFs [m^3/kg]: volatilization factor
- Q/C_{vol} [g/m^2-s per kg/m^2]: dispersion factor for volatiles emitted from the soil; inverse of the ratio of the geometric mean air concentration to the emission flux at the center of the source
- D_A [cm^2/s]: apparent diffusivity
- CF [m^2/cm^2]: a 10^{-4} conversion factor
- ρ_b [g/cm^3]: dry soil bulk density

The following details the equations to determine Q/C_{vol} (climate-zone specific)[7] and D_A (chemical specific): [8]

Equation 9. Q/Cvol Equation for Receptor and Pathway Specific Dispersion Factors

$$Q/C_{vol} = A \times \exp\left[\frac{(\ln A_s - B)^2}{C}\right]$$

Where:

- Q/C_{vol} [g/m^2-s per kg/m^2]: dispersion factor for volatiles emitted from the soil; inverse of the ratio of the geometric mean air concentration to the emission flux at the center of the source
- A, B, C: values based on air dispersion modeling for specific climate zones
- A_s [acres]: areal extent of the site or contamination

[6] Hanford R/S and Rocky Mountain Flats—additional information to be added.

[7] United States Environmental Protection Agency. 1996. Soil Screening Guidance: User's Guide. Publication 9355.4-23. Office of Solid Waste and Emergency Response, Washington, D.C. Equation D-1; pD-2.

[8] United States Environmental Protection Agency. 1996. Soil Screening Guidance: User's Guide. Publication 9355.4-23. Office of Solid Waste and Emergency Response, Washington, D.C. Equation 4-8; p4-24.

Equation 10. Apparent Soil Diffusivity Equation

$$D_A = \frac{[(\theta_a^{10/3} \times D_i \times H' + \theta_w^{10/3} \times D_w)/n^2]}{\rho_b \times K_d + \theta_w + \theta_a \times H'}$$

Where:

- D_A [cm^2/s]: apparent diffusivity
- θ_a [L_{air}/L_{soil}]: air-filled soil porosity
- D_i [cm^2/s]: diffusivity in air
- H': dimensionless Henry's law constant determined by H×41
  - H [atm-m^3/mol]: Henry's law constant
  - 41: units conversion factor
- D_w [cm^2/s]: diffusivity in water
- n [L_{pore}/L_{soil}]: total soil porosity
- ρ_b [g/cm^3]: dry soil bulk density
- K_d [cm^3/g]: soil-water partition coefficient determined by $K_{oc} \times f_{oc}$
  - K_{oc} [cm^3/g]: soil organic carbon partition coefficient
  - f_{oc} [g/g]: fraction organic carbon in soil
- θ_w [L_{water}/L_{soil}]: water-filled soil porosity

The dispersion factor (Q/C_{vol}) and apparent diffusivity (D_A) were derived first in order to determine VFs. [9] Additionally, as a parameter influenced by meteorological factors (e.g. temperature and pressure), it is difficult to identify and determine values to calculate chemical specific VFs without certain assumptions concerning climate conditions—namely temperature and pressure. Therefore, a temperature of 25°C and a pressure of 1atm were assumed.

[9] The Risk Assessment Information System: PRG Equations. http://rais.ornl.gov/prg/equations/vf.shtml

Dispersion Factor (Q/C_{vol})

The following table details the data used to determine Q/C_{vol}: [10]

Table 3: Table of A, B, C constants based on air dispersion modeling for specific climate zones

Meteorological Station	A Constant	B Constant	C Constant
Zone 1			
Salem, OR	12.3783	18.9683	218.2086
Seattle, WA	14.2253	18.8366	218.1845
Zone 2			
Fresno, CA	10.2152	19.2654	220.0604
Los Angeles, CA	11.9110	18.4385	209.7845
San Francisco, CA	13.8139	20.1624	234.2869
Zone 3			
Albuquerque, NM	14.9421	17.9869	205.1782
Las Vegas, NV	13.3093	19.8387	230.1652
Phoenix, AZ	10.2871	18.7124	212.2704
Zone 4			
Boise, ID	11.3161	19.6437	224.8172
Casper, WY	17.6482	18.8138	217.0390
Denver, CO	11.3612	19.3324	221.2167
Salt Lake City, UT	13.2559	19.2978	221.3379
Winnemucca, NV	12.8784	17.9804	204.1028
Zone 5			
Bismarck, ND	15.0235	18.2526	207.3387
Lincoln, NE	14.1901	18.5634	210.5281
Minneapolis, MN	16.2302	18.7762	216.1080
Zone 6			
Atlanta, GA	14.8349	17.9259	204.1516
Charleston, SC	13.7674	18.0441	204.8689
Houston, TX	13.6482	18.1754	206.7273
Little Rock, AR	12.4964	18.4476	210.2128
Raleigh, NC	12.3675	18.6337	212.7284
Zone 7			
Chicago, IL	16.8653	18.7848	215.0624
Cleveland, OH	12.8612	20.5164	237.2798
Harrisburg, PA	15.5169	18.4248	211.7679
Huntington, WV	9.9253	18.6636	211.8862
Zone 8			
Hartford, CT	12.5907	18.8368	215.4377
Philadelphia, PA	14.0111	19.6154	225.3397
Portland, ME	10.4660	20.9077	238.0318
Zone 9			
Miami, FL	12.1960	19.0645	215.3923

[10] United States Environmental Protection Agency. 1996. Soil Screening Guidance: User's Guide. Publication 9355.4-23. Office of Solid Waste and Emergency Response, Washington, D.C. Exhibit D-3; pD-7.

The values for A, B, and C in Table 1 for each of the 29 national sites were empirically derived using the Industrial Source Complex 3 (ISC3)[11] dispersion model to estimate the maximum annual average on-site air concentration. The estimations were conducted for a series of geographic areas ranging in size from 0.5 to 500 acres. [12]

To account for the varying climate conditions across the state of Washington, a distribution was separately fit to the data in columns A, B, and C using the Oracle Crystal Ball®, (Fusion Edition Release 11.1.1.1.00). Goodness-of-fit tests performed by the software—Anderson-Darling (A-D), Kolmogorov-Smirnov (K-S), and chi-square—and professional judgment helped evaluate the appropriate distribution for each variable. The best-fit distribution was used to describe the distribution of each data set in columns A, B, and C. The following table summarizes goodness-of-fit test results and descriptive statistics associated with the distributions for constants in columns A, B, and C.

Table 4: Summary of goodness-of-fit data and descriptive statistics associated with the chosen distribution for each constant

Constant	Distribution	Goodness of Fit						Descriptive Statistics
		A-D	A-D p-value	K-S	K-S p-value	Chi-square	Chi-square p-value	
A	Normal	0.1795	0.912	0.0964	0.784	0.5385	0.764	μ=13.46, σ=1.96
B	Lognormal	0.2154	0.717	0.0799	0.864	2.2414	0.326	μ=18.94, σ=0.81, Min=17.35, Max=∞
C	Lognormal	0.2319	0.651	0.0761	0.930	0.2222	0.637	μ=216.79, σ=11.47, Min=198.47, Max=∞

A uniform distribution was used to describe the variable A_s (the contaminated site area), to consider the range of square site areas to derive Q/C_{vol}.

