

# **Environmental Risk Assessment (ERA)**

# Environmental Risk Assessment (ERA)

- Environmental Risk Assessment is a process for estimating the likelihood or probability of an adverse outcome or event due to pressures or changes in environmental conditions resulting from human activities.

# Risk Assessment and management

- Risk assessment is gathering of data that are used to relate response to dose
- Such dose-response data can then be combined with estimates of likely human exposure to produce overall assessments of risk
- Risk management is the process of deciding what to do. It is the decision making, under extreme uncertainty, about how to allocate national resources to protect public health and the environment
- Difficult decision making in risk management:
  - Is a one-in-a-million lifetime risk of getting cancer acceptable?
  - how do we go for it?
  - Zero risk achievement would cost infinite amount of money

# Perspectives on Risks

**Leading Causes of Death in the United States, 1992**

Cause	Annual Deaths (thousands)	Percent
Cardiovascular (heart) disease	720	33
Cancer (malignant neoplasms)	521	24
Cerebrovascular diseases (strokes)	144	7
Pulmonary diseases (bronchitis, emphysema, asthma)	91	4
Pneumonia and influenza	76	3
Diabetes mellitus	50	2
Nonmotor vehicle accidents	48	2
Motor vehicle accidents	42	2
HIV/AIDS	34	1.6
Suicides	30	1.4
Homicides	27	1.2
All other causes	394	18
Total annual deaths (rounded)	2,177	100

Source: Kolluru et al., 1996.

### **Annual Risks of Death Associated with Certain Activities**

Activity/Exposure	Annual Risk (Deaths per 100,000 Persons)
Motorcycling	2,000
Smoking, all causes	300
Smoking (cancer)	120
Hang gliding	80
Coal mining	63
Farming	36
Motor vehicles	24
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

TABLE 7.3

**Activities That Increase Mortality Risk by One in a Million**

Activity	Type of Risk
Smoking 1.4 cigarettes	Cancer, heart disease
Drinking 1/2 liter of wine	Cirrhosis of the liver
Spending 1 hour in a coal mine	Black lung disease
Living 2 days in New York or Boston	Air pollution
Traveling 300 miles by car	Accident
Flying 1,000 miles by jet	Accident
Flying 6,000 miles by jet	Cancer by cosmic radiation
Traveling 10 miles by bicycle	Accident
Traveling 6 minutes by canoe	Accident
Living 2 summer months in Denver (vs. sea level)	Cancer by cosmic radiation
Living 2 months with a cigarette smoker	Cancer, heart disease
Eating 40 tablespoons of peanut butter	Liver cancer caused by aflatoxin
Eating 100 charcoal-broiled steaks	Cancer from benzopyrene
Living 50 years within 5 miles of a nuclear reactor	Accident releasing radiation

Source: Wilson, 1979.

**Cigarette Smoking** - In the US, 627 billion cigarettes were made in 1975 which is equivalent to 3,000 per person (including children).

It is estimated that in the US, 15% of all Americans (30% of all smokers) die from lung cancer or heart diseases due to smoking.

Average life time risk = 0.15

Annual risk =  $0.15/70 = 0.002$  (life expectancy in U.S. = 70 years)

Risk per cigarette =  $0.02/3000 = 0.7 \times 10^{-6}$

Increased mortality risk per million = 1.4 cigarettes

TABLE III

**Estimated Expenditures per Life-Year Saved for Selected Programs**

Program	1990 U.S.\$
Childhood immunizations	Direct savings
Eliminating lead in gasoline	Direct savings
Safety rules at underground construction sites	52,000
Hemodialysis at a dialysis center	56,000
Coronary artery bypass surgery	68,000
Front seat air bags in new cars	109,000
Dioxin effluent controls at paper mills	5,570,000

*Source:* Kolluru et al., 1996, based on data from the Harvard School of Public Health.

# Perception of Risk

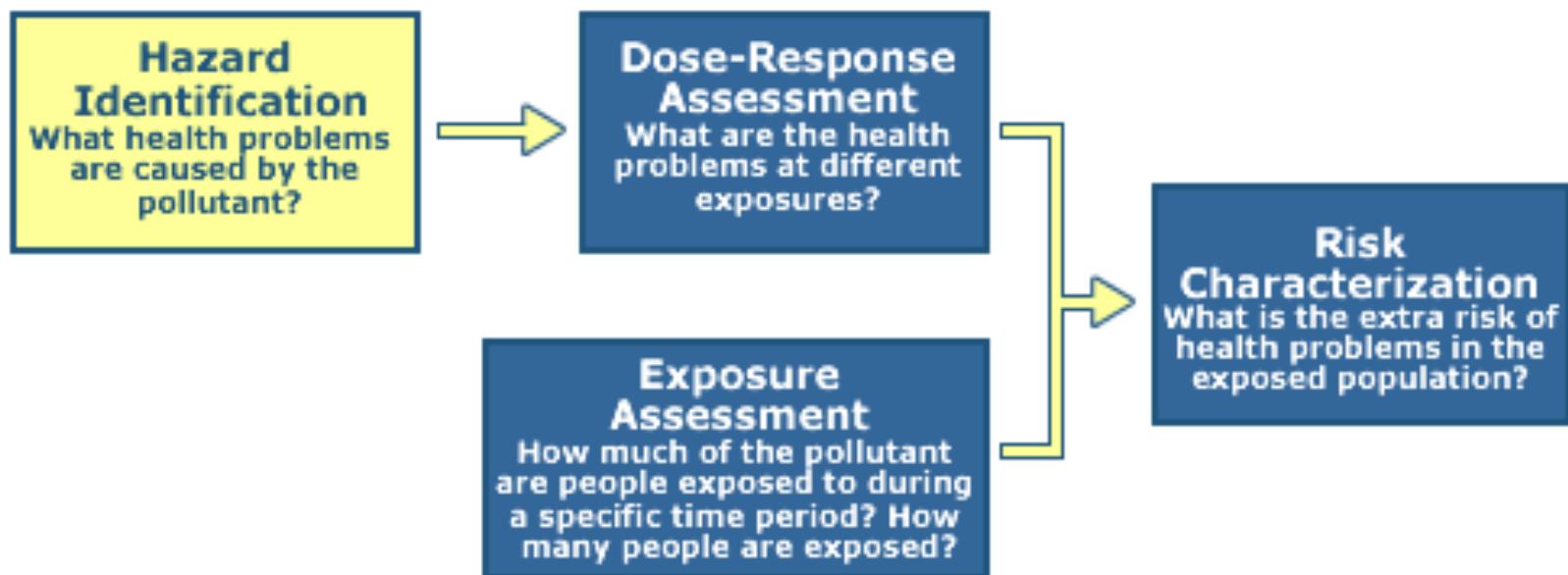
- Perception of risk as seen by an engineer/scientist familiar with the numbers are very different from those of an individual who lives next to a toxic waste site.

Some Characteristics That Change Our Perception of Risk	
Attributes That Elevate the Perception	Attributes That Lower the 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.

# Risk Assessment

## The 4 Step Risk Assessment Process



[http://www.epa.gov/risk\\_assessment/hazardous-identification.htm](http://www.epa.gov/risk_assessment/hazardous-identification.htm)

# Step 1 - Hazard Identification

- Hazard Identification is the process of determining whether exposure to a stressor can cause an increase in the incidence of specific adverse health effects (e.g., cancer, birth defects) and whether the adverse health effect is likely to occur in humans.
- In the case of chemical stressors, the process examines the available scientific data for a given chemical (or group of chemicals) and develops a weight of evidence to characterize the link between the negative effects and the chemical agent.

# Step 1 - Hazard Identification

## Sources of Data

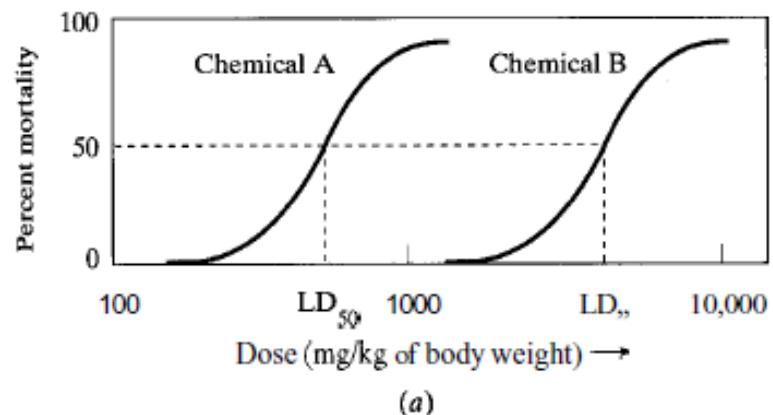
- Epidemiological studies involve a statistical evaluation of human populations to examine whether there is an association between exposure to a stressor and a human health effect. The advantage of these studies is that they involve humans while their weakness results from generally not having accurate exposure information and the difficulty of teasing out the effects of multiple stressors.
- When data from human studies are unavailable, data from animal studies (rats, mice, rabbits, monkeys, dogs, etc) are relied on to draw inference about the potential hazard to humans. Animal studies can be designed, controlled, and conducted to address specific gaps in knowledge, but there are uncertainties associated with extrapolating results from animal subjects to humans.
- Statistically controlled clinical studies on humans provide the best evidence linking a stressor, often a chemical, to a resulting effect. However, such studies are frequently not available since there are significant ethical concerns associated with human testing of environmental hazards.

# Toxic Effects

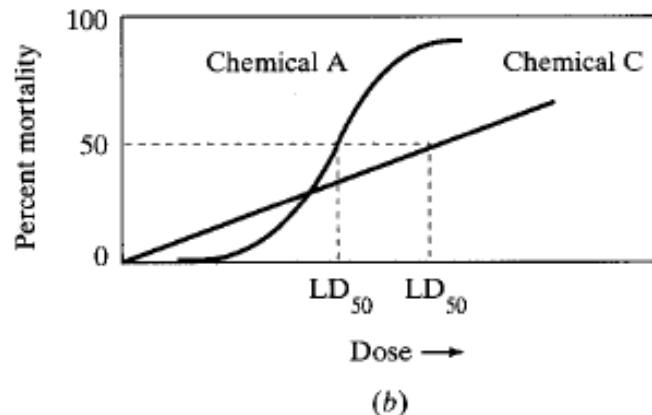
- **Acute Toxicity** happen very rapidly after a single exposure has occurred (food poisoning, breathing fumes from a chlorine spill). Sweating, nausea, paralysis, and death are examples of acute effects.
- **Chronic Toxicity** happen only after repeated long-term exposure (cigarette smoking, eating foods with low levels of contaminants, breathing polluted air). Cancer, organ damage, reproductive difficulties, and nervous system impairment are examples of chronic effects.
- These **chronic effects** fall into two categories: **carcinogenic** effects and **non-carcinogenic** effects.
- **Examples of non-carcinogenic chronic effects:**
  - **Organ damage:** cirrhosis of the liver from long-term alcohol consumption; emphysema from long-term tobacco smoking.
  - **Reproductive difficulty:** decreased fertility from the pesticide DBCP (di bromo chloro propane).
  - **Nervous system impairment:** mental retardation in people exposed to high levels of lead during early childhood.

