Spring 2007, Norm Brown

ESM 223

Lecture 4 –
Risk Analysis and Hazardous Waste Sites

Risk-Based Action

Risk Assessment

- Systematic process for:
  - generating estimates of all significant risk factors
  - range of exposure scenarios
  - release of pollutants into any compartment in environment
  - for specific receptors or general population

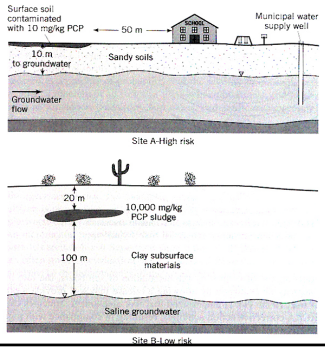
Risk Assessment

- Answer to these questions:
  - What could potentially go wrong?
  - What are the chances that it will happen?
  - What are the anticipated consequences if this should happen?
  - Who are the potential receptors?
  - How likely is it that they will be adversely affected?
  - Is this probability acceptable?
- Also useful in determining:
  - How safe is safe enough?
  - How clean is clean enough?

Risk Assessment

- Objectives:
  - Provide sufficient information to decision makers to make decisions concerning a potentially hazardous condition
  - Rational allocation of resources to increase safety and/or reduce the risk of exposure to pollutants and the effects on human and environmental health
  - Determine for a particular site what is the appropriate course of action: monitoring, containment or remediation
  - Provide guidelines for clean-up levels that are cost-effective and within certain risk objectives

Risk Assessment



Risk Assessment

- Steps in Risk Assessment Process
  - Hazard Identification & Accounting
  - Toxicity Assessment (Dose-Response)
  - Exposure Assessment (Fate and Transport to determine exposure pathways and concentrations)
  - Risk Characterization

Toxicity Assessment

- Objective: quantitatively determine the potential for adverse health effects as a result of exposure to the contaminants
  - Hazard assessment: determine if exposure causes an increase in the incidence of an adverse health effect (e.g. cancer, birth defects)
  - Dose-response assessment: quantitative evaluation of toxicity and characterization of the dose-response relationship

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Toxicity Assessment

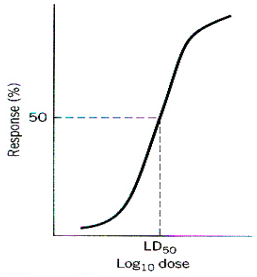
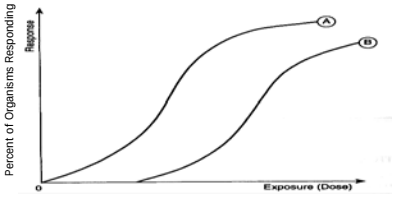


Figure 10.2 Toxicity effects based on a natural log cumulative Gaussian distribution.

Toxicity Assessment

- Threshold vs. Non-threshold
  - Some pollutants require an exposure above a threshold level or dose during a continuous exposure episode to cause toxic effects



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Toxicity Assessment

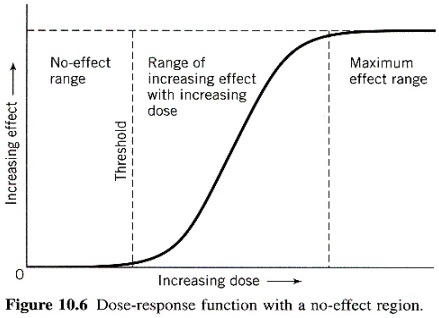

Figure 10.6 Dose-response function with a no-effect region.

Toxicity Assessment

Table 10.1 Hodge-Sterner Table for Degree of Toxicity

Experimental LD_{50} Dose per kg Body Weight	Degree of Toxicity	Probable Lethal Dose for a 70-kg Person
<1.0 mg	Dangerously toxic	A taste
1.0–50 mg	Seriously toxic	A teaspoonful
50–500 mg	Highly toxic	An ounce
0.5–5 g	Moderately toxic	A pint
5–15 g	Slightly toxic	A quart
>15 g	Extremely low toxicity	More than a quart

See Table 10.2 in Watts for specific LD_{50} values

Toxicity Assessment

- Carcinogenic vs. Non-carcinogenic
  - NOTE: Carcinogens may also provoke other toxic effects (i.e. may also have non-carcinogenic risk)
  - EPA categories for carcinogens:
    - A Known human carcinogen
    - B1 Limited human evidence
    - B2 Sufficient evidence in animals, but insufficient in humans
    - C Possible human carcinogen
    - D Not classifiable as human carcinogen
    - E No evidence of carcinogenicity

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Toxicity Assessment: Non-carcinogens

- Reference Dose (RfD)
  - Maximum amount of a chemical that an organism can absorb without experiencing chronic health effects
  - Provides estimate of continuous daily exposure for the general population (including sensitive groups) without an appreciable deleterious effect
  - Units are [mg/kg body weight - day]
- Acceptable Daily Intakes (ADI)
  - Experimentally determined from "Lowest Observable Adverse Effect Level" (LOAEL)

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Toxicity Assessment: Non-carcinogens

- Sample calculation of RfD:
  - A study is made with 250 rats that determines that there is "No Observable Adverse Effect" (NOAEL) at 5 mg/kg-day
  - The RfD is calculated as follows:

$$RfD = \frac{NOAEL}{UF \quad x \quad MF}$$

  - Uncertainty factor (UF):
    - Use a factor of 10 for extrapolating from valid experiments to prolonged exposure of healthy humans, accounting for sensitivity. (10H)

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Toxicity Assessment: Non-carcinogens

