Risk Assessment

(Nazaroff & Alvarez-Cohen, 2001, pages 396-397 and pages 568-573)
(Masters, 1998, Sections 4.1-4.9 pages 117-157)

Our industrial activities and consumer products have led to the creation of more than 70,000 chemicals. The rate at which new chemicals are formulated outpaces the rate at which their safety can be evaluated. So, there is a *hazard*.

Furthermore, there is not always a threshold below which there is no adverse health effect. For example, carcinogens always cause a risk no matter how low the dose is. So, there is a matter of *exposure* level.

$$Risk = f\,(hazard,\ exposure)$$

How bad the substance is (hazard) — How much have we taken in (exposure)

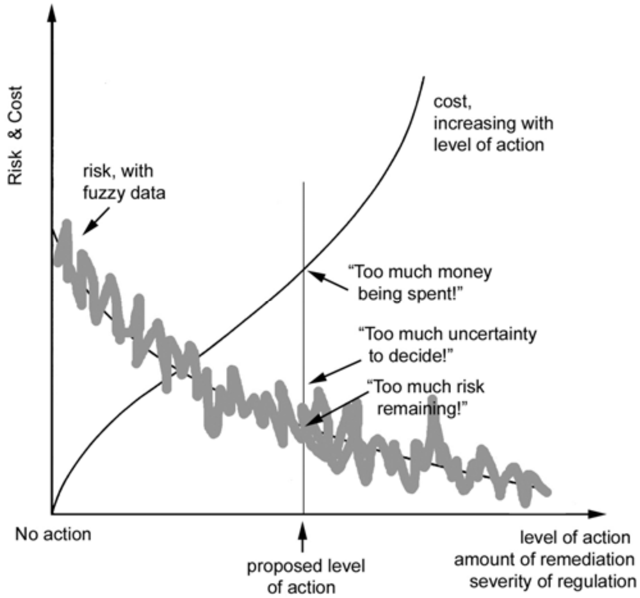
Primary questions: How clean is clean? How safe is safe?

Hazard categories and examples of potential hazard manifestations

Human Toxicity Hazards	Environmental Toxicity Hazards	Physico-chemical Hazards	Regional and Global Hazards
Carcinogenicity	Aquatic toxicity	Explosivity	Acid rain
Neurotoxicity	Avian (bird) toxicity	Corrosion	Ozone depletion
Hepatoxicity	Amphibian toxicity	Oxidation	Climate change
Nephrotoxicity	Mammalian toxicity	Reduction	Extreme weather
Cardiotoxicity		pH (acid or base)	Water scarcity
Pulmonary toxicity		Violent reaction	Security threats
Hematological toxicity			Loss of biodiversity
Endocrine toxicity			Persistence
Immunotoxicity			Bioaccumulation
Reproductive toxicity			
Teratogenicity			
DNA toxicity			
Dermal toxicity			
Ocular toxicity			
Enzyme toxicity			

(Mihelcic & Zimmerman, Table 6.1)

The cost of avoidance or treatment goes up as the risk is being reduced.
There is a need to accept *some* level of risk.



Nobody is ever happy:

- Corporations resist spending money;
- Scientists object to reduction of data;
- Residents complain about remaining risks.

And, then, there is the *perception* element.
What people think is risky or pretty safe is not always correct…

How do you feel about Ebola?
How do you feel about crossing the street in Boston?

TABLE 4.5 Some characteristics that elevate the perception of risk.

Attributes that elevate the perception of risk	Attributes that lower perception
Involuntary	Voluntary
Exotic	Familiar
Uncontrollable	Controllable
Controlled by others	Controlled by self
Dread	Accept
Catastrophic	Chronic
Caused by humans	Natural
Inequitable	Equitable
Permanent effect	Temporary effect
No apparent benefits	Visible benefits
Unknown	Known
Uncertainty	Certainty
Untrusted source	Trusted source

Source: based on Slovic (1987) and Slovic et al. (1980).

(*Source:* Masters, 1998, page 122)

What is the thinking here?

