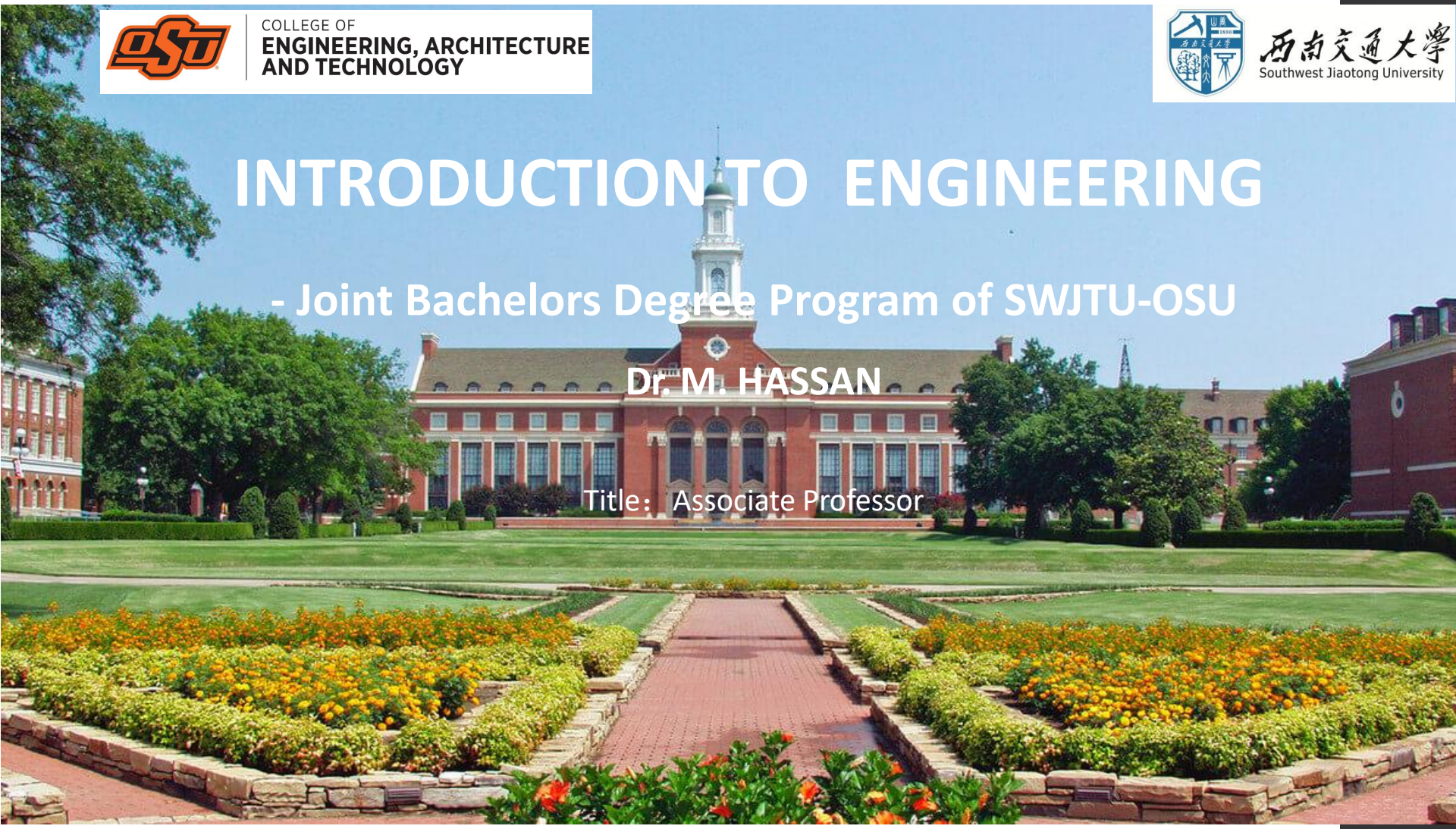