- Use another factor of 10 when extrapolating from valid studies on animals (in the absence of valid human studies). (10A)
- Use another factor of 10 for extrapolating from less than chronic results on animals (sub-chronic). (10S)
- Use an additional factor of 10 when the results from animal studies are "incomplete" or "inconclusive" but warrant taking precautions. (10L)

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Toxicity Assessment: Non-carcinogens

- Modifying Factor (MF)
  - Additional uncertainty factor, determined by "professional judgment" when the uncertainties in the study warrant it. Varies from 0.1 to 10. Default value is 1.
- For the sample case:
  - UF = 10H x 10A x 10S = 1000
  - MF = 0.75 given the large number of animals used in the study
  - RfD = 5/(1000 x 0.75) = 0.007 mg/kg day

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Toxicity Assessment: Non-carcinogens

- If instead of the NOAEL the LOAEL is used, then the UF is corrected by another factor of 10, to correct for the extrapolation from LOAEL to NOAEL.
- Example: LOAEL = 25 mg/kg day
  - UF = 10Hx10Ax10Sx10L = 10,000
  - MF = 0.75 (same number of rats)
  - RfD = LOAEL/(UF x MF) = 0.003 mg/kg day

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Toxicity Assessment: Carcinogens

- Usually assume that there is no threshold level for carcinogenic effects
- Estimate the "excess" cancer per unit dose, measured by
  - UCR - unit cancer risk
  - SF - slope factor: measures the carcinogenic toxicity, and is in units of risk per mg/kg day
- Determined as the increased lifetime risk per unit of dose

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Toxicity Assessment: Carcinogens

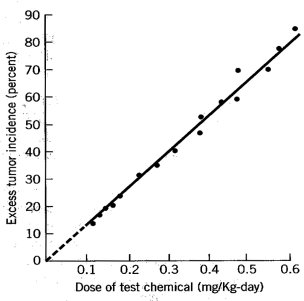

Figure 10.7 Dose-response relationship for carcinogens.

Toxicity Assessment: Carcinogens

- Calculation of risk-specific concentrations in air:

$$C^*_a = [mg/m^3] = \frac{\text{specified risk level x body weight}}{SF_i \text{ x inhalation rate x } 10^{-3}}$$

specified risk level = $1/10^6$
body weight = 70 kg
inhalation rate = 20 m^3/day

$$C^*_a = [mg/m^3] = 3.5 \times 10^{-3} / SF_i$$

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Toxicity Assessment: Carcinogens

Calculation of risk-specific concentrations in water:

$$C^*_w = [mg/m^3] = \frac{\text{specified risk level x body weight}}{SF_o \text{ x ingestion rate x } 10^{-3}}$$

specified risk level = $1/10^6$
body weight = 70 kg
ingestion rate = 2 L/day

$$C^*_w = [mg/m^3] = 3.5 \times 10^{-2} / SF_o$$

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Toxicity Assessment:

- Additional References:
  - USEPA 1996: Guidelines for Carcinogenic Risk Assessment
  - USEPA 1986: Guidelines for Health Risk Assessment of Chemical Mixtures
  - USEPA 1989: Exposure Factors Handbook
  - USEPA 1989: Interim Methods for Development of Inhalation Reference Doses
  - Search the Web: lots of info!

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Toxicity Assessment:

- Based on RfDs and CR, USEPA developed Maximum Contaminant Levels (MCLs) for drinking water
- Same methodology to set air quality standards
- For occupational exposure (acute, subchronic or chronic), OSHA uses NOAEL and LOAEL data to generate Time Weighted Average (TWA) values

Summary

- Two main approaches
  - RBCA
    - Mostly for remediation, spill clean-up
    - Used to determine course of action
    - Determine clean-up goals
  - TMDL
    - On-going sources of pollution
    - PS => treatment, maybe BMP
    - NPS => BMP, maybe treatment

Exposure Assessment

- Fate and Transport Calculation
  - Contaminant source(s)
  - Mechanism(s) of contaminant movement through the environment
  - Degradation pathways
  - Estimation of the concentration of pollutant in the different media (air, water, soil, food) at the point of exposure
  - Receptor exposure routes (inhalation, oral, dermal, ingestion)
  - Dose calculation

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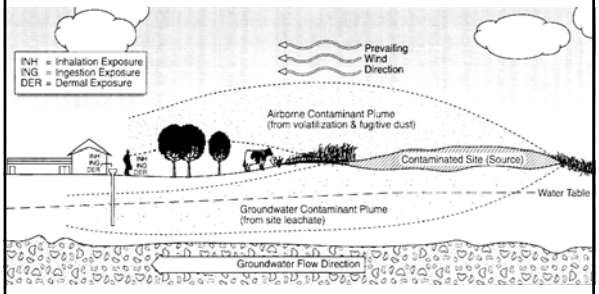
Exposure Assessment



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Exposure Assessment

- Examples of computer models available:
  - **SLAB 3D View** (Lakes Environmental) is a three-dimensional model for analyzing the creation and air toxics plume caused by an accidental release of chemicals. Demo
  - **Visual MODFLOW** (Waterloo Hydrologic, USGS): groundwater modeling tool which includes transport and fate (degradation), can simulate biodegradation and pumping wells, trenches, etc. Can convert concentrations to risk after exporting data to text file.