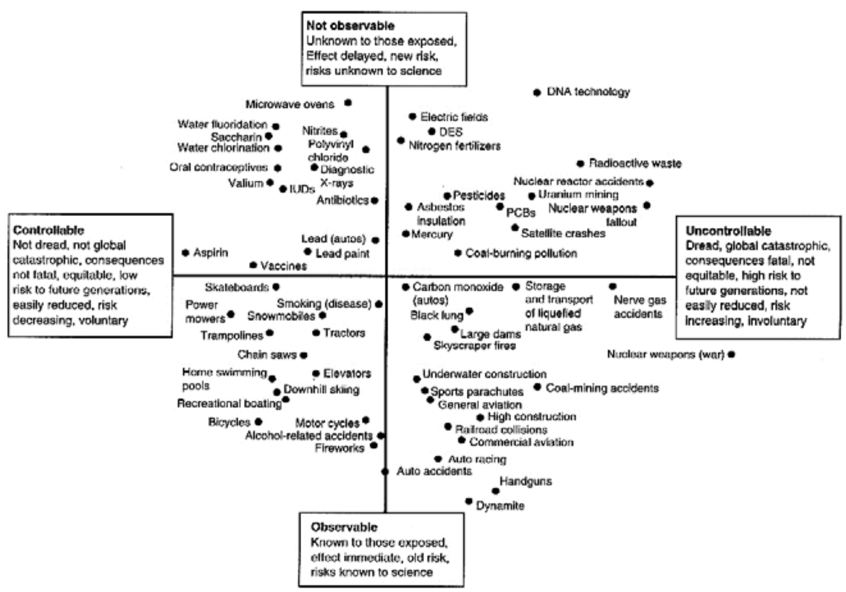


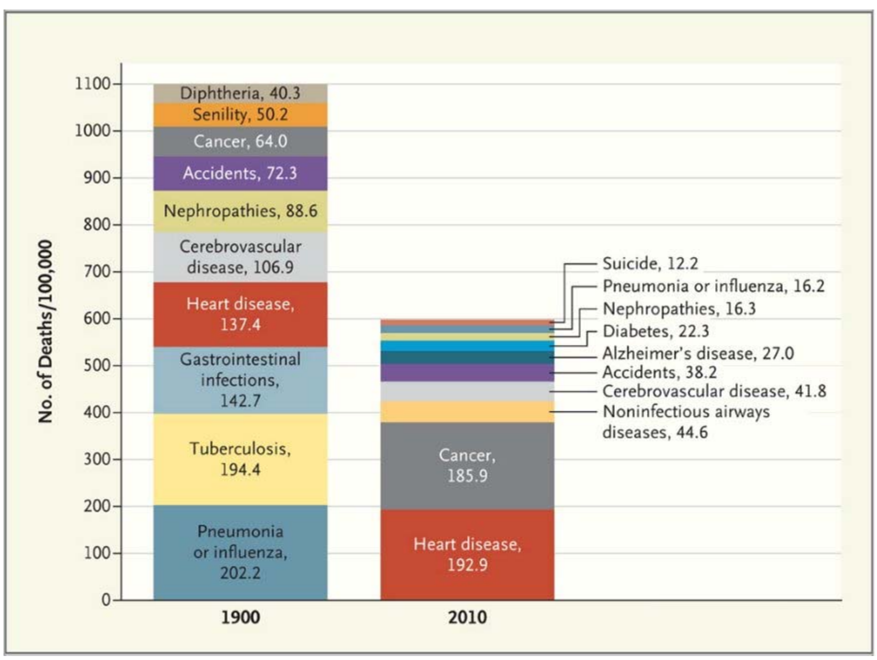
Figure 4.1 The location of risks in "risk space". The axes are the degree to which the risks are controllable and observable. (Reproduced with permission from M. G. Morgan, Risk analysis and management, *Scientific American, 269* (1): 32–41. Copyright 1993 by Scientific American, Inc.)

(Graedel & Allenby, 1995)

Leading causes of death in the United States

Cause	Annual deaths	Risk
1. Heart disease	597,689	24.2%
2. Cancer	574,743	23.3%
3. Chronic low respiratory disease	138,080	5.6%
4. Strokes	129,476	5.2%
5. Accidents	120,859	4.9%
6. Alzheimer's	83,494	3.4%
7. Diabetes	69,071	2.8%
8. Nephritis	50,476	2.0%
9. Influenza & pneumonia	50,097	2.0%
10. Suicide	38,364	1.6%
11. Septicemia	34,812	1.4%
12. Chronic liver cirrhosis	31,903	1.3%
13. Hypertension & related renal disease	26,634	1.1%
14. Parkinson's disease	22,032	0.89%
15. Pneumonitis due to solids and liquids	17,011	0.69%
16. Homicide	16,361	0.66%
All other causes	467,333	18.9%
Total	**2,468,435**	**100%**

(2010 data from http://www.cdc.gov/nchs/data/nvsr/nvsr61/nvsr61_04.pdf)



Annual risks of death associated with certain activities.

