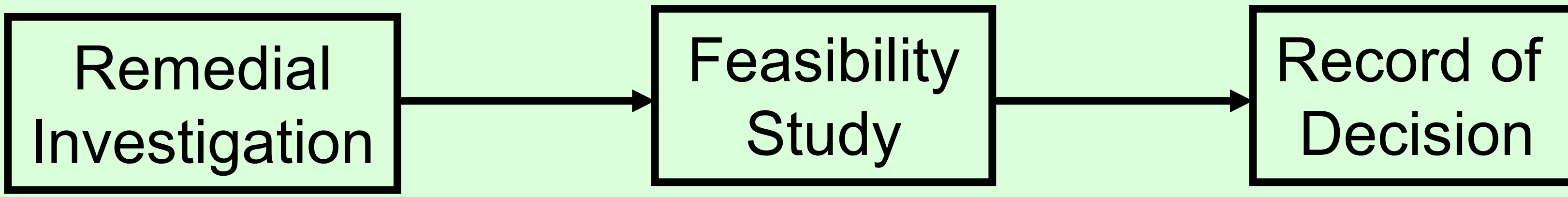
Lecture 15

Remedy Selection and Risk Assessment

Superfund remedy selection



Completes characterization of site as basis for remedial selection

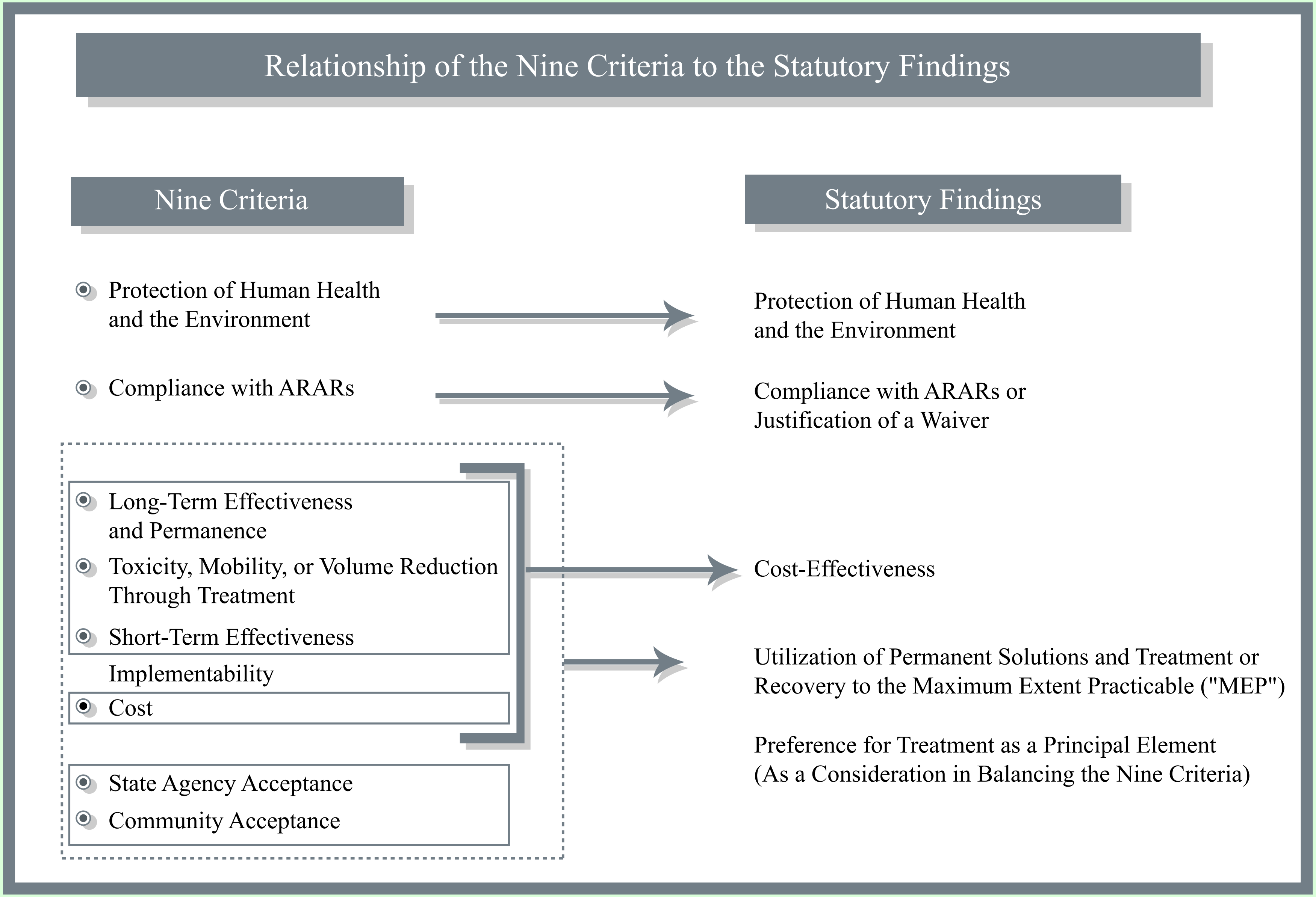
Selects remedial technologies and alternative remedies