[11] ISC3: steady-state Gaussian plume model software provided by the EPA to assess air pollutant concentrations from a variety of sources associated with industrial complexes. United States Environmental Protection Agency. 2005. Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities. Publication EPA530-R-05-006. Office of Solid Waste and Emergency Response, Washington, D.C. p3-6.

[12] United States Environmental Protection Agency. 1996. Soil Screening Guidance: User's Guide. Publication 9355.4-23. Office of Solid Waste and Emergency Response, Washington, D.C. pD-1.

Deriving VFs Distributions

The following table summarizes the data used to determine VFs for TCE: [13]

Table 5: Summary of values used to determine VFs for TCE

Parameters	Values	Distribution	Assumption	Definition (units)
T	9.50E+08	N/A	N/A	exposure interval **(s)**
ρ_b	1.5	N/A	N/A	dry soil bulk density **(g/cm^3)**
θ_a	0.28	N/A	N/A	air-filled soil porosity **(L_{air}/L_{soil})**
n	0.43	N/A	N/A	total soil porosity **(L_{pore}/L_{soil})**
θ_w	0.15	N/A	N/A	water-filled soil porosity **(L-water/L-soil)**
ρ_s	2.65	N/A	N/A	soil particle density **(g/cm^3)**
D_i	0.079	N/A	N/A	diffusivity in air **(cm^2/s)**, chemical specific
H	0.0103	N/A	N/A	Henry's law constant **(atm-m^3/mol)**, chemical specific
H'	0.422	N/A	N/A	dimensionless Henry's law constant, chemical specific
D_w	9.10E-06	N/A	N/A	diffusivity in water **(cm^2/s)**, chemical specific
K_d	0.996	N/A	N/A	soil-water partition coefficient **(cm^3/g)**, chemical specific
K_{oc}	166	N/A	N/A	soil organic carbon partition coefficient **(cm^3/g)**, chemical specific
f_{oc}	0.006	N/A	N/A	fraction organic carbon in soil **(g/g)**
A	μ=13.46, σ=1.96	Normal	Variable	constants based on air dispersion modeling for specific climate zones
B	μ=18.94, σ=0.81, Min=17.35, Max=∞	Lognormal	Variable	constants based on air dispersion modeling for specific climate zones
C	μ=216.79, σ=11.47, Min=198.47, Max=∞	Lognormal	Variable	constants based on air dispersion modeling for specific climate zones
A_s	0.5-500	Uniform	Variable	contamination or site area extent **(acres)**

The following table summarizes the data used to determine VFs for epichlorohydrin[14] :

Table 6: Summary of values used to determine VF for epichlorohydrin

Parameters	Values	Distribution	Assumption	Definition (units)
T	9.50E+08	N/A	N/A	exposure interval **(s)**
ρ_b	1.5	N/A	N/A	dry soil bulk density **(g/cm^3)**
θ_a	0.28	N/A	N/A	air-filled soil porosity **(L_{air}/L_{soil})**
n	0.43	N/A	N/A	total soil porosity **(L_{pore}/L_{soil})**
θ_w	0.15	N/A	N/A	water-filled soil porosity **(L-water/L-soil)**
ρ_s	2.65	N/A	N/A	soil particle density **(g/cm^3)**
D_i	0.0929	N/A	N/A	diffusivity in air **(cm^2/s)**, chemical specific
H	3.024E-05	N/A	N/A	Henry's law constant **(atm-m^3/mol)**, chemical specific
H'	0.00124	N/A	N/A	dimensionless Henry's law constant, chemical specific
D_w	1.09E-05	N/A	N/A	diffusivity in water **(cm^2/s)**, chemical specific
K_d	0.02694	N/A	N/A	soil-water partition coefficient **(cm^3/g)**, chemical specific
K_{oc}	4.49	N/A	N/A	soil organic carbon partition coefficient **(cm^3/g)**, chemical specific
f_{oc}	0.006	N/A	N/A	fraction organic carbon in soil **(g/g)**
A	μ=13.46, σ=1.96	Normal	Variable	constants based on air dispersion modeling for specific climate zones
B	μ=18.94, σ=0.81, Min=17.35, Max=∞	Lognormal	Variable	constants based on air dispersion modeling for specific climate zones
C	μ=216.79, σ=11.47, Min=198.47, Max=∞	Lognormal	Variable	constants based on air dispersion modeling for specific climate zones
A_s	0.5-500	Uniform	Variable	contamination or site area extent **(acres)**

Crystal Ball® generated Q/C_{vol} outputs when the A_s distribution and the distributions fit to the data in columns A, B, and C, were inserted into Equation 2. Crystal Ball ® inserted the constants listed in Table 3 or 4 and the Q/C_{vol} outputs into Equation 1 to generate VFs outputs. A distribution was fit to the VFs outputs generated by Crystal Ball® to determine a descriptive statistic for use in the soil cleanup model. Again, goodness-of-fit tests and professional judgment helped to evaluate the appropriate distribution

[13] United States Environmental Protection Agency. 2002. Soil Screening Guidance: User's Guide. Publication 9355.4-24. Office of Solid Waste and Emergency Response, Washington, D.C. Exhibit C-1, pC-4.

[14] The Risk Assessment Information System--Chemical Toxicity; http://rais.ornl.gov/cgi-bin/tox/TOX_select?select=nrad

for VFs. The table below summarizes goodness-of-fit test results and VFs descriptive statistics for TCE and epichlorohydrin.

Table 7: Summary of goodness-of-fit data and descriptive statistics associated with the VFs distribution for TCE and epichlorohydrin

Chemical	Distribution	Goodness of Fit						Descriptive Statistics
		A-D	A-D p-value	K-S	K-S p-value	Chi-square	Chi-square p-value	
TCE	Lognormal	1.6375	0	0.0309	0	32.9800	0.132	μ=1578.87, σ=366.66, Min=744.08, Max=3358.81
Epichlorohydrin	Lognormal	1.5629	0	0.0306	0	28.6300	0.28	μ=8749.83, σ=2168.77, Min=3620.43, Max=22041.74

The VFs distribution for TCE and epichlorohydrin were used to evaluate the exposure parameters and pathways to establish soil cleanup levels for TCE and epichlorohydin.

4.4.2 Descriptive Statistics of Exposure Distributions

The descriptive statistics of the exposure distributions and exposure parameters [arithmetic means (mean), standard deviations (StdDev), minimum (min), and maximum (max)] values are defined in Table 11, below.