Activity/exposure	Annual risk (Deaths per 100,000 persons at risk)
Motorcycling	~~2000~~ 100
Smoking, all causes	300
Smoking (cancer)	120
Hang gliding	80
Coal mining	63
Farming	36
Motor vehicles	~~24~~ 18
Chlorinated drinking water (chloroform)	0.8
4 tbsp peanut butter per day (aflatoxin)	0.8
3 oz charcoal broiled steak per day (PAHs)	0.5
1-in-a-million lifetime risk ← EPA's standard	0.0014

Source: Based on Wilson and Crouch, 1987.

↑ $10^5/10^6$ of 1/70 years

(Revised numbers from Laudan, 1994)

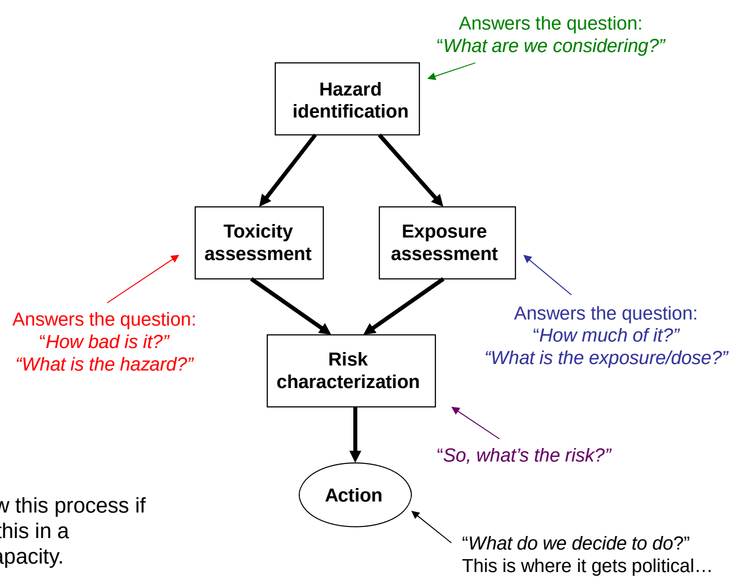
Below are activities that all amount to the same level of risk, namely increasing the mortality risk by one in a million in a lifetime (= one chance of dying in a million, = one death in a population of 1,000,000 people engaging in the same activity)

Activity	**Amount**	**Type of death**
Smoking cigarettes	1.4 cigarettes	Cancer or heart disease
Drinking wine	0.5 liters	Cirrhosis of the liver
Time in a coal mine	1 hour	Black lung disease
Living in New York or Boston	2 days	Air-pollution illness
Riding a bicycle	10 miles	Road accident
Traveling by car	300 miles	Car accident
Traveling by bus or subway	6000 miles	Accident
Traveling by airplane	1,000 miles	Airplane crash
Traveling by airplane	6,000 miles	Cancer by cosmic radiation
Paddling a canoe	6 minutes	Drowning
Living in Denver (as opposed to sea level)	2 summer months	Cancer by cosmic radiation
Living with a cigarette smoker	2 months	Cancer or heart disease
Eating peanut butter	40 tablespoons	Aflatoxin-caused liver cancer
Eating charcoal-broiled steaks	100 steaks	Cancer by benzopyrene
Living within 5 miles of a nuclear reactor	50 years	Accidental radioactive exposure

(*Source*: Masters, Table 4.3, page 121; Mines & Lackey, Table 5.2, pages 100-101)

Quantitative Risk Analysis

(Nazaroff & Alvarez-Cohen, section 8.E.2)



You must follow this process if you are doing this in a professional capacity.