Chooses the site remedy

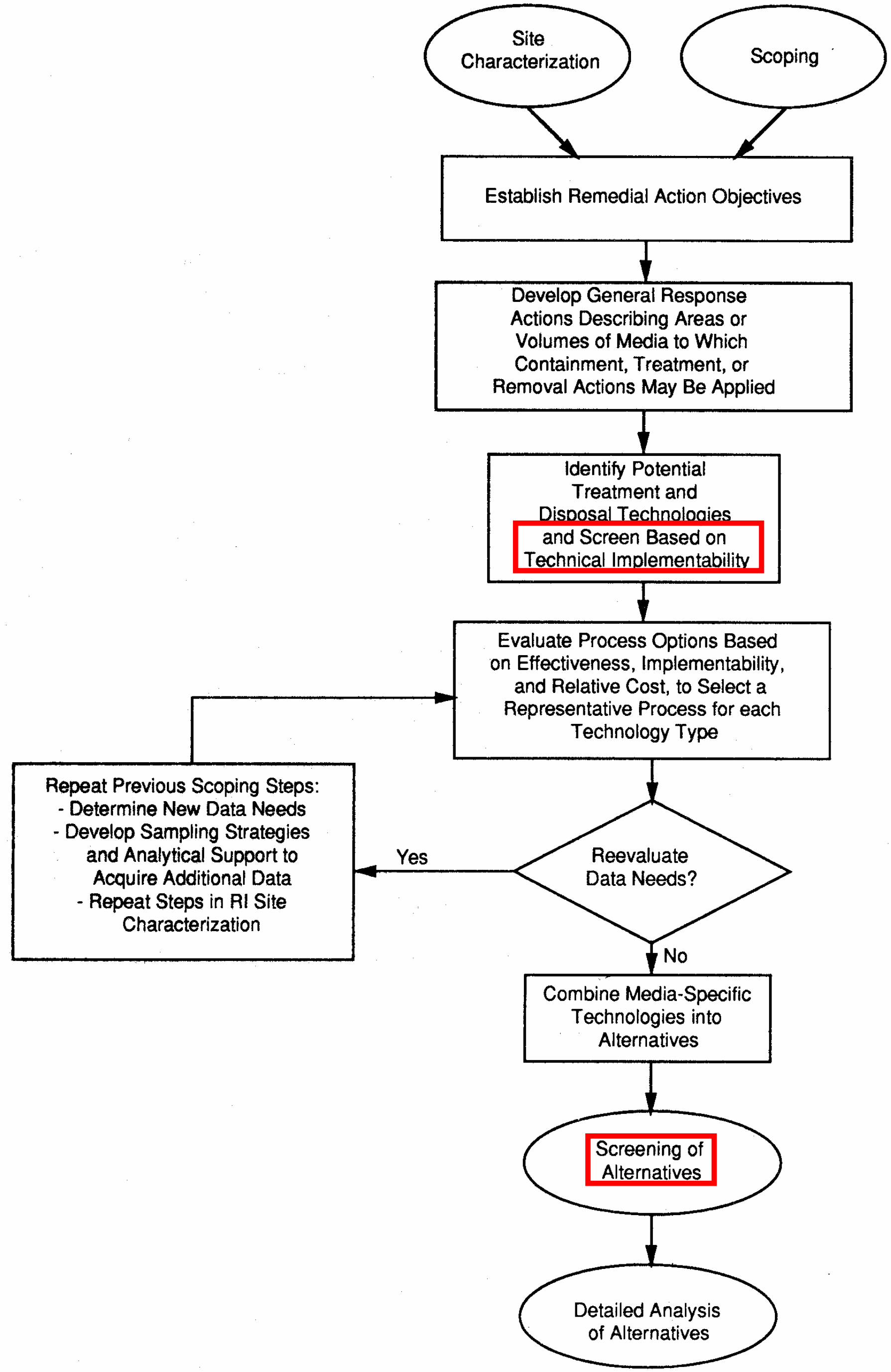
Requirements for Superfund Remedies

- Protect human health and the environment
- Comply with applicable or relevant and appropriate requirements (ARARs)
- Be cost-effective
- Utilize permanent solutions and alternatives or resource-recovery technologies
- Favor treatment as principal element

Criteria for evaluating alternatives



Process of evaluating alternatives



Source: U.S. EPA, 1988. Guidance for conducting remedial investigations and feasibility studies under CERCLA (OSWER Directive 9355.3-01). Report Number EPA/540/G-89/004. U.S. Environmental Protection Agency, Washington, D.C. October 1988.

The Concept of "Screening"

- Uses indicators to identify candidates most likely to be found favorable
- Proceeds from coarse screening analysis to more refined
- Eventually, candidates from final screened list need detailed analysis

Screening makes practical an otherwise enormous task of evaluating all candidates

Example: Screening Criteria for Low-Level Radioactive Waste Disposal Site

Exclusionary factors:

- Freestanding water
- Earthquake zones
- Federally-protected
- State-protected
- Landslide areas
- Subsidence areas
- Floodplain

Favorability factors:

- Low permeability
- Simple geology
- No surficial sand & gravel
- Far from water supplies
- No high-yield aquifer
- No shallow aquifer
- Low erosion

Example (continued)

- Mapped areas with no aquifer within 50 feet of surface to evaluate “No shallow aquifer”
- Final site not within shallow aquifer area
- BUT…detailed site study discovered an unmapped shallow aquifer
- Site still found favorable based on <u>all</u> factors

Screening criteria are not final selection criteria!

Broome County Landfill Site, New York

Broome County Landfill Web site:
http://www.gobroomecounty.com/dpw/DPWLandfill.php

Timeline for Example Site: Broom County Landfill, Colesville, New York

1969-84 – Operated as MSW landfill

1973-75 – Drummed industrial waste accepted

1983 – Ground-water contamination discovered in private wells

1984 – Site nominated for NPL

1986 – Listed on NPL

August 1986 – RI work plan by PRPs

April 1988 – Draft RI report

Timeline, continued

Sept. 1988 – Final RI report

Dec. 1990 – Draft FS report

March 1991 – Record of Decision

June 1992 – Conceptual design report

1994-95 – Landfill capped for $3 million

Identification of ARARs

Ground water:	Federal MCLs and New York State standards
Sediments:	none
Action-specific:	example: NYSDEC regulations for landfills
Location-specific:	example: Clean Water Act for stream and river

Technology screening

Colesville Landfill Screening of Technology Types and Process Options			
General Response Action	Technology Type	Process Option	Retained as Representative Process Option
Waste Containment	Capping	• Synthetic membrane/soil	No
		• Single Layer	No
		• Multi-Media	Yes
	Barriers	• Slurry Walls	Yes
		• Vitrified Wall Barrier	No
		• Sheet Piles	No
		• Grout Curtains	No
		• Bottom Sealing	No
Waste Removal	Excavation	• Backhoes, excavators	Yes

Colesville Landfill
Screening of Technology Types and Process Options

Waste Treatment	**Contaminant Containment**		
	Stabilization/Solidification	• In situ	No
		• On-site	Yes
		• Off-site	Yes
	Contaminant Removal		
	Soil washing	• In situ	No
		• On-site	No
	Stripping	• In situ vacuum extraction	No
		• In situ steam extraction	No
		• On-site low temperature	No
		• On-site high temperature	No
	Contaminant Destruction		
	Bioremediation	• On-site composting	No
		• In situ bioremediation	No
		• On-site slurry bioreactor	No
		• On-site leach bed	No
	Vitrification	• In situ vitrification	No
		• On-site vitrification	Yes
	Incineration	• On-site rotary kiln	Yes
		• On-site fluidized bed	No
		• On-site infrared incinerator	No
		• Off-site commercial incinerator	Yes
	Chemical Treatment	• In situ	No

Colesville Landfill
Screening of Technology Types and Process Options

General Response Action	Technology Type	Process Option	Retained as Representative Process Option
Waste Disposal	Land Disposal	• On-site landfill • On-site RCRA vault • Off-site TSD	Yes No Yes
Groundwater Containment *(See Waste Containment)*			
Groundwater Collection	Pumping Subsurface Drains	• Well Point Dewatering • Pumping Wells • Trench Drains • Horizontal Drains	No Yes No No
Groundwater Treatment	Physical/Chemical Biophysical	• Chemical Precipitation • Neutralization • Chemical Oxidation • Granular Activated Carbon • Steam stripping • Air stripping • Solids Filtration • Chlorination • Powdered Activated Carbon (PACT) • Fluidized Carbon Bed	Yes (ancillary) Yes (ancillary) Yes No No Yes Yes (ancillary) Yes (ancillary) No No
Groundwater Disposal/Discharge	Off-site On-site	• Local POTW • Surface Water • Groundwater • Off-site TSDF	No Yes No No

Colesville Landfill
Screening of Technology Types and Process Options

General Response Action	Technology Type	Process Option	Retained as Representative Process Option
Ancillary Process	Regrading	• Not applicable	Yes, with any construction
	Backfilling	• Not applicable	Yes, with any construction
	Surface Water Controls	• Dikes/berms	Yes, with any construction
		• Channel, ditches, trenches	Yes, with any construction
		• Terraces and benches	Yes, with any construction
	Air Pollution Controls	• Catalytic incinerator	Yes, with air stripping
		• Catalytic oxidizer	Yes, with air stripping
		• Carbon adsorption	Yes, with air stripping
		• Wet precipitator	Yes, with incineration processes
		• Ionized wet scrubber	Yes, with incineration processes
		• Venturi/packed tower system	Yes, with incineration processes
		• Spray dryer/baghouse system	Yes, with incineration processes
		• Thermal de-NOX (ammonia injection)	Yes, with incineration processes
		• Dust suppression	Yes, with any construction operations
	Miscellaneous Materials Handling	• Conveyors	Yes, with on-site treatment alternatives
		• Shredders	Yes, with excavation alternatives
		• Crushers	Yes, with excavation alternatives
		• Mills	Yes, with excavation alternatives
		• Screens	Yes, with excavation alternatives

