

Prelude to Risk Characterization
 Exposure Calculations from “Risk and Decision Making”

RISK & DECISION MAKING - A Workshop in Risk Assessment, Risk Management & Risk Communication

Table 15A			
EXPOSURE ASSESSMENT - COYOTE KNOLLS CURRENT EXPOSURE			
Exposure Assumptions	Coyote Knolls Residents		
	Central Tendency	High End	
Exposure Duration (ED):	9/70	30/70	years exposed/lifetime
Exposure Frequency (EF):	350/365	350/365	days exposed/days per year
Percent Contam'd Air Exposure:	33%	33%	based on wind direction
Body Weight (BW):	70	70	kilograms
Air Intake Rate (CR-air):	20	30	cubic meters/day
Water Intake Rate (CR-water):	1.4	2	liters/day
DNC Concentration - Air:	0.010	0.013	mg/m ³ (= 0.001 x µg/m ³)
DNC Concentration - Water:	ND	ND	mg/l (=0.001 x µg/l)

Exposure Calculations: Coyote Knolls - Current									
	[DNC]	x	CR	x	ED	x	EF	+ BW	= Daily Dose
Central Tendency:									
Water:	ND	x	1.4	x	9/70	x	350/365	+ 70	= - mg/kg/d
Air:	0.010	x	20	x	9/70	x	350/365 x 33%	+ 70	= 1.2E-4 mg/kg/d
High End:									
Water:	ND	x	2	x	30/70	x	350/365	+ 70	= - mg/kg/d
Air:	0.013	x	30	x	30/70	x	350/365 x 33%	+ 70	= 7.6E-4 mg/kg/d

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Table 15B

EXPOSURE ASSESSMENT - COYOTE KNOLLS FUTURE EXPOSURE

Exposure Assumptions	Coyote Knolls Residents		
	Central Tendency	High End	
Exposure Duration (ED):	9/70	30/70	years exposed/lifetime
Exposure Frequency (EF):	350/365	350/365	days exposed/days per year
Percent Contam'd Air Exposure:	33%	33%	based on wind direction
Body Weight (BW):	70	70	kilograms
Air Intake Rate (CR-air):	20	30	cubic meters/day
Water Intake Rate (CR-water):	1.4	2	liters/day
DNC Concentration - Air:	0.010	0.013	mg/m3 (= 0.001 x µg/m3)
DNC Concentration - Water:	0.0055	0.0057	mg/l (=0.001 x µg/l)

Exposure Calculations: Coyote Knolls - Future

$$\frac{[DNC] \times CR \times ED \times EF}{BW} = \text{Daily Dose}$$

Central Tendency:

Water: $0.0055 \times 1.4 \times 9/70 \times 350/365 \div 70 = 1.4E-5$ mg/kg/d

Air: _____ x _____ x _____ x _____ ÷ _____ = _____ mg/kg/d

High End:

Water: _____ x _____ x _____ x _____ ÷ _____ = _____ mg/kg/d

Air: $0.013 \times 30 \times 30/70 \times 350/365 \times 33\% \div 70 = 7.6E-4$ mg/kg/d

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Table 15C

EXPOSURE ASSESSMENT - SMITH RIVER ESTATES FUTURE EXPOSURE

<i>Exposure Assumptions</i>	<i>Smith River Estates Residents</i>		
	<u>Central Tendency</u>	<u>High End</u>	
Exposure Duration (ED):	9/70	30/70	years exposed/detime
Exposure Frequency (EF):	350/365	350/365	days exposed/days per year
Percent Contam'd Air Exposure:	10%	10%	based on wind direction
Body Weight (BW):	70	70	kilograms
Air Intake Rate (CR-air):	20	20	cubic meters/day
Water Intake Rate (CR-water):	1.4	2	liters/day
DNC Concentration - Air:	NA	NA	mg/m3 (= 0.001 x µg/m3)
DNC Concentration - Water:	0.188	0.198	mg/l (=0.001 x µg/l)

Exposure Calculations: Smith River Estates - Future

$$\frac{[DNC] \times CR \times ED \times EF}{BW} = \text{Daily Dose}$$

Central Tendency:

Water: $0.188 \times 1.4 \times 9/70 \times 350/365 \div 70 = 4.6E-4$ mg/kg/d

Air: $NA \times 20 \times 9/70 \times 350/365 \times 10\% \div 70 = -$ mg/kg/d

High End:

Water: $0.198 \times 2 \times 30/70 \times 350/365 \div 70 = 2.3E-3$ mg/kg/d

Air: $NA \times 30 \times 30/70 \times 350/365 \times 10\% \div 70 = -$ mg/kg/d

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Table 15D

EXPOSURE ASSESSMENT - UTOPIA & REGIONAL RESIDENTS FUTURE EXPOSURE

<i>Exposure Assumptions</i>	<i>Utopia & Regional Residents</i>		
	<i>Central Tendency</i>	<i>High End</i>	
Exposure Duration (ED):	9/70	30/70	years exposed/lifetime
Exposure Frequency (EF):	350/365	350/365	days exposed/days per year
Percent Contam'd Air Exposure:	10%	10%	based on wind direction
Body Weight (BW):	70	70	kilograms
Air Intake Rate (CR-air):	20	30	cubic meters/day
Water Intake Rate (CR-water):	1.4	2	liters/day
DNC Concentration - Air:	zero	zero	mg/m ³ (= 0.001 x µg/m ³)
DNC Concentration - Water:	0.0055	0.0057	mg/l (=0.001 x µg/l)