Table 8: Descriptive Statistics For Exposure Distributions

Parameter	Definition	Distribution		References
ABW	Average body weight	Normal	Mean=14.50, StdDev=4.50, Min=3.00, Max=30.00	[1]
BWc	Body weight of child	Truncated Lognormal	Mean=14.50, StdDev=4.50, Min=3.00, Max=30.00	[1]
BWa	Body weight of adult	Truncated Lognormal	Mean=71.00, StdDev=15.30, Min=30.00, Max=136.00	[1]
SIR	Soil ingestion rate	Truncated Lognormal	Mean=44.6, StdDev= 79.9, Min=0, Max=1000	[2]
$SIR_{<6}$	Child soil ingestion rate	Truncated Lognormal	Mean=44.6, StdDev= 79.9, Min=0, Max=1000	[2]
$SIR_{7\text{-}31}$	Adult soil ingestion rate	Uniform	Min=0, Max=130	[3]
SA	Dermal surface area exposed	CFD[a]	Min %tile=0, Max %tile=1, Min Value=5960, Max Value=9100	[4]
$SA_{<6}$	Child dermal surface area exposed	CFD[a]	Min %tile=0, Max %tile=1, Min Value=5960, Max Value=9100	[4]
$SA_{7\text{-}31}$	Adult dermal surface area exposed	Truncated Lognormal	Mean=18400, StdDev=2300, Min=15000, Max=23000	[5]
AF	Soil adherence factor	Lognormal	Mean=0.14, StdDev=0.11	[6]
$AF_{<6}$	Child soil adherence factor	Lognormal	Mean=0.14, StdDev=0.11	[6]
$AF_{7\text{-}31}$	Adult soil adherence factor	Lognormal	Mean=0.14, StdDev=0.11	[6]
VF-tce	Volatilization factor for Trichloroethylene	Lognormal	Mean=1578.87, StdDev=366.66, Min=744.08, Max=3558.81	[7], [8], [9]
VF-epi	Volatilization factor for Epichlorohydrin	Lognormal	Mean=8749.83, StdDev=2168.77, Min=3620.43, Max=22041.74	[7], [8], [9]
ED	Exposure duration	PERT-beta	Min=1, Most Likely=3.5, Max=6, Opt Wt.=4	[10]
$ED_{<6}$	Child exposure duration	PERT-beta	Min=1, Most Likely=3.5, Max=6, Opt Wt.=4	[10]
$ED_{7\text{-}31}$	Adult exposure duration	Truncated Lognormal	Mean=12.6, StdDev=16.2, Min=1, Max=87	[11]

[a]: Cumulative frequency distribution

[1] U.S. EPA. Interim Final Guidance: Developing Risk-Based Cleanup Level At Resource Conservation and Recovery Act Sites in Region 10. EPA 910/R-98-001. Pages 6-23 to 6-24.

[2] U.S. EPA. Rocky Mountain Flats Human Health Risk Assessment. Task 3 Report and Appendices: Calculation of Surface Radionuclide Soil Action Levels for Plutonium, Americium, and Uranium. September 30, 2002. Table A-8, page 152 & page 166.

[3] U.S. EPA. Rocky Mountain Flats Human Health Risk Assessment. Task 3 Report and Appendices: Calculation of Surface Radionuclide Soil Action Levels for Plutonium, Americium, and Uranium. September 30, 2002. Figure A-5, page 139.

[4] U.S. EPA, 2002. Child-Specific Exposure Factors Handbook, (EPA-600-P-00-002B), Table 8-1, page 8-13

[5] Exposure Factors Source Book. American Industrial Health Council. May 1994. Pages 4.20 - 4.23

[6] U.S. EPA, February 2005. A Probabilistic Exposure Assessment for Children Who Contact CCA-Treated Playsets and Decks. Table 49, page 164.

[7] U.S. EPA, 1996. Soil Screening Guidance: User's Guide. Publication 9355.4-23. Office of Solid Waste and Emergency Response, Washington, D.C.

[8] The Risk Assessment Information System: PRG Equations. http://rais.ornl.gov/prg/equations/vf.shtml;

[9] The Risk Assessment Information System--Chemical Toxicity; http://rais.ornl.gov/cgi-bin/tox/TOX_select?select=nrad

[10] U.S. EPA. Rock Mountain Flats Human Health Risk Assessment. Task 3 Report and Appendices. Sept. 30, 2002. Appendix C, Table C-3, page 254.

[11] U.S. EPA. Rock Mountain Flats Human Health Risk Assessment. Task 3 Report and Appendices. Sept. 30, 2002. Table 4-5.

4.4.3 Simulation tools

Two simulation tools were used in this exposure evaluation. The primary simulation tool was the YASAIw developed by Rutgers University and enhanced by the Department of Ecology's Environmental Assessment Program. YASAIw is an enhanced version of the free open-source Monte Carlo simulation

tool add-in to Microsoft Excel that features additional distributions, correlated random variables, sensitivity analysis, and the ability to run user-defined macros during simulation.[15] In addition to the YASAIw Monte Carlo simulation tool, Oracle's Crystal Ball was used to derive the distributions for soil volatilization factors and to check/validate/verify the results of the simulations using YASAIw.

4.4.4 Selection of Chemicals to be Evaluated, Chemical-Specific and Exposure Parameters

An initial suite of five chemicals were used to evaluate soil carcinogenic cleanup levels.

- Arsenic
- Benzo[a]pyrene, [B(a)P]
- Chlordane
- Epichlorohydrin
- Trichloroethylene (TCE)

The basis for the selection of these chemicals includes:

- Availability of carcinogenic toxicity values for different routes of exposure (oral cancer potency values and inhalation unit risk values);
- Range of physical/chemical properties that may influence the dominance of one exposure pathway over another (different dermal absorption values, an inorganic non-volatile chemical and/or varying organic chemical volatility);
- Use of this evaluation for future analysis, such as, the potential that early life exposures may contribute to cancer exhibited later in life.

Chemical-specific information required for probabilistic analysis and deterministic evaluations are provided in Table 12, below.

Table 9: Chemical - Specific Information

Chemical	CAS #	Oral Cancer Potency Factor CPFo	Dermal Cancer Potency Factor CPFd	Dermal Absorption Fraction ABS	Inhaltion Unit Risk Factor InhUR
Arsenic	7440-38-2	1.50	1.58	1×10^{-2}	4.3×10^{-3}
Benzo[a]pyrene	50-32-8	7.30	8.20	1.3×10^{-1}	1.1×10^{-3}
Chlordane	57-47-9	3.5×10^{-1}	4.3×10^{-1}	4.0×10^{-2}	1.0×10^{-4}
Epichlorohydrin	106-89-8	9.9×10^{-3}	1.2×10^{-2}	3.0×10^{-2}	1.2×10^{-6}
Trichloroethylene	79-01-6	8.9×10^{-2}	1.1×10^{-1}	3.0×10^{-2}	2.0×10^{-5}

Exposure point estimates used in the exposure models (Equations 1-5) for deterministic calculations for comparisons with probabilistic evaluations are provided in Table XX, below. Table xxx, provides the ingestion and dermal age adjustment factors based on Equations 6 and 7.