Remedial alternatives

1. No action
   - monitoring
2. No further action
   - monitoring
   - individual drinking-water supply
3. Limited action
   - 3a. Land purchase
   - 3b. New public water supply

Remedial alternatives

4. Source containment
   - 4a. Landfill cap, natural attenuation
   - 4b. Landfill cap, ground-water pump and treat
   - 4c. Landfill cap, expanded pump and treat
   - 4d. Landfill cap, downgradient cutoff wall
   - 4e. Landfill cap, slurry wall

   Sub-options for each:

   1. upgraded monitoring/maintenance of private systems
   2. new community water-supply system

Remedial alternatives

5. Source removal/treatment/disposal
   - 5a. Landfill excavation, solidification/stabilization
   - 5b. Landfill excavation, on-site vitrification
   - 5c. Landfill excavation, off-site treatment/disposal
   - 5d. Landfill excavation, on-site treatment/disposal

Remedial alternatives

1. No action

   Required alternative

2. No further action

   Not effective on all counts

3. Limited action

   3a. Land purchase

   3b. New public water supply

   Carried through as health-protective baseline

Screening of alternatives

4. Source containment

   4a. Landfill cap, natural attenuation

   Not effective for ground-water baseflow

   4b. Landfill cap, ground-water pump and treat

   4c. Landfill cap, expanded pump and treat

   4d. Landfill cap, downgradient cutoff wall

   4e. Landfill cap, slurry wall

   No more effective than 4c but much more expensive

Screening of alternatives

5. Source removal/treatment/disposal

   ~~5a~~. Landfill excavation, solidification/stabilization

   ~~5b~~. Landfill excavation, on-site vitrification

   ~~5c~~. Landfill excavation, off-site treatment/disposal

   ~~5d~~. Landfill excavation, on-site treatment/disposal

   Implementability for all four alternatives is questionable

18 alternatives → 9 alternatives

Evaluation of alternatives

- Detailed analysis of alternatives
  - Conceptual design
  - Comparison with nine Superfund criteria
- Comparative analysis
  - Ranking of alternatives with respect to nine criteria

Comparative analysis

		Short-Term Effectiveness	Long-Term Effectiveness	Reduction of Toxicity, Mobility, Volume	Implementability	Compliance with ARARs	Protection of Health and Environment	Total Score	Present-Value Cost ($ million)
1	No Action	4	4	2	11	5	8	34	0.1
3a	Home Purchase	10	9	2	14	5	8	48	0.7
3b	New Water Supply	10	9	2	14	5	8	48	0.6
4b1	Cap, Pump & Treat, Upgraded Supply	7	11	16	14	10	20	78	5.6
4b2	Cap, Pump & Treat, New Supply	7	11	16	14	10	20	78	5.6
4c1	Cap, Expanded P&T, Upgraded Supply	7	11	16	14	10	20	78	5.0
4c2	Cap, Expanded P&T, New Supply	7	11	16	14	10	20	78	5.1
4d1	Cap, Slurry Wall, Upgraded Supply	7	11	16	14	10	20	78	11.0
4d2	Cap, Slurry Wall, New Supply	7	11	16	14	10	20	78	11.2
	Maximum score	**10**	**15**	**15**	**15**	**10**	**20**	**85**	

Note: NYSDEC no longer uses this specific methodology!

Example of detailed analysis

Short-Term Effectiveness (Relative Weight = 10)

Analysis Factor	Basis for Evaluation During Detailed Analysis	Score
1. Protection of Community During Remedial Actions	Are there significant short-term risks to the community that must be addressed? **(If answer is no, go to Factor 2.)**	Yes — 0 No — 4
	Can the risk be easily controlled?	Yes — 1 No — 0
	Does the mitigative effort to control risk impact the community life-style?	Yes — 0 No — 2
Subtotal (maximum = 4)		
2. Environmental Impacts	Are there significant short-term risks to the environment that must be addressed? **(If answer is no, go to Factor 3.)**	Yes — 0 No — 4
	Are the available mitigative measures reliable to minimize potential impacts?	Yes — 3 No — 0
Subtotal (maximum = 4)		
3. Time to Implement the Remedy	What is the required time to implement the remedy?	≤ 2yr. — 1 > 2yr. — 0
	Required duration of the mitigative effort to control short-term risk.	≤ 2yr. — 1 > 2yr. — 0
Subtotal (maximum = 2)		
TOTAL (maximum = 10)		

Selected remedy

		Short-Term Effectiveness	Long-Term Effectiveness	Reduction of Toxicity, Mobility, Volume	Implementability	Compliance with ARARs	Protection of Health and Environment	Total Score	Present-Value Cost ($ million)
1	No Action	4	4	2	11	5	8	34	0.1
3a	Home Purchase	10	9	2	14	5	8	48	0.7
3b	New Water Supply	10	9	2	14	5	8	48	0.6
4b1	Cap, Pump & Treat, Upgraded Supply	7	11	16	14	10	20	78	5.6
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4c2	Cap, Expanded P&T, New Supply	7	11	16	14	10	20	78	5.1
4d1	Cap, Slurry Wall, Upgraded Supply	7	11	16	14	10	20	78	11.0
4d2	Cap, Slurry Wall, New Supply	7	11	16	14	10	20	78	11.2

Post-ROD Timeline

Oct. 1995 – Draft Focused Feasibility Study (FFS) report on new ground-water remedy

Demonstrated alternative technology was feasible, selected remedy would take much longer than predicted

Oct. 1996 – Revised FFS report

1996-99 – Additional field sampling and pilot studies

Jan. 2000 – 95% Design Report for ground-water remedial action

What's wrong with this process?