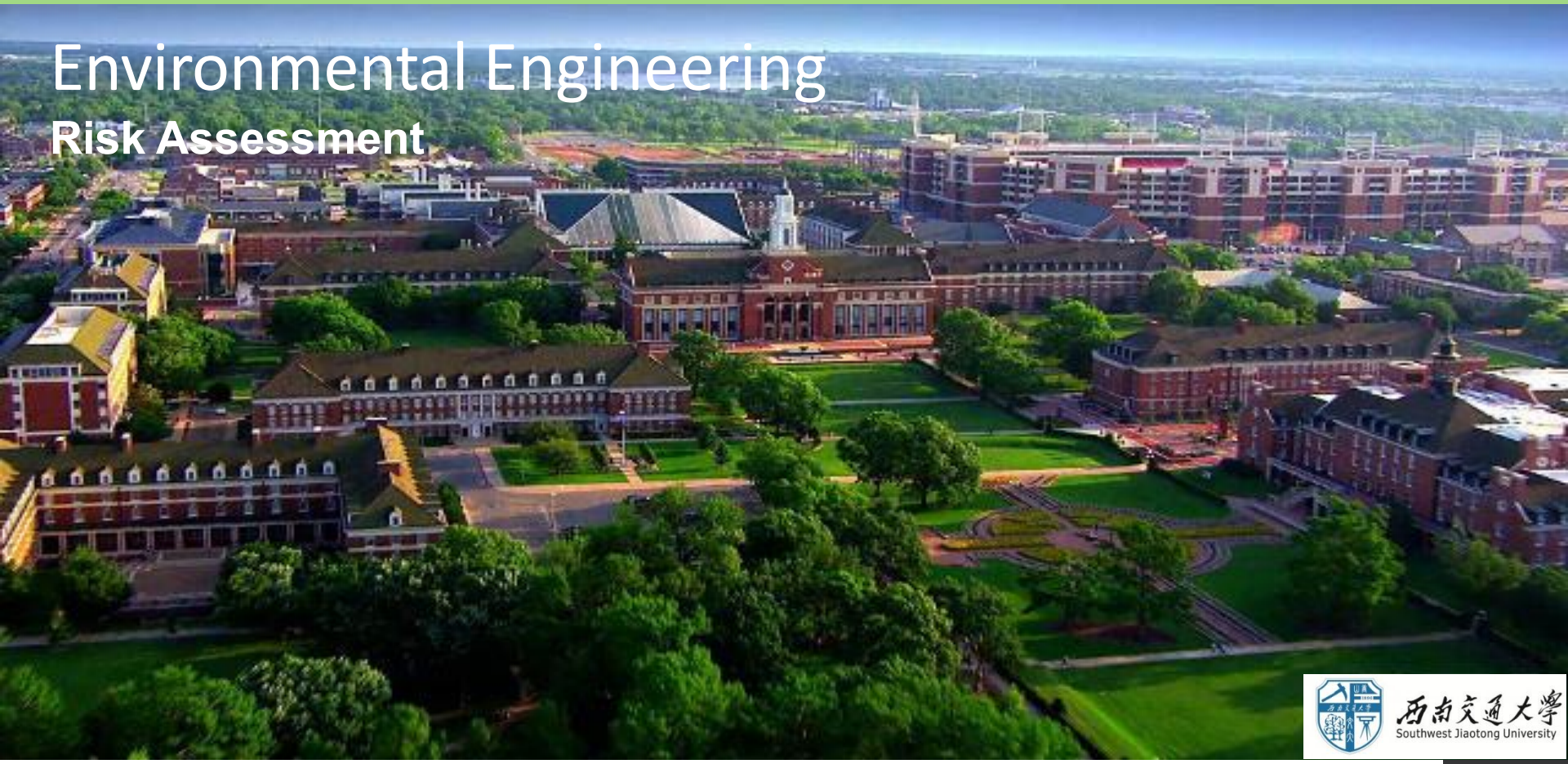