[15] YASAIw and user manual located at following link: http://www.ecy.wa.gov/programs/eap/models.html

Table 10: Exposure Point Estimates

Parameter	Definition	Point Estimate	References[a]
ABW	Average body weight	16	MTCA
BWc	Body weight of child	16	MTCA
BWa	Body weight of adult	70	MTCA
SIR	Soil ingestion rate	200	MTCA
$SIR_{<6}$	Child soil ingestion rate	200	MTCA
SIR_{7-31}	Adult soil ingestion rate	50	MTCA
SA	Dermal surface area exposed	2200	MTCA
$SA_{<6}$	Child dermal surface area exposed	2200	MTCA
SA_{7-31}	Adult dermal surface area exposed	2500	[1]
AF	Soil adherence factor	0.2	MTCA
$AF_{<6}$	Child soil adherence factor	0.2	MTCA
AF_{7-31}	Adult soil adherence factor	0.2	MTCA
VF-tce	Volatilization factor for Trichloroethylene	1.8×10^4	[2]
VF-epi	Volatilization factor for Epichlorohydrin	2.5×10^3	[2]
ED	Exposure duration	6 or 30	MTCA / EPA
$ED_{<6}$	Child exposure duration	6	MTCA
ED_{7-31}	Adult exposure duration	24	EPA

[a]: MTCA: Model Toxics Control Act; EPA: U.S. Environmental Protection Agency

[1] U.S. EPA, 1997. Exposure Factors Handbook (1997 Final Report), (EPA-600-P-95-002F a-c)

[2] U.S. EPA-Region 6 PRG tables

Table 11: Soil Ingestion & Dermal Age Adjustment Factors

Parameter	Definition	Point Estimate
IFSadj	Age adjusted ingestion factor for soil	92
SFSadj	Age adjusted dermal exposure factor for soil	336

The one dimensional Monte Carlo simulations conducted for this analysis assumed that the total body surface area was positively correlated with body weight, with an assumed rank correlation coefficient of 1. Referencing Phillips et. Al, 1993, EPA's Exposure Factors Handbook (page 6-3), notes a strong correlation (0.986) between body surface area and body weight.[16]

5.0 Observations, Discussion and Conclusions

5.1 General observations for not age and age adjusted, two concurrent exposure pathway model outputs

Except for epichlorohydrin and trichloroethylene, the child's soil ingestion rate is the most influential exposure parameter followed by the adult exposure duration through the ingestion pathway for the age adjusted, three concurrent exposure model. Benzo[a]pyrene showed a more uniform distribution between the ingestion and dermal exposure pathways with the dermal exposure pathway contributing over 20% to variance. Epichlorohydrin and trichloroethylene, two volatile chemicals with empirically

[16] Phillips, L.J.; Fares, R.J.; Schweer, L.G. 1993. Distributions of Total Skin Surface Area to Body Weight Ratios For Use In Dermal Exposure Assessments. J. Exposure Anal. Environ. Epidemiol. 3(3):331-338.

determined soil volatilization factors, show that the adult's exposure duration (inhalation exposure pathway) is the most influential exposure parameter followed by the soil volatilization factor for the age adjusted, three concurrent exposure pathway model. For epichlorohydrin and trichloroethylene, the adult's exposure duration contributes approximately 90% to variance while the soil volatilization factor contributes about 10% contribution to variance. The high contribution to variance by adult exposure duration through the inhalation exposure pathway and for the soil volatilization factor for epichlorohydrin and trichloroethylene suggests the dominant influence the inhalation exposure pathway has for the age adjusted, three concurrent exposure model output.

Although the percent contribution to variance was larger for the not age adjusted compared to the age adjusted two concurrent exposure models (ingestion and dermal exposure pathways), for all 5 chemicals, the child's soil ingestion rate was the most influential exposure parameter for model outputs. Age adjustments for the two concurrent exposure model resulted in the adult exposure duration having the second highest percent contribution to variance, approximately a range of 30% to 40% contribution to variance for 4 out of 5 chemicals evaluated. For both not age adjusted and age adjusted two concurrent exposure models, benzo[a]pyrene illustrated a more uniform distribution between the ingestion and dermal exposure pathways with the age adjusted model showing approximately 25% contribution to variance for each of the different exposure parameters (child's soil ingestion rate, Dermal and ingestion adult exposure duration).

Table 15 illustrates the influence of the different exposure parameters on the two concurrent exposure pathway model outputs.

Table 12: Relative Sequence & Magnitude of Exposure Parameters From Stochastic Analysis/Contribution to Variance (Sensitivity Analysis) For Two Concurrent Exposure Pathway Model

Two Concurrent Exposure Pathways

Chemical	Sequence of Exposure Parameters & Pathways	Dominant Pathway(s)
	Not Age Adjusted (NAAdj)	
Arsenic	Child's Soil Ingestion Rate (SIR)>Body Surface Area Exposed (SAtot)~Average Body Weight (ABW)	Ingestion
Benzo[a]pyrene	Child's Soil Ingestion Rate (SIR) >>Soil Adherence Factor (AF)>Child's Exposure Duration (EDc)	Ingestion and Dermal
Chlordane	Child's Soil Ingestion Rate (SIR)>>>Child Exposure Duration (EDc)>Body Surface Area Exposed (SAtot)	Ingestion
Epichlorohydrin	Child's Soil Ingestion Rate (SIR)>>>Body Surface Area Exposed (SAtot)~Average Body Weight (ABW)	Ingestion
Trichloroethylene	Child's Soil Ingestion Rate (SIR)>>>Body Surface Area Exposed (SAtot)~Average Body Weight (ABW)	Ingestion
	Age Adjusted (AAdj)	
Arsenic	Child's Soil Ingestion Rate (SIRc)>Adult Exposure Duration (EDa(Ing))>>Adult Soil Ingestion Rate (SIRa)	Ingestion
Benzo[a]pyrene	Child's Soil Ingestion Rate (SIRc)>Adult Exposure Duration (EDa(D))>Adult Soil Ingestion Rate (EDa(Ing))	Ingestion and Dermal
Chlordane	Child's Soil Ingestion Rate (SIRc)>Adult Exposure Duration (EDa(Ing))>>Adult Soil Ingestion Rate (EDa(Ing))	Ingestion
Epichlorohydrin	Child's Soil Ingestion Rate (SIRc)>Adult Exposure Duration (EDa(Ing))>>Adult Soil Ingestion Rate (SIRa)	Ingestion
Trichloroethylene	Child's Soil Ingestion Rate (SIRc)>Adult Exposure Duration (EDa(Ing))>>Adult Soil Ingestion Rate (SIRa)	Ingestion

General observations for not age and age adjusted, three concurrent exposure pathway model outputs

For not age adjusted and age adjusted, the high contribution to variance for inhalation exposure parameters suggests the important influence the inhalation exposure pathway has for epichlorohydrin and trichloroethylene for the three concurrent exposure model output. For the other three chemicals evaluated, age adjustments change both the percent contribution to variance and the sequence with which the exposure parameters contribute to variance.

Table 16 illustrates the influence of the different exposure parameters on the three concurrent exposure pathway model outputs.