# Assessing Toxicity-Acute

- Most information about acute toxicity of chemicals to humans comes from accidental poisonings or exposures, such as drug overdoses or chemical spills. Physicians/researchers know or estimate the level of exposure and observe and document the effects.
- Scientists also use animal tests called LD<sub>50</sub> (L-D-fifty) studies to assess acute toxicity. These studies determine the amount of a substance that will kill half the **test animals in 14 days**. This amount is called the LD50-- Lethal Dose for 50% of the animals.
- LD50 is stated in milligrams per kilogram (mg/kg): milligram of chemical per kilogram of body weight.
- Lower the LD50-the lower the lethal dose-the more toxic the substance.



(a)



(b)

**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<sub>50</sub>.

# LD<sub>50</sub> Comparison

Chemical	LD <sub>50</sub> (mg/kg)
Ethyl Alcohol	10,000
Sodium Chloride	4,000
Ferrous Sulfate	1,500
Morphine Sulfate	900
Strychnine Sulfate	150
Nicotine	1
Black Widow	0.55
Curare	0.50
Rattle Snake	0.24
Dioxin (TCDD)	0.001
Botulinum toxin	0.0001

# A conventional rating system for the acute toxicity of chemicals in humans

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Toxicity rating	Probable lethal oral dose for humans	
	Dose (mg/kg of body weight)	For average adult
1. Practically nontoxic	more than 15,000	More than 1 quart
2. Slightly toxic	5,000–15,000	1 pint to 1 quart
3. Moderately toxic	500–5,000	1 ounce to 1 pint
4. Very toxic	50–500	1 teaspoon to 1 ounce
5. Extremely toxic	5–50	7 drops to 1 teaspoon
6. Supertoxic	Less than 5	Less than 7 drops

# Assessing Chronic Toxicity

## Non-Carcinogenic Assessment

- Scientists assess non-carcinogenic chronic toxicity by administering varying amounts of a substance (dose) to laboratory animals and noting the effects (responses), if any, at each dose.
- Essentially, the scientists look for the smallest dose that causes any detectable effect. This smallest dose is called the **Lowest Observable Effect Level (LOEL)**.
- **To conduct these dose-response studies, scientists:**

Administer different small doses of a substance to several groups of test animals every day over a lifetime. Periodically examine and finally autopsy the animals to determine if any effects have occurred. The effects may be:

- damage to an organ,
- behavioral modifications,
- change in the level of an essential body chemical.

Determine the smallest dose at which an effect occurs--the **Lowest Observable Effect Level (LOEL)**.

LOEL is measured in milligrams (mg) of substance per kilogram (kg) of body weight, or in parts per million (ppm) of substance in food.

# Assessing Chronic Toxicity

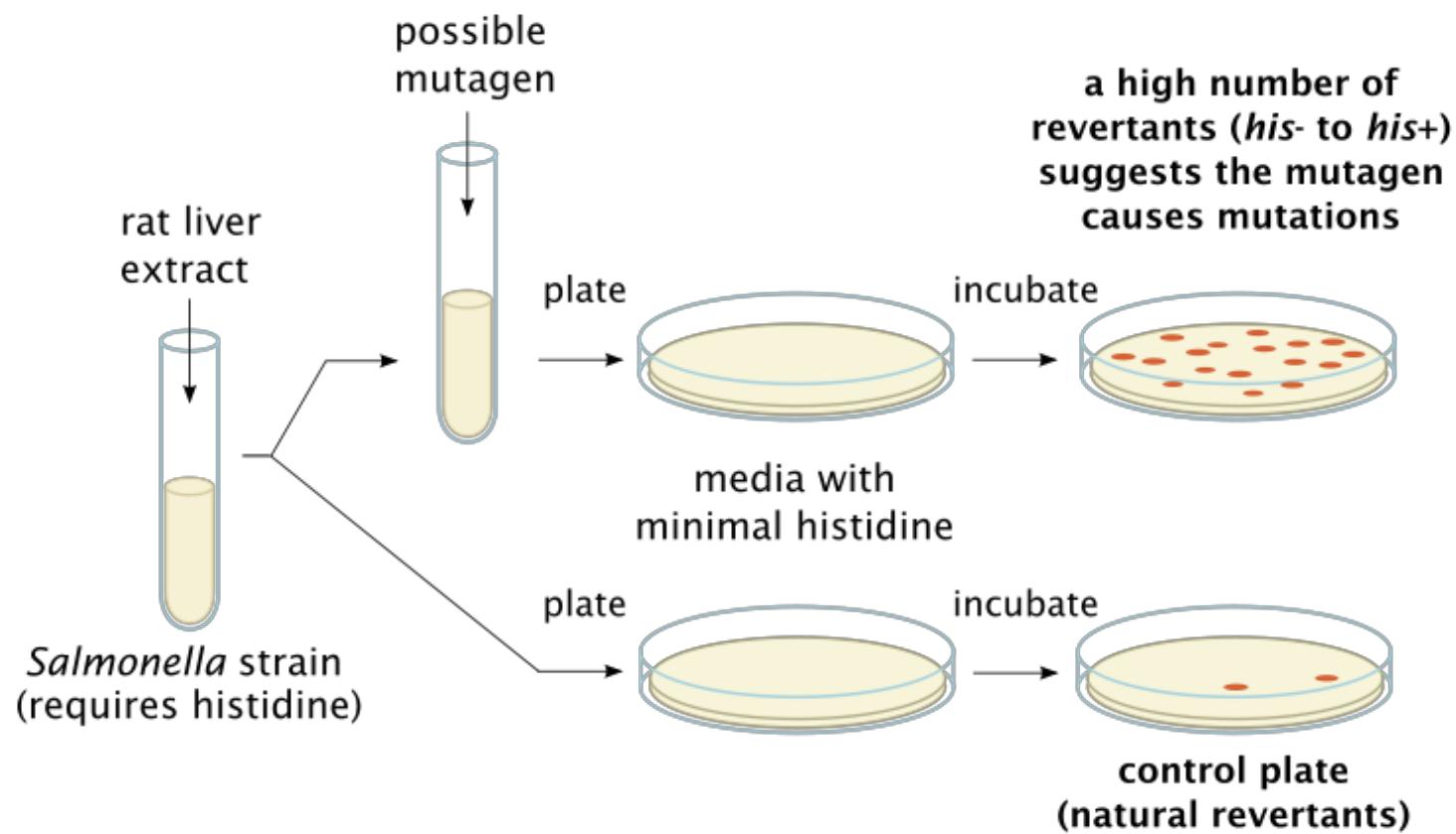
## Carcinogenic Assessment

- The prevailing carcinogenesis theory, that human cancers are initiated by gene mutations, has led to the development of short-term, *in vitro* (in glassware) screening procedures, which are one of the first steps taken to determine whether a chemical is carcinogenic.
- If a chemical can be shown to be mutagenic, then it *may* be carcinogenic, and further testing may be called for **Ames mutagency test**

### **Ames mutagency test**

- subjects special tester strains of bacteria to the chemical in question.
- These tester strains have previously been rendered incapable of normal bacterial division so, unless they mutate back to a form that is capable of division, they will die. Bacteria that survive and form colonies do so through mutation; therefore, the greater the survival rate of these special bacteria, the more mutagenic is the chemical.
- **Intermediate testing procedures** involve relatively short-term (several months duration) carcinogenesis bioassays in which specific organs in mice and rats are subjected to known mutagens to determine whether tumors develop.

# Ames mutagenicity test



[https://en.wikipedia.org/wiki/Ames\\_test](https://en.wikipedia.org/wiki/Ames_test)

# Chronic Carcinogenesis bioassay

- Involves hundreds or thousands of animals over a time period of several years.
- National Toxicology Program in the United States has established minimum test requirements for an acceptable chronic bioassay, which includes:
  - Two species of rodents must be tested. Mice and rats, using specially inbred strains for consistency, are most often used. They have relatively short lifetimes, and their small size makes them easier to test in large numbers.
  - At least 50 males and 50 females of each species for each dose must be tested.
  - At least two doses must be administered (plus a no-dose control). One dose is traditionally set at the maximum tolerated dose (MTD), a level that can be administered for a major portion of an animal's lifetime without significantly impairing growth or shortening the lifetime. The second dose is usually one-half or fourth the MTD.

# Chronic Carcinogenesis bioassay

- Exposure begins at **6 weeks of age and ends when the animal reaches 24 months** of age. At the end of the test, all animals are killed and their remains are subjected to detailed pathological examinations.
- These tests are expensive as well as time consuming.
- Testing a typical new chemical costs between \$0.5-1.5 million, takes **up to** two or three years, and may entail the sacrifice of thousands of animals (Goldberg and Frazier, 1989).
- The **minimum number of animals** required for a bioassay is **600** (2 species 100 animals X 3 doses), and at that number it is still only relatively high risks that can be detected.
- With this number of animals, for the test to show a statistically significant effect, the exposed animals must have at least *5 or 10 percent more tumors than the controls in order to conclude that* the extra tumors were caused by the chemical being tested.
- That is, the risk associated with this chemical can be measured only down to roughly 0.05 or 0.10 unless we test a lot more animals.

# Epidemiologic studies

# 2X2 matrix for an epidemiologic rate comparison

	With disease	Without disease
Exposed	a	b
Not Exposed	c	d

Relative risk =  $(a/(a+b))/(c/(c+d))$  For

Attributable risk =  $(a/(a+b)) - (c/(c+d))$

Odd ratio=  $ad/bc$

# 2X2 matrix for an epidemiologic rate comparison

- An evaluation of personnel records for employees of a plant that manufactures vinyl chloride finds out that of 200 works, 15 developed liver cancer. A control group consisting of individuals with smoking histories similar to the exposed workers, and who were unlikely to have encountered vinyl chloride, had 24 with liver cancer and 450 did not develop liver cancer. Find the relative risk, attributable risk, and odds ratio for these data
- RR= 1.48
- AR=0.024
- OR= 1.52

### **Weight-of-Evidence Categories for Human Carcinogenicity**

Human Evidence	Animal Evidence				
	Sufficient	Limited	Inadequate	No Data	No Evidence
Sufficient	A	A	A	A	A
Limited	B1	B1	B1	B1	B1
Inadequate	B2	C	D	D	D
No data	B2	C	D	D	E
No evidence	B2	C	D	D	E

Source: U.S. EPA, 1986a.