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Exposure Assessment

- Computer models
  - **RivRisk** (EPRI) is a model designed for making risk calculations in surface waters, considering estimated inputs from:
    - Point sources
    - Groundwater contamination
    - Air deposition
    - Allows input of distribution of values, for uncertainty analysis

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Exposure Assessment

- From exposure point concentrations one has to calculate chemical intake or dose
  - intake is defined as the amount of pollutant coming into contact with the receptor's body or exchange boundaries (mouth, lungs, skin, gastrointestinal tract, etc.)
  - dose is the amount absorbed by the body into the bloodstream
  - intake = dose ?
  - if absorption rate is unknown, then 100% absorption is assumed

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Table F.1 Examples of Case-Specific Parameters for Exposure Assessment

Parameter	Children up to 6 years	Children 6–12 years	Adult (>12 years)	Ref. Sources
Physical characteristics				
Average body weight	16 kg	29 kg	70 kg	(a,b,c)
Average total skin surface area	6980 cm^2	10,470 cm^2	18,150 cm^2	(a,b,e,h)
Average lifetime	70 yrs	70 yrs	70 yrs	(a,b,c,e)
Average lifetime exposure period	5 yrs	6 yrs	58 yrs	(b,e)
Activity characteristics				
Inhalation rate	0.25 m^3/hr	0.46 m^3/hr	0.83 m^3/hr	(b,e)
Retention rate of inhaled air	100%	100%	100%	(e)
Frequency of fugitive dust inhalation				
Off-site residents, schools, and passers-by	365 days/yr	365 days/yr	365 days/yr	(b,e)
Off-site workers	—	—	260 days/yr	(b,e)
Duration of fugitive dust inhalation (outside)				
Off-site residents, schools and passers-by	12 hr/day	12 hr/day	12 hr/day	(b,e)
Off-site workers	—	—	8 hr/day	(b,e)
Amount of soil ingested incidentally	200 mg/day	100 mg/day	50 mg/day	(a,b,c,e,h,i)
Frequency of soil contact				
Off-site residents, schools, and passers-by	330 days/yr	330 days/yr	330 days/yr	(b,e)
Off-site workers	—	—	260 days/yr	(b,e)
Duration of soil contact				
Off-site residents, schools, and passers-by	12 hr/day	8 hr/day	8 hr/day	(b,e)
Off-site workers	—	—	8 hr/day	(b,e)
Percentage of skin area contacted by soil	20%	20%	10%	(b,e,h)
Material characteristics				
Soil to skin adherence factor	0.75 mg/cm^2	0.75 mg/cm^2	0.75 mg/cm^2	(a,b,e,f,g)
Soil matrix attenuation factor	15%	15%	15%	(d)

Note: The exposure factors represented here are for potential maximum exposures (for conservative estimates), and could be modified as appropriate to reflect the most reasonable exposure patterns anticipated. For instance, soil exposure will be reduced by snow cover and rainy days, thus reducing potential exposures for children playing in contaminated areas.

Exposure Assessment

- Calculation of Intake through Inhalation:

$$INH = \frac{C_a \ IR \ RR \ ABS \ ET \ EF \ ED}{BW \ AT}$$

INH = inhalation rate (mg/kg day)
C_a = concentration in air (mg/m^3)
IR = inhalation rate (m^3/hr)
RR = retention rate of inhaled air (%)
ABS = percent absorbed into blood
ET = exposure time (hr/day)
EF = exposure frequency (days/year)
ED = exposure duration (years)

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Exposure Assessment

- Calculation of Intake through Inhalation:

BW = body weight (kg)
AT = averaging period, i.e. period over which exposure is averaged:

for noncarcinogens use ED x 365 days/yr

for carcinogens use 70 yr x 365 days/yr

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Exposure Assessment

- Example:

C_a = 0.05 mg/m^3
IR = 0.25 m^3/hr
RR = 100%
ABS = 50%
ET = 6hr/day
EF = 330 days/year
ED = 5 years
BW = 16 kg
AT = 5 x 365 = 1825 days

INH = 0.002 mg/kg day

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Exposure Assessment

- Calculation of Intake through Ingestion of contaminated drinking water:

$$ING = \frac{C_w \ IR \ FI \ ABS \ EF \ ED}{BW \ AT}$$

IR = average water ingestion rate (L/day)
FI = fraction ingested from contaminated source

Calculation of Intake through Ingestion during Recreational Activities:

$$ING = \frac{C_w \ CR \ ABS \ ET \ EF \ ED}{BW \ AT}$$

CR = contact rate (L/hr)

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Exposure Assessment

Calculation of Intake through Ingestion of Seafood:

$$ING = \frac{C_w \ FIR \ BCF \ FI \ ABS \ EF \ ED}{BW \ AT}$$

FIR = average fish ingestion rate (kg/day)
FI = fraction ingested from contaminated source
BCF = bioconcentration factor

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Exposure Assessment

Calculation of Dermal Exposure through Soil Contact:

$$DEX = \frac{C_s \ CF \ SA \ AF \ SM \ ABS \ EF \ ED}{BW \ AT}$$

DEX = dermal exposure (mg/kg day)
C_s = soil concentration (mg/kg)
CF = conversion factor = 10^{-6} kg/mg
SA = skin surf.area available (cm^2/event)
AF = soil to skin adherence factor (mg/cm^2)
SM = factor for soil matrix effects (%)

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Exposure Assessment

Calculation of Dermal Exposure through contact with contaminated water:

$$DEX = \frac{C_w \ SA \ PC \ CF \ ABS \ ET \ EF \ ED}{BW \ AT}$$

DEX = dermal exposure (mg/kg day)
C_w = water concentration (mg/L)
CF = conversion factor = 10^{-3} L/ cm^3
SA = skin surf.area available (cm^2)
PC = chemical-specific dermal permeability factor (cm/hr)

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Risk Characterization

- Final step in Risk Assessment!
- Leads into Risk Management …
- Evaluates risks to potentially exposed populations
- Brings together Toxicity and Exposure Assessment, resulting in
  - Non-carcinogenic hazard quotients
  - Indices of Carcinogenic Risk
- Mixtures of pollutants are handled by adding their individual risk, unless other information is available

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Risk Characterization: Carcinogenic Risks