1983 – Ground-water contamination discovered in private wells

1994-95 – Landfill capped for $3 million

2004 – ground-water remedial design under review

"Fixing" Superfund is a continuing issue

1/5/2001 – GAF declared bankrupcy

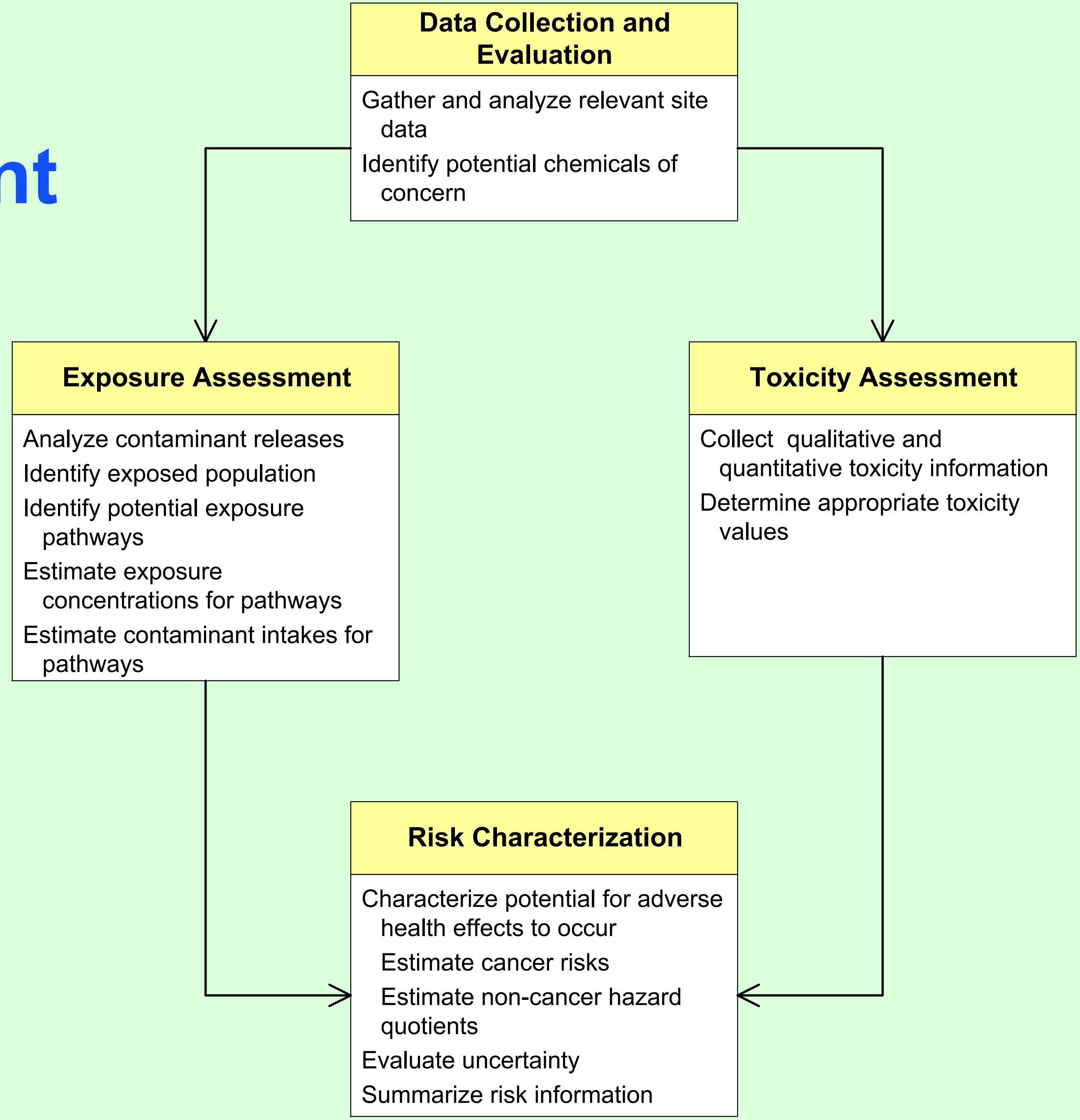
How clean is clean?

Need to determine **clean-up levels**
to protect human health and the environment

Possible clean-up levels:

- Analytical detection limits
- Background levels
- Regulatory standards or criteria
- Site-specific risk assessment
- Protection of ground-water quality
- Mass removal

Site-specific risk assessment



EPA 1989, *Risk Assessment Guidance for Superfund: Volume I – Human Health Evaluation Manual (Part A, Baseline Risk Assessment),* December 1989, Report No. EPA/540/1-89/002.

Alternative terminology for risk assessment

RAGs terminology	Alternative terminology
1. Data collection and identification	1. Hazard identification
2. Exposure assessment	2. Exposure assessment
3. Toxicity assessment	3. Dose-response assessment
4. Risk characterization	4. Risk characterization

Hazard identification

Identification of health effects by specific toxic chemicals:

- Human exposure data
  - Epidemiological studies
  - Workplace studies
- Animal studies
  - Laboratory animals used as models of human response

Hazard types:

- Carcinogenic
- Noncarcinogenic

Hazard identification

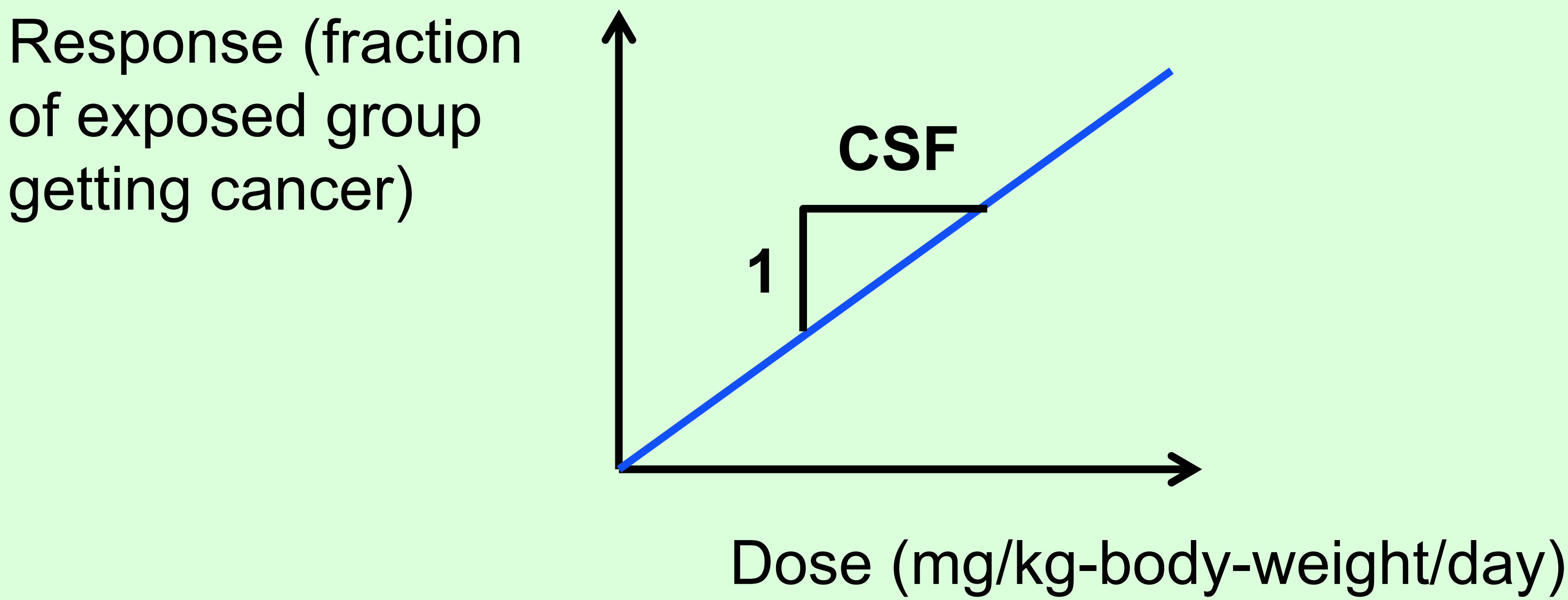
Carcinogenic effects:

- Class A – *Known* human carcinogens
- Class B – *Probable* human carcinogens based on human data and laboratory animal studies
- Class C – *Possible* human carcinogens based on laboratory animal studies
- Class D – Not classifiable
- Class E – Noncarcinogenic