Exposure Calculations: Utopia & Region - Future

$$\frac{[DNC] \times CR \times ED \times EF}{BW} + \frac{DNC \times CR}{BW} = \text{Daily Dose}$$

Central Tendency:

Water: $0.0055 \times 1.4 \times 9/70 \times 350/365 + 70 = 1.4E-5$
mg/kg/d

Air: $zero \times 20 \times 9/70 \times 350/365 \times 10\% + 70 = -$
mg/kg/d

High End:


Water: _____ x _____ x _____ x _____ + _____ = _____
mg/kg/d

Air: _____ x _____ x _____ x _____ + _____ = _____
mg/kg/d


Risk Characterization

Inputs Needed


1. Exposure point concentrations

- o of n chemicals
- o in m media
- o at p points where a population is exposed
- o with central tendency and upper bound values for each
 a total of $n \cdot m \cdot p \cdot 2$ concentration values

2. Intake rates

- o of m media
- o at p exposure points
- o over chronic (noncancer) and lifetime (cancer) durations
- o with central tendency and upper bound values for each
 a total of $m \cdot p \cdot 2 \cdot 2$ intake rates

3. Chemical toxicity values

- o for n chemicals
- o for noncancer (RfD) and cancer (SF) toxicities
- o [with central tendency and upper bound values for each – someday]
 a total of $n \cdot 2 \cdot [2]$ toxicity values

Risk Characterization Calculations

For each population

1. Calculate noncancer risk

A. Calculate 2 (central tendency plus upper bound) chronic doses

- ◆ of each chemical $i = 1$ to n
- ◆ from each medium $j = 1$ to m
- ◆ for each exposed population $k = 1$ to p

$$\text{Dose}_{i,j,k}^{\text{chronic}} = \text{Concentration}_{i,j} \bullet \text{IR}_{j,k}^{\text{chronic}}$$

B. Calculate 2 (central tendency plus upper bound) Hazard Quotients

- ◆ of each chemical $i = 1$ to n
- ◆ from each medium $j = 1$ to m
- ◆ for each exposed population $k = 1$ to p

$$\text{HQ}_{i,j,k} = \frac{\text{Dose}_{i,j,k}^{\text{chronic}}}{\text{RfD}_i}$$

C. Calculate 2 (central tendency plus upper bound) Hazard Indices

- ◆ for each population $k = 1$ to p
- ◆ summing over m chemicals in n media

$$\text{HI}_k = \sum_{i=1}^{i=n} \sum_{j=1}^{j=m} \text{HQ}_{i,j,k}$$

D. Examine each HI_k

i) Population is at risk if any HI_k is greater than 1

- a) If any HI_k is greater than 1, see which chemical(s) have $\text{HQ}_{i,k}$ greater than 1
- b) If no individual $\text{HQ}_{i,k}$ is greater than 1, see if chemicals adding to HI_k greater than 1 have the same critical effect

Risk Characterization Calculations (continued)

2. Calculate cancer risk

A. Calculate 2 (central tendency plus upper bound) lifetime doses

- ◆ of each chemical $i = 1$ to n
- ◆ from each medium $j = 1$ to m
- ◆ for each exposed population $k = 1$ to p

$$\text{Dose}_{i,j,k}^{\text{lifetime}} = \text{Concentration}_{i,j} \bullet \text{IR}_{j,k}^{\text{lifetime}}$$

B. Calculate 2 (central tendency plus upper bound) risks

- ◆ of each chemical $i = 1$ to n
- ◆ from each medium $j = 1$ to m
- ◆ for each exposed population $k = 1$ to p

$$\text{Risk}_{i,j,k} = \text{Dose}_{i,j,k}^{\text{lifetime}} \bullet \text{SF}_i$$

C. Calculate 2 (central tendency plus upper bound) total cancer risks

- ◆ for each population $k = 1$ to p
- ◆ summing over m chemicals in n media

$$\text{Risk}_k = \sum_{i=1}^{i=n} \sum_{j=1}^{j=m} \text{Risk}_{i,j,k}$$

D. Calculate population risk for members of population k :

$$\text{Population}_k \text{ Risk} = \text{Risk}_k \bullet \{\text{Number of people exposed in 70 years}\}$$