*Group A: Known carcinogen.* This group is put into this category only when sufficient epidemiologic evidence supports a causal association between exposure to the agent and cancer.

*Group B: Probable human carcinogen.* This group is actually made up of two subgroups. An agent is categorized as B1 if there is limited epidemiologic evidence; and an agent is put into B2 if there is inadequate human data but sufficient evidence of carcinogenicity in animals.

*Group C: Possible human carcinogen.* This group is used for agents with limited evidence of carcinogenicity in animals and an absence of human data.

*Group D: Not classified.* This group is for agents with inadequate human and animal evidence or for which no data are available.

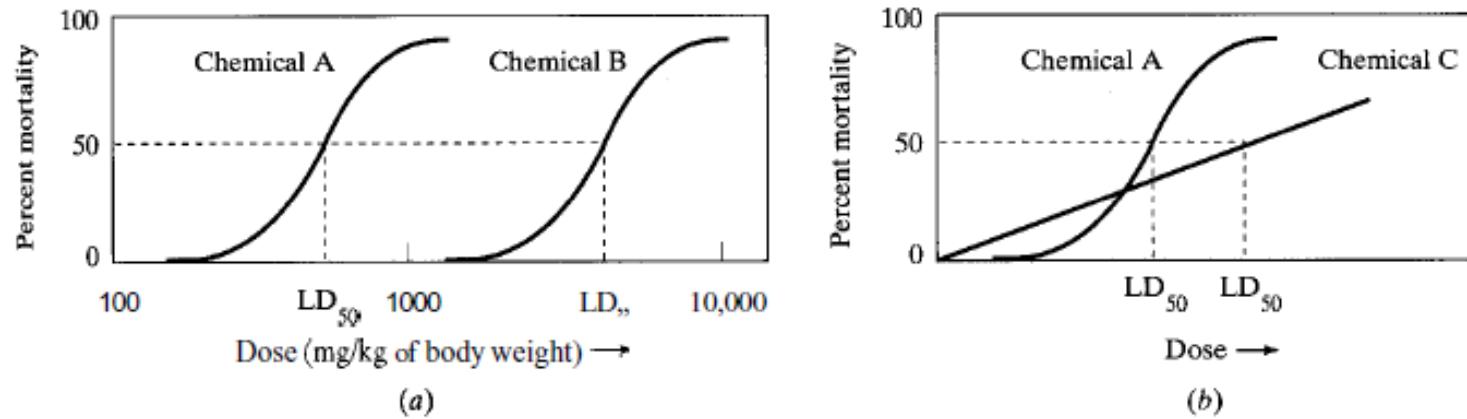
*Group E: Evidence of noncarcinogenicity.* This group is used for agents that show no evidence for carcinogenicity in at least two adequate animal tests in different species or in both adequate epidemiologic and animal studies.

## **Step 2 - Dose-Response Assessment**

# Step 2 - Dose-Response Assessment:

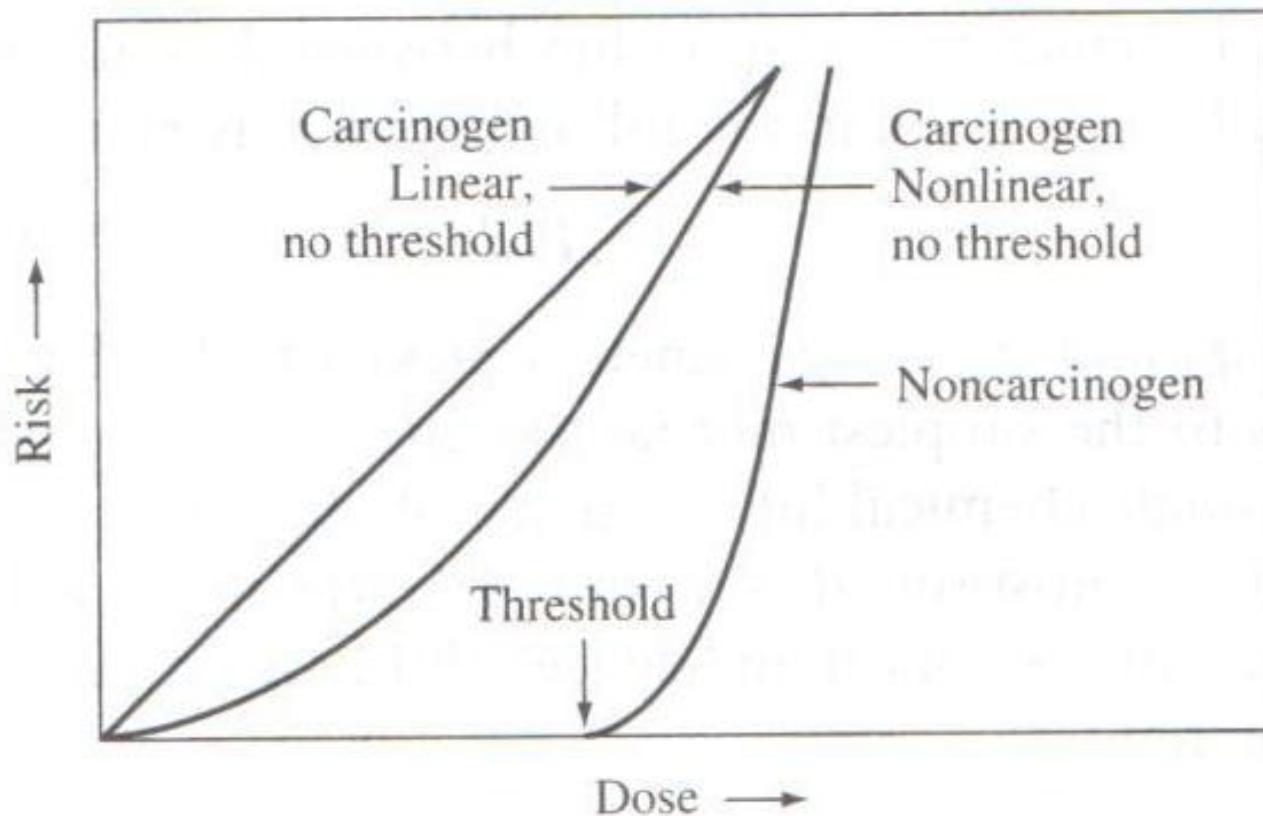
- A dose-response assessment is to obtain a mathematical relationship between the amount of a toxicant that a human is exposed to and the risk that there will be an unhealthy response to that dose.
- Dose is normalized as milligrams of substance or pathogen ingested, inhaled, or absorbed (in the case of chemicals) through the skin per kilogram of body weight per day ( $\text{mg kg}^{-1} \text{ day}^{-1}$ )
- To apply dose-response data obtained from animal bioassays to humans, a *scaling factor* must be introduced. Sometimes the scaling factor is based on the assumption that doses are equivalent if the dose per unit of body weight in the animal and human is the same.
- For example, if prolonged exposure to some chemical would be expected to produce 700 cancers in a population of 1 million, the response could be expressed as 0.07 percent. The annual risk would be obtained by spreading that risk over an assumed 70-year lifetime, giving a risk of 0.00001 or  $1\times 10^{-5}$

# Dose-response for acute toxicity



**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<sub>50</sub>.

# Step 2 - Dose-Response Assessment:



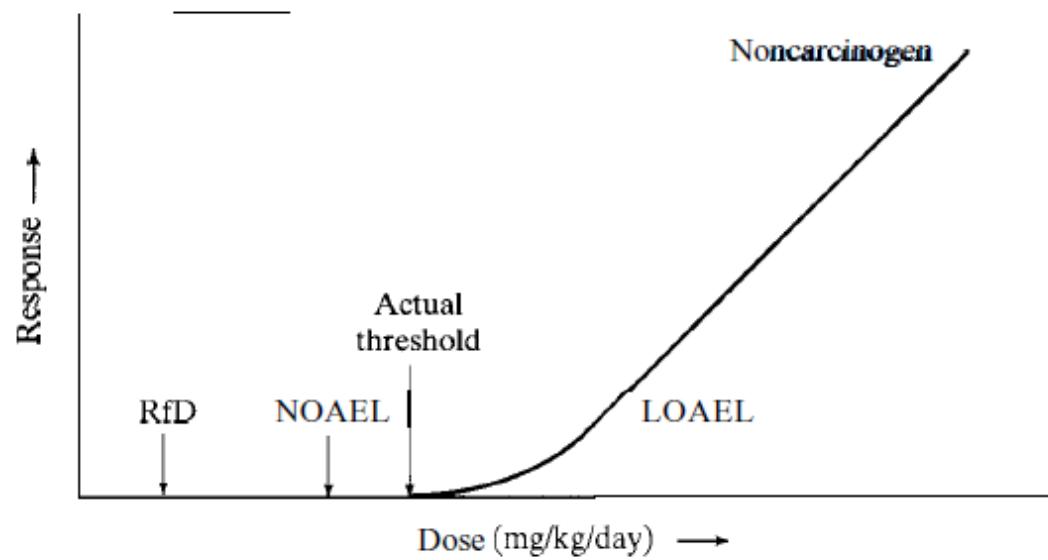
# Step 2 - Dose-Response Assessment:

- **The Reference Dose for Noncarcinogenic Effects**
- The key assumption for noncarcinogens **is that there is an exposure threshold; that is**, any exposure less than the threshold would be expected to show no increase in adverse effects above natural background rates.
- Suppose there exists a precise threshold for some particular toxicant for some particular animal species. To determine the threshold experimentally, we might imagine a testing program in which animals would be exposed to a range of doses.
- Doses below the threshold would elicit no response; doses above the threshold would produce responses.
- The lowest dose administered that results in a response is given a special name: the ***lowest-observed-effect level (LOEL)***
- *Conversely, the highest dose administered that does not create a response is called the ***no-observed-effect level (NOEL)****
- And are often further refined by noting a distinction between effects that are *adverse to health and effects that are not*

# Step 2 - Dose-Response Assessment:

## The Reference Dose for Noncarcinogenic Effects

- *Reference dose (RfD), or acceptable daily intake (ADI)*, and is intended to give an indication of a level of human exposure that is likely to be without appreciable risk
- *RfD = NOAEL / uncertainty factor (or safety factor)*
- A 10-fold uncertainty factor is used to account for differences in sensitivity between the most sensitive individuals in an exposed human population, such as pregnant women, babies, and the elderly, and “normal, healthy” people.
- Another factor of 10 is introduced when the NOAEL is based on animal data that is to be extrapolated to human
- Another factor of 10 is sometimes applied when there are no good human data and the animal data available are limited
- Human levels are established at doses that are anywhere from one-tenth to one-thousandth of the NOAEL, which is itself somewhat below the actual threshold.