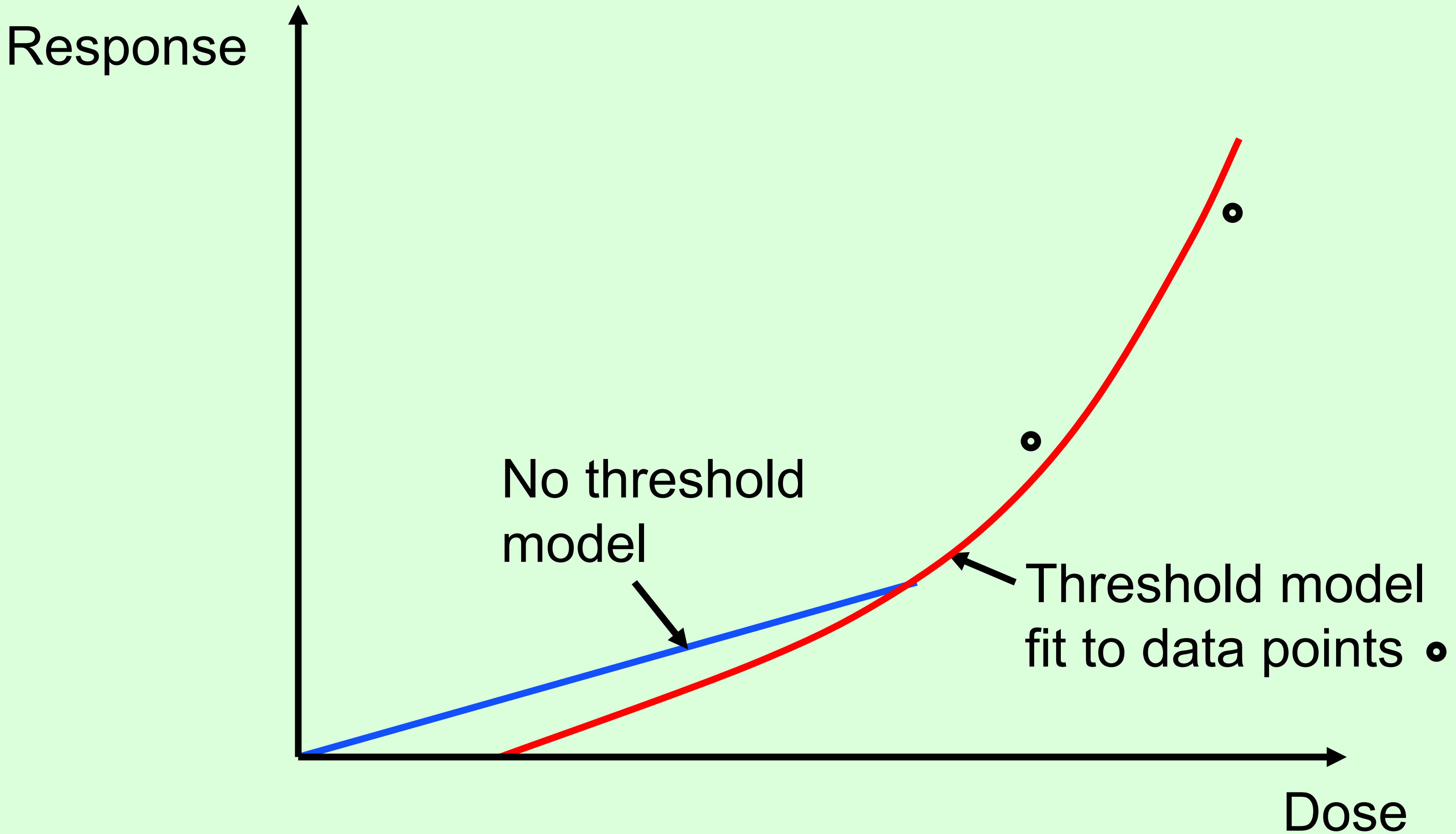
Dose-response assessment

Carcinogenic effects:

Cancer slope factor (CSF) – potential to cause cancer when inhaled, ingested, or adsorbed [units of $(mg/kg/day)^{-1}$]



Dose-response assessment



Dose-response assessment

Carcinogenic effects

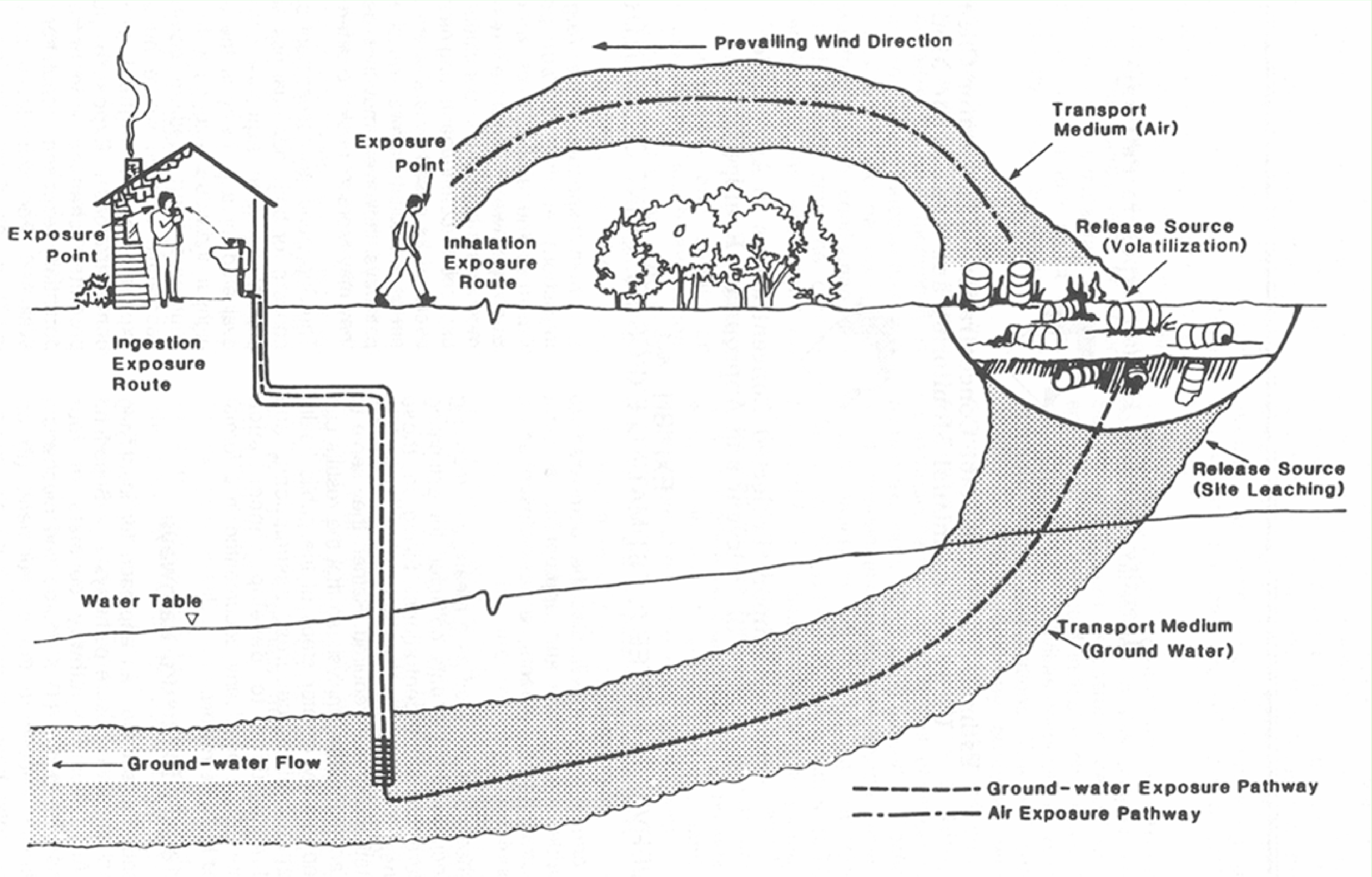
- Quantified via cancer slope factors – CSFs