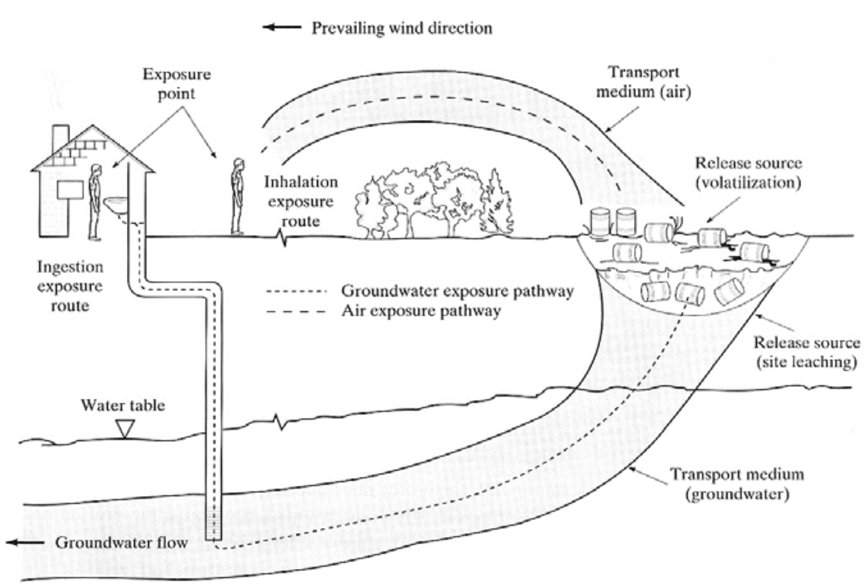


Illustration of exposure pathways. (Source: U.S. EPA, 1986b)

(*Source:* Masters, 1998, page 148)

Table 8.E.3 Typical Pathways for Human Exposure to Environmental Contaminants at Hazardous Waste Sites

Medium	Residential land use	Industrial land use
Groundwater	Ingestion from drinking Inhalation of volatiles Dermal absorption from bathing	Ingestion from drinking Inhalation of volatiles Dermal absorption from direct contact
Surface water	Ingestion from drinking Inhalation of volatiles Dermal absorption from bathing or swimming Ingestion during swimming Ingestion of contaminated fish	Ingestion from drinking Inhalation of volatiles Dermal absorption from direct contact
Soil	Ingestion Inhalation of particles Inhalation of volatiles Exposure to indoor air from soil gas Exposure to groundwater contaminated by soil Ingestion via plant, meat, or dairy products Dermal absorption from gardening	Ingestion Inhalation of particles Inhalation of volatiles Exposure to indoor air from soil gas Exposure to groundwater contaminated by soil Inhalation of particles from trucks and heavy equipment Dermal absorption from direct contact

Source: Derived from USEPA, 1991.

(*Source:* Nazaroff & Alvarez-Cohen, page 570)

'Before I say "Yes" I'd like to carry out a risk assessment'

Dose – Intake Rate
(Nazaroff & Alvarez-Cohen, Page 570)

The *Intake Rate* (in mg of contaminant per kg of body weight and per day) is calculated as follows:

$$I = C \frac{CR \times EF \times ED}{BW \times AT}$$

where

C = average concentration of contaminant at exposure
(in mg/L if in water, or mg/mg if in soil, or mg/m^3 if in air)
CR = contact rate (in L/day, mg/day or m^3/day)
EF = exposure frequency (in days per year)
ED = exposure duration (in years)
BW = body weight (in kg)
AT = period over which exposure is averaged (in days)

The ratio CR / BW is called the dose

The intake rate I is sometimes denoted CDI, which stands for the *Chronic Daily Intake.*

EPA default values for use in exposure assessment calculations, for residents and workers

So-called "Maximally Exposed Individual" (MEI)