## **Step 2 - Dose-Response Assessment: Hazard Index for Noncarcinogenic Effects**

- Hazard Quotient = Average daily dose during exposure period/ RfD
- **The daily dose is averaged only over the period of exposure, which is different from the average daily dose used in risk calculations for carcinogens**
- For non-carcinogens, the toxicity is important only during the time of exposure.
- The hazard quotient has been defined so that if it is less than 1.0, there should be no significant risk of systemic toxicity. Ratios above 1.0 could represent a potential risk, but there is no way to establish that risk with any certainty
- When exposure involves more than one chemical, the sum **of the individual hazard** quotients for each chemical is used as a measure of the potential for harm. This sum is called the ***hazard index***:
- Hazard index = **Sum of the hazard quotients**

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**TABLE 4.11** Oral RfDs for chronic noncarcinogenic effects of selected chemicals.

Chemical	RfD (mg/kg-day)
Acetone	0.100
Arsenic	0.0003
Cadmium	0.0005
Chloroform	0.010
1,1-dichloroethylene	0.009
cis-1,2-Dichloroethylene	0.010
Fluoride	0.120
Mercury (inorganic)	0.0003
Methylene chloride	0.060
Phenol	0.600
Tetrachloroethylene	0.010
Toluene	0.200
1,1,1-Trichloroethane	0.035
Xylene	2.000

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*Source:* U.S. EPA. <http://www.epa.gov/iris>

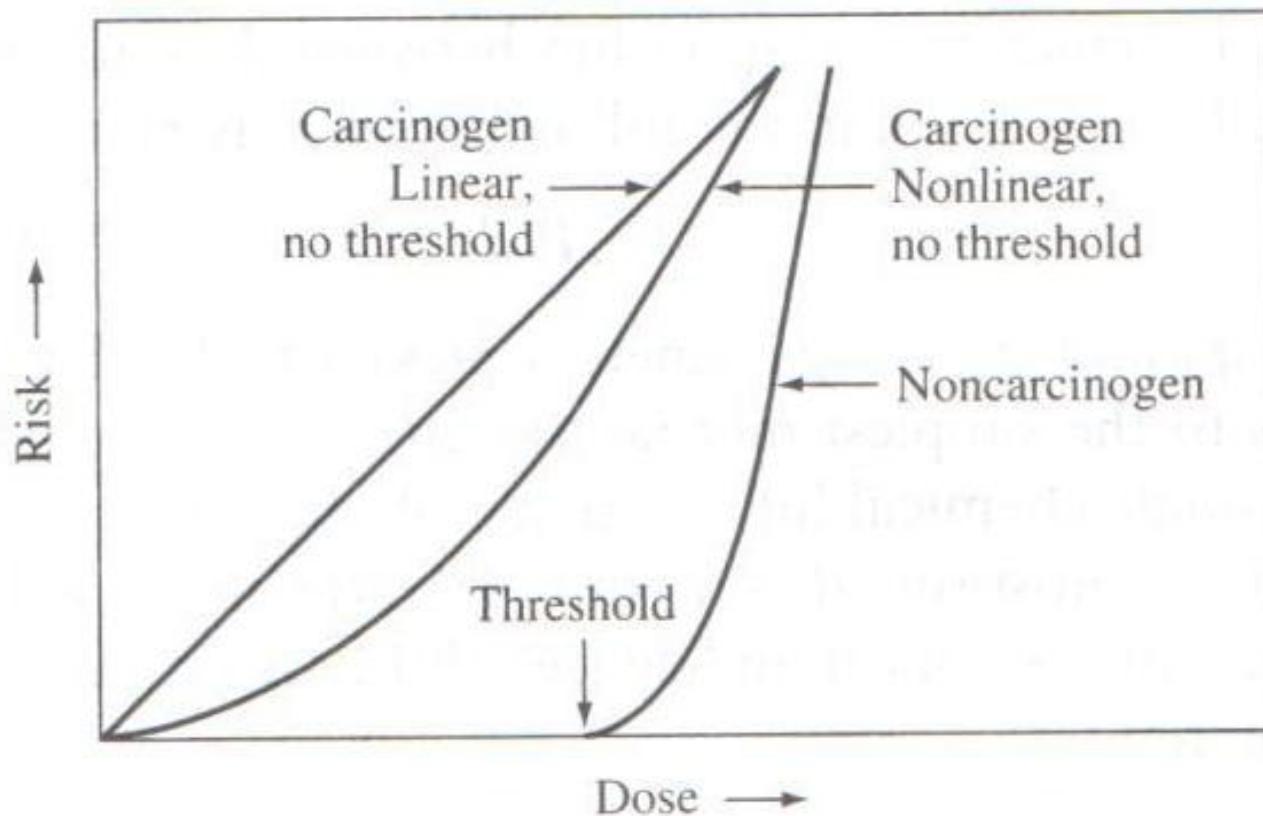
- Due to contamination from hazardous waste originating from a hazardous waste industry, drinking water contains 1.0 mg/L of toluene and 0.01 mg/L of tetrachloroethylene. A 70-kg adult drinks 2 L per day of this water for 10 years.
- **Would the hazard index suggest that this was a safe level of exposure?**

# *Solution*

- First we need to find the average daily doses (ADD) for each of the chemicals and then their individual hazard quotients.
- For toluene, the RfD = 0.200 mg/kg-day
- $\text{ADD (toluene)} = 1.0 \text{ mg/L} * 2 \text{ L/day} / 70 \text{ kg} = 0.029 \text{ mg/kg-day}$
- **Hazard quotient (toluene)** = ADD/RfD=  $0.029/0.200 = 0.14$
- The RfD for tetrachloroethylene = 0.01 mg/kg-day
- **Hazard quotient (tetrachloroethylene)** =  $0.00029/0.01 = 0.029$
- **Hazard index** =  $0.14 + 0.029 = 0.17 < 1.0$

**The hazard index suggests that this water is safe**

# Step 2 - Dose-Response Assessment:



# Dose-Response Assessment:

## Extrapolation from High Doses to Low Doses

- The most controversial aspects of dose-response curve for carcinogens is the method chosen to extrapolate from the high doses actually administered to test animals to the low doses to which humans are likely to be exposed
- Many mathematical models proposed but no model is proved or disproved
- That a single chemical “hit,” or exposure, is capable of inducing malignant change (i.e., a single hit causes inducing malignant change (i.e., a single hit causes irreversible damage of DNA, leading to tumor development)
- Once the biological target is hit, the process leading to tumor formation continues independently of dose

# Dose-Response Assessment:

## Extrapolation from High Doses to Low Doses

- The **multistage model** assumes that tumors are the result of a sequence of biological events, or stages.
- In simplistic terms, the biological rationale for the multistage model is that there are a series of biological stages that chemical must pass through (e.g., metabolism, covalent bonding, DNA repair, and so on) without being deactivated before the expression of a tumor is possible.
- The rate at which the cell passes through one or more of these stages is a function of the dose rate. The multistage model also has the desirable feature of producing a linear relationship between risk and dose

# Dose-Response Assessment:

## Extrapolation from High Doses to Low Doses

- The **multihit model** assumes that a number of dose related hits are needed before a cell becomes malignant. The most important difference between the multistage and multihit model is that in the multihit model, all hits must result from the dose, whereas in the multistage model, passage through some of the stages can occur spontaneously.
- The practical implication of this is that the multihit models are generally much flatter at low doses and consequently predict a lower risk than the multistage model

# Dose-Response Assessment:

## Extrapolation from High Doses to Low Doses

- The linear multistage model, a modified version of the multistage model, is the EPA's model of choice, because this agency chooses to err on the side of safety and overemphasize risk. This model assumes that there are multiple stages for cancer (i.e., a series of mutations or biotransformations) involving many carcinogens, co-carcinogens, and promoters that can best be modeled by a series of mathematical functions.

$$P(d) = 1 - e^{-(q_0 + q_1 d + q_2 d^2 + \dots + q_n d^n)}$$

# Dose-Response Assessment:

## Extrapolation from High Doses to Low Doses

- **One hit-model** (commonly used): Gives relationship between dose ( $d$ ) and lifetime risk (probability of cancer),  $P(d)$  is given as (Crump, 1984):
- Where  $q_0$  and  $q_1$  are parameters picked to fit the data. The one-hit model corresponds to the simplest mechanistic model of carcinogenesis, in which it is assumed that a single chemical hit is capable of inducing a tumor

$$P(d) = 1 - e^{-(q_0 + q_1 d)}$$

# Dose-Response Assessment:

## Extrapolation from High Doses to Low Doses

- If we substitute  $d = 0$  into the equation, the result will be an expression for the background rate of cancer incidence,  $P(0)$ .
- Using the mathematical expansion for an exponential

$$e^x = 1 + x + \frac{x^2}{2!} + \cdots + \frac{x^n}{n!} \cong 1 + x \quad (\text{for small } x)$$

- and assuming that the background cancer rate is small allows us to write

$$P(0) = 1 - e^{-q_0} \cong 1 - [1 + (-q_0)] = q_0$$

- That is, the background rate for cancer incidence corresponds to the parameter  $q_0$ . Using the exponential expansion again, the one-hit model suggests that the lifetime probability of cancer for small dose rates can be expressed as

$$P(d) \cong 1 - [1 - (q_0 + q_1 d)] = q_0 + q_1 d = P(0) + q_1 d$$

- For low doses, the additional risk of cancer above the background rate would be