Noncarcinogenic effects

- Quantified via reference doses – RfDs
- Represents No Observed Adverse Effect Level (NOAEL)

Data available from EPA Integrated Risk Information System (www.epa.gov/IRIS)

Exposure assessment



Source: U.S. EPA, 1989. Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A), Interim Final. Report Number EPA/540/1-89/002. Office of Emergency and Remedial Response, U.S. Environmental Protection Agency, Washington, D.C. December 1989. (http://www.epa.gov/superfund/programs/risk/ragsa/index.htm)

Exposure assessment

- Ingestion
  - Eating contaminated soil
  - Drinking contaminated water
- Inhalation
  - Breathing contaminated air
  - Breathing contaminated dust
  - Showering in contaminated water
- Adsorption
  - Skin contact with contaminated soil
  - Showering in contaminated water

Exposure assessment

Intake [mg/kg-body-weight/day]:

$$I = \frac{C \cdot CR \cdot EF \cdot ED}{W \cdot AT}$$

C = chemical concentration [mg/kg or mg/L]

CR = contact rate [kg/day or L/day]

EF = exposure frequency [days/year]

ED = exposure duration [years in lifetime]

W = average body weight [kg]

AT = averaging time [days]

Risk characterization

Carcinogens:

Risk level = I·CSF

I = intake [mg/kg/day]

CSF = cancer slope factor [(mg/kg/day)$^{-1}$]

Noncarcinogens:

HQ = Hazard quotient for individual chemical

HI = Hazard index summed over all chemicals

$$HQ = \frac{I}{RfD}$$

RfD = Reference dose

$$HI = \sum HQ$$

Example

Example: Drinking-water consumption of benzene

C = concentration = 0.005 mg/L

CR = contact rate = 2 liters/day

EF = exposure frequency = 350 days/year

ED = exposure duration = 70 years

W = average body weight = 70 kg

AT = averaging time 70 years

$$I = \frac{C \cdot CR \cdot EF \cdot ED}{W \cdot AT} = \frac{0.005\ \text{mg/L} \cdot 2\ \text{L/day} \cdot 350\ \text{day/yr} \cdot 70\ \text{yr}}{70\ \text{kg} \cdot 70\ \text{yr} \cdot 365\ \text{day/yr}} = 0.0001 \quad \text{mg/kg} \cdot \text{day}$$

Example

Risk level = CSF·I

- CSF = 1.5×10^{-2} to 5.5×10^{-2} per (mg/kg)/day
  - from IRIS web site
- Risk level = 2×10^{-6} to 8×10^{-6}

Put these causes of mortality in order of risk and estimate the risk

Heart disease
Struck by lightning
Murder
Drown
Cancer
Plane crash
Earthquake
Automobile accident
Drown in bathtub
Shark attack

Risk levels

Acceptable risk levels for cancer: 10^{-6} to 10^{-4}

Heart disease	1 in 5	2×10^{-1}
Cancer	1 in 7	1.4×10^{-1}
Automobile accident	1 in 100	10^{-2}
Murder	1 in 200	5×10^{-3}
Drown	1 in 1000	10^{-3}
Drown in bathtub	1 in 10,000	10^{-4}
Struck by lightning	1 in 60,000	1.7×10^{-5}
Plane crash	1 in 100,000	10^{-5}
Earthquake	1 in 1,000,000	10^{-6}
Shark attack	1 in 5,000,000	2×10^{-7}

Calculating clean-up levels

$$I = \frac{C \cdot CR \cdot EF \cdot ED}{W \cdot AT}$$

Target risk level = TR = I·CSF $= \dfrac{C \cdot CR \cdot EF \cdot ED}{W \cdot AT} \cdot CSF$

Solve for clean-up level = C:

$$C = \frac{TR \cdot W \cdot AT}{CSF \cdot CR \cdot EF \cdot ED}$$

Approaches for incorporating risk in cleanup decisions

- Risk-based corrective action
  - Allows site cleanup to appropriate level for site use
- Screening level concentrations
  - Allow expeditious screening of site risks

Exposure assessment

See American Society for Testing and Materials (ASTM), "Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites," Designation: E 1739 – 95.

RBCA Tiered Approach

1. Site assessment – identify chemicals, receptors
2. Site classification – determine urgency for action
3. Tier 1 evaluation – generic risk-based screening levels (RBSLs)
4. Tier 2 evaluation – site-specific target levels (SSTLs)
5. Tier 3 evaluation – site-specific target levels using more site characterization, complex models, etc.
6. Remedial action

RBCA scenarios

1. Inhalation of vapors
2. Ingestion of ground water
3. Inhalation of outdoor vapors from ground water
4. Inhalation of indoor vapors from ground water
5. Ingestion of surficial soil, inhalation of vapors and particulates from surficial soils, and dermal absorption of from surficial soil contact
6. Inhalation of outdoor vapors from subsurface soils
7. Inhalation of indoor vapors from subsurface soils
8. Ingestion of ground water contaminated by leaching from subsurface soils