COLLEGE OF
ENGINEERING, ARCHITECTURE
AND TECHNOLOGY
西南交通大學
Southwest Jiaotong University
INTRODUCTION TO ENGINEERING
- Joint Bachelors Degree Program of SWJTU-OSU
Dr. M. HASSAN
Title： Associate Professor

COLLEGE OF
ENGINEERING, ARCHITECTURE
AND TECHNOLOGY

INTRODUCTION TO ENGINEERING

Environmental Engineering

Risk Assessment



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Risk Assessment

- Objectives
  - Concept or perception of risk
  - How to calculate risk
  - The steps involved in performing risk assessments
  - Environmental impact statements

Risk Assessment

- **Risk assessment** is a process used to identify potential hazards and analyze what could happen if a disaster or hazard occurs.
- The main purpose of risk assessment is to avoid negative consequences related to risk or to evaluate possible opportunities.

Risk Assessment

- Concept or Perception of Risk:

Table 5.1 Fifteen Leading Causes of Death in the United States, 2004

Cause	Annual deaths	Risk (%)
1. Heart disease	654,092	27.3
2. Malignant neoplasms (cancer)	550,270	22.9
3. Cerebrovascular (strokes)	150,147	6.3
4. Chronic low respiratory disease	123,884	5.2
5. Accidents (unintentional injury)	108,694	4.5
6. Diabetes mellitus	72,815	3.0
7. Alzheimer's disease	65,829	2.7
8. Influenza and pneumonia	61,472	2.6
9. Nephritis	42,762	1.8
10. Septicemia	33,464	1.4
11. Suicide	31,647	1.3
12. Chronic liver and cirrhosis	26,549	1.1
13. Essential hypertension and hypertensive renal disease	22,953	1.0
14. Parkinson's disease	18,018	0.8
15. Pneumonitis due to solids and liquids	16,959	0.7
All other causes	418,810	17.5
Total deaths	**2,398,365**	**100.0**

Source: Centers for Disease Control, http://webappa.cdc.gov, final 2003 and preliminary 2004.

Risk Assessment

- Concept or Perception of Risk:

Calculating risk

Using the data in Table 5.1, estimate the risk or probability of an American dying from influenza (flu) or pneumonia in 2004. Express the risk as a fraction and as a percentage.

- Total deaths in 2004 = 2,398,365
- Death from influenza = 61,472
- Risk of dying from influenza = $\frac{61,472}{2,398,365}$ = 0.26 or **26%**

Risk Assessment

- **Concept or Perception of Risk:**

Additional risk calculation

Bath County, Virginia, is located in the northwest portion of the state. The county population is approximately 5000. Using the data from Table 5.1, estimate the number of persons in Bath County who died from cancer in 2004. Assume that 100 persons passed away in Bath County in 2004.

- Total Deaths in Bath County in 2004 = 100
- Total deaths in US in 2004 = 2,398,365
  - 2,398,365 – 100 = 2,398,264 deaths
- Deaths from cancer in US in 2004 = 550,270
- Risk of dying from cancer in Bath county in 2004 = $\frac{550,270}{2,398,264}$ = **23%**