Table 13: Relative Sequence & Magnitude of Exposure Parameters From Stochastic Analysis/Contribution to Variance (Sensitivity Analysis) For Three Concurrent Exposure Pathway Model

Three Concurrent Exposure Pathways

Chemical	Sequence of Exposure Parameters & Pathways	Dominant Pathway(s)
	Not Age Adjusted (NAAdj)	
Arsenic	Child's Soil Ingestion Rate (SIR)>>>Child Exposure Duration (EDc)>Body Surface Area Exposed (Satot)~Average Body Weight (ABW)	Ingestion
Benzo[a]pyrene	Child's Soil Ingestion Rate (SIR)>>Soil Adherence Factor (AF)>Child's Exposure Duration (EDc)	Ingestion and Dermal
Chlordane	Child's Soil Ingestion Rate (SIR)>>>Child Exposure Duration (EDc)>Body Surface Area Exposed (Satot)~Average Body Weight (ABW)	Ingestion
Epichlorohydrin	Child's Exposure Duration (Edc)>Soil Volatilization Facto (VF-epi)>Child's Soil Ingestion Rate (SIR)	Ingestion
Trichloroethylene	Child's Exposrue Duration (Edc)>>Soil Volatilization Factor (VF-tce)	Ingestion
	Age Adjusted (AAdj)	
Arsenic	Child's Soil Ingestion Rate (SIRc)>Adult Exposure Duration (EDa(Ing))>>Adult Soil Ingestion Rate (SIRa)	Ingestion
Benzo[a]pyrene	Child's Soil Ingestion Rate (SIRc)>Adult Exposure Duration (EDa(D))>Adult Exposure Duraction (EDa(Ing))	Ingestion and Dermal
Chlordane	Child's Soil Ingestion Rate (SIRc)>Adult Exposure Duration (EDa(Ing))>>Adult Soil Ingestion Rate (SIRa)	Ingestion
Epichlorohydrin	Adult Exposure Duration (EDa(Inh))>>>Volatilization Factor (VF-epi)>Child's Soil Ingestion Rate (SIRc)	Inhalation and Ingestion
Trichloroethylene	Adult Exposure Duration (EDa(Inh))>>>Volatilization Factor (VF-tce)>Child's Exposure Duration (Edc(Inh))	Inhalation

5.2 Percent Contribution to Variance, Sensitivity Analysis

Tables 17 through 20 provide the sensitivity analysis from YASAIw simulation outputs as percent contribution to variance. The percent contribution to variance provides information regarding which of the different exposure parameters has the greatest influence on the simulation outputs. Also, the dominance of one exposure parameter over that of another may be attributed to different exposure pathways for the two and three concurrent exposure models used in this analysis. Observations regarding the percent contribution to variance follows tables 17 through 20.

Table 14: Tabular Results of YASAIw Sensitivity Analysis

YASAI Simulation Output As Percent Contribution to Variance	
Two Concurrent Exposure Pathway Model, Not Age Adjusted	
ARSENIC	
Exposure Parameter	**Per Cent Contribution to Variance**
Soil Ingestion Rate (SIR)	82%
Body Surface Area Exposed (SA)	6%
Average Body Weight (ABW)	6%
Exposure Duration, Child ($ED_{<6}$)	5%
BENZO[a]PYRENE	
Soil Ingestion Rate (SIR)	50 %
Soil Adherence Factor (AF)	19%
Exposure Duration, Child ($ED_{<6}$)	12%
Body Surface Area Exposed (SA)	9%
Average Body Weight (ABW)	9%
CHLORDANE	
Soil Ingestion Rate (SIR)	71 %
Exposure Duration, Child ($ED_{<6}$)	8 %
Body Surface Area Exposed (SA)	8 %
Average Body Weight (ABW)	8 %
Soil Adherence Factor(AF)	5 %
EPICHLOROHYDRIN	
Soil Ingestion Rate (SIR)	74%
Body Surface Area Exposed (SA)	7%
Average Body Weight (ABW)	7%
Exposure Duration, Child ($ED_{<6}$)	7%
Soil Adherence Factor(AF)	3%
TRICHLOROETHYLENE	
Soil Ingestion Rate (SIR)	74%
Body Surface Area Exposed (SA)	7%
Average Body Weight (ABW)	7%
Exposure Duration, Child($ED_{<6}$)	7%
Soil Adherence Factor (AF)	3%

General Observation: The soil ingestion rate is the most influential exposure parameter to derive soil cleanup levels for all chemicals for a not age adjusted, two concurrent exposure pathway model. Hence, the soil ingestion pathway is the dominant exposure pathway. However, for not age adjusted, two concurrent exposure pathway model benzo[a]pyrene more uniformly distributes the exposure parameters across both ingestion and dermal exposure pathways.

Table 15: Tabular Results of YASAIw Sensitivity Analysis

YASAI Simulation Output As Percent Contribution to Variance	
Two Concurrent Exposure Pathway Model, Age Adjusted	
ARSENIC	
Exposure Parameter	**Per Cent Contribution to Variance**
Soil Ingestion Rate, Child	50 %
Exposure Duration, Adult/Ingestion Pathway	36 %
Soil Ingestion Rate, Adult	9 %
Average Body Weight, child/Ingestion Pathway	3 %
Exposure Duration, Child/Ingestion Pathway	2 %
BENZO[a]PYRENE	
Soil Ingestion Rate, Child	28 %
Exposure Duration, Adult/Dermal Pathway	23 %
Exposure Duration, Adult/Ingestion Pathway	21 %
Soil Adherence Factor, Child	10 %
Soil Adherence Factor, Adult	6 %
Soil Ingestion Rate, Adult	5 %
CHLORDANE	
Soil Ingestion Rate, Child	43 %
Exposure Duration, Adult/Ingestion Pathway	32 %
Soil Ingestion Rate, Adult	8 %
Exposure Duration, Adult/Dermal Pathway	7 %
Soil Adherence Factor, Child	3 %
Soil Adherence Factor, Adult	2 %
EPICHLOROHYDRIN	
Soil Ingestion Rate, Child	45 %
Exposure Duration, Adult/Ingestion Pathway	33 %
Soil Ingestion Rate, Adult	8 %
Exposure Duration, Adult/Dermal Pathway	5 %
Average Body Weight, child/Ingestion Pathway	2 %
TRICHLOROETHYLENE	
Soil Ingestion Rate, Child	45 %
Exposure Duration, Adult/Ingestion Pathway	33 %
Soil Ingestion Rate, Adult	8 %
Exposure Duration, Adult/Dermal Pathway	5 %
Average Body Weight, child/Ingestion Pathway	2 %

General Observation: The child's soil ingestion rate and the adult exposure duration (ingestion pathway) are the most influential exposure parameters for all chemicals for age adjusted, two concurrent exposure pathway model. Except for benzo[a]pyrene, the soil ingestion pathway is the dominant exposure pathway. Benzo[a]pyrene showed a more uniform distribution between the ingestion and dermal exposure pathways with the dermal pathway contributing almost 40% to variance through its different exposure parameters. All chemicals, except benzo[a]pyrene, showed the same sequence of exposure parameters with epichlorohydrin and trichloroethylene having the same sequence and percent contributions to variance.