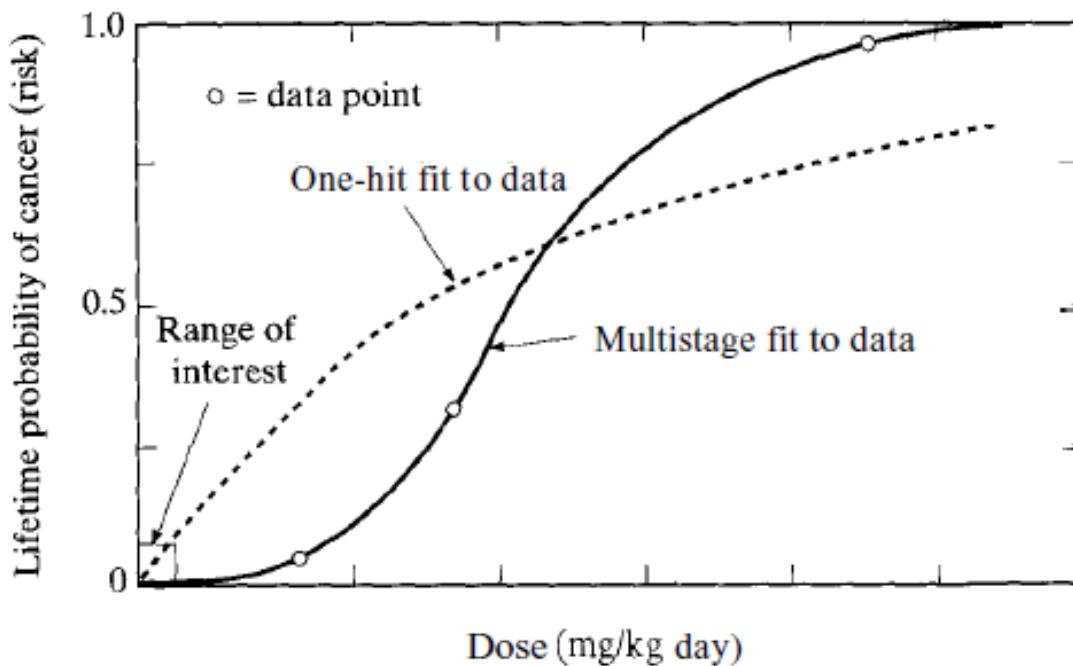
$$\text{Additional risk} = A(d) = P(d) - P(0)$$

$$\text{Additional risk} = A(d) \cong q_1 d$$

- That is, the one-hit model predicts that for low doses the extra lifetime probability of cancer is linearly related to dose.
- The ***multistage model expresses the relationship between risk and dose as***

$$P(d) = 1 - e^{-(q_0 + q_1 d + q_2 d^2 + \cdots + q_s d^n)}$$

For small values of dose  $d$ , the ***multistage*** model also has the simplifying feature of producing a linear relationship between additional risk and dose.



**FIGURE 4.9** Dose-response curves showing two methods of fitting an equation to the data. The range of interest is well below the point where any data actually exist. (Based on Crump, 1984)

- Since the choice of an appropriate low-dose model is not based on experimental data, there is no model that can be proved to be more correct than another.
- To protect public health, EPA chooses to err on the side of safety and overemphasize risk. The model of choice is a modified multistage model, called the ***linearized multistage model***.
- It is linear at low doses with the constant of proportionality picked in a way that the probability of overestimating the risk is 95 percent.

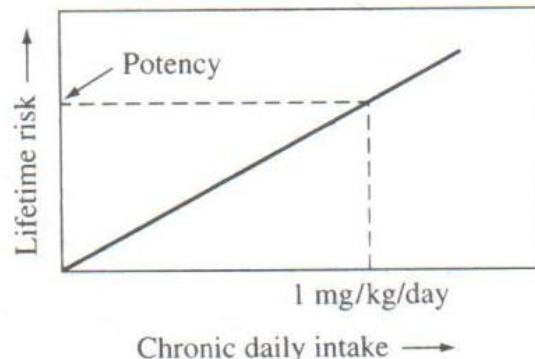
# Dose-Response Assessment:

## Extrapolation from High Doses to Low Doses

- At low doses, the slope of the dose-response curve produced by the linear multistage model is called the potency factor (PF) or slope factor (SF) which is the reciprocal of the concentration of chemical measured in milligrams per kilogram of animal body weight per day, that is,  $1/(\text{mg kg}^{-1} \text{ day}^{-1})$ , or the risk produced by a lifetime average dose (AD) of  $1 \text{ mg kg}^{-1} \text{ day}^{-1}$
- Thus the dose-response equation for a carcinogen is:
- Lifetime Risk = AD X PF
- The probability of getting cancer (not the probability of dying of cancer) and the associated dose, consist of an average taken over an assumed 70-year human lifetime
- This dose is called the lifetime average daily dose or chronic daily intake.

# Potency Factor for Carcinogens

- At low doses, where the dose-response curve is assumed to be linear, the slope of the dose-response curve is called the *potency factor (PF)*, or *slope factor*.
- **Potency factor** = Incremental lifetime cancer risk/**Chronic daily intake** (mg/kg/day)
- **Potency factor** = Incremental lifetime cancer risk *for* Chronic daily intake (CDI) of 1 mg/kg/day
- Incremental lifetime cancer risk = CDI \* **Potency factor**



**TABLE 4.9** Toxicity data for selected potential carcinogens

Chemical	Category	Potency factor oral route (mg/kg-day) <sup>-1</sup>	Potency factor inhalation route (mg/kg-day) <sup>-1</sup>
Arsenic	A	1.75	50
Benzene	A	$2.9 \times 10^{-2}$	$2.9 \times 10^{-2}$
Benzol(a)pyrene	B2	11.5	6.11
Cadmium	B1	—	6.1
Carbon tetrachloride	B2	0.13	—
Chloroform	B2	$6.1 \times 10^{-3}$	$8.1 \times 10^{-2}$
Chromium VI	A	—	41
DDT	B2	0.34	—
1,1-Dichloroethylene	C	0.58	1.16
Dieldrin	B2	30	—
Heptachlor	B2	3.4	—
Hexachloroethane	C	$1.4 \times 10^{-2}$	—
Methylene chloride	B2	$7.5 \times 10^{-3}$	$1.4 \times 10^{-2}$
Nickel and compounds	A	—	1.19
Polychlorinated biphenyls (PCBs)	B2	7.7	—
2,3,7,8-TCDD (dioxin)	B2	$1.56 \times 10^5$	—
Tetrachloroethylene	B2	$5.1 \times 10^{-2}$	$1.0 - 3.3 \times 10^{-3}$
1,1,1-Trichloroethane (1,1,1-TCA)	D	—	—
Trichloroethylene (TCE)	B2	$1.1 \times 10^{-2}$	$1.3 \times 10^{-2}$
Vinyl chloride	A	2.3	0.295

Source: U.S. EPA <http://www.epa.gov/liris>.

# Example: Risk assessment of chloroform in drinking water

When drinking water is disinfected with chlorine, an undesirable product, chloroform ( $\text{CHCl}_3$ ), may be formed. Suppose a 70-kg person drinks 2L of water every day for 70 years with a chloroform concentration of **0.10 mg/L (drinking water standard in USA)**

- a. Find the upper bound cancer risk for this individual
- b. If a city with 500, 000 people in it also drinks the same amount of this water, how many extra cancers per year would be expected?
- c. Compare the extra cancers per year caused by chloroform in the drinking water with the expected number of cancer deaths from all causes. The cancer death rate in the United States is 189 per 100,000 per year

**Potency factor for  $\text{CHCl}_3 = 6.1 \times 10^{-3} \text{ (mg/kg-day)}^{-1}$**

# Solution

**a.** daily intake (CDI)= Average daily dose/ Body weight (kg)  $= (0.10 \text{ mg/L} * 2\text{L/day}) / 70 \text{ kg}$   $= 0.00286 \text{ mg/kg-day}$

- The incremental lifetime cancer risk

Risk = CDI X Potency factor

$$= 0.00286 \times 6.1 \times 10^{-3} = 17.4 \times 10^{-6}$$

So over a 70-year period the upper-bound estimate of the probability that a person will get cancer from this drinking water is about **17 in one million**.

**b.** If there are 17.4 cancers per million people over a 70-year period, then in any given year in a population of one-half million, the number of cancers caused by chloroform would be

$$500,000 \text{ people} \times 17.4 \text{ cancer}/10^6 \text{ people} \times 1/70 \text{ yr} = 0.12 \text{ cancers/yr}$$

**c.** The total number of cancer deaths that would be expected in a city of 500,000 would be **500,000 people X (189 cancer/yr/100,000 people) = 945 cancer deaths /yr**

It would seem that an additional 0.12 new cancers per year would not be detectable.

# Drinking water concentration of chloroform for a $10^{-6}$ risk

- Another use for these risk calculations is to estimate the concentration of a contaminant in drinking water that would result in a politically acceptable risk level.
- Often that risk goal is  $10^{-6}$  and the concentration that will produce that risk is called the *Drinking water equivalent level (DWEL)*.
- *To find the DWEL, it is usually assumed that a 70-kg adult consumes 2 L of water per day.*
- Find the concentration of chloroform in drinking water that would result in a 70-kg person who drinks 2L/day throughout his or her entire lifetime.
- Ans: 6  $\mu\text{g/L}$

# Occupational Exposure

- Estimate the incremental cancer risk for a 60-kg worker exposed to a particular carcinogen under the following circumstances. Exposure time is 5 days per week, 50 weeks per year, over a 25-year period of time. The worker is assumed to breathe 20 m<sup>3</sup> of air per day. The carcinogen has a potency factor of 0.02 and its average concentration is 0.05 mg/m<sup>3</sup>
- Ans: Incremental risk =  $81 \times 10^{-6}$

### **Example EPA Exposure Factors Recommended for Risk Assessments**

Land Use	Exposure Pathway	Daily Intake	Exposure Frequency, Days/Year	Exposure Duration, Years	Body Weight, kg
Residential	Ingestion of potable water	2 L (adult) 1 L (child)	350	30	70 (adult) 15 (child)
	Ingestion of soil and dust	200 mg (child) 100 mg (adult)	350	6	15 (child)
	Inhalation of contaminants	20 m <sup>3</sup> (adult) 12 m <sup>3</sup> (child)	350	24	70 (adult) 70
				30	
Industrial and commercial	Ingestion of potable water	1 L	250	25	70
	Ingestion of soil and dust	50 mg	250	25	70
	Inhalation of contaminants	20 m <sup>3</sup> (workday)	250	25	70
Agricultural	Consumption of homegrown produce	42 g (fruit) 80 g (veg.)	350	30	70
Recreational	Consumption of locally caught fish	54 g	350	30	70

Source: U.S. EPA, 1991.