Risk Assessment

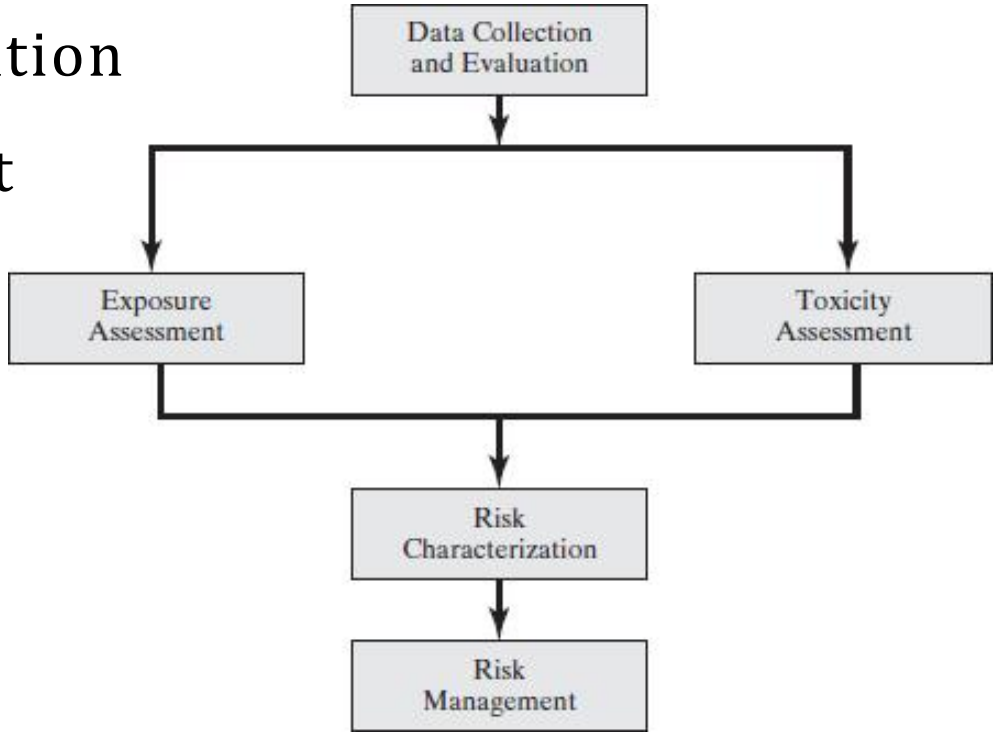
- Concept or Perception of Risk:
  - Risk vs Safety:
    - **Risk** – probability that an adverse effect or outcome will occur
    - **Safety** – probability that no adverse effect will occur
  - Risk:
    - Expressed numerically and has no units
    - Reported as a fraction between 0 and 1 or as a percentage
    - The closer risk is to 1, the higher the probability of the event happening
    - May be calculated as lifetime risk or annual risk

Risk Assessment

- **Risk Assessment:**
  - A Risk is the chance that a hazard will cause harm.
  - Risk is a function of **hazards** and **exposures.**
  - ***Hazard*** – anything that produces an adverse effect on human health and the environment or ecosystem.
    - e.g. work accidents, emergency situations, toxic chemicals, employee conflicts, stress
  - ***Exposure*** – qualitative or quantitative assessment of **contact to the skin or body by a chemical**

Risk Assessment

- Data Collection and Evaluation
- Toxicity Assessment
- Exposure Assessment
- Risk Characterization
- Risk Management



Risk Assessment

Data Collection and Evaluation

- **Objective:** Gather relevant information about the substance or exposure scenario.
- **Activities:**
  - Identify the chemical or biological agent of concern.
  - Collect data on its physical & chemical properties.
  - Review existing literature, studies, & databases for toxicity & exposure data.
  - Assess historical data on human exposure & health effects.

Risk Assessment

- **Toxicity Assessment**
  - Toxicity involves **studying the adverse effects of exposure of living organisms to chemicals or toxicants**
  - The result of exposure depends on an individual's exposure
    - Factors that affect exposure:
      - Gender
      - Age
      - Diet
      - Genetics
      - Prior Exposure

Risk Assessment

- **Toxicity Assessment**

Objective: Determine the relationship between exposure to a substance and the occurrence of adverse health effects.

Activities:

- Identify toxicological endpoints (e.g., cancer, reproductive effects).
- Review dose-response relationships to determine the level of exposure that may cause harm.
- Establish reference doses (RfD) or cancer slope factors (CSF) based on animal studies, epidemiological studies, and clinical data.