- Carcinogenic risk

$$CR_j = CDI_j \ x \ SF_j$$

  - CR_j = prob. of an individual developing cancer (unitless)
  - CDI_j = chronic daily intake, averaged over a lifetime (mg/kg d)
  - SF_j = slope factor $(mg/kg\ d)^{-1}$

valid for $CR < 10^{-2} = 1/100$

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Risk Characterization: Carcinogenic Risks

- If the pollutant intake is high (with $CR > 10^{-2}$), then the "one-hit" model is used:

$$CR_j = [1 - \exp(-CDI_j \ SF_j)]$$

To aggregate multiple pollutants and exposure pathways:

$$Risk = \sum_{k=1}^{p} \sum_{j=1}^{n} (CDI_{jk} \ SF_{jk})$$

$$Risk = \sum_{k=1}^{p} \sum_{j=1}^{n} [1 - exp(CDI_{jk} \ SF_{jk})]$$

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Risk Characterization: Carcinogenic Risks

- Risk assessment is site/region specific
- Best to express cancer risks in terms of individual and population risk
- Commonly accepted risk level is 1 excess cancer per million people

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Risk Characterization: Non-Carcinogenic Hazards

- Reported as Hazard Index (HI or Hazard Quotient (HQ):

$$HQ_{total} = \sum_{j=1}^{p} \sum_{i=1}^{n} \frac{CDI_{ij}}{RfD_{ij}}$$

CDI_{ij} = chronic daily intake, averaged over a lifetime (mg/kg d) for the i^{th} contaminant and j^{th} pathway

RfD_{ij} = chronic reference dose, (mg/kg d)

Commonly accepted level is a total HQ ✪ 1

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Risk Assessment

EXAMPLE:

- A site was used for ~ 2 decades as a manufacturing plant for machine components and as an automotive repair shop
- Current rezoning may allow for light industrial or residential use
- Soils and ground water have been contaminated with a number of pollutants, organic and inorganic
- Site characterization provides analytical information

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Risk Assessment

- Baseline Risk Assessment steps
  - Compile list & conc. of pollutants
  - Compile toxicological information
  - Determine all possible exposure pathways
  - Identify potential groups exposed, in particular sensitive receptors
  - Develop a conceptual model
  - Develop exposure scenarios
  - Calculate carcinogenic risks and noncarcinogenic hazards

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Table 5.1 Summary of the Chemicals of Potential Concern at the A2Z Site

Chemicals of Potential Concern in Soils	Important Synonyms or Trade Names, or Chemical Formula	Chemical Abstracts Service number (CAS No.)	95% UCL Soil Concentration (mg/kg)	Chemicals of Potential Concern in Groundwater	Important Synonyms or Trade Names, or Chemical Formula	Chemical Abstracts Service number (CAS No.)	95% UCL Groundwater Concentration (ug/L)
Inorganic chemicals				Inorganic chemicals			
Antimony	Sb	7440-36-0	4.6	Antimony	Sb	7440-36-0	3.4
Arsenic	As	7440-38-2	17.2	Arsenic	As	7440-38-2	7.5
Beryllium	Be	7440-41-7	1.4	Cadmium	Cd	7440-43-9	4.8
Cadmium	Cd	7440-43-9	4.5	Chromium (total)	Cr	16065-83-1	8,600
Chromium (total)	Cr	16065-83-1	92.2	Chromium (hexavalent)	Cr(VI)	7440-47-3	435
Chromium (hexavalent)	Cr(VI)	7440-47-3	4.6	Manganese	Mn	7439-96-5	299
Cobalt	Co	7440-48-4	7.8	Molybdenum	Mo	7439-98-7	164
Manganese	Mn	7439-96-5	512	Nickel	Ni	7440-02-0	82.2
Mercury	Hg	7439-97-6	0.25	Vanadium	V	7440-62-2	34
Molybdenum	Mo	7439-98-7	16.6	Zinc	Zn	7440-66-6	84.6
Nickel	Ni	7440-02-0	90.9				
Selenium	Se	7782-49-2	1.4				
Vanadium	V	7440-62-2	62.9				
Zinc	Zn	7440-66-6	413				
Organic compounds				Organic compounds			
Chloroform	Trichloromethane	67-66-3	0.008	Vinyl chloride	VC	75-01-4	9.729
Trichloroethene	TCE	79-01-6	32	1,1-Dichloroethene	1,1-DCE	75-35-4	3.31
1,1,2-Trichloroethane	1,1,2-TCA	79-00-5	0.020	trans-1,2-Dichloroethene	1,2-trans-DCE	156-60-5	11.8
Tetrachloroethene	PCE	127-18-4	0.033	cis-1,2-Dichloroethene	cis-1,2-DCE	540-59-0	1,229
Ethylbenzene	EB; Phenylethane	100-41-4	0.009	Trichloroethene	TCE	79-01-6	548
Xylenes (mixed)	Dimethylbenzene	1330-20-7	0.044				

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Risk Assessment

- Hypothetical Residential Population exposure
  - Via inhalation of airborne contaminants (particulates and volatile emissions)
  - Via ingestion of contaminated soil
  - Via dermal contact with contaminated soils at the site
  - Via inhalation of volatiles from groundwater
  - Via ingestion of contaminated water
  - Via dermal contact with contaminated water

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Table 5.2A Risk Screening for a Hypothetical Residential Population Exposure to Soils at the A2Z Site