Exposure assessment

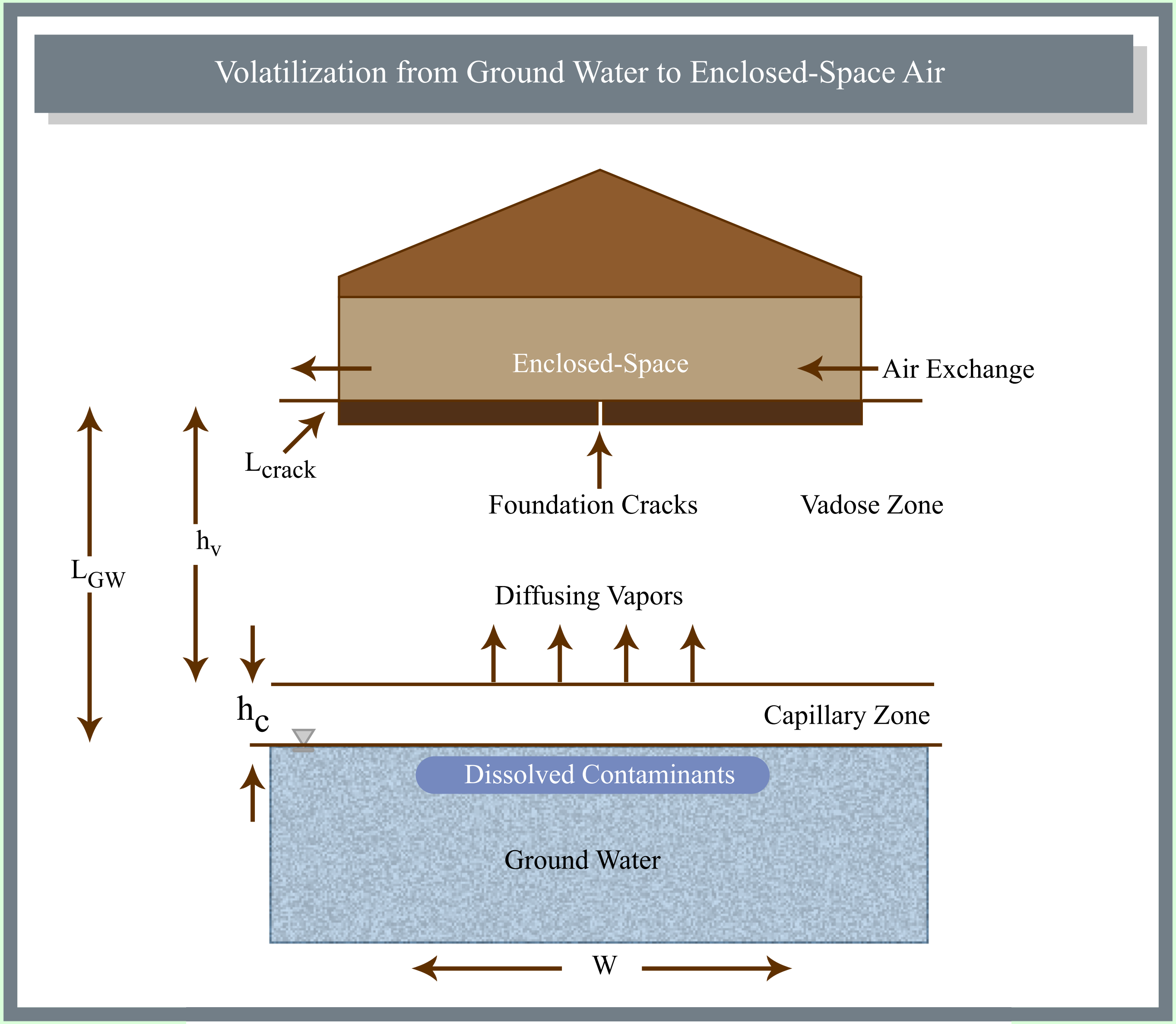


Image adapted from: American Society for Testing and and Materials (ASTM), "Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites," Designation: E 1739 –95.

RBCA Tier 1 RBSLs

Example Tier 1 Risk-Based Screening Level (RBSL) Look-Up Table

Exposure Pathway	Receptor Scenario	Target Level	Benzene	Ethylbenzene	Toluene	Xylenes (Mixed)	Napthalenes	Benzo (a)pyrene
Air								
Indoor Air	Residential	Cancer Risk = 1E-06	3.92E-01					1.86E-03
Screening		Cancer Risk = 1E-04	3.92E+01					1.86E-01
Levels for		Chronic HQ = 1		1.39E+03	5.56E+02	9.73E+03	1.95E+01	
Inhalation	Commercial/ Industrial	Cancer Risk = 1E-06	4.93E-01					2.35E-03
Exposure,		Cancer Risk = 1E-04	4.93E+01					2.35E-01
μ/m^3		Chronic HQ = 1		1.46E+03	5.84E+02	1.02E+04	2.04E+01	
Outdoor Air	Residential	Cancer Risk = 1E-06	2.94E-01					1.40E-03
Screening		Cancer Risk = 1E-04	2.94E+01					1.40E-01
Levels for		Chronic HQ = 1		1.04E+03	4.17E+02	7.30E+03	1.46E+01	
Inhalation	Commercial/ Industrial	Cancer Risk = 1E-06	4.93E-01					2.35E-03
Exposure,		Cancer Risk = 1E-04	4.93E+01					2.35E-01
μg/m^3		Chronic HQ = 1		1.46E+03	5.84E+02	1.02E+04	2.04E+01	
OSHA TWA PEL, μg/m^3			3.20E+03	4.35E+05	7.53E+05	4.35E+06	5.00E+04	2.00E+02
Mean Odor Detection, Threshold, μg/m^3			1.95E+05		6.00E+03	8.70E+04	2.00E+02	
National Indoor Background Concentration Range, μg/m^3			3.25E+00 to 2.15E+01	2.20E+00 to 9.70E+00	9.60E-01 to 2.91E+01	4.85E+00 to 4.76E+01		

Note---- This table is presented here only as an example set of Tier 1 RBSLs. It is not a list of proposed standards. The user should review all assumptions prior to using any values.

Image adapted from: American Society for Testing and Materials (ASTM), “Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites,” Designation: E 1739 –95.

RBCA RBSL and SSTL equations

Equations Used to Develop Example Tier 1 Risk-Based Screening Level (RBSLs) Appearing in "Look-Up" Table - Carcinogenic Effects

Medium	Exposure Route	Risk-Based Screening Level (RBSL)
Air	Inhalation	$RBSL_{air}\left[\frac{\mu g}{m^3\text{-}air}\right] = \frac{TR \times BW \times AT_c \times 365 \frac{days}{years} \times 10^3 \frac{\mu g}{mg}}{SF_i \times IR_{air} \times EF \times ED}$
Ground Water	Ingestion (Potable Ground Water Supply only)	$RBSL_w\left[\frac{mg}{L\text{-}H_2O}\right] = \frac{TR \times BW \times AT_c \times 365 \frac{days}{years}}{SF_o \times IR_w \times EF \times ED}$
Ground Water	Enclosed-Space (Indoor) Vapor Inhalation	$RBSL_w\left[\frac{mg}{L\text{-}H_2O}\right] = \frac{RBSL_{air}\left[\frac{\mu g}{m^3\text{-}air}\right]}{VF_{wesp}} \times 10^{-3} \frac{mg}{\mu g}$
Ground Water	Ambient (Outdoor) Vapor Inhalation	$RBSL_w\left[\frac{mg}{L\text{-}H_2O}\right] = \frac{RBSL_{air}\left[\frac{\mu g}{m^3\text{-}air}\right]}{VF_{wamb}} \times 10^{-3} \frac{mg}{\mu g}$

Image adapted from: American Society for Testing and Materials (ASTM), “Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites,” Designation: E 1739 –95.

RBCA RBSL and SSTL equations

Volatilization Factors (VF_i), Leaching Factor (LF_{sw}), and Effective Diffusion Coefficients (Di^{eff})