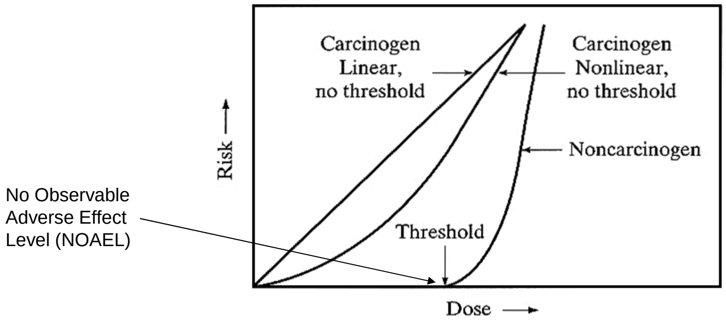
Parameter	Resident	Worker
CR	2 L/day drinking water	1 L/day drinking water
	100 mg/day soil and dust ingestion	50 mg/day soil and dust ingestion
	30 m^3/day air inhalation	30 m^3/day air inhalation
EF	350 days/year	250 days/year
ED	Actual event duration or 30 years if chronic	Actual event duration or 25 years if chronic
BW	70 kg (adult), 15 kg (child)	70 kg
AT	Actual event duration if not carcinogenic or 365 days/year x 70 years if carcinogenic	Actual event duration if not carcinogenic or 365 days/year x 70 years if carcinogenic

For non-carcinogenic substances, take $AT = ED$.
For carcinogenic substances, take AT = 365 days/year x 70 years.

(*Source:* USEPA, 1989; Nazaroff & Alvarez-Cohen, page 571)

Noncarcinogenic substances are characterized by a threshold below which the body is able to cope with or recover from the exposure.
A brief or low exposure leaves no consequence until the next exposure.

Carcinogenic substances are different as they have no such threshold.
All repeated exposures to a carcinogenic substance add up, and the risk is never zero.
At low doses, the risk is proportional to the exposure.



Dose-response curves for carcinogens are assumed to have no threshold; that is, any exposure produces some chance of causing cancer.

(*Source:* Masters, 1998, Figure 4.8 page 137)

Watch out! Do not jump to conclusions if considering the lethal dose.

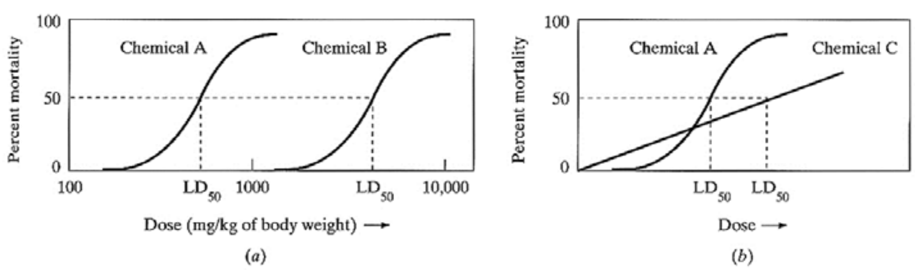


FIGURE 4.4 Dose-response mortality curves for acute toxicity: (a) Chemical A is always more toxic than B; (b) but Chemical A is less toxic than C at low doses even though it has a lower LD_{50}.

LD_{50} is the lethal dose that kills 50% of the population.

(*Source:* Masters, 1998, page 127)

Risk characterization

(Nazaroff & Alvarez-Cohen, page 572)

For non-carcinogenic substances, the risk is determined as the *hazard quotient* HQ:

$$HQ = \frac{I_{\text{noncarcinogenic}}}{RfD}$$

where RfD is the *Reference Dose Factor*. The RfD is the ratio of the No-Observable Averse Effect Level (NOAEL) over the Uncertainty Factor (UF): $RfD = NOAEL / UF$. RfD values are found in prepared tables.

HQ is a dimensionless quantity, and the RfD values that go in its denominator are such that the critical value for HQ is unity:

$$HQ < 1 \quad \Rightarrow \quad \text{safe}$$
$$HQ > 1 \quad \Rightarrow \quad \text{unsafe}$$

When several substances are simultaneously present, simply add the HQ's.

Estimated Reference Dose Factors (RfD) and Slope Factors (SF)

Substance	**Oral RfD** mg/(kg.day)	**Oral SF** [mg/ (kg.day)]$^{-1}$	**Inhalation SF** [mg/ (kg.day)]$^{-1}$
Arsenic	3.0×10^{-4}	1.5	50
Benzene	4.0×10^{-3}	1.5×10^{-2}	2.9×10^{-2}
Benzo(*a*)pyrene	(no data)	7.3	6.1
Cadmium	5.0×10^{-4}	(no data)	6.1
Chlordane	5.0×10^{-4}	0.35	0.35
Chloroform	0.010	6.1×10^{-3}	8.1×10^{-2}
Chromium VI	0.003	(no data)	41
1,1-Dichloroethylene	0.05	0.58	1.16
Methyl mercury	1.0×10^{-4}	(no data)	(no data)
Naphthalene	0.02	(no data)	(no data)
PCBs	(no data)	7.7	(no data)
Dioxin	(no data)	$1.5 \times 10^{+5}$	$1.5 \times 10^{+5}$
TCE	5×10^{-4}	0.046	0.002
Toluene	0.08	(no data)	(no data)
Vinyl chloride (VC)	0.003	1.4	0.295