Chemical of Potential Concern	95% UCL Soil Concentration (mg/kg)	Chemical-Specific Dermal Absorption (ABS$_d$)	Toxicity Criteria: Oral RfD (mg/kg-day)	Toxicity Criteria: Oral SF (1/mg/kg-day)	Toxicity Criteria: Inhalation RfD (mg/kg-day)	Toxicity Criteria: Inhalation SF (1/mg/kg-day)	Risk for Air	Hazard for Air	Risk for Soil	Hazard for Soil	Total Risk (Air + Soil)	Total Hazard (Air + Soil)
Inorganic chemicals												
Antimony	4.6	0.03	4.00E-04					3.29E-04	2.39E-06	1.41E-01		
Arsenic	17.2	0.03	3.00E-04	1.75E+00		1.51E+01	1.84E-06	1.82E-02	5.41E-05	5.34E-01		
Beryllium	1.4	0.01	5.00E-03	4.30E+00		8.40E+00	8.75E-06	8.65E-06	1.53E-05	3.34E-03		
Cadmium	4.5	0.01	5.00E-04			1.80E+01	5.03E-07	2.98E-04	2.39E-06	1.41E-01		
Chromium (total)	92.2	0.03	1.00E+00					2.98E-06	1.96E-06	1.93E-02		
Chromium (VI)	4.6	0.06	5.00E-03	4.20E+01		5.10E+02	1.75E-05	2.98E-05	3.92E-06	1.16E-02		
Cobalt	7.8	0.03	2.00E-02		5.70E-04		0.00E+00	8.59E-04	0.00E+00	2.76E-01		
Manganese	512	0.03	1.40E-01		1.40E-04		0.00E+00	1.46E-01	3.99E-04	5.19E-02		
Mercury	0.25	0.01	3.00E-04		8.60E-05		0.00E+00	5.22E-05	2.13E-06	1.77E-02		
Molybdenum	16.6	0.03	5.00E-03		5.20E-03		0.00E+00	1.06E-04	7.73E-06	4.57E-02		
Nickel	90.9	0.03	2.00E-02			8.40E-01	6.13E-07	1.45E-04	4.23E-06	8.40E-02		
Selenium	1.4	0.03	5.00E-03				0.00E+00	8.95E-06	2.06E-06	3.34E-04		
Vanadium	62.9	0.03	7.00E-03				0.00E+00	2.87E-04	2.88E-06	4.27E-01		
Zinc	413	0.03	3.00E-01				0.00E+00	4.40E-05	1.89E-06	1.94E-02		
Organic compounds												
Chloroform	0.008	0.10	1.00E-02	3.10E-02	1.00E-02	1.90E-02	1.03E-09	2.98E-06	9.60E-10	2.76E-04		
Trichloroethene	32	0.10	6.00E-03	1.50E-02	6.00E-03	7.00E-02	2.01E-06	1.44E-01	1.66E-06	1.77E-01		
1,1,2-Trichloroethane	0.020	0.10	4.00E-03	5.70E-02	4.00E-03	5.60E-02	3.54E-09	6.77E-05	3.92E-09	1.39E-04		
Tetrachloroethene	0.033	0.10	1.00E-02	5.10E-02	1.00E-02	5.10E-02	5.19E-09	4.29E-05	5.79E-09	8.64E-05		
Ethylbenzene	0.009	0.10	1.00E-01		2.90E-01		0.00E+00	5.47E-07	2.00E-09	2.39E-06		
Xylenes	0.044	0.10	2.00E+00		2.00E-01		0.00E+00	3.76E-06	2.00E-09	5.63E-07		
							2.22E-05	2.39	7.54E-05	2.1	1.60E-04	2.4

Notes: The computational formulas and models used in this evaluation are discussed in this chapter and further elaborated in Appendices F and I.

Risk/hazard for air accounts for the volatilization effects (for volatile organic compounds) and airborne emissions of contaminated particulates (for nonvolatile chemicals) present at the site (see Section 5.6.1 and DTSC, 1994).

Case-specific exposure parameters used in the calculations were obtained from the following sources — DTSC (1994), OSA (1992), and USEPA (1989b, 1989d, 1992).

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Table 5.2B Risk Screening for a Hypothetical Residential Population Exposure to Groundwater at the A2Z Site

Chemical of Potential Concern	95% UCL Water Concentration (µg/L)	Chemical-Specific K_p (cm/hr)	Toxicity Criteria: Oral RfD (mg/kg-day)	Oral SF (1/mg/kg-day)	Inhalation RfD (mg/kg-day)	Inhalation SF (1/mg/kg-day)	Risk for Water	Hazard for Water
Inorganic chemicals								
Antimony	3.4	1.60E – 04	4.00E – 04				0.00E + 00	5.43E – 01
Arsenic	7.6	1.60E – 04	3.00E – 04	1.75E + 00		1.20E + 01	1.98E – 04	1.62E + 00
Cadmium	4.6	1.60E – 04	5.00E – 04			1.50E + 01	0.00E + 00	5.88E – 01
Chromium (total)	8.693	1.60E – 04	1.20E + 00				0.00E + 00	5.55E – 01
Chromium (hexavalent)	435	1.60E – 04	5.00E – 03	4.20E – 01		5.10E – 02	2.72E – 03	5.56E + 00
Manganese	299	1.60E – 04	5.00E – 03		1.10E – 04		0.00E + 00	3.82E + 00
Molybdenum	164	1.60E – 04	5.00E – 03		5.00E – 03		0.00E + 00	2.10E + 00
Nickel	82.2	1.60E – 04	2.00E – 02			9.10E – 01	0.00E + 00	2.53E – 01
Vanadium	54	1.60E – 04	7.00E – 03				0.00E + 00	4.83E – 01
Zinc	64.6	1.60E – 04	3.00E – 01				0.00E + 00	1.38E – 02
Organic compounds								
Vinyl Chloride	0.729	7.36E – 03		2.70E – 01		2.70E – 01	5.91E – 06	0.00E + 00
1,1-Dichloroethene	3.31	1.60E – 02	9.00E – 03	6.00E – 01	5.00E – 03	1.20E + 00	8.98E – 05	4.74E – 02
trans-1,2-Dichloroethene	11.8	1.60E – 02	2.00E – 02		2.00E – 02		0.00E + 00	7.58E – 02
cis-1,2-Dichloroethene	1,220	1.60E – 02	1.00E – 02		1.00E – 02		0.00E + 00	1.57E + 01
Trichloroethene	548	1.60E – 02	6.00E – 03	1.50E – 02	1.00E – 02	1.50E – 02	2.49E – 04	3.43E + 00
							3.27E – 03	40.8

Notes: The computational formulas and models used in this evaluation are discussed in this chapter and further elaborated in Appendices F and I.