Risk Assessment

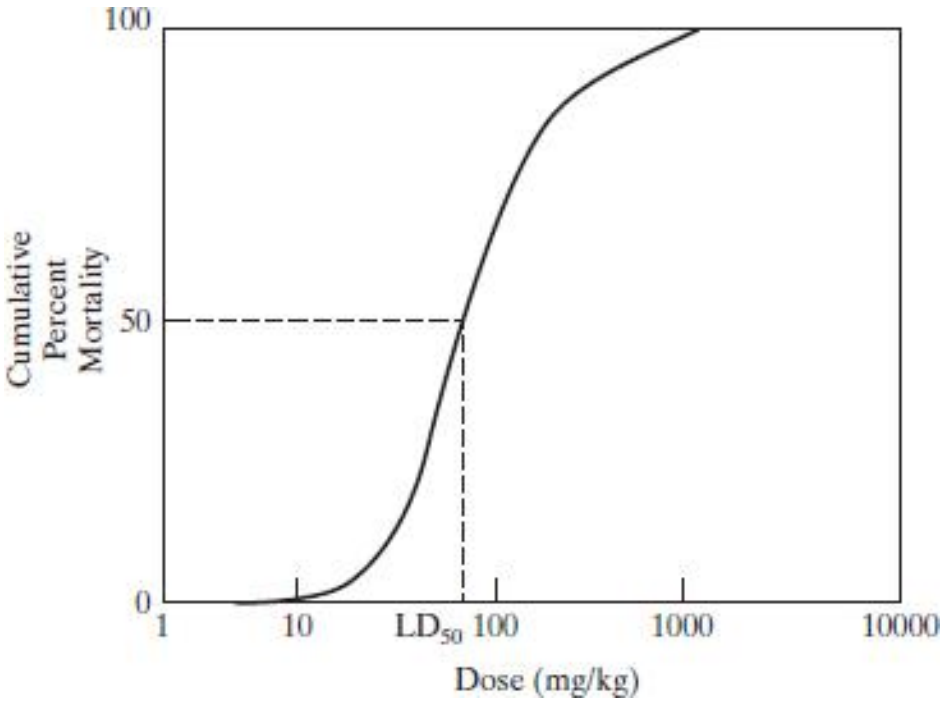
- **Toxicity Assessment**
  - ***Hazard Identification*** – process of determining whether exposure to a toxicant is linked to a particular health effect (examples: cancer, birth defects, etc.)
    - Many times, **studies** are **conducted on animals (*in vivo*)** or **cells/ tissue (*in vitro*).** These studies are called **bioassays**
  - Toxicants can promote **acute** toxicity (short period of time) or **chronic** toxicity (long term exposure)
    - Chronic toxicity may result in mutation of genetic material
  - ***Carcinogens*** – toxicants capable of causing cancer
  - ***Teratogens*** – toxicants capable of causing birth defects

Risk Assessment

- **Toxicity Assessment**
  - ***Dose-response Assessment*** – process of evaluating the **relationship between** the **level of exposure to the toxicant and** the extent of **adverse effect on the individual**
    - Carcinogenic or noncarcinogenic
    - Acute or chronic
  - ***Dose*** – mass of a chemical received by the exposed individual, expressed in milligrams per kilogram (mg/kg) of body weight

Risk Assessment

- **Toxicity Assessment**
  - The **quantity of a specific chemical required to kill an organism** normally follows a S-shaped curve
  - The **dose** at which **50% of the organisms die** is the median **lethal dose (LD_{50})**



Typical dose-response mortality curve and LD_{50}.

Smaller LD_{50} does is **more efficient** than **higher LD_{50}** dose For example; LD_{50}= 1mg/kg > LD_{50} = 5 mg/kg

Risk Assessment

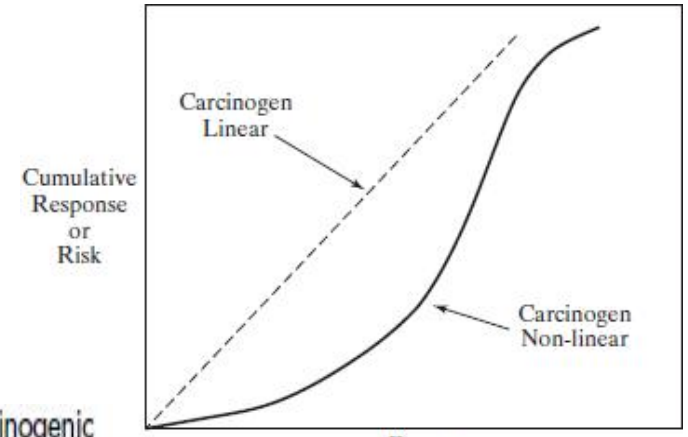
Reference Dose (RfD) for Chronic Noncarcinogenic Effects of Selected Chemicals

Chemical	RfD (mg/kg·day)
Acetone	0.900
Arsenic	0.0003
Benzene	0.004
Chlorine	0.100
Chloroform	0.010
Fluorine (soluble fluoride)	0.060
Mercuric chloride ($HgCl_2$)	0.0003
Methyl mercury (MeHg)	0.0001
Nitrate	1.60
Phenol	0.300
Strontium	0.600
Vinyl chloride	0.003
Xylenes	0.200

Source: U.S. Environmental Protection Agency, http://www.epa.gov/IRIS.