(Nazaroff & Alvarez-Cohen, Table 8.E.5 page 572)

For additional values, consult: http://cfpub.epa.gov/ncea/iris/compare.cfm

Example of risk associated with a non-carcinogenic substance

(Nazaroff & Alvarez-Cohen, Example 8.E.2 on pages 573-574)

When chlorine is used for disinfection of drinking water, chloroform can be produced by the reaction of chlorine with residual organics in the water.
Estimate the ingestion intake rate for non-carcinogenic effects on an adult resident in a home receiving tap water with an average chloroform concentration of 65 μg/L. What is the risk?

SOLUTION:

To calculate the ingestion intake for non-carcinogenic effects, we calculate the intake rate I:

$$I = C\,\frac{CR \times EF \times ED}{BW \times AT} = (0.065\ \text{mg/L})\,\frac{(2\text{L/d})(350\ \text{d/year})(30\ \text{years})}{(70\ \text{kg})(365\ \text{d/year} \times 30\ \text{years})}$$

$$= 1.8 \times 10^{-3}\ \text{mg/(kg} \cdot \text{d)}$$

To assess the risk, we then form the hazard quotient HQ:

$$HQ = \frac{I}{RfD} = \frac{1.8 \times 10^{-3}\ \text{mg/(kg} \cdot \text{d)}}{0.010\ \text{mg/(kg} \cdot \text{d)}}$$

$$= 0.18 \quad < 1$$

This ratio is less than unity,
and we conclude that this level of chloroform constitutes an acceptable risk.

Carcinogenic substances

(Nazaroff & Alvarez-Cohen, page 573)

For carcinogenic substances, there is no threshold and the effect of episodic doses accumulate. There is no zero risk if there is exposure at all.

The key parameter here is the *Slope Factor* (SF) of the dose-response curve.

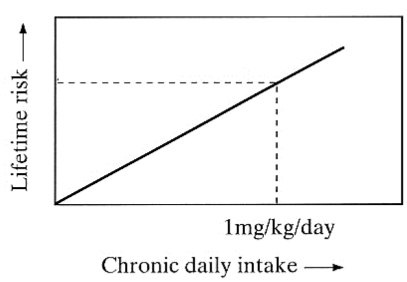


FIGURE 4.10 The potency factor is the slope of the dose-response curve. It can also be thought of as the risk that corresponds to a chronic daily intake of 1 mg/kg-day.

(*Source:* Masters, 1998, page 140)

The risk is then evaluated as the *individual excess lifetime cancer risk* ($IELCR$):

$$IELCR = I_{\text{carcinogenic}} \times SF$$

Acceptable threshold is 10^{-6} (= 1 in a million).

Example of risk associated with a carcinogenic substance

(Mihelcic & Zimmerman, Example 6.7 on page 244)

Assume that the chemical benzene, a known carcinogen, is found in air at a constant concentration of 1 μg/m^3.
Calculate the risk for exposure to this benzene for an average adult who inhales 20 m^3/day with 50% absorption for a lifetime.
Benzene's slope factor is SF = 0.015 (mg/kg.day)$^{-1}$ [*Note*: This is the inhalation value, not the oral intake value].

SOLUTION:

$$I = (0.50)(1\,\mu g / m^3)(1\,mg / 1000\,\mu g)\frac{(20\,m^3 / day)(350\,day / yr)(70\,yrs)}{(70\,kg)(365\,day / yr)(70\,yrs)}$$

$$= 1.37 \times 10^{-4}\ mg / kg \cdot day$$

The risk is

$$\begin{aligned} Risk &= I \times SF \\ &= (1.37 \times 10^{-4}\ \text{mg/kg.day})(0.015\ \text{kg.day/mg}) \\ &= 2.05 \times 10^{-6} \end{aligned}$$

Because it exceeds 10^{-6}, this risk is unacceptable.