Risk/hazard for water account for both volatile chemical emissions and nonvolatile chemical contributors present at the site (see Section 5.8.1 and DTSC, 1994).

Case-specific exposure parameters used in the calculations were obtained from the following sources — DTSC (1994), OSA (1993), and USEPA (1989b, 1989d, 1992).

K_p = chemical-specific dermal permeability coefficient for water.

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Risk Assessment

- Site Worker exposure
  - Assume contaminated soils remain in place
  - Inhalation of particulate emissions and volatile emissions (50 µg/m^3)
  - Incidental ingestion of soil (50 mg/day)
  - Dermal contact with soil
  - Exposed 250 days per year over a 25-year period

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Table 5.3 Risk Screening for a Hypothetical Residential Population Exposure to Soil at the A2Z Site

Chemical of Potential Concern	95% UCL Soil Concentration (mg/kg)	Chemical-Specific Dermal Absorption (ABS$_d$)	Toxicity Criteria: Oral RfD (mg/kg-day)	Oral SF (1/mg/kg-day)	Inhalation RfD (mg/kg-day)	Inhalation SF (1/mg/kg-day)	Risk for Air	Hazard for Air	Risk for Soil	Hazard for Soil	Total Risk (Air + Soil)	Total Hazard (Air + Soil)
Inorganic chemicals												
Antimony	4.6	0.01	4.00E – 04				0.00E + 00	9.76E – 05	0.00E + 00	1.06E – 02		
Arsenic	17.2	0.03	3.00E – 04	1.75E + 00		1.20E + 01	7.31E – 07	5.61E – 04	2.33E – 05	1.20E – 01		
Beryllium	1.4	0.01	5.00E – 03	4.30E + 00		8.40E + 00	4.11E – 08	2.74E – 06	2.27E – 06	3.96E – 04		
Cadmium	4.5	0.001	5.00E – 04			1.50E + 01	2.36E – 07	8.91E – 05	0.00E + 00	4.99E – 03		
Chromium (total)	92.2	0.01	1.00E + 00				0.00E + 00	0.00E + 00	0.00E + 00	3.74E – 03		
Chromium (VI)	4.6	0.03	5.00E – 03	4.20E – 01		5.10E + 02	8.30E – 05	0.00E + 00	3.78E – 07	4.52E – 04		
Cobalt	7.8	0.01	2.90E – 04		2.90E – 04		0.00E + 00	2.93E – 04	0.00E + 00	2.94E – 02		
Manganese	512	0.01	1.40E – 01		1.10E – 04		0.00E + 00	4.15E – 02	0.00E + 00	2.96E – 03		
Mercury	0.23	0.01	3.00E – 04		3.00E – 05		0.00E + 00	2.84E – 05	0.00E + 00	8.91E – 04		
Molybdenum	16.6	0.01	5.00E – 03		5.00E – 03		0.00E + 00	3.01E – 05	0.00E + 00	3.31E – 03		
Nickel	90.9	0.01	2.00E – 02			9.10E – 01	2.86E – 07	4.42E – 05	0.00E + 00	4.95E – 03		
Selenium	1.4	0.01	5.00E – 03				0.00E + 00	2.74E – 06	0.00E + 00	2.96E – 04		
Vanadium	62.9	0.01	7.00E – 03				0.00E + 00	8.79E – 05	0.00E + 00	9.50E – 03		
Zinc	413	0.01	3.00E – 01				0.00E + 00	1.35E – 05	0.00E + 00	1.45E – 03		
Organic compounds												
Chloroform	0.008	0.10	1.00E – 02	3.10E – 02	1.00E – 02	1.90E – 02	5.31E – 13	7.83E – 09	5.46E – 10	4.90E – 06		
Trichloroethene	32	0.10	6.00E – 03	1.10E – 02	6.00E – 03	1.00E – 02	1.12E – 09	5.23E – 05	1.08E – 06	3.26E – 02		
1,1,2-Trichloroethane	0.020	0.10	4.00E – 03	5.70E – 02	4.00E – 03	5.60E – 02	3.91E – 12	4.89E – 08	2.51E – 09	2.36E – 05		
Tetrachloroethene	0.033	0.10	1.60E – 02	5.10E – 02	1.60E – 02	5.10E – 02	5.98E – 12	3.23E – 08	3.71E – 09	2.35E – 05		
Ethylbenzene	0.005	0.10	1.00E – 01		2.90E – 01		0.00E + 00	6.81E – 10	0.00E + 00	6.56E – 07		
Xylenes	0.044	0.10	2.00E + 00		2.00E – 01		0.00E + 00	2.15E – 10	0.00E + 00	1.36E – 07		
							5.46E – 06		0.23	3.62E – 01	0.3	

Notes: The computational formulas and models used in this evaluation are discussed in this chapter and further elaborated in Appendices F and I.