Risk Assessment

- **Toxicity Assessment**



Typical carcinogenic dose-response curves.

- ***Slope Factor*** – slope of the dose-response curve

$$\text{slope factor} = \frac{\text{incremental lifetime cancer risk}}{\text{CDI}}$$

- Where,
  - Slope factor = slope of dose-response curve, (kg*day)/mg
  - Incremental Lifetime Cancer Risk = incremental risk of cancer in a lifetime above the background rate, dimensionless
  - Chronic Daily Intake (CDI) = the average dose of toxicant absorbed per kilogram of body weight over an entire lifetime, (70 years), mg/(kg*day)

Risk Assessment

- **Toxicity Assessment**

Slope Factors for Selected Chemicals for Oral Route

Chemical	Slope factor (kg·day/mg)
Arsenic	1.5
Benzene	1.5×10^{-2} to 5.5×10^{-2}
Carbon tetrachloride	1.3×10^{-1}
Chloroform	6.1×10^{-3}
DDT	3.4×10^{-1}
Dieldrin	1.5×10^{1}
Heptachlor	4.5
PCB	4×10^{-2} low risk; 2.0 high risk
2,4,6-trinitrotoluene	3×10^{-2}
Vinyl chloride	7.2×10^{-1} to 1.5

Source: U.S. Environmental Protection Agency, http://www.epa.gov/IRIS.

Risk Assessment

Exposure Assessment

- **Objective:** Estimate the magnitude, duration, and frequency of exposure to the substance.
- **Activities:**
- Identify exposure pathways (e.g., inhalation, ingestion, dermal contact).
  - Evaluating toxicant releases
  - Estimating exposure-point toxicant concentrations
  - Estimating toxicant intakes for specific pathways

Risk Assessment

Exposure Assessment

- A toxicant can enter the body by:
  - Inhalation – air
  - Ingestion – food and liquids
  - Absorption – dermal
- Exposure media:
  - Surface water
  - Groundwater
  - Sediment
  - Air
  - Soil and dust
  - Food
- ***Exposure Period***
  - Acute (1 day)
  - Subacute (10 days)
  - Subchronic (2 weeks to 7 years)
  - Chronic (7 years to lifetime)

Risk Assessment

- **Exposure Assessment**
  - Generic equation for estimating chronic daily intake (CDI)

$$CDI = \frac{C \times IR \times EF \times ED}{BW \times AT}$$

where:

AT = averaging time, the period over which exposure is averaged, d,
BW = body weight, the average body weight over the exposure period, kg,
C = chemical concentration, the average concentration contacted over the exposure period (e.g., mg/L for water),
CDI = chronic daily intake, mg/kg · d,
ED = exposure duration, yr,

EF = exposure frequency, d/yr, and
IR = intake or contact rate, the amount of contaminated medium taken in or contacted per unit time or event (e.g., L/d, mg/d, kg/meal, m^3/h).

Risk Assessment

- **Exposure Assessment**
  - Reasonable Maximum Exposure (RME) is determined by the EPA

Table 5.5 Residential Exposure Equations for Various Pathways

Exposure route	Intake equation
Ingestion of drinking water	$CDI = \frac{CW \times IR \times EF \times ED}{BW \times AT}$
Ingestion of surface water while swimming	$CDI = \frac{CW \times CR \times EF \times ED}{BW \times AT}$
Dermal contact with water	$CDI = \frac{CW \times SA \times PC \times EF \times ED \times CF}{BW \times AT}$
Ingestion of chemicals in soil	$CDI = \frac{CS \times IR \times CF \times FI \times EF \times ED}{BW \times AT}$
Dermal contact with soil	$CDI = \frac{CS \times CF \times SA \times AF \times ABS \times EF \times ED}{BW \times AT}$
Inhalation of airborne (vapor phase) chemicals	$CDI = \frac{CA \times IR \times ET \times EF \times ED}{BW \times AT}$
Ingestion of contaminated fish, shellfish, fruits, and vegetables	$CDI = \frac{CF \times IR \times FI \times EF \times ED}{BW \times AT}$

Source: U.S. Environmental Protection Agency (1989).