- Suppose drinking water contains 1.0 mg/L of toluene and 0.01 mg/L of tetrachloroethylene. A 70-kg adult drinks 2 L per day of this water for 10 years.
- a. Would the hazard index suggest that this was a safe level of exposure?
- b. Tetrachloroethylene is a B2 carcinogen. What would be the carcinogenic risk faced by someone drinking this water? Would it be less than a goal of  $10^{-6}$

# *Solution*

- First we need to find the average daily doses (ADD) for each of the chemicals and then their individual hazard quotients.
- For toluene, the RfD is given as 0.200 mg/kg-day
- **ADD (toluene) =  $1.0 \text{ mg/L} * 2 \text{ L/day} / 70 \text{ kg} = 0.029 \text{ mg/kg-day}$**
- Hazard quotient (toluene) = **ADD/RfD=  $0.029/.200 = 0.14$**
- The RfD for tetrachloroethylene is 0.01
- And ADD ( $\text{C}_2\text{Cl}_4$ )= 0.00029 mg/kg-day
- Hazard index =  $0.14 + 0.029 = 0.17 < 1.0$

**The hazard index suggests that this water is safe**

**b. The incremental carcinogenic risk associated with the C<sub>2</sub>Cl<sub>4</sub> is**

Risk = CDI X Potency factor

$$\text{CDI} = (0.01 \text{ mg/l} \times 2 \text{ L/day} \times 365 \text{ days/yr} \times 10 \text{ yrs}) / (70 \text{ kg} \times 365 \text{ days} \times 70 \text{ yrs}) \\ = 4.0 \times 10^{-5} \text{ mg/kg-day}$$

P.F. is  $5.1 \times 10^{-2} \text{ (mg/kg-day)}^{-1}$

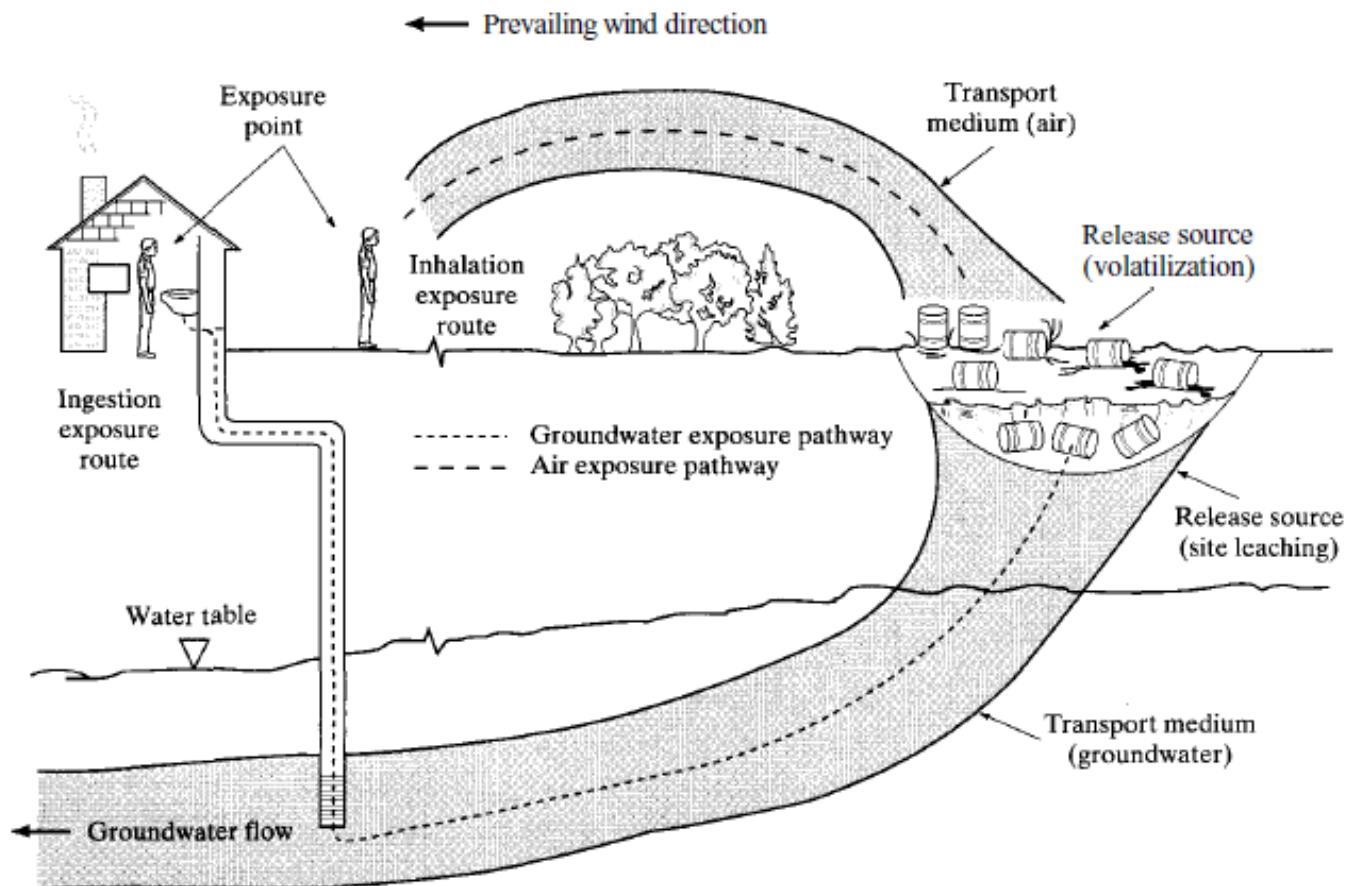
$$\text{Hence Risk} = 4.0 \times 10^{-5} \text{ mg/kg-day} \times 5.1 \times 10^{-2} \text{ (mg/kg-day)}^{-1} \\ = 2 \times 10^{-6}$$

- So, from a cancer risk standpoint, this water does not meet the risk goal of  $10^{-6}$ .
- Notice how the tetrachloroethylene was way below the RfD but was above the desired risk goal.
- Not uncommon

# Step 3 - Exposure Assessment

- Exposure assessment is the **process of measuring or estimating the magnitude, frequency, and duration of human exposure to an agent in the environment**, or estimating future exposures for an agent that has not yet been released.
- An exposure assessment includes some discussion of the size, nature, and types of human populations exposed to the agent, as well as discussion of the uncertainties in the above information.
- A **human exposure assessment is a two-part process**.
- First, **pathways** that allow toxic agents to be transported from the source to the point of contact with people must be evaluated.
- Second, an estimate must be made of the **amount of contact** that is likely to occur between people and those contaminants.

# Illustration of exposure pathways



- Once the exposure pathways have been analyzed, an estimate of the concentrations of toxicants in the air, water, soil, and food at a particular exposure point can be made
- With the concentrations of various toxic agents established, human contact with those contaminants must be estimated.
- Necessary information includes numbers of people exposed, duration of exposure, and amounts of contaminated air, water, food, and soil that find their way into each exposed person's body.

# Bioconcentration

- **Bioconcentration factor** is a measure of the tendency for a substance to accumulate in the body.
- Concentration in fish = (concentration in water) X (bioconcentration factor)

**TABLE 4.12** Bioconcentration Factors (BCFs) for a Selected List of Chemicals.

Chemical	Bioconcentration Factor (L/kg)
Aldrin	28
Arsenic and compounds	<b>44</b>
Benzene	5.2
Cadmium and compounds	81
Carbon tetrachloride	19
Chlordane	14,000
Chloroform	3.75
Chromium III, VI, and compounds	16
Copper	200
DDE	51,000
DDT	54,000
1,1-Dichloroethylene	5.6
Dieldrin	4760
Formaldehyde	0
Heptachlor	<b>15,700</b>
Hexachloroethane	87
Nickel and compounds	47
Polychlorinated biphenyls (PCBs)	100,000
2,3,7,8-TCDD (Dioxin)	5000
Tetrachloroethylene	31
1,1,1-Trichloroethane	5.6
Trichloroethylene (TCE)	10.6
Vinyl chloride	1.17

*Source:* U.S. EPA (1986b).

# EXAMPLE

- Using the standard exposure factors, for a person eating locally caught fish, estimate the lifetime cancer risk from fish taken from waters containing a concentration of trichloroethylene (TCE) equal to 100ppb ( 0.1 mg/l)
- Bioconcentration factor for TCE is 10.6 L/kg
- Standard exposure factors include a 70-kg person consuming 54g of fish, 350 days per year for 30 years
- Potency factor for an oral dose of TCE is  $1.1 \times 10^{-2}$  (mg/kg-day) $^{-1}$

# Solution

- TCE concentration in fish =  $0.1 \text{ mg/L} \times 10.6 \text{ L/kg} = 1.06 \text{ mg TCE/kg fish}$
- chronic daily intake CDI =  $1.06 \text{ mg/kg} \times 54 \text{ g/day} \times 1\text{kg}/1000\text{g} \times 350 \text{ days}/365 \text{ days} \times 30 \text{ years}/70 \text{ years}/ 70 \text{ kg}$   
 $= 3.36 \times 10^{-4} \text{ mg/kg-day}$
- Risk = CDI X potency factor  
 $= 3.36 \times 10^{-4} \times 1.1 \times 10^{-2} = 3.6 \times 10^{-6}$   
 $= 4 \text{ in a million}$

# Step 4 - Risk Characterization

- The final step in a risk assessment is to bring the various studies together into an overall risk characterization.
- In its most primitive sense, this step could be interpreted to mean simply multiplying the exposure (dose) by the potency to get individual risk, and then multiplying that by the number of people exposed to get an estimate of overall risk to some specific population.
- While there are obvious advantages to presenting a simple, single number for extra cancers, or some other risk measure, a proper characterization of risk should be much more comprehensive.
- The final expressions of risk derived in this step will be used by regulatory decision makers in the process of weighing health risks against other societal costs and benefits, and the public will use them to help them decide on the adequacy of proposed measures to manage the risks.
- It must always be emphasized that these estimates are preliminary, subject to change, and extremely uncertain.

The National Academy of Sciences (1983) suggests a number of questions that should be addressed in a final characterization of risk, including the following:

- What are the **statistical uncertainties** in estimating the extent of health effects? How are these uncertainties to be computed and presented?
- What are the **biological uncertainties**? What are their origins? How will they be estimated? What effect do they have on quantitative estimates? How will the uncertainties be described to agency decision makers?
- Which dose-response assessments and exposure assessments should be used?
- Which population groups should be the primary targets for protection, and which provide the most meaningful expression of the health risk?