Risk/hazard for air accounts for only the airborne emissions of contaminated particulates for all chemicals present at the site (see Section 5.8.1 and DTSC, 1994); volatilization effects are not included in this screening analysis.

Case-specific exposure parameters used in the calculations were obtained from the following sources — DTSC (1994), OSA (1993), and USEPA (1989b, 1989d, 1992).

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Risk Assessment

Construction Worker

- Assume contaminated soils remain in place
- Inhalation of particulate emissions and volatile emissions (1000 mg/m^3)
- Incidental ingestion of soil (480 mg/day)
- Dermal contact with soil
- Exposed 250 days per year over a 1-year period

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Table 5.4 Risk Screening for a Construction Worker Exposure to Soil at the A2Z Site

Chemical of Potential Concern	95% UCL Soil Concentration (mg/kg)	Chemical-Specific Dermal Absorption (ABS$_d$)	Toxicity Criteria: Oral RfD (mg/kg-day)	Oral SF (1/mg/kg-day)	Inhalation RfD (mg/kg-day)	Inhalation SF (1/mg/kg-day)	Risk for Air	Hazard for Air	Risk for Soil	Hazard for Soil	Total Risk (Air + Soil)	Total Hazard (Air + Soil)
Inorganic chemicals												
Antimony	4.6	0.01	4.00E – 04				0.00E + 00	1.95E – 05	0.00E + 00	5.29E – 03		
Arsenic	17.2	0.03	3.00E – 04	1.75E + 00		1.20E + 01	5.77E – 07	1.12E – 04	4.70E – 06	2.67E – 02		
Beryllium	1.4	0.01	5.00E – 03	4.30E + 00		8.40E + 00	3.23E – 08	5.48E – 06	4.53E – 07	1.47E – 03		
Cadmium	4.5	0.001	5.00E – 04			1.50E + 01	1.86E – 07	1.78E – 03	0.00E + 00	4.99E – 03		
Chromium (total)	92.2	0.01	1.00E + 00				0.00E + 00	1.87E – 03	0.00E + 00	4.85E – 04		
Chromium (VI)	4.6	0.03	5.00E – 03	4.20E – 01		5.10E + 02	6.56E – 06	1.90E – 04	1.30E – 07	4.52E – 03		
Cobalt	7.8	0.01	2.90E – 04		2.90E – 04		0.00E + 00	3.26E – 03	0.00E + 00	1.47E – 01		
Manganese	512	0.01	1.40E – 01		1.10E – 04		0.00E + 00	5.11E – 01	0.00E + 00	1.89E – 02		
Mercury	0.23	0.01	3.00E – 04		3.00E – 05		0.00E + 00	2.09E – 04	0.00E + 00	4.09E – 03		
Molybdenum	16.6	0.01	5.00E – 03		5.00E – 03		0.00E + 00	1.30E – 04	0.00E + 00	1.15E – 02		
Nickel	90.9	0.01	2.00E – 02			9.10E – 01	2.21E – 07	1.80E – 04	0.00E + 00	2.03E – 02		
Selenium	1.4	0.01	5.00E – 03				0.00E + 00	1.48E – 05	0.00E + 00	1.47E – 03		
Vanadium	62.9	0.01	7.00E – 03				0.00E + 00	3.76E – 03	0.00E + 00	4.73E – 02		
Zinc	413	0.01	3.00E – 01				0.00E + 00	2.89E – 04	0.00E + 00	7.25E – 03		
Organic compounds												
Chloroform	0.008	0.10	1.00E – 02	3.10E – 02	1.00E – 02	1.90E – 02	4.25E – 13	3.87E – 07	3.47E – 11	6.30E – 06		
Trichloroethene	32	0.10	6.00E – 03	1.50E – 02	6.00E – 03	1.00E – 02	8.59E – 10	1.04E – 03	7.71E – 08	5.53E – 02		
1,1,2-Trichloroethane	0.020	0.10	4.00E – 03	5.70E – 02	4.00E – 03	5.60E – 02	3.13E – 12	9.70E – 07	1.63E – 10	5.19E – 03		
Tetrachloroethene	0.033	0.10	1.60E – 02	5.10E – 02	1.60E – 02	5.10E – 02	4.71E – 12	6.40E – 07	2.49E – 10	3.42E – 03		
Ethylbenzene	0.005	0.10	1.00E – 01		2.90E – 01		0.00E + 00	6.27E – 09	0.00E + 00	5.93E – 07		
Xylenes	0.044	0.10	2.00E + 00		2.00E – 01		0.00E + 00	4.31E – 09	0.00E + 00	3.29E – 07		
							7.59E – 06		0.54	3.41E – 01	0.79	1.3E – 01

Notes: The computational formulas and models used in this evaluation are discussed in this chapter and further elaborated in Appendices F and I.

Risk/hazard for air accounts for only the airborne emissions of contaminated particulates for all chemicals present at the site (see Section 5.8.1 and DTSC, 1994); volatilization effects are not included in this screening analysis.

Case-specific exposure parameters used in the calculations were obtained from the following sources — DTSC (1994), OSA (1993), and USEPA (1989b, 1989d, 1992).

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Risk Assessment

Table 5.5 Summary of the Risk Screening for the A2Z Site

Receptor Group	Risk Parameter	Exposure Routes and Pathways: Inhalation Exposure to Soils	Oral Exposure to Soils	Total Exposure to Soils	Total Exposure to Groundwater	Overall Total Risk
Hypothetical resident	Cancer Risk	2.2×10^{-5}	7.9×10^{-5}	1.0×10^{-4}	3.3×10^{-3}	3.4×10^{-3}
	Hazard Index	0.3	2.1	2.4	40.8	43.2
Nearby worker	Cancer Risk	9.5×10^{-6}	2.7×10^{-5}	3.7×10^{-5}	—	3.7×10^{-5}
	Hazard Index	0.1	0.2	0.3	—	0.3
Construction worker	Cancer Risk	7.6×10^{-6}	3.4×10^{-6}	1.1×10^{-5}	—	1.1×10^{-5}
	Hazard Index	0.9	0.8	1.7	—	1.7

Note: Risk due to oral exposure is the total contribution from ingestion and dermal absorption of chemicals present in the contaminated medium.