Table 16: Tabular Results of YASAIw Sensitivity Analysis

YASAI Simulation Output As Percent Contribution to Variance	
Three Concurrent Exposure Pathway Model, Not Age Adjusted	
ARSENIC	
Exposure Parameter	**Per Cent Contribution to Variance**
Soil Ingestion Rate, Child	83 %
Exposure Duration, Child	6 %
Body Surface Area Exposed	5 %
Average Body Weight	5 %
BENZO[a]PYRENE	
Soil Ingestion Rate, Child	51 %
Soil Adherence Factor	18 %
Exposure Duration, Child	12 %
Body Surface Area Exposed	9 %
Average Body Weight	9 %
CHLORDANE	
Soil Ingestion Rate, Child	72 %
Exposure Duration, Child	9 %
Body Surface Area Exposed	7 %
Average Body Weight	7 %
Soil Adherence Factor	5 %
EPICHLOROHYDRIN	
Exposure Duration, Child	56 %
Soil Volatilization Factor	25 %
Soil Ingestion Rate, Child	15 %
TRICHLOROETHYLENE	
Exposure Duration, Child	63 %
Soil Volatilization Factor	37 %
Soil Ingestion Rate, Child	<1 %

General Observation: Except for epichlorohydrin and trichloroethylene, the child's soil ingestion rate is the most influential exposure parameter for the not age adjusted, three concurrent exposure model. Benzo[a]pyrene showed a more uniform distribution between the ingestion and dermal exposure pathways with the dermal exposure pathway contributing almost 20% to variance. Epichlorohydrin and trichloroethylene, two volatile chemicals with empirically determined soil volatilization factors, show that the child's exposure duration is the most influential exposure parameter followed by the soil volatilization factor for the not age adjusted, three concurrent exposure pathway model. For

epichlorohydrin and trichloroethylene, the child's exposure duration contributes almost 60% to variance while the soil volatilization factor contributes 25% to variance for epichlorohydrin and 37% to variance for trichloroethylene. The high contribution to variance by the soil volatilization factor for epichlorohydrin and trichloroethylene suggests the important influence the inhalation exposure pathway has for the not age adjusted, three concurrent exposure model output.

Table 17: Tabular Results of YASAIw Sensitivity Analysis

YASAI Simulation Output As Percent Contribution to Variance	
Three Concurrent Exposure Pathway Model, Age Adjusted	
ARSENIC	
Exposure Parameter	**Per Cent Contribution to Variance**
Soil Ingestion Rate, Child	52 %
Exposure Duration, Adult, Ing	35 %
Soil Ingestion Rate, Adult	8 %
Average Body Weight, Child, Ingestion Pathway	3 %
Exposure Duration, Child, Ing	1 %
BENZO[a]PYRENE	
Soil Ingestion Rate, Child	32 %
Exposure Duration, Adult, D	22 %
Exposure Duration, Adult, Ing	20 %
Soil Adherence Factor, Child	9 %
Soil Adherence Factor, Adult	6 %
Soil Ingestion Rate, Adult	5 %
CHLORDANE	
Soil Ingestion Rate, Child	46 %
Exposure Duration, Adult, Ing	31 %
Soil Ingestion Rate, Adult	7 %
Exposure Duration, Adult, D	7 %
Soil Adherence Factor, Child	3 %
Average Body Weight, Child, Ingestion Pathway	2 %
EPICHLOROHYDRIN	
Exposure Duration, Adult, Inh	87 %
Soil Volatilization Factor	9 %
Soil Ingestion Rate, Child	2 %
Exposure Duration, Adult, Ing	<1 %
TRICHLOROETHYLENE	
Exposure Duration, Adult, Inh	92 %
Soil Volatilization Factor	7 %
Exposure Duration, Child, Inh	<1 %

General Observation: Except for epichlorohydrin and trichloroethylene, the child's soil ingestion rate is the most influential exposure parameter followed by the adult exposure duration through the ingestion pathway for the age adjusted, three concurrent exposure model. Benzo[a]pyrene showed a more uniform distribution between the ingestion and dermal exposure pathways with the dermal exposure

pathway contributing over 20% to variance. Epichlorohydrin and trichloroethylene, two volatile chemicals with empirically determined soil volatilization factors, show that the adult's exposure duration (inhalation exposure pathway) is the most influential exposure parameter followed by the soil volatilization factor for the age adjusted, three concurrent exposure pathway model. For epichlorohydrin and trichloroethylene, the adult's exposure duration contributes approximately 90% to variance while the soil volatilization factor contributes about 10% contribution to variance. The high contribution to variance by adult exposure duration through the inhalation exposure pathway and for the soil volatilization factor for epichlorohydrin and trichloroethylene suggests the dominant influence the inhalation exposure pathway has for the age adjusted, three concurrent exposure model output.

5.3 Comparison of Deterministic Risk-Based Soil Cleanup Levels Corresponding to Percentiles From Simulated Exposure Distributions

Tables 21, 22, and 23 (page 28 and 29) provide deterministic risk-based cleanup levels for the five chemicals used in this analysis. The risk-based cleanup levels are calculated based on MTCA Method B Equation 740-2 representing a single direct contact ingestion exposure pathway (Equation 5, page 7), MTCA Modified Method B Equation 740-5 representing two concurrent (ingestion and dermal), not age adjusted, exposure pathway (Equation 1, page 6), and age adjusted two concurrent exposure and age and not age adjusted three concurrent exposure models (Equations 2, 3, and 4, pages 6 and 7). The deterministic risk-based cleanup levels are compared to the corresponding percentiles from the simulated exposure distributions to estimate the percent probabilities that the cleanup levels based on the outputs from the exposure models will be protective of human health. Tables 23 through 26 (Section 5.4, pages 30 and 32) provide these estimated percent probabilities with observations and conclusions provided at the end of the tables.

Table 18: Soil Deterministic Risk - Based Single Ingestion Pathway Cleanup Levels

Deterministic Risk-Based Soil Cleanup Levels (CUL) MTCA Method B Risk-Based Soil Cleanup Levels for Carcinogens Eqn 740-2, 6 Year Exp. Duration	
Chemical (CAS#)	MTCA Method B Soil Cleanup Level, Eqn 740-2 [mg/kg]
Arsenic (7440-38-2)	6.67E-01
Benzo[a]pyrene (50-32-8)	1.37E-01
Chlordane (57-47-9)	2.86E+00
Epichlorohydrin (106-89-8)	1.01E+02
Trichloroethylene (79-01-6)	1.12E+01

Table 19: Soil Deterministic risk-Based Concurrent Ingestion Pathway-6 Year Exp. Duration

Deterministic Risk-Based Soil Cleanup Levels (CUL) Concurrent Exposure Risk-Based Soil CUL for Carcinogens Using 6 Year Exposure Duration		
Chemical (CAS#)	**MTCA Modified Method B (Eqn 740-5) (Ingestion + Dermal) [mg/kg]**	**Ingestion + Dermal+Inhalation [mg/kg]**
	Not Age Adjusted (NAAdj)	
Arsenic (7440-38-2)	6.52E-01	6.51E-01
Benzo[a]pyrene (50-32-8)	1.04E-01	1.04E-01
Chlordane (57-47-9)	2.57E+00	2.57E+00
Epichlorohydrin (106-89-8)	9.03E+04	6.23E+01
Trichloroethylene (79-01-6)	1.04E+01	1.36E+00
	Age Adjusted (AAdj)	
Arsenic (7440-38-2)	5.23E-01	5.23E-01
Benzo[a]pyrene (50-32-8)	7.28E-02	7.28E-02

Chlordane (57-47-9)	1.97E+00	1.97E+00
Epichlorohydrin (106-89-8)	7.24E+01	5.22E+01
Trichloroethylene (79-01-6)	8.06E+00	1.31E+00

Table 20: Soil Deterministic Risk-Based Concurrent Ingestion Pathway-30 Year Exposure Duration

Deterministic Risk-Based Soil Cleanup Levels (CUL) Concurrent Exposure Risk-Based Soil CUL for Carcinogens Using 30 Year Exposure Duration		
Chemical (CAS#)	**MTCA Modified Method B (Eqn 740-5) (Ingestion + Dermal) [mg/kg]**	**Ingestion + Dermal+Inhalation [mg/kg]**
	Not Age Adjusted (NAAdj)	
Arsenic (7440-38-2)	1.30E-01	1.30E-01
Benzo[a]pyrene (50-32-8)	2.07E-02	2.07E-02
Chlordane (57-47-9)	5.15E-01	5.15E-01
Epichlorohydrin (106-89-8)	1.09E+01	1.25E+01
Trichloroethylene (79-01-6)	2.08E+00	2.72E-01
	Age Adjusted (AAdj)	
Arsenic (7440-38-2)	5.23E-01	5.23E-01
Benzo[a]pyrene (50-32-8)	7.28E-02	7.28E-02
Chlordane (57-47-9)	1.97E+00	1.97E+00
Epichlorohydrin (106-89-8)	7.24E+01	2.47E+01
Trichloroethylene (79-01-6)	8.06E+00	3.01E-01

5.4 Deterministic Risk – Based Soil Cleanup Levels Compared to Corresponding Percentiles from Simulated Exposure Distributions

Table 21: Deterministic Risk-Based Soil Cleanup Levels Compared to Corresponding Percentiles From Simulated Exposure Distributions - Arsenic

Arsenic				
Stochastic Exposure Model	**Deterministic Point Estimate Exposure Model**			
	Risk Based CUL (30yr ED)	Risk Based CUL (6yr ED)	Method B Eqn 740-2	Mod Meth B Eqn 740-5
Ing+D (Mod Method B Eqn 740-5) Not AgeAdjusted (NAAdj) Child	<1%	1%-5%	1%-5%	1%-5%
Ing+D Age Adjusted (AAdj) Child + Adult	1%-5%	1%-5%	1%-5%	1%-5%
Ing+D+Inh Not Age Adjusted (NAAdj) Child	<1%	1%-5%	1%-5%	1%-5%
Ing+D+Inh Age Adjusted (AAdj) Child + Adult	1%-5%	1%-5%	1%-5%	1%-5%

Observations/Conclusions for Inorganic Chemical-Arsenic: Comparing 6 or 30 year exposure duration, regardless of age adjustments, the 2 and 3-concurrent deterministic cleanup levels with the corresponding percentiles from a simulated exposure distribution indicates there is approximately 1 to 5% probability that the cleanup level will not be protective of human health; conversely, approximately a 95% probability that the cleanup level will be protective of human health.

Table 22: Deterministic Risk-Based Cleanup Levels Compared to Corresponding Percentiles From Simulated Exposure Distributions - Benzo[a]pyrene

Benzo[a]pyrene				
Stochastic Exposure Model	**Deterministic Point Estimate Exposure Model**			
	Risk Based CUL (30yr ED)	Risk Based CUL (6yr ED)	Method B Eqn 740-2	Mod Meth B Eqn 740-5
Ing+D (Mod Method B Eqn 740-5) Not AgeAdjusted (NAAdj) Child	<1%	1%-5%	1%-5%	5-Jan
Ing+D Age Adjusted (AAdj) Child + Adult	1%-5%	1%-5%	5% - 10%	≈ 5%
Ing+D+Inh Not Age Adjusted (NAAdj) Child	<1%	< 5%	1%-5%	< 5%
Ing+D+Inh Age Adjusted (AAdj) Child + Adult	1%-5%	1%-5%	< 5%	≈ 5%

Table 23: Deterministic Risk - Based Cleanup Levels Compared to Corresponding Percentiles From Simulated Exposure Distributions - Chlordane

Chlordane				
Stochastic Exposure Model	**Deterministic Point Estimate Exposure Model**			
	Risk Based CUL (30yr ED)	Risk Based CUL (6yr ED)	Method B Eqn 740-2	Mod Meth B Eqn 740-5
Ing+D (Mod Method B Eqn 740-5) Not AgeAdjusted (NAAdj) Child	< 1%	1% - 5%	1% - 5%	1% - 5%
Ing+D Age Adjusted (AAdj) Child + Adult	1% - 5%	1% - 5%	≈ 5%	≈ 5%
Ing+D+Inh Not Age Adjusted (NAAdj) Child	<1%	1% - 5%	1% - 5%	1% - 5%
Ing+D+Inh Age Adjusted (AAdj) Child + Adult	1% - 5%	1% - 5%	1% - 5%	≈ 5%

Observations/Conclusions for Semi-Volatile Chemicals-Benzo[a]pyrene and Chlordane: Comparing 6 or 30 year exposure duration, regardless of age adjustments, the 2 and 3-concurrent deterministic cleanup levels with the corresponding percentiles from a simulated exposure distribution indicates there is approximately 1 to 5% probability that the cleanup level will not be protective of human health; conversely, approximately a 95% probability that the cleanup level will be protective of human health.

Table 24: Deterministic Risk-Based Soil Cleanup Levels Compared to Corresponding Percentiles From Simulated Exposure Distributions - Chlordane

Epichlorohydrin				
Stochastic Exposure Model	**Deterministic Point Estimate Exposure Model**			
	Risk Based CUL (30yr ED)	Risk Based CUL (6yr ED)	Method B Eqn 740-2	Mod Meth B Eqn 740-5
Ing+D (Mod Method B Eqn 740-5) Not AgeAdjusted (NAAdj) Child	< 1%	1% - 5%	1% - 5%	1% - 5%
Ing+D Age Adjusted (AAdj) Child + Adult	1% - 5%	1% - 5%	≈ 5%	≈ 5%
Ing+D+Inh Not Age Adjusted (NAAdj) Child	<1%	≈ 5%	25% - 50%	≈ 25%
Ing+D+Inh Age Adjusted (AAdj) Child + Adult	10% - 25%	≈ 50%	75% - 90%	75% - 90%

Table 25: Deterministic Risk-Based Soil Cleanup Levels Compared to Corresponding Percentiles From Simulated Exposure Distributions - Trichloroethylene

Trichloroethylene				
Stochastic Exposure Model	**Deterministic Point Estimate Exposure Model**			
	Risk Based CUL (30yr ED)	Risk Based CUL (6yr ED)	Method B Eqn 740-2	Mod Meth B Eqn 740-5
Ing+D (Mod Method B Eqn 740-5) Not AgeAdjusted (NAAdj) Child	≈ 5%	≈ 1%	1% - 5%	≈ 1%
Ing+D Age Adjusted (AAdj) Child + Adult	1% - 5%	1% - 5%	1% - 5%	≈ 5%
Ing+D+Inh Not Age Adjusted (NAAdj) Child	<1%	25% - 50%	> 99%	> 99%
Ing+D+Inh Age Adjusted (AAdj) Child + Adult	10% - 25%	25% - 50%	> 99%	> 99%

Observations/Conclusions for Volatile Organic Chemicals-Epichlorohydrin and Trichloroethylene: For selected volatile organic chemicals, comparing 6 or 30 year exposure duration, regardless of age adjustments, the 2-concurrent deterministic cleanup levels, with corresponding percentiles from a simulated exposure distribution indicates there is approximately a 1 to 5% probability that the cleanup level will not be protective of human health; conversely, approximately a 95% probability that the cleanup levels will be protective of human health. Comparing 6 or 30 year exposure duration, regardless of age adjustments, the 3-concurrent deterministic cleanup levels, with corresponding percentiles from a simulated exposure distribution indicates there is approximately 50 to 75% that the cleanup levels will be protective of human health;; conversely, a 25 to 50% probability that the cleanup level is not protective of human health. For volatile chemicals, with a 6 year exposure duration, cleanup levels may not be as protective of human health compared with cleanup levels established using a 30 years exposure duration. For volatile chemicals, the cleanup levels established based on MTCA Method B equations 740-2 and MTCA Modified Method B equations 740-5 is not protective of human health compared to simulated soil cleanup level percentiles from simulated exposure distributions for 2 or 3-concurrent exposure pathways, regardless of age adjustments.