Risk Assessment

- **Exposure Assessment**

ABS = absorption factor, dimensionless;
AF = soil-to-skin adherence factor, mg/cm^2;
AT = averaging time, period over which exposure is averaged, days;
AT = equal to exposure duration for noncarcinogens and 70 years for carcinogens;
BW = body weight, the average body weight over the exposure period, kg;
C = chemical concentration, the average concentration contacted over the exposure period (e.g., mg/L for water);
CA = chemical concentration in air, mg/m^3;
CDI = chronic daily intake, mg/kg · day;
CF = conversion factor (e.g.,1L = 1000 cm^3, 10^{-6} mg/kg);
CR = contact rate, L/h;
CS = chemical concentration in soil, mg/kg;
CW = chemical concentration in water, mg/L;
ED = exposure duration, years;
EF = exposure frequency, days/year;
ET = exposure time, h/day;
FI = pathway specific, fraction ingested, dimensionless;
IR = intake or contact rate, the amount of contaminated medium taken in or contacted per unit time or event (e.g., L/day, mg/day, kg/meal,m^3/h);
PC = chemical specific dermal permeability constant, cm/h; and
SA = skin surface area available for contact, cm^2.

Risk Assessment

- **Exposure Assessment**

Table 5.6 Summary of Standard Default Exposure Factors

Land Use	Exposure pathway	Daily intake	Exposure frequency (days/year)	Exposure duration (years)	Body weight (kg)
Residential	Ingestion of potable water	2 L	350	30	70 (adult) 15 (child)
	Ingestion of soil and dust	200 mg (child) 100 mg (adult)	350	6 (child) 24 (adult)	15 (child) 70 (adult)
	Inhalation of contaminants	20 m^3 (total) 15 m^3 (indoor)	350	30	70
Commercial/ industrial	Ingestion of potable water	1 L	250	25	70
	Ingestion of soil and dust	50 mg	250	25	70
	Inhalation of contaminants	20 m^3 (workday)	250	25	70
Agricultural	Ingestion of potable water	2 L	350	30	70
	Ingestion of soil and dust	200 mg (child) 100 mg (adult)	350	6 (child) 24 (adult)	15 (child) 70 (adult)
	Inhalation of contaminants	20 m^3 (total) 15 m^3 (indoor)	350	30	70
	Consumption of homegrown produce	42 g (fruit) 80 g (vegetable)	350	30	70
Recreational	Consumption of locally caught fish	54 g	350	30	70

Source: U.S. Environmental Protection Agency (1991).

Risk Assessment

- **Exposure Assessment (Calculating chronic daily intake)**

Estimate the chronic daily intake (CDI) of arsenic exposure to a city water supply that contains an arsenic cencentration of 0.010 mg/L, the maximum contaminant level (MCL) established by the EPA. Suppose that a 70-kg person consumes 2 L of the water each day for 70 years. Determine CDI of arsenic in mg/kg.d.

Solution:

$$\text{CDI} = \frac{\text{C} \times \text{IR} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}}$$

C = 0.010 mg/L
IR = 2 L/day
EF = 365 days/year (assuming daily exposure)
ED = 70 years
BW = 70 kg
AT = ED×EF = 70 years×365 days/year = 25,550 days

$$CDI = \frac{0.010\ mg/L \times 2L/day \times 365 days/year \times 70 years}{70\ \text{kg} \times 25{,}550\ \text{days}}$$

CDI = 2.85×10^{-4} mg/kg.day

Risk Assessment

- **Risk Characterization**

Objective: Integrate toxicity and exposure data to estimate the overall risk.

Activities:

- Calculate the risk for different health effects based on exposure levels and toxicity assessments.
- Present findings in terms of risk estimates (e.g., excess cancer risk, hazard index).
- Discuss uncertainties and variability in the data and risk estimates.
- Provide context for the risk estimates (e.g., comparison to regulatory standards).