Example Data

Upper Bound Intake Rates

Exposed Population	Exposure Point	Exposure Medium	Exposure Route	IR ^{chronic}	IR ^{lifetime}	Units
Current Worker	Work site	Soil	Oral	1.1E-6	3.8E-7	kg/kg/day
	Work site	Soil	Dermal*	8.8E-6	3.2E-6	kg/kg/day
Current child trespasser	Site	Soil	Oral	2.2E-7	<i>Not Calculated</i>	kg/kg/day
	Site	Soil	Dermal*	1.9E-7		kg/kg/day
	Pond	Surface water	Oral	1.3E-6		L/kg/day
	Pond	Surface water	Dermal**	9.4E-4		L/kg/day
	Pond	Sediments	Oral	2.5E-8		kg/kg/day
	Pond	Sediments	Dermal*	9.8E-7		kg/kg/day
Future adult resident	Home	Yard soil	Oral	1.4E-6	5.9E-7	kg/kg/day
	Home	Yard soil	Dermal*	1.8E-6	7.9E-7	kg/kg/day
	Home	Groundwater	Oral	2.7E-2	1.2E-2	L/kg/day
	Home	Groundwater	Inhalation***	5.4E-2	2.4E-2	L/kg/day
Future child resident	Home	Yard soil	Oral	1.3E-5	<i>Not Calculated</i>	kg/kg/day
	Home	Yard soil	Dermal*	3.4E-5		kg/kg/day
	Home	Groundwater	Oral	6.4E-2		L/kg/day
	Home	Groundwater	Inhalation***	1.3E-1		L/kg/day

*Assuming ABS=0.25 for volatiles, 0.1 for semivolatiles and pesticides/PCBs and 0 for inorganics

**Assuming PC = 1 cm/hr for all organics

***Assuming inhalation exposure = twice oral exposure

Exposure Point Concentrations

Chemical	Soil		Groundwater		Surface water		Sediment	
	Mean	UCL	Mean	UCL	Mean	UCL	Mean	UCL
VOLATILES								
Acetone	1.1E-2	1.1E-2	4.1E-2	9.7E-2	6.9E-3	9.1E-3	7.0E-2	1.1E-1
2-Butanone	5.5E-3	2.2E-2	9.1E-3	1.6E-2	5.0E-3	1.6E-2	1.6E-2	2.1E-2
⋮								
Xylenes	3.0E-3	3.8E-3	2.5E-3	2.9E-3	2.5E-3	2.5E-3	7.8E-3	1.1E-2
SEMIVOLATILES								
Benzoic acid	9.3E-1	1.7E+0	3.0E-2	3.5E-2	2.5E-2	5.1E+0	5.1E+0	8.4E+0
Benzyl alcohol	2.3E-1	3.3E-1	5.0E-3	7.0E-3	5.0E-3	5.0E-3	1.0E+0	1.7E+0
⋮								
Pyrene	4.1E-1	6.7E-1	5.9E-3	7.0E-3	5.0E-3	5.0E-3	1.0E+0	1.7E+0
PESTICIDES/PCBs								
Aldrin	1.4E-2	2.1E-2	2.5E-5	4.1E-5	2.6E-5	2.7E-5	1.2E-2	1.7E-2
4,4'-DDT	1.6E-2	1.9E-2	5.8E-5	6.8E-5	5.1E-5	5.3E-5	4.8E-2	8.3E-2
⋮								
Endosulfan I	1.4E-2	2.1E-2	2.9E-5	4.1E-5	2.6E-5	2.7E-5	1.2E-2	1.7E-2
INORGANICS								
Antimony	2.4E+1	6.6E+1	1.7E-2	2.2E-2	1.7E-2	2.3E-2	1.5E-2	2.0E-2
Arsenic	2.5E+0	4.5E+0	8.8E-3	2.0E-2	2.5E-3	3.7E-3	2.4E-3	3.6E-3
⋮								
Vanadium	1.7E+1	2.6E+1	1.5E-3	3.1E-3	2.8E-3	4.2E-3	1.5E-2	2.1E-2

Toxicity Values – Noncancer

Chemical	Effect	Oral		Inhalation	
		RfD	Confidence	RfC	Confidence
VOLATILES					
Acetone	Increased liver, kidney weight, nephrotoxicity – oral	1E-1	Low	–	–
2-Butanone	Central nervous system toxicity, fetotoxicity – inhalation	5E-2	Medium	9E-2	–
⋮					
Xylenes	Central nervous system toxicity – oral & inhalation; developmental effects – inhalation	2E-1	Medium	9E-2	–
SEMIVOLATILES					
Benzoic acid	Irritation, malaise – oral	4E+0	–	–	–
Benzyl alcohol	Forestomach epithelial hyperplasia	3E-1	–	–	–
⋮					
Pyrene	Kidney damage – oral	3E-2	Low	–	–
PESTICIDES/PCBs					
Aldrin	Liver toxicity – oral	3E-5	Medium	–	–
4,4'-DDT	Liver damage – oral	5E-4	Medium	–	–
⋮					
Endosulfan I	Mild kidney lesions – oral	5E-5	Medium	–	–
INORGANICS					
Antimony	Decreased longevity, changes in blood glucose and cholesterol – ingestion	4E-4	Low	–	–
Arsenic	Membrane irritation – inhalation; keratosis, hyperpigmentation, neurological disorders – inhalation and oral	1E-3	–	–	–
⋮					
Vanadium	Renal & gastrointestinal toxicity – oral; respiratory irritation – inhalation	2E-2	Medium	–	–