Estimated potential risks are high for both carcinogenic and non-carcinogenic pollutants

Remediation of the site is warranted after this assessment

Immediate measures can be taken to reduce the risk and hazard from GW

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Risk Assessment

- Baseline Risk Assessment
  - Analysis of potential adverse health and environmental effects caused by the release of hazardous pollutants in a site in the absence of control or remediation actions (i.e. the “no-action” option)
  - Helps to determine if additional action is needed at the site
  - Characterize the risks present at the site
  - Provides remediation priorities

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Risk Screening

- **Case study**: Radian Corporation conducted a risk screening assessment at an Air Force base in New Mexico to determine how to manage risks (Hixson et al., 1993)
  - AFB had 29 waste sites requiring CERCLA and RCRA assessments
  - Screening was performed to classify waste sites as “clean”, “dirty” or “borderline”
  - Preliminary results used for the screening process

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Risk Screening

- Dirty sites did not require full scale risk assessment since remediation was clearly required
- Clean and Borderline sites required full-scale risk assessment
- Clean sites must justify the no-action decision
- Borderline sites would use risk assessment to determine if they would need remediation or not

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Risk Screening

- AFB used for flight-training, guided-missile research and testing
- Nearest city is 7 miles east of AFB
- Climate is arid
- Top soils are well-drained sandy loams and gypsum
- Lower soils are moderately permeable, calcareous, mildly alkaline
- Groundwater is 2 to 40 ft below surface, with high TDS so non-potable

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Risk Screening

- Risk Screening Method
  - Use information from preliminary site assessment for each waste site
  - Soils and groundwater assessed separately
  - Maximum pollutant concentration at each site used for screening
  - Exposure pathways considered: soil ingestion and water ingestion (despite not being used for drinking water due to TDS…)
  - Intakes calculated based on EPA methods

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Risk Screening

- Lifetime soil ingestion calculated at 1.5×10^{6} (mg/kg d)/(mg/kg), which is multiplied by the soil concentration (mg/kg) to give the Chronic Daily Intake (mg/kg d)
- Cancer slope factors and RfD from USEPA 1992 guidelines
- Risk ranking:
  - Phase I: separate carcinogenic from non-carcinogenic risk, adding soil to groundwater risk to rank sites

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Risk Screening

– Phase II: Sites that were ranked differently based on carcinogenic and noncarcinogenic risks were evaluated to determine the most appropriate overall rank

Ranking Estimated Risks

	Clean	Borderline	Dirty
Carcinogenic risk estimate	$<10^{-5}$	$10^{-5} < \text{risk} < 10^{-3}$	$>10^{-3}$
Noncarcinogenic risk estimate	<1	1 < risk < 3	>3

After phase II, 4 sites ranked dirty, 14 were borderline and 7 were clean

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Risk Screening

- To evaluate the effectiveness of the screening method, 21 sites received a full risk assessment, according to USEPA 1989 guidelines
- Three exposure scenarios evaluated:
  - direct residential exposure from inhalation as well as recreational exposure to contaminated water
  - indirect residential exposure based on cattle feeding on contaminated water
  - occupational exposure

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Risk Screening

- Five sites had the potential for direct residential exposure of pollutants

Comparison of Results for Sites with Potential Residential Exposure

	Screening results			Comprehensive assessment		
Site	Carcinogenic	Noncarcinogenic	Risk*	Carcinogenic	Noncarcinogenic	Result
Waste storage/spill	1.6E-7	12.1	C/D	7E-8	1.0	Feasibility study
Main substation	1.7E-5	0.16	B/C	6E-7	→ᵇ	Site closeout
Old entomology shop	9.0E-4	0.3	B/C	5E-9	3E-6	Site closeout
New entomology shop	3.2E-4	0.2	B/C	5E-12	5E-8	Site closeout
Grit burial site	6.0E-4	7.1	B/D	2E-10	0.002	Site closeout

* Rank for carcinogenic risk/rank for noncarcinogenic risk.
ᵇ No noncarcinogenic constituents were confirmed at the site.

Results indicate that the initial screening overestimated both risks, so was more conservative in its assumptions, as expected

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Risk Screening

- Results for indirect exposure and occupational exposure were similar, i.e. risk was overestimated in almost all cases
- The sites selected for remediation during the initial screening had definitely high concentrations and/or a high probability of exposure to sensitive populations

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Risk Screening

Sites Selected as Candidates for Remediation

Site	Pathway	Carcinogenic	Noncarcinogenic	Rank	Pathway evaluation
POL spill site	Water	2.9E-3	0.66	D/C	Water discharges directly into an arroyo where children play
	Soil	2.1E-5	1.6	B/B	Site access is controlled
Lead disposal trench	Water	4.8E-3	12.7	D/D	Water discharges directly into arroyo where children play
	Soil	2.0E-8	1.9	C/B	Trench located on the side of the arroyo
Truck washrack	Water	1.1E-2	4.2	D/D	Water travels ~1/2 mile to discharge to arroyo
	Soil	1.6E-4	13.9	B/D	Site access not controlled; surface runoff likely
Disposal pits and trenches	Water	7.9E-4	12.3	B/D	Water travels several miles to discharge to arroyo
	Soil	2.3E-3	50.6	D/D	Site access uncontrolled, pits are open