# Example of qualifying statement

- Rodricks, 1992 offers the following example of the sort of qualifying statement that ought to accompany all risk assessments (in this case for a hypothetical contaminant difluoromuckone, DFM):

Difluoromuckone (DFM) has been found to increase the risk of cancer in several studies involving experimental animals. Investigations involving groups of individuals exposed in the past to relatively high levels of DFM have not revealed that the chemical increases cancer risk in humans. Because these human studies could not detect a small increase in risk, and because there is a scientific basis for assuming results from animal experiments are relevant to humans, exposure to low levels of DFM may create an increase in risk of cancer for people. The magnitude of this risk is unknown, but probably does not exceed one in 50,000. This figure is the lifetime chance of developing cancer from a daily exposure to the highest levels of DFM detected in the environment. Average levels, which are more likely to be experienced over the course of a lifetime, suggest a lifetime risk more like one in 200,000. These risk figures were derived using scientific assumptions that are not recognized as plausible by all scientists, but which are consistently used by regulatory scientists when attempting to portray the risks of environmental chemicals. It is quite plausible that actual risks are lower than the ones cited above; higher risks are not likely but cannot be ruled out. Regulators typically seek to reduce risks that exceed a range of one in 100,000 to one in 1,000,000. Note that the lifetime cancer risk we face from all sources of these diseases is about 1 in 5 (1 in 10 for non-smokers), so that, even if correct, the DFM risk is a minor contributor to the overall cancer problem. Prudence may dictate the need for some small degree of risk reduction for DFM in the environment.

# COMPARATIVE RISK ANALYSIS

- In 1987, the EPA released a report entitled *Unfinished Business: A Comparative Assessment Environmental Problems*
- The concepts of risk assessment were applied to a variety of pressing environmental problems
- The goal of the study was to attempt to use risk as a policy tool for ranking major environmental problems in order to help the agency establish broad, long-term priorities.
- Direct comparisons of different environmental problems would be next to impossible
- Not only are the data usually insufficient to quantify risks, but the kinds of risk associated with some problems, such as global warming, are virtually incomparable with risks of others, such as hazardous waste.

- The study was organized around a list of 31 environmental problems
- Each of these 31 problems was analyzed in terms of four different types of risk: cancer risks, non-cancer health risks, ecological effects, and welfare effects (visibility impairment, materials damage, etc.). by four different groups
- In each assessment, it was assumed that existing environmental control programs continue so that the results represent risks as they exist now, rather than what they would have been had abatement programs not already been in place.
- Rankings were based primarily on overall cancer risk to the entire U.S. population, although high risks to specific groups of individuals, such as farm workers, were noted

**TABLE 4.14** Consensus Ranking of Environmental Problem Areas on the Basis of Population Cancer Risk

Rank	Problem Area	Selected Comments
1 (tied)	Worker exposure to chemicals	About 250 cancer cases per year estimated based on exposure to 4 chemicals; but workers face potential exposures to over 20,000 substances. Very high individual risk possible.
1 (tied)	Indoor radon	Estimated 5000 to 20,000 lung cancers annually from exposure in homes.
3	Pesticide residues on foods	Estimated 6000 cancers annually, based on exposure to 200 potential carcinogens.
4 (tied)	Indoor air pollutants (nonradon)	Estimated 3500 to 6500 cancers annually, mostly due to tobacco smoke.
4 (tied)	Consumer exposure to chemicals	Risk from 4 chemicals investigated is about 100 to 135 cancers annually; an estimated 10,000 chemicals in consumer products. Cleaning fluids, pesticides, particleboard, and asbestos-containing products especially noted.
6	Hazardous/toxic air pollutants	Estimated 2000 cancers annually based on an assessment of 20 substances.
7	Depletion of stratospheric ozone	Ozone depletion projected to result in 10,000 additional annual deaths in the year 2100. Not ranked higher because of the uncertainties in future risk.
8	Hazardous waste sites, inactive	Cancer incidence of 1000 annually from 6 chemicals assessed. Considerable uncertainty since risk based on extrapolation from 35 sites to about 25,000 sites.
9	Drinking water	Estimated 400 to 1000 annual cancers, mostly from radon and trihalomethanes.
10	Application of pesticides	Approximately 100 cancers annually; small population exposed but high individual risks.
11	Radiation other than radon	Estimated 360 cancers per year. Mostly from building materials. Medical exposure and natural background levels not included.
12	Other pesticide risks	Consumer and professional exterminator uses estimated cancers of 150 annually. Poor data.
13	Hazardous waste sites, active	Probably fewer than 100 cancers annually; estimates sensitive to assumptions regarding proximity of future wells

**TABLE 4.14** Continued

Rank	Problem Area	Selected Comments
14	Nonhazardous waste sites, industrial	No real analysis done, ranking based on consensus of professional opinion.
15	New toxic chemicals	Difficult to assess; done by consensus.
16	Nonhazardous waste sites, municipal	Estimated 40 cancers annually, not including municipal surface impoundments.
17	Contaminated sludge	Preliminary results estimate 40 cancers annually, mostly from incineration and landfilling.
18	Mining waste	Estimated 10 to 20 cancers annually, largely due to arsenic. Remote locations and small population exposure reduce overall risk though individual risk may be high.
19	Releases from storage tanks	Preliminary analysis, based on benzene, indicated low cancer incidence (< 1).
20	Nonpoint-source discharges to surface water	No quantitative analysis available; judgment.
21	Other groundwater contamination	Lack of information; individual risks considered less than $10^{-6}$ , with rough estimate of total population risk at < 1.
22	Criteria air pollutants	Excluding carcinogenic particles and volatile organic chemicals (VOCs) (included under Hazardous/Toxic Air Pollutants); ranked low because remaining criteria pollutants have not been shown to be carcinogens.
23	Direct point-source discharges to surface water	No quantitative assessment available. Only ingestion of contaminated seafood was considered.
24	Indirect, point-source discharges to surface water	Same as above.
25	Accidental releases—toxics	Short-duration exposure yields low cancer risk; noncancer health effects of much greater concern.
26	Accidental releases—oil spills	See above. Greater concern for welfare and ecological effects.

Not ranked: Biotechnology; global warming; other air pollutant; discharges to estuaries, coastal waters and oceans; discharges to wetlands/

*Source:* Based on data from U.S. EPA (1987).

# General Results of all four groups

The other working groups had considerably greater difficulty ranking the **31** environmental problem areas since there are no accepted guidelines for quantitatively assessing relative risks.

The general results:

- No **problems** rank relatively high in all four types of risk, or relatively low in all four.
- Problems that rank relatively high in three of the four risk types, or at least medium in all four, include **criteria air pollutants ; stratospheric ozone depletion; pesticide residues on food.**
- Problems that rank relatively high in cancer and noncancer health risks, but low in ecological and welfare risks, include **hazardous air pollutants; indoor radon; indoor air pollution other than radon; pesticide application; exposure to consumer products; and worker exposures to chemicals.**
- Problems that rank relatively high in ecological and welfare risks, but low in both health risks, include **global warming; point and nonpoint sources of surface water pollution; physical alteration of aquatic habitats (including estuaries and wetlands), and mining wastes.**
- Areas related to groundwater consistently rank medium or low.



# Lifetime risks of cancer derived from different extrapolation models

MODEL APPLIED	LIFETIME RISK ( $1.0 \text{ mg kg}^{-1} \text{ day}^{-1}$ ) OF TOXIC CHEMICAL <sup>a</sup>	
One-hit	$6.0 \times 10^{-5}$	(1 in 17,000)
Multistage	$6.0 \times 10^{-6}$	(1 in 167,000)
Multihit	$4.4 \times 10^{-7}$	(1 in 2.3 million)
Probit	$1.9 \times 10^{-10}$	(1 in 5.3 billion)

<sup>a</sup>All risks for a full lifetime of daily exposure. The lifetime is used as the unit of risk measurement, because the experimental data reflect the risk experienced by animals over their full lifetimes. The values shown are upper confidence limits on risk.

Source: U.S. EPA, 1990. From *Pollution Science* © 1996, Academic Press, San Diego, CA.

# Hazard Identification

## Key Components of Hazard Identification

- **Toxicokinetics** considers how the body absorbs, distributes, metabolizes, and eliminates specific chemicals.
- **Toxicodynamics** focus on the effects that chemicals have on the human body. Models based on these studies can describe mechanisms by which a chemical may impact human health, thus providing insights into the possible effects of a chemical.

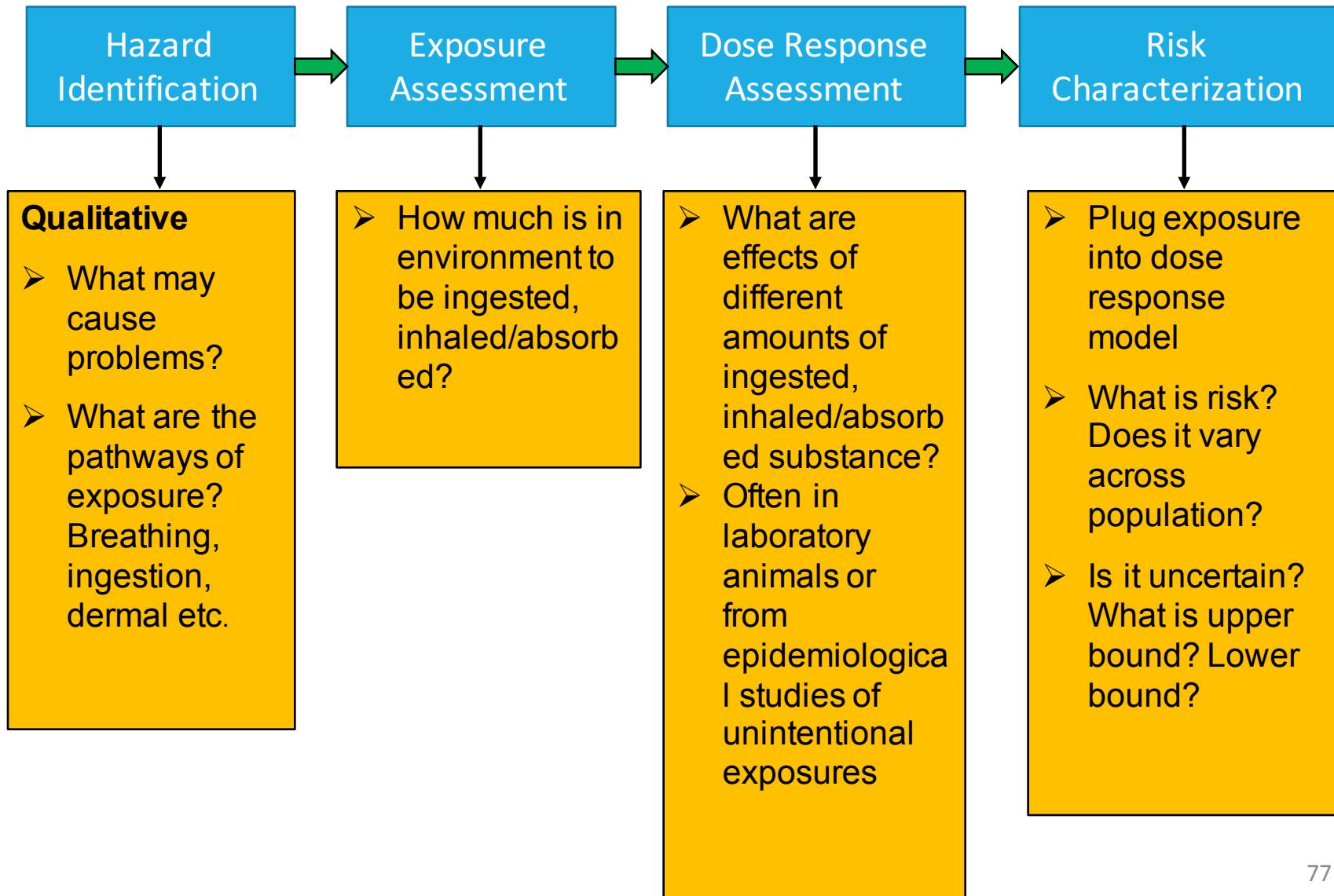
# Indirect Assessment of Human Health Risk