Toxicity Values – Cancer

Chemical	Tumor Type	Weight of Evidence	Oral	Inhalation
VOLATILES				
Chloroform	Liver & kidney – oral & inhalation	B2	6.1E-3	8.1E-2
Methylene chloride	Liver – oral & inhalation	B2	7.5E-3	1.6E-3
⋮				
Trichloroethene	Liver – oral; lung – inhalation	B2	1.1E-2	6.0E-3
SEMIVOLATILES				
1,4-Dichlorobenzene	Liver – oral		2.4E-2	–
2,6-Dinitrotoluene	Liver & kidney – oral	B2	6.8E-1	–
⋮				
Pentachlorophenol	Liver, adrenal, vascular – oral	B2	1.2E-1	–
PESTICIDES/PCBs				
Aldrin	Liver – oral	B2	1.2E+1	6.1E+0
4,4'-DDT	Liver – oral	B2	3.4E-1	3.4E-1
⋮				
Arochlor-1254	Liver – oral	B2	7.7E+0	–
INORGANICS				
Arsenic	Lung – inhalation; skin – oral		1.8E+0	1.5E+1
Beryllium	Lung – inhalation; bone – injection	B2	4.3E+0	8.4E+0
⋮				
Cadmium	Lung, prostate – inhalation	B1 – inhalation	–	6.3E+0

Output – Risk Characterization

Major chemicals contributing risk for Current Worker

Chemical	Noncancer			Cancer		
	Oral	Dermal	Percent	Oral	Dermal	Percent
Polycyclic aromatic hydrocarbons	4.2E-5	NC		1.6E-5	NC	16
Aroclor-1260	NC	NC		3.8E-5	3.2E-5	79
Antimony	1.8E-1	NC	65	NC	NC	
Arsenic	4.9E-3	NC	2	3.0E-6	NC	3
Cadmium	6.5E-2	NC	23	NC	NC	
Pathway totals	3E-1	2E-3		6E-5	4E-5	
Population totals	HI = 3E-1			Risk = 1E-4		

NC = Not calculated

Major chemicals contributing risk from groundwater to Future Resident

Chemical	Noncancer			Cancer		
	Oral	Inhalation	Percent	Oral	Inhalation	Percent
Hexachlorobenzene	2.4E-1	NC	7	1.3E-4	NC	2
Polycyclic aromatic hydrocarbons	1.9E-3	NC		6.8E-3	NC	91
Antimony	1.5E+0	NC	44	NC	NC	
Arsenic	5.5E-1	NC	16	4.3E-4	NC	6
Thallium	6.4E-1	NC	19	NC	NC	
Pathway totals	3E+0	4E-2		8E-3	6E-6	
Population totals	HI = 3E+0			Risk = 8E-3		

NC = Not calculated

Characterization of Uncertainty – Qualitative

<u>Factor</u>	<u>Potential Effect</u>
Lack of quantification of some exposure pathways	Underestimate exposure
Lack of quantification of TICs	Underestimate risk
Lack of complete toxicity values for every chemical, duration, route, and endpoint	Underestimate risk
Assumption that all chemicals of concern are present in all site samples	Overestimate exposure
Assumption that concentrations in soil and groundwater will remain constant over time	Overestimate exposure
Assumption of a future residential use of the site	Overestimate exposure
Use of conservative toxicity values	Overestimate risk
Use of conservative exposure assumptions	Overestimate exposure
Lack of complete site characterization	Overestimate or underestimate risk
Assumption that risks from multiple chemicals are additive	Overestimate or underestimate risk

Characterization of Uncertainty – Quantitative

- o Compare central tendency and high-end values
- o Monte Carlo analysis – “Simulation of the distribution of output variables by repeated calculations using random input variables of defined distributions.”

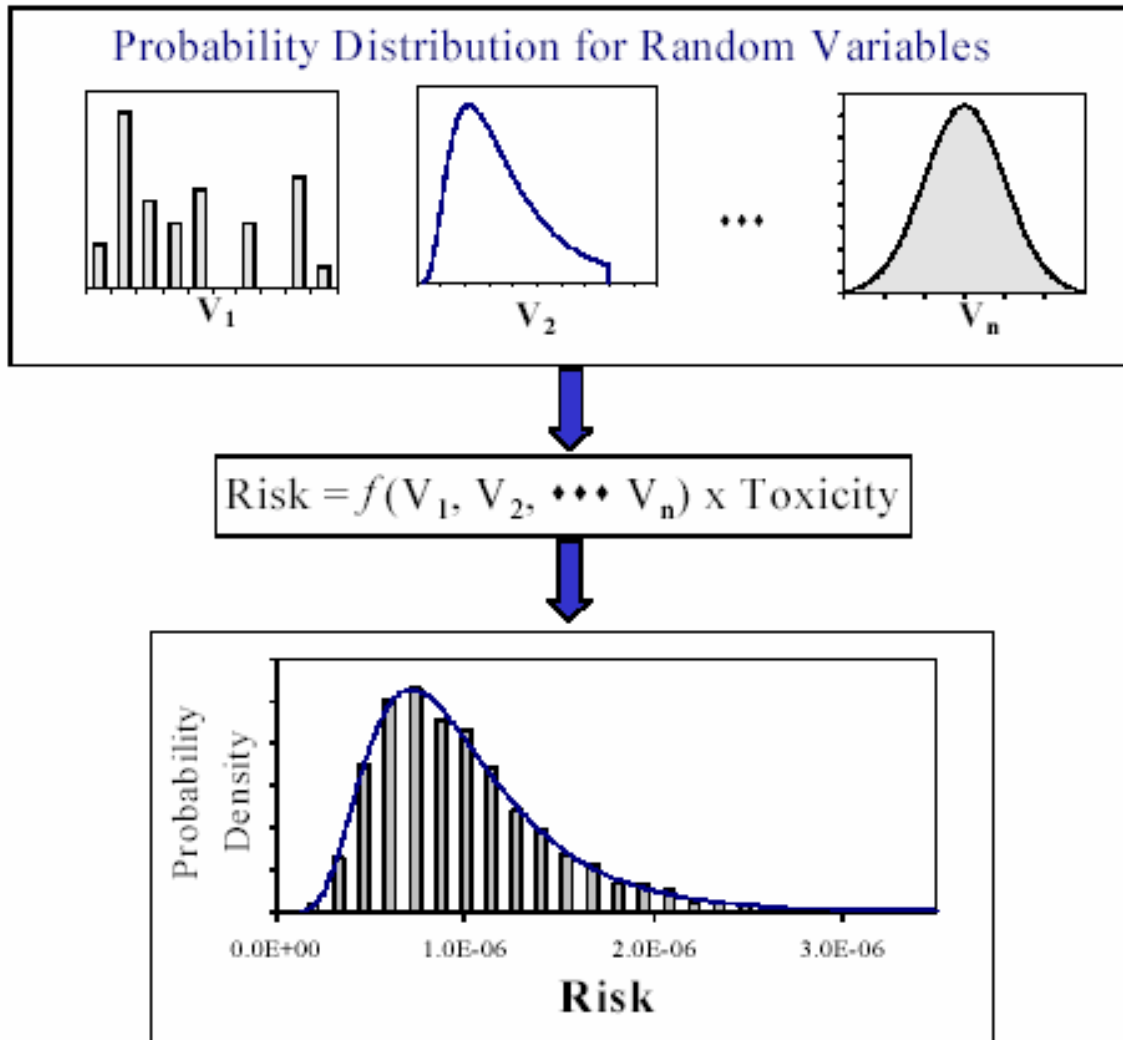


Figure 1-2. Conceptual model of Monte Carlo analysis. Random variables (V_1, V_2, \dots, V_n) refer to exposure variables (e.g., body weight, exposure frequency, ingestion rate) that are characterized by probability distributions. A unique risk estimate is calculated for each set of random values. Repeatedly sampling (V_i) results in a frequency distribution of risk, which can be described by a PDF. In human health risk assessments, the toxicity term should be expressed as a point estimate. In ecological risk assessment (see Sections 1.4 and 1.4.1) the toxicity term may be expressed as a point estimate or as a probability distribution.

From USEPA “Risk Characterization Handbook”, December 2000

Principle	Definition	Criteria for a Good Risk Characterization
Transparency	Explicitness in the risk assessment process.	<ul style="list-style-type: none"> ✓ Describe assessment approach, assumptions, extrapolations and use of models ✓ Describe plausible alternative assumptions ✓ Identify data gaps ✓ Distinguish science from policy ✓ Describe uncertainty ✓ Describe relative strength of assessment
Clarity	The assessment itself is free from obscure language and is easy to understand.	<ul style="list-style-type: none"> ✓ Employ brevity ✓ Use plain English ✓ Avoid technical terms ✓ Use simple tables, graphics, and equations
Consistency	The conclusions of the risk assessment are characterized in harmony with other EPA actions.	<ul style="list-style-type: none"> ✓ Follow statutes ✓ Follow Agency guidance ✓ Use Agency information systems ✓ Place assessment in context with similar risks ✓ Define level of effort ✓ Use review by peers
Reasonableness	The risk assessment is based on sound judgment.	<ul style="list-style-type: none"> ✓ Use review by peers ✓ Use best available scientific information ✓ Use good judgment ✓ Use plausible alternatives

Coda to Risk Characterization
 Risk Characterization Calculations from “Risk and Decision Making”

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<p>Table 16A</p> <p>LIFETIME EXCESS CANCER RISKS - COYOTE KNOLLS CURRENT EXPOSURE</p> <p>Risk Characterization Assumptions:</p> <p style="margin-left: 40px;"> Population Size: 80 people in Coyote Knolls Population Turnover: 70/9 = 7.8 number of populations exposed in 70 years (9 years exposure for each population) </p>																																																
<p>Risk Calculations: Current Exposures</p> <table style="width: 100%; border-collapse: collapse; margin-top: 10px;"> <thead> <tr> <th style="width: 15%;"></th> <th style="width: 15%; text-align: center;">DNC Cancer Slope Factors (/mg/kg/d)</th> <th colspan="2" style="width: 20%; text-align: center;">Daily Dose* (mg/kg/d)</th> <th colspan="2" style="width: 20%; text-align: center;">Lifetime Individual Risk**</th> <th style="width: 10%; text-align: center;">Lifetime Population Risks (# potential excess cancer cases)</th> </tr> <tr> <th></th> <th></th> <th style="text-align: center;">Central Tendency</th> <th style="text-align: center;">High End</th> <th style="text-align: center;">Central Tendency</th> <th style="text-align: center;">High End</th> <th></th> </tr> </thead> <tbody> <tr> <td colspan="7">Coyote Knolls</td> </tr> <tr> <td style="padding-left: 20px;">Water:</td> <td style="text-align: center;">0.65</td> <td style="text-align: center;">-</td> <td style="text-align: center;">-</td> <td style="text-align: center;">-</td> <td style="text-align: center;">-</td> <td style="text-align: center;">-</td> </tr> <tr> <td style="padding-left: 20px;">Air:</td> <td style="text-align: center;">0.42</td> <td style="text-align: center;">1.2E-4</td> <td style="text-align: center;">7.6E-4</td> <td style="text-align: center;">5.0E-5</td> <td style="text-align: center;">3.2E-4</td> <td style="text-align: center;">0.03</td> </tr> <tr> <td colspan="4" style="padding-left: 20px;">Coyote Knolls Current Risk Totals:</td> <td style="text-align: center;">5.0E-5</td> <td style="text-align: center;">3.2E-4</td> <td style="text-align: center;">0.03</td> </tr> </tbody> </table>								DNC Cancer Slope Factors (/mg/kg/d)	Daily Dose* (mg/kg/d)		Lifetime Individual Risk**		Lifetime Population Risks (# potential excess cancer cases)			Central Tendency	High End	Central Tendency	High End		Coyote Knolls							Water:	0.65	-	-	-	-	-	Air:	0.42	1.2E-4	7.6E-4	5.0E-5	3.2E-4	0.03	Coyote Knolls Current Risk Totals:				5.0E-5	3.2E-4	0.03
	DNC Cancer Slope Factors (/mg/kg/d)	Daily Dose* (mg/kg/d)		Lifetime Individual Risk**		Lifetime Population Risks (# potential excess cancer cases)																																										
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<p>* From tables 15A, 15B, 15C and 15D</p> <p>** Individual Water Risk = Ingestion Cancer Slope Factor x Ingested Dose Individual Air Risk = Inhalation Cancer Slope Factor x Inhaled Dose</p> <p># Population Risk = Central Tendency Individual Risk x Population Size x Population Turnover</p>																																																

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Table 16B

LIFETIME EXCESS CANCER RISKS - FUTURE EXPOSURE

Risk Characterization Assumptions:

	Coyote Knolls	Smith River Estates	Utopia
Population Size:	80	1,000	50,000
Population Turnover:	70/9 = 7.8	number of populations exposed in 70 years (9 years exposure for each population)	

Risk Calculations: Future Exposures

	DNC Cancer Slope Factors (mg/kg/d)	Daily Dose* (mg/kg/d)		Lifetime Individual Risk**		Lifetime Population Risk# (# potential excess cancer cases)
		Central Tendency	High End	Central Tendency	High End	
Coyote Knolls:						
Water:	0.65	1.4E-5	6.7E-5	9.1E-6	4.4E-5	0.01
Air:	0.42	1.2E-4	7.6E-4	5.0E-5	3.2E-4	0.03
Coyote Knolls Future Risk Totals:				6.0E-5	3.6E-4	0.04
Smith River Estates:						
Water:	0.65	4.6E-4	2.3E-3	3.0E-4	1.5E-3	2.33
Air:	0.42	-	-	-	-	-
Smith River Ests Future Risk Totals:				3.0E-4	1.5E-3	2.33
Utopia:						
Water:	0.65	1.4E-5	6.7E-5	9.1E-6	4.4E-5	3.54
Air:	0.42	-	-	-	-	-
Utopia Future Risk Totals:				9.1E-6	4.4E-5	3.54

* From tables 15A, 15B, 15C and 15D

** Individual Water Risk = Ingestion Cancer Slope Factor x Water Dose
 Individual Air Risk = Inhalation Cancer Slope Factor x Air Dose

Population Risk = Central Tendency Individual Risk x Population Size x Population Turnover

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Table 17			
RISK ASSESSMENT SUMMARY			
CURRENT RISKS:			
	Individual Excess Lifetime Cancer Risks		Lifetime Population Risk (# potential excess cancer cases)
	<i>Central Tendency Estimate</i>	<i>High End Estimate</i>	
Coyote Knolls			
Water:	-	-	-
Air:	5.0E-5	3.2E-4	0.03
Total Risk:	5.0E-5	3.2E-4	0.03
FUTURE RISKS:			
	Individual Excess Lifetime Cancer Risks		Lifetime Population Risk (# potential excess cancer cases)
	<i>Central Tendency Estimate</i>	<i>High End Estimate</i>	
Coyote Knolls			
Water:	9.1E-6	4.4E-5	0.01
Air:	5.0E-5	3.2E-4	0.03
Total Risk:	5.9E-5	3.6E-4	0.04
Smith River Estates			
Water:	3.0E-4	1.5E-3	2.3
Air:	-	-	-
Total Risk:	3.0E-4	1.5E-3	2.3
Utopia & General Area			
Water:	9.1E-6	4.4E-5	3.54
Air:	-	-	-
Total Risk:	9.1E-6	4.4E-5	3.5