6.0 Regulatory Interpretation

6.1 3-Concurrent Exposure Model

Volatiles: When establishing soil cleanup levels for epichlorohydrin and trichloroethylene, two volatile organic chemicals with known soil volatilization factors, the inhalation exposure pathway has a larger influence than the ingestion or dermal exposure pathways. The large influence of the inhalation exposure pathway for these two chemicals reflects the large percent contribution to variance by the adult inhalation exposure duration and the soil volatilization factor when age adjusted. When the 3-concurrent exposure model is not age adjusted the inhalation exposure pathway remains influential based on the soil volatilization factor. However the soil ingestion pathway is more influential compared to the age adjusted 3-concurrent exposure model.

The deterministic risk-based cleanup levels compared to the corresponding percentiles from simulated exposure distributions indicates the deterministic exposure models currently used in the MTCA cleanup regulation (MTCA Method B, Equation 740-2, and MTCA Modified Method B, Equation 740-5) are not protective of human health and do not reflect MTCA's reasonable maximum exposure for these selected volatile organic chemicals. Although still not protective of human health, the age adjusted, 3-concurrent exposure model appears to begin to be more protective when the exposure duration is 30 years as opposed to the MTCA 6 year exposure duration. The percent probabilities that are not protective varies between trichloroethylene and epichlorohydrin but consistently reflect that the current exposure models are not protective with increasing level of protection conferred with a 30 years exposure duration. The deterministic risk-based 3-concurrent exposure model with a 30 year exposure duration, not age adjusted, compared to the corresponding percentiles from simulated exposure distributions appears to be protective of human health.

Semi-volatiles: Regardless of age adjustments, for benzo[a]pyrene the 3-concurrent exposure model illustrated the important influence of the ingestion and dermal exposure pathways with some variation in the sequence and percent contribution to variance for the selected exposure parameters (soil ingestion, soil adherence factor, and child and adult exposure durations). For chlordane the ingestion exposure pathway was the most influential pathway for age and not age adjusted 3- concurrent exposure model.

Regardless of age adjustments, the inhalation exposure pathway did not contribute to variance for these selected semi-volatile chemicals (benzo[a]pyrene and chlordane) for the 3-concurrent exposure model. The ingestion and dermal exposure pathway are the two dominant exposure pathways. Although age adjustments to the 3-concurrent exposure model does not seem to influence the significant contribution the ingestion and dermal exposure pathways have on the model outputs, the age adjustment more evenly distributes the contribution to variance across different exposure parameters.

Inorganics: Regardless of age adjustments, the soil ingestion route of exposure was the most influential, dominant, exposure pathway for arsenic 3-concurrent exposure model outputs. The age adjusted 3-concurrent exposure model for arsenic more evenly distributes the contribution to variance across different exposure parameters.

6.2 2-concurrent exposure model

Volatiles: For epichlorohydrin and trichloroethylene, regardless of age adjustments the soil ingestion exposure pathway was more influential than the dermal exposure pathway with the 2-concurrent exposure model. While age adjustments to the 2-concurrent exposure model for epichlorohydrin and trichloroethylene more evenly distributed the per cent contribution of variance for selected exposure parameters for the model output the ingestion pathway remained dominant.

Semi-volatiles: Regardless of age adjustments to the 2-concurrent exposure model for benzo[a]pyrene and chlordane, the soil ingestion exposure pathway was dominant compared to the dermal exposure pathway. Regardless of age adjustments to the 2-concurrent exposure model, benzo[a]pyrene more evenly distributed the percent contribution to variance for the model output for selected exposure parameters but the ingestion pathway remained dominant. An age adjusted, 2-concurrent exposure model for benzo[a]pyrene and chlordane more evenly distributed the percent contribution to variance for the model output for selected exposure parameters.

Inorganics: For arsenic the soil ingestion exposure pathway is the most influential exposure pathway that contributes to the percent contribution to variance for the 2-concurrent exposure model output. While age adjustments to the 2-concurrent exposure model more evenly distributed the percent contribution to variance for the model output for selected exposure parameters but the ingestion pathway remained dominant.

References

American Industrial Health Council. *Exposure Factors Source Book.* May 1994. Pages 4.20-4.23.

Department of Ecology, Environmental Assessment Program. *YASAIw*. http://www.ecy.wa.gov/programs/eap/models.html

Eckstein, Jonathan, and Steven T. Riedmueller. *YASAI: Yet Another Add-in for Teaching Elementary Monte Carlo Simulation n Excel.* INFORMs Transactions on Education 2:2.

The Risk Assessment Information System: PRG Equations. http://rais.ornl.gov/prg/equations/vf.shtml.

The Risk Assessment Information System—Chemical Toxicity. http://rais.ornl.gov/cgi-bin/tox/TOX_select?select=nrad.

Rutgers University. *YASAI, Version 2.0*. http://www.yasai.rutgers.edu/

U.S. EPA. *A Probabilistic Exposure Assessment for Children Who Contact CCA-Treated Playsets and Decks.* February 2005. Table 49, page 164.

U.S. EPA. *Child-Specific Exposure Factors Handbook*. (EPA-600-P-00-002B). 2002. Table 8-1, page 8-13.

U.S. EPA. *Interim Final Guidance: Developing Risk-Based Cleanup Level At Resource Conservation and Recovery Act Sites in Region 10.* EPA 910/R-98-001. Pages 6-23 to 6-24.

U.S. EPA. *Soil Screening Guidance: User's Guide.* Office of Solid Waste and Emergency Response, Washington D.C. 1996.

U.S. EPA. “Task 3 Report and Appendices: Calculation of Surface Radionuclide Soil Action Levels for Plutonium, Americium, and Uranium”. *Rocky Mountain Flats Human Health Risk Assessment.* September 30, 2002. Figure A-5, page 139.

U.S. EPA. “Task 3 Report and Appendices: Calculation of Surface Radionuclide Soil Action Levels for Plutonium, Americium, and Uranium”. *Rocky Mountain Flats Human Health Risk Assessment.* September 30, 2002. Table A-8, page 152 & page 166.

U.S. EPA. “Task 3 Report and Appendices”. *Rocky Mountain Flats Human Health Risk Assessment.* September 30, 2002. Appendix C, Table C-3, page 254.

U.S. EPA. “Task 3 Report and Appendices”. *Rocky Mountain Flats Human Health Risk Assessment.* September 30, 2002. Table 4-5.