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# Risk Assessment Tools

- Epidemiological Studies: Direct assessment of public health risk. For eg. Comparison of affected exposed population with the unexposed population.
- QMRA: Quantitative Microbial Risk Assessment is an indirect assessment of human health risk.
  - ✓ It is an engineered model which uses density of pathogen, ingestion rate and dose-response model for computation of human health risk (WHO, 2006).
  - ✓ Various scenarios and pathways of risk of infection and illness can be calculated using this approach.

# The Risk Assessment Framework



## Example on Assessment of Risk

- Considering someone goes for the swim in the ocean.
- Ocean is dumping zone for a lot of human waste
- There may be health risk due to presence of waste
- How can we compute the human health risk associated with swimming in the ocean?

# Which is Which?

- Exposure assessment
  - Dose response
  - Risk characterization
1. Volunteers ingest varying amounts of cryptosporidium oocysts and we observe how many become infected
  2. We ask volunteers to keep a journal of how many times they go swimming
  3. We calculate a probability of infection given the number of oocysts ingested
  4. We observe how much water someone swallows while swimming
  5. We ask how much confidence we should have in our assessment
  6. We measure concentrations of oocysts at a beach
  7. We observe the proportion of infected people who die during an outbreak

# Exposure Assessment

- How much is in environment to be ingested, inhaled, absorbed, etc.?
- In this case  $c=13$  oocysts/liter
- Ingested volume = 0.1 L/swim
- Dose = concentration \* uptake
- Dose = 13 oocyst/liter \* 0.1 liter/swim
- Dose = 1.3 oocysts/swim

# Dose Response

- Now we look to the literature for how to relate this specific dose to a probability of an adverse outcome
- Assume our humans of concern respond like other humans have as reported in literature

# Online Resources

Table of Recommended Best-Fit Parameters

Please click on the tab headings to navigate between tabs. We generally recommend a single dose response model, and we justify the decision in terms of these criteria. This decision is somewhat subjective, since dose response datasets seldom meet all of these criteria. If all available models are unsatisfactory, we choose a single model to 'recommend with reservations'. Our recommended model will seldom (if ever) be the best model for all applications. The user should carefully choose the model that is most appropriate for their particular problem.

\*Please click on the tab headings to navigate between tabs.

Agent	Best fit model*	Optimized parameter(s)	LD <sub>50</sub> /ID <sub>50</sub>	Host type	Agent strain	Route	# of doses	Dose units	Response	Reference
<i>Cryptosporidium parvum</i> and <i>Cryptosporidium hominis</i> : Dose Response Models	exponential	k = 5.72E-02	1.21E+01	human	TAMU isolate	oral	4	oocysts	infection	Messner et al. 2001
<i>Endamoeba coli</i> : Dose Response Models	beta-Poisson	$\alpha = 1.01E-01$ , $N_{50} = 3.41E+02$	3.41E+02	human	From an infected human	oral	5	Cysts	infection	Rendtorff 1954
<i>Giardia</i>			4.9E+01	human	From an infected human	oral	0	Cysts	infection	Rendtorff 1954

- Dose is the number of oocysts ingested

# From Wiki

- Exponential model
  - $\text{Prob}[\text{response}] = 1 - \exp(-k * \text{dose})$
- Response = infection
- $k=0.0572$

# Risk Characterization

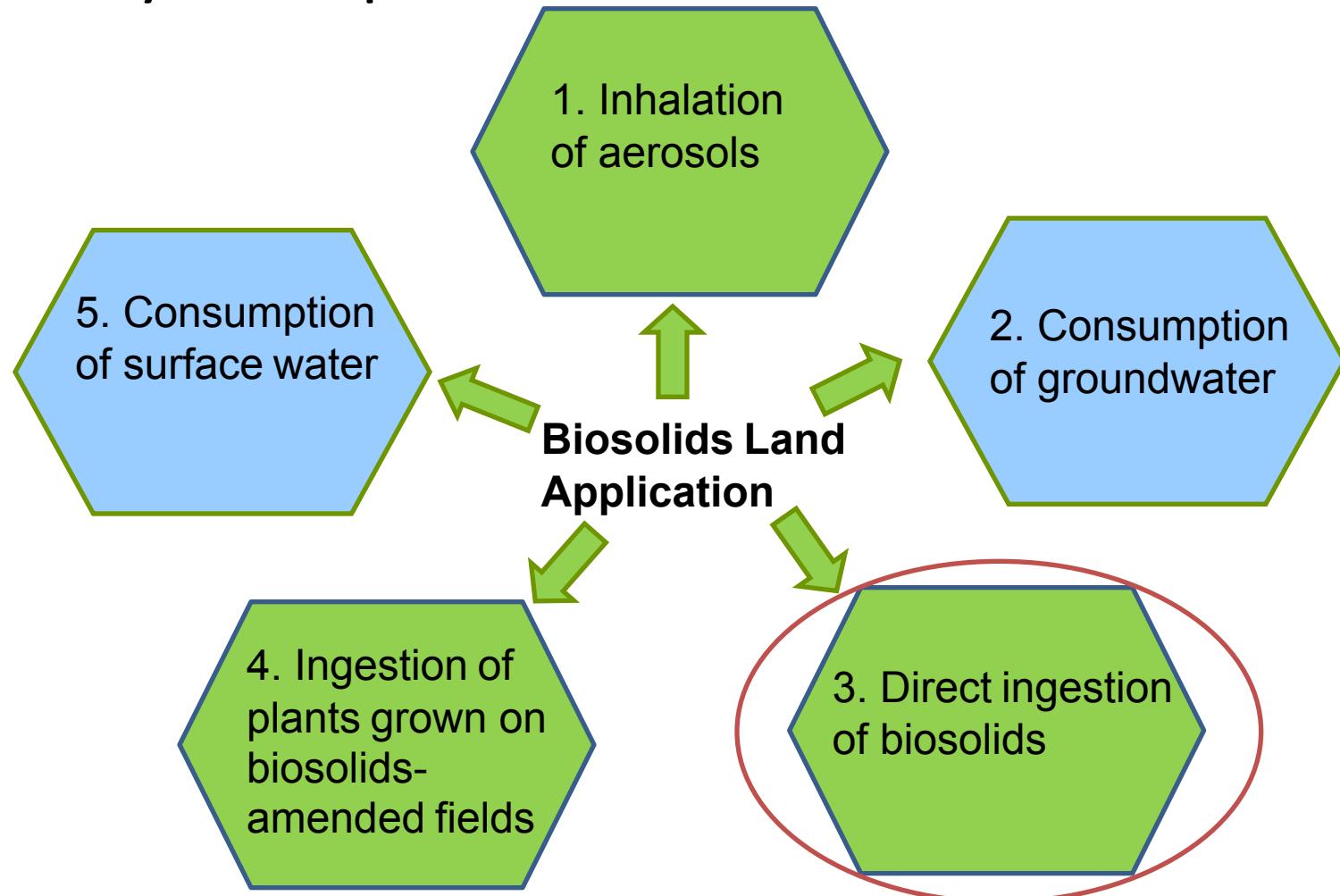
- $\text{Prob}[\text{infection}] = 1 - \exp(-0.0572 * \text{dose})$
- Dose = 1.3 oocysts
- k=0.0572
- $\text{Prob}[\text{infection}] = 1 - \exp(-1.3 \times 0.0572)$
- $\text{Prob}[\text{infection}] = 1 - \exp(-0.0054483)$
- $\text{Prob}[\text{infection}] = 1 - 0.928$
- $\text{Prob}[\text{infection}] = 0.0717$

# Biosolids Case Study

- ❑ Biosolids are the treated solid residuals from sewage
- ❑ Two classes:
  - ✓ Class A – No measurable pathogens
  - ✓ Class B – Treated but measurable pathogens are allowed

# Hazard Identification

- Pathways of Exposure



# Exposure Assessment : Direct Ingestion

- This pathway assumes incidental ingestion of soil after a user specified waiting period.
- Immediate dilution of biosolids when applied to soil:

$$C_{\text{soil},0} = C_{\text{biosolids}} * 0.01 \text{ (per Gerba et al. 2008)}$$

- Gerba, C.P., Castro-del, C., Brooks, J.O., and Pepper, I.L. 2008. Exposure and risk assessment of *salmonella* in recycled residuals. *Wat. Sci. Technol.*, 57 (7): 1061-1065.
- First order decay:

$$C_{\text{soil}}(t) = C_{\text{soil},0} \exp(-k_d * t)$$

Continues ...  
87

# ...Continues

- Dose =  $C_{soil}(t) * \text{soil uptake}$
- For an adult assume 50 mg/day of soil is ingested

(EPA Exposure Factors Handbook, 1997)

- A Monte Carlo analysis was performed
  - Means and ranges identified

# Pathogen – Specific Results

<b>Soil model</b>	<b>Residential adult</b>
<b>Pathogen</b>	<b>Average</b>
Ascaris	1.0913E-05
Cryptosporidium	5.3428E-11
Giardia lamblia	2.6715E-09
Salmonella spp.	2.4492E-13
Shigella spp.	3.1756E-11

# Interpreting Results

- According to this analysis *ascaris* would dominate the risk
- Risk is below 1 in 10,000 benchmark often used for microbial risk
- This may help inform both response and public communication efforts
  - Public confidence will be key issue