Risk Management

Guiding principles:

- o Equity
- o Economic efficiency
- o Ease of implementation

Types of standards:

- o Concentration based
- o Technology based
- o Risk based
 - “Rule of thumb”
 - If risk $\leq 10^{-6}$, rarely act
 - If risk $> 10^{-4}$, usually act

Realities:

- o Information is expensive
- o Uncertainty is omnipresent
- o 80/20 rule

Risk Management for Hazardous Waste Sites

Applicable or Relevant and Appropriate Requirements (ARARs)

- o chemical-specific
- o location-specific
- o action-specific

To reduce the risk

- o Reduce exposure
- o Reduce concentration

Available Technologies

- o Excavation – soil
- o Clay cap – soil
- o Treatment:
 - ◆ wash – soil
 - ◆ stabilize – soil
 - ◆ biodegrade – soil
 - ◆ vapor extract – soil or groundwater
 - ◆ chemical destruction – soil or groundwater
 - ◆ carbon absorption – water
 - ◆ metals precipitation – water

Role of risk assessment:

- o how much soil/water must be treated
- o what risks remain from residual concentrations
- o fate and transport modeling

Remediation Goals

When have multiple chemicals, make sum of HIs ≤ 1 , make sum of risks $\leq 10^{-4}$

Approaches:

- o reduce all concentrations by the same proportion
- o reduce chemical concentrations by classes
- o consider treatment options, spatial distribution of most risky chemicals, etc.

EXAMPLE

	Baseline	
	Soil	Water
Arsenic	1E-4	3E-5
Chloroform	2E-4	8E-5
PCBs	6E-4	1E-6
Pathway totals	9E-4	1E-4
Total	1E-3	

Reduce all by 90%	Reduce soil by 99%	Reduce all but Arsenic						
Soil	Water	Soil	Water	Soil	Water			
Arsenic	1E-5	3E-4	Arsenic	1E-6	3E-5	Arsenic	1E-4	3E-5
Chloroform	2E-5	8E-4	Chloroform	2E-6	8E-5	Chloroform	2E-6	8E-6
PCBs	6E-5	1E-7	PCBs	6E-6	1E-6	PCBs	6E-6	1E-7
Pathway totals	9E-5	1E-5	Pathway totals	9E-6	1E-4	Pathway totals	1E-4	4E-5
Total	1E-4		Total	1E-4		Total	1E-4	

Cost-Benefit Analysis

Risk analysis: How many premature deaths would action \mathcal{X} prevent?

Cost analysis: How much would action \mathcal{X} cost?

Benefit analysis: How much is preventing a premature death worth?

Approaches to benefit analysis:

- o Human capital
- o Willingness-to-pay
 - ◆ Survey
 - ◆ Occupational behavior
 - ◆ Consumer behavior

Credible range: \$2,100,000 to \$11,000,000 (1995 dollars)

\$2,700,000 to \$14,000,000 (2005 dollars)

Risk Management of DNC
 Risk Reduction Calculations from “*Risk and Decision Making*”

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Table 21A RISK REDUCTION SUMMARY - CENTRAL TENDENCY						
CENTRAL TENDENCY Estimates of Risks - FUTURE Exposures						
	Residual Individual Risk			Population	Risk	Costs
	Air	+ Water	= Total	Risk	Reduction	(Annual)
CL 'OTE KNOLLS						
<i>No Action</i>	<i>5.0E-5</i>	<i>9.1E-6</i>	<i>6E-5</i>	<i>0.04</i>	-	-
1) Replace Tank	4.0E-5	9.1E-7	4E-5	0.03	31%	\$180,000
2) Replace + Asphalt Cap	2.0E-5	9.1E-7	2E-5	0.01	65%	\$296,000
3) Replace + Gas Extraction	1.0E-6	9.1E-8	1E-6	0.0007	98%	\$500,000
4) Replace + Pump & Treat	1.0E-7	3.6E-9	1E-7	0.00007	99.8%	\$700,000
5) Replace/P&T + Excavate Soil	1.0E-8	3.6E-10	1E-8	0.000007	99.98%	\$1,110,000
SMITH RIVER ESTATES						
<i>No Action</i>	-	<i>3.0E-4</i>	<i>3E-4</i>	<i>2.3</i>	-	-
1) Replace Tank	-	3.0E-5	3E-5	0.2	90%	\$180,000
2) Replace + Asphalt Cap	-	3.0E-5	3E-5	0.2	90%	\$296,000
3) Replace + Gas Extraction	-	3.0E-6	3E-6	0.02	99%	\$500,000
4) Replace + Pump & Treat	-	1.2E-7	1E-7	0.0008	99.96%	\$700,000
5) Replace/P&T + Excavate Soil	-	1.2E-8	1E-8	0.00008	99.996%	\$1,110,000
UTOPIA						
<i>No Action</i>	-	<i>9.1E-6</i>	<i>9E-6</i>	<i>3.5</i>	-	-
1) Replace Tank	-	9.1E-7	9E-7	0.4	90%	\$180,000
2) Replace + Asphalt Cap	-	9.1E-7	9E-7	0.4	90%	\$296,000
3) Replace + Gas Extraction	-	9.1E-8	9E-8	0.04	99%	\$500,000
4) Replace + Pump & Treat	-	3.6E-9	4E-9	0.002	99.96%	\$700,000
5) Replace/P&T + Excavate Soil	-	3.6E-10	4E-10	0.0002	99.996%	\$1,110,000