Symbol	Cross-Media Route (or Definition)	Equation
VF_{wesp}	Ground Water → Enclosed-Space Vapors	$VF_{wesp}\left[\frac{(mg/m^3\text{-}air)}{(mg/L\text{-}H_2O)}\right] = \frac{H\left[\frac{D_{ws}^{eff}/L_{GW}}{ER\ L_B}\right]}{1+\left[\frac{D_{ws}^{eff}/L_{GW}}{ER\ L_B}\right]+\left[\frac{D_{ws}^{eff}/L_{GW}}{(D_{crack}^{eff}/L_{crack})\eta}\right]} \times 10^3 \frac{L}{m^3}$ A
VF_{wamb}	Ground Water → Ambient (Outdoor) Vapors	$VF_{wamb}\left[\frac{(mg/m^3\text{-}air)}{(mg/L\text{-}H_2O)}\right] = \frac{H}{1+\left[\frac{U_{air}\delta_{air}L_{GW}}{WD_{ws}^{eff}}\right]} \times 10^3 \frac{L}{m^3}$ B
VF_{ss}	Surficial Soils → Ambient Air (Vapors)	$VF_{ss}\left[\frac{(mg/m^3\text{-}air)}{(mg/kg\text{-}soil)}\right] = \frac{2W\rho_s}{U_{air}\delta_{air}}\sqrt{\frac{D_s^{eff}H}{\pi\left[\theta_{ws}+k_s\rho_s+H\theta_{as}\right]\tau}} \times 10^3 \frac{cm^3\text{-}kg}{m^3\text{-}g}$ C or, $VF_{ss}\left[\frac{(mg/m^3\text{-}air)}{(mg/kg\text{-}soil)}\right] = \frac{W\rho_s d}{U_{air}\delta_{air}\tau} \times 10^3 \frac{cm^3\text{-}kg}{m^3\text{-}g}$; whichever is less D
VF_p	Surficial Soils → Ambient Air (Particulates)	$VF_p\left[\frac{(mg/m^3\text{-}air)}{(mg/kg\text{-}soil)}\right] = \frac{P_a W}{U_{air}\delta_{air}} \times 10^3 \frac{cm^3\text{-}kg}{m^3\text{-}g}$ E
VF_{samb}	Subsurface Soils → Ambient Air	$VF_{samb}\left[\frac{(mg/m^3\text{-}air)}{(mg/kg\text{-}soil)}\right] = \frac{H\rho_s}{\left[\theta_{ws}+k_s\rho_s+H\theta_{as}\right]\left(1+\frac{U_{air}\delta_{air}L_s}{D_s^{eff}W}\right)} \times 10^3 \frac{cm^3\text{-}kg}{m^3\text{-}g}$ F

Image adapted from: American Society for Testing and Materials (ASTM), “Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites,” Designation: E 1739 –95.

Soil Screening Guidance

EPA procedure to evaluate soil contamination levels

If soils test below screening levels, no further action needed under CERCLA

Inverts intake equation to determine acceptable concentrations

EPA web site:
http://www.epa.gov/superfund/resources/soil/introtbd.htm

Screening Level Equation for Ingestion of Noncarcinogenic Contaminants in Residential Soil

$$\text{Screening Level (mg/kg)} = \frac{THQ \times BW \times AT \times 365\ d/yr}{1/RfD_o \times 10^{-6}\ kg/mg \times EF \times ED \times IR}$$

Parameter/Definition (units)	Default
THQ/target hazard quotient (unitless)	1
BW/body weight (kg)	15
AT/averaging time (yr)	6[a]
RfD_o/oral reference dose (mg/kg-d)	Chemical-specific
EF/exposure frequency (d/yr)	350
ED/exposure duration (yr)	6
IR/soil ingestion rate (mg/d)	200

[a]For noncarcinogens, averaging time equals to exposure duration.

Screening Level Equation for Ingestion of Carcinogenic Contaminants in Residential Soil

$$\text{Screening Level (mg/kg)} = \frac{TR \times AT \times 365 \text{ d/yr}}{SF_o \times 10^{-6} \text{ kg/mg} \times EF \times IF_{soil/adj}}$$

Parameter/Definition (units)	Default
TR/target cancer risk (unitless)	10^{-6}
AT/averaging time (yr)	70
SF_o/oral slope factor $(mg/kg\text{-}d)^{-1}$	Chemical-specific
EF/exposure frequency (d/yr)	350
$IF_{soil/adj}$/age-adjusted soil ingestion factor (mg-yr/kg-d)	114

Screening Level Equation for Inhalation of Carcinogenic Fugitive Dusts from Residential Soil	Derivation of the Particulate Emission Factor
$$\text{Screening Level (mg/kg)} = \frac{TR \times AT \times 365\ \text{d/yr}}{URF \times 1{,}000\ \mu g/mg \times EF \times ED \times \frac{1}{PEF}}$$	$$PEF\ (m^3/kg) = Q/C \times \frac{3{,}600\ s/h}{0.036 \times (1-V) \times (U_m/U_t)^3 \times F(x)}$$

Parameter/Definition (units)	Default
TR/target cancer risk (unitless)	10^{-6}
AT/averaging time (yr)	70
URF/inhalation unit risk factor ($\mu g/m^3$)$^{-1}$	Chemical-specific
EF/exposure frequency (d/yr)	350
ED/exposure duration (yr)	30
PEF/particulate emission factor (m^3/kg)	**1.32×10^9**

Parameter/Definition (units)	Default
PEF/particulate emission factor (m^3/kg)	1.32×10^9
Q/C/inverse of mean conc. at center of a 0.5-acre-square source (g/m^2 -s per kg/m^3)	**90.80**
V/fraction of vegetative cover (unitless)	**0.5 (50%)**
U_m /mean annual windspeed (m/s)	**4.69**
U_t / equivalent threshold value of windspeed at 7 m (m/s)	**11.32**
F(x)/function dependent on U_m /U_t derived using Cowherd et al. (1985) (unitless)	**0.194**

The emissions part of the PEF equation is based on the "unlimited reservoir" model developed to estimate particulate emissions due to wind erosion (Cowherd et al., 1985).

Screening Level Equation for Inhalation of Carcinogenic Volatile Contaminants in Residential Soil

$$\text{Screening Level (mg/kg)} = \frac{TR \times AT \times 365 \text{ d/yr}}{URF \times 1{,}000\ \mu\text{g/mg} \times EF \times ED \times \frac{1}{VF}}$$

Parameter/Definition (units)	Default
TR/target cancer risk (unitless)	10^{-6}
AT/averaging time (yr)	70
URF/inhalation unit risk factor $(\mu g/m^3)^{-1}$	Chemical-specific
EF/exposure frequency (d/yr)	350
ED/exposure duration (yr)	30
VF/soil-to-air volatilization factor (m^3/kg)	**Chemical-specific**

Derivation of the Volatilization Factor

$$VF\ (m^3/kg) = \frac{Q/C \times (3.14 \times D_A \times T)^{1/2} \times 10^{-4}\ (m^2/cm^2)}{(2 \times \rho_b \times D_A)}$$

where

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

Parameter/Definition (units)	Default
VF/Volatilization Factor (m^3/kg)	— -
D_A/Apparent Diffusivity (cm^2/s)	— -
Q/C/Inverse of the mean conc. at the center of a 0.5-acre-square source (g/m^2-s per kg/m^3)	**68.81**
T/Exposure Interval (s)	9.5×10^8
ρ_b /Dry Soil Bulk Density (g/cm^3)	**1.5**
θ_a /Air-Filled Soil Porosity (L_{air}/L_{soil})	$n - \theta_w$
n/Total Soil Porosity (L_{pore}/L_{soil})	$1-(\rho_b/\rho_s)$
θ_w /Water-Filled Soil Porosity (L_{water}/L_{soil})	**0.15**
ρ_s /Soil Particle Density (g/cm^3)	2.65
D_i /Diffusivity in Air (cm^2/s)	Chemical-Specific
H'/Dimensionless Henry's Law Constant	Chemical-Specific
D_w /Diffusivity in Water (cm^2/s)	Chemical-Specific
K_d /Soil-Water Partition Coefficient (cm^3/g) = $K_{oc}\ f_{oc}$ (organics)	Chemical-Specific
K_{oc} /Soil Organic Carbon Partition Coefficient (cm^3/g)	Chemical-Specific
f_{oc} /Fraction Organic Carbon in Soil (g/g)	**0.006 (0.6%)**