Risk Assessment

- **Risk Characterization**
  - ***Carcinogens***

Using the chronic daily intake (CDI) value of 2.86×10^{-4} $mg.kg^{-1}.d^{-1}$, determined along with the other data provided, determine:
A) The upper-bound cancer risk per person.
B) The number of extra cancers that would be expected per year in a city of 100,000 people if they consumed the same water containing arsenic.

Solution:

CDI: 2.86×10^{-4} mg/kg/day
Cancer slope factor (CSF) for arsenic: 1.5 $mg/kg/day^{-1}$

Cancer Risk = CDI × CSF= $(2.86 \times 10^{-4}$ mg/kg/day) × (1.5 $mg/kg/day^{-1}$) = **4.29×10^{-4}**

Expected Cancers = Population × Cancer Risk = $100{,}000 \times 4.29 \times 10^{-4}$ = **42.9 cancers**

Risk Assessment

- **Risk Characterization**
  - ***Non-carcenogens***
    - EPA uses a hazard index for noncarcinogenic compounds
    - Hazard Index (HI) is a measure used to assess the potential health risk associated with exposure to multiple chemicals.
    - When more than one non-carcinogenic compound is present, the sum of HIs is determined.
    - A hazard index of less than 1.0 is acceptable

$$HI = \frac{CDI}{RfD}$$

CDI*i* = Chronic Daily Intake for substance *i* (mg/kg/day)

RfD*i*= Reference Dose for substance *i* (mg/kg/day)

Risk Assessment

- **Risk Characterization (Calculating Hazard Index)**

Suppose a 70-kg adult drinks 2.0 liters per day water for a 29-years period. Assume that the water contains 0.05 mg/L of chloroform and 0.6 mg/L of nitrates.

A) Determine the hazard index and state whether this is acceptable or unacceptable. $RfD_{chloroform}$ is 0.01 mg/kg.d and $RfD_{nitrate}$ is 1.60 mg/kg.d.

B) Chloroform is a potential carcinogen. Determine the carcinogen risk associated with drinking water containing 0.05 mg/L of chloroform. Would it meet the goal of 1×10^{-6} that is usually recommended by EPA? [Cancer Slope Factor (CSF) for chloroform is 6.1×10^{-3} kg.d/mg]

$$HI = \frac{CDI}{RfD}$$

Solution:

$C_{chloroform}$ = 0.05 mg/L

$C_{nitrates}$ = 0.6 mg/L

IR = 2 L/day

EF = 365 days/year (assuming daily exposure)

ED = 70 years

BW = 70 kg

AT = ED×EF = 29 years×365 days/year = 10,585 days

$$CDI_{chlroform} = \frac{C \times IR \times EF \times ED}{BW \times AT} = 1.43 \times 10^{-3} \text{ mg/kg.d}$$

$CDI_{nitrate} = 1.71 \times 10^{-2}$ mg/kg.d

$$HI_{chloroform} = \frac{1.43 \times 10^{-3}\ mg/kg.d}{0.01\ mg/kg.d} = 0.143$$

$$HI_{nitrate} = \frac{1.71 \times 10^{-2} \text{ mg/kg.d}}{1.6 \text{ mg/kg.d}} = 0.0107$$

HI = $HI_{chloroform} + HI_{nitrates}$ = **0.154**

acceptable as **HI < 1**.

Cancer Risk = $CDI_{chlroform} \times CSF$ = $(1.43 \times 10^{-3}$ mg/kg.d)×$(6.1 \times 10^{-3}$ kg.d/mg) = **8.73×10^{-6} does not meet EPA goal** (1×10^{-6})

Risk Assessment

- **Risk Management**
  - **Objective:** Develope strategies to mitigate identified risks
- Identify risk management options (e.g. regulatory actions, community education, pollution controls).
- Evaluate feasibility & effectiveness of different strategies.
- Engage stakeholders (利益相关者) & public to gather input & address concerns.
- Implement selected risk management approaches & monitor their effectiveness.
- Review & revise risk management approaches

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