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Table 21B RISK REDUCTION SUMMARY - HIGH END

HIGH END Estimates of Risks - FUTURE Exposures

	Residual Individual Risk			Population Risk	Risk Reduction	Costs (Annual)
	Air	+ Water	= Total			
COYOTE KNOLLS						
<i>No Action</i>	3.2E-4	4.4E-5	4E-4	0.04	-	-
1) Replace Tank	2.5E-4	4.4E-6	3E-4	0.03	29%	\$180,000
2) Replace + Asphalt Cap	1.3E-4	4.4E-6	1E-4	0.01	64%	\$296,000
3) Replace + Gas Extraction	6.3E-6	4.4E-7	7E-6	0.00	98.1%	\$500,000
4) Replace + Pump & Treat	6.3E-7	1.8E-8	6E-7	0.00	99.8%	\$700,000
5) Replace/P&T + Excavate Soil	6.3E-8	1.8E-9	6E-8	0.00	99.98%	\$1,110,000
SMITH RIVER ESTATES						
<i>No Action</i>	-	1.5E-3	2E-3	2.3	-	-
1) Replace Tank	-	1.5E-4	2E-4	0.2	90%	\$180,000
2) Replace + Asphalt Cap	-	1.5E-4	2E-4	0.2	90%	\$296,000
3) Replace + Gas Extraction	-	1.5E-5	2E-5	0.02	99%	\$500,000
4) Replace + Pump & Treat	-	6.0E-7	6E-7	0.00	99.96%	\$700,000
5) Replace/P&T + Excavate Soil	-	6.0E-8	6E-8	0.00	99.996%	\$1,110,000
UTOPIA						
<i>No Action</i>	-	4.4E-5	4E-5	3.5	-	-
1) Replace Tank	-	4.4E-6	4E-6	0.4	90%	\$180,000
2) Replace + Asphalt Cap	-	4.4E-6	4E-6	0.4	90%	\$296,000
3) Replace + Gas Extraction	-	4.4E-7	4E-7	0.04	99%	\$500,000
4) Replace + Pump & Treat	-	1.8E-8	2E-8	0.00	99.96%	\$700,000
5) Replace/P&T + Excavate Soil	-	1.8E-9	2E-9	0.00	99.996%	\$1,110,000

Risk Reductions and Remediation Costs

Action	Individual Risks				Popula- tion Risk	Cost
		Pop. 1	Pop. 2	Pop. 3		
Baseline – none	central	6×10^{-5}	3×10^{-4}	9×10^{-6}	5.84	
	high	4×10^{-4}	3×10^{-3}	4×10^{-5}		
1)	central	4×10^{-5}	3×10^{-5}	9×10^{-7}	0.63	\$1,1100,00
	high	3×10^{-4}	2×10^{-4}	4×10^{-6}		
1)&2)	central	2×10^{-5}	3×10^{-5}	9×10^{-7}	0.61	\$1,820,000
	high	1×10^{-4}	2×10^{-4}	4×10^{-6}		
1)&2)&3)	central	1×10^{-6}	3×10^{-6}	9×10^{-8}	0.061	\$3,085,000
	high	7×10^{-6}	2×10^{-5}	4×10^{-7}		
1)&2)&3)&4)	central	1×10^{-7}	1×10^{-7}	9×10^{-9}	0.0028	\$4,300,000
	high	6×10^{-7}	6×10^{-7}	2×10^{-8}		
1)&2)&3)&4)&5)	central	1×10^{-8}	1×10^{-8}	9×10^{-10}	0.00028	\$6,835,000
	high	6×10^{-8}	6×10^{-8}	2×10^{-9}		

Apply Cost-Benefit Analysis

Cost	Population Risk Reduction		Cost per Life	
	From baseline	From previous	From baseline	From previous
1) \$1,100,000	5.21		\$210,000	\$210,000
2) \$1,820,000	5.23	0.02	\$350,000	\$36,000,000
3) \$3,085,000	5.779	0.55	\$530,000	\$2,300,000* \$3,400,000**
4) \$4,310,000	5.8372	0.0606	\$740,000	\$7,600,000
5) \$6,835,000	5.8397	0.00906	\$1,200,000	\$280,000,000

*Compared to 2)

** Compared to 1)