This lecture will help you understand:

- Environmental health and environmental hazards
- Toxic substances in the environment
- Movement of toxic substances and their effects
- Chemical hazards
- Risk assessment and risk management
- Philosophical approaches to risk
Central Case Study: Bisphenol A Is Everywhere — But Is It Safe?

- Bisphenol A (BPA) is in hundreds of products
  - Cans, utensils, baby bottles, laptops, toys
- BPA causes cancer, nerve damage, and miscarriages
  - In extremely low doses
- BPA leaches into food, air, and bodies
  - 93% of Americans have it in their bodies
Central Case Study: Bisphenol A Is Everywhere — But Is It Safe? (cont’d)

• BPA mimics estrogen, a female hormone
  • The body reacts to it as it would to estrogen

• Researchers, doctors, and consumer advocates want governmental regulation
  • The chemical industry insists it is safe

• Some countries and states have banned it
  • Many companies are voluntarily removing it
Environmental Health

• Environmental health
  • Assesses environmental factors that influence human health and quality of life
  • Includes natural and human-caused factors
  • Practitioners try to prevent adverse effects on human health and ecological systems
We face four types of environmental hazards

1. *Physical hazards*
   - Occur naturally in our environment
   - UV radiation, earthquakes, volcanoes, fires, floods, landslides, hurricanes, droughts, etc.
   - We can’t prevent them, but we can prepare for them with proper planning and, in some cases, avoid causing them
   - We increase our vulnerability by deforesting slopes (landslides), channelizing rivers (flooding), etc.
We face four types of environmental hazards (cont’d)

2. **Chemical hazards**
   - Synthetic chemicals such as pharmaceuticals, disinfectants, pesticides
   - Some natural chemicals (e.g., lead) are also harmful

3. **Biological hazards**
   - Result from ecological interactions
   - Infectious disease
     - Viruses, bacteria, and other pathogens (e.g., malaria, cholera) parasitize humans
   - We can’t avoid risk, but we can reduce infection through monitoring, sanitation, and treatment
We face four types of environmental hazards (cont’d)

4. **Cultural hazards**
   - Result from where we live, our socioeconomic status, occupation, or behavioral choices
   - We can minimize some, but not all, of these hazards
   - Examples include smoking, drug use, diet and nutrition, crime, mode of transportation
   - Risks (e.g., living near toxic waste) are often correlated with poverty or lack of political clout
Disease is a major focus of environmental health

- Despite our technology, disease kills most of us
- Noninfectious diseases
  - Genetic, lifestyle, and environmental basis
  - Not spread from one person to another
  - Cancer, heart disease
  - Poverty and poor hygiene foster illnesses
Disease is a major focus of environmental health (cont’d)

- Leading cause of death by infectious disease
  - Respiratory infections
- **Vector**
  - An organism that transfers disease to a host
- Infectious diseases account for 50% of deaths in poor nations
- Developed countries can pay for
  - Nutrition, sanitation, hygiene, and medicine

![Bar chart](chart.png)

(b) Leading causes of death by infectious diseases
Data Question

- AIDS is a well-known infectious disease, but respiratory and diarrheal diseases claim far more lives every year than AIDS.

- According to the figure, how many times more lives were lost to respiratory infections and diarrheal diseases than to AIDS?
Disease is a major focus of environmental health (cont’d)

- Public health has decreased some infectious diseases
  - Others (e.g., AIDS) are spreading
  - Some (e.g., malaria, tuberculosis) develop resistance to antibiotics
  - New diseases can spread rapidly (e.g., avian flu, swine flu)
  - Rapidly evolving diseases (e.g., influenza) can become more dangerous and cause a global pandemic
Toxicology is the study of chemical hazards

- **Toxicology**
  - The study of the effects of poisonous substances on humans and other organisms

- **Toxicity**
  - The degree of harm a chemical can inflict

- **Toxicant**
  - Any toxic substance (poison)
  - “The dose makes the poison”: toxicity depends on the combined effect of the chemical and its quantity
Toxicology is the study of chemical hazards (cont’d)

• **Environmental toxicology**
  • Deals with toxic substances that come from or are discharged into the environment
  • Studies animals and plants to determine whether they indicate human health threats
Most environmental health hazards exist indoors

- Most Americans spend 90% of their time indoors
- Cigarette smoke and radon cause lung cancer
- Mold in homes and offices produces toxic compounds
- Asbestos used for insulation causes problems if inhaled
- Lead in pipes and gasoline damages organs and causes learning problems, hearing loss, and death
  - Education and phaseout decreased lead poisoning
Most environmental health hazards exist indoors (cont’d)

- **Polybrominated diphenyl ethers (PBDEs)**
  - Used in computers, televisions, plastics, and furniture
  - Act as hormone disruptors
  - Now banned in Europe, but not in the U.S.
Risks must be balanced against rewards

• Chemicals have given us our high standard of living
  • Industrial agriculture’s production of food
  • Medical advances to protect our health and prolong our lives
  • Modern materials and conveniences
• We need to remember the benefits
  • Examine negative side effects
  • Search for better alternatives
Toxic substances and their effects on organisms

• Natural chemicals in the environment may pose risks

• Toxins
  • Toxic chemicals made in tissues of living organisms (e.g., plants produce chemicals to ward off being eaten)

• But synthetic chemicals are also in our environment
  • Every one of us carries traces of hundreds of industrial chemicals in our bodies

• Babies are born with chemicals already in their bodies

• Not all synthetic chemicals pose health risks
  • But few of the 100,000 chemicals on the market have been tested
Synthetic chemicals travel through the environment

- Synthetic chemicals travel through the environment
- People receive toxicants from many sources
Silent Spring began the public debate over synthetic chemicals

- In the 1960s, untested pesticides were sprayed with the assumption that they would not harm people
- Rachel Carson’s Silent Spring (1962) showed DDT’s risk to people, wildlife, and ecosystems
  - This best-seller generated social change in views and actions towards the environment
- DDT was banned in the U.S. in 1973
  - But developing countries with tropical climates still use it to control mosquitoes that cause malaria
Weighing the Issues

- Ethics and Insecticides
  - Although many nations have banned the use of DDT, the compound is still manufactured in India and exported to developing nations that lack such bans.
  - How do you feel about this?
  - Is it unethical for a company to sell a substance that has been deemed toxic by so many nations?
  - Or would it be unethical not to sell DDT to tropical nations if they desire it for improving public health, such as controlling mosquitoes that transmit malaria?
Not all toxic substances are synthetic

- Toxic chemicals also exist naturally and in our food
  - Don’t assume natural chemicals are all healthy and synthetic ones are all harmful
- Plants (even crops) contain harmful chemicals
- Meat contains toxins that animals got from the plants and animals they ate
- Scientists are debating how much risk natural toxicants pose
Toxicants come in different types

- **Carcinogens**: cause cancer
  - Hard to identify because of the long time between exposure and onset of cancer
- **Mutagens**: cause DNA mutations
  - Can cause cancer and harm sperm or egg cells
- **Teratogens**: cause birth defects in embryos
- **Neurotoxins**: affect the nervous system (lead, mercury)
- **Allergens**: overactivate the immune system
- **Pathway inhibitors**: interrupt biochemical processes
  - Rat poison stops blood clotting
Toxicants come in different types (cont’d)

- Endocrine disruptors: affect the endocrine (hormone) system
  - Regulate brain function, appetite, sex drive, etc.
- Hormones stimulate growth, development, sexual maturity
  - Synthetic chemicals can block or mimic hormones
Organisms have natural defenses

• Organisms have been exposed to natural toxicants (mercury, arsenic, venom, etc.) for millions of years
• Skin, scales, feathers are barriers that prevent toxin intake
  • But toxins can enter through food, water, air
• Biochemical pathways can detoxify (metabolize) toxins or make them water soluble so they can be excreted
Organisms have natural defenses (cont’d)

- Organisms can store toxins (e.g., heavy metals) in the body
- Defenses can be overwhelmed if levels get too high
  - Other toxicants are harmful at any level
- Organisms have no natural defense against synthetics
Individuals vary in their responses to hazards

- Different individuals respond differently to hazards
  - Genetics can affect responses
  - People in poor health are more sensitive
  - Sensitivity also varies with sex, age, and weight
  - Fetuses, infants, and young children are more sensitive
- U.S. Environmental Protection Agency (EPA)
  - Sets standards for responses based on adult responses
  - Standards may not be low enough to protect the young
The type of exposure affects the response

- **Acute exposure**
  - High exposure to a hazard for short periods of time
  - Easy to recognize
  - Stem from discrete events: ingestion, oil spills, nuclear accident, etc.
  - Toxicity tests reflect effects of acute toxicity

- **Chronic exposure**
  - Low exposure for a long time
  - More common but harder to detect and diagnose
  - Affects organs gradually: for example, lung cancer, liver damage
  - Cause and effect may not be easily apparent
Toxic substances and their effects on ecosystems

• When toxicants harm individuals, populations become smaller
  • This decline affects other species
• If predator species are affected…
  • Prey species can experience population growth
• If prey species are affected…
  • Predators decline as their food source declines
• Cascading impacts change the community’s composition
  • Threaten ecosystem function
  • Toxins concentrate and persist in systems in many ways
Airborne substances can travel widely

- Chemicals can travel by air
  - Impact areas far from the site of use
- Synthetic chemicals are found globally
  - In Arctic polar bears, Antarctic penguins, and people in Greenland
- Pesticide drift
  - Airborne transport of pesticides
Toxins substances may concentrate in water

- Runoff concentrates contaminants in surface water
- Wastewater treatment plants
  - Release toxins, pharmaceuticals, and detoxification products from humans
  - Contaminate drinking water
- Water-soluble chemicals enter organisms through drinking or absorption
  - Fish, frogs, stream invertebrates indicate pollution
- Contaminants in streams and rivers enter drinking water and the air
  - Toxicants move long distances through aquatic systems
Some toxicants persist in the environment

- Toxins can degrade quickly and become harmless
  - Or they may remain unaltered and persist for decades
  - Rates of degradation depend on the substance, temperature, moisture, and sun exposure
- Toxicants can degrade into simpler breakdown products
  - May be more, or less, harmful than the original substance
  - DDT degrades into DDE, which is also highly persistent and toxic
Toxicants can accumulate and biomagnify

• **Bioaccumulation**
  - Fat-soluble toxicants build up in animal tissues
  - Can transfer toxins to others through the food chain

• **Biomagnification**
  - Toxicant concentrations are magnified through trophic levels
  - Resulted in the near extinction of peregrine falcons and bald eagles
Toxic substances can threaten ecosystem services

- Toxicants can change the composition of ecosystems
  - Affect how organisms interact with each other and the environment
  - Threaten ecosystem services
- Pesticides have killed bees
  - Farmers must hire beekeepers to pollinate their crops
- Pesticides and antifungals kill decomposers and detritivores in the soil
  - Nutrient cycling rates are changed
  - Reduced nutrients slow plant growth
Wildlife studies integrate work in the field and lab

• Studying the impacts of hazards on wild animals can help
  • Conserve wild populations
  • Clarify risks to humans

• Fieldwork and lab experiments test the effects of hazards

• Alligators and frogs show reproductive abnormalities caused by endocrine disruption from pesticides

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Human studies rely on case histories, epidemiology, and animal testing

- **Case history approach**
  - Process of observing and analyzing individual patients

- **Epidemiological study**
  - Compares a group of people who were exposed to a hazard to a group who were not exposed
  - Studies can last for years
  - If rates of death, cancer, etc., are higher in the exposed group, the hazard may be responsible
  - Does not show that the hazard caused the effect

- **Manipulative experiments show causation**
  - But are unethical in humans
  - Mammals (rats, mice, etc.) are used because they elicit fewer ethical objections
Dose-response analysis is a mainstay of toxicology

- **Dose-response analysis**
  - Quantifies a substance’s toxicity
  - Measures the strength of toxicant’s effects or the number of animals affected at different doses

- **Dose**
  - Amount of substance the test animal receives

- **Response**
  - The type or magnitude of negative effects

- **Dose-response curve**
  - The dose plotted against the response
Dose-response analysis is a mainstay of toxicology (cont’d)

- \(LD_{50}/ED_{50}\) (lethal dose/effective dose)
  - The amount of toxicant required to kill/affect 50% of the subjects
  - A high number indicates low toxicity
- Threshold dose
  - The level where a response occurs
  - Organs can metabolize or excrete low doses of a toxicant
- Estimating human effects requires extrapolation, so regulatory agencies set standards below minimum toxicity levels
Dose-response analysis is a mainstay of toxicology (cont’d)

- Sometimes a response decreases as a dose increases
  - U- or J-shaped or an inverted-U dose-response curve
  - “The dose does not make the poison!”
- Counterintuitive curves occur with endocrine disruptors
  - The hormone system responds to tiny concentrations of hormones
  - Endocrine system is vulnerable to extremely low concentrations of chemicals
Chemical mixes may be more than the sum of their parts

• We can’t determine the impact of mixed hazards
  • They may act in ways that cannot be predicted from the effects of each in isolation
  • Mixed toxicants can sum, cancel out, or multiply each other’s effects

• Synergistic effects
  • Interactive impacts that are greater than the sum of their constituent effects
  • DDE may cause or inhibit sex reversal, depending on the presence of other chemicals

• Scientists cannot test all chemical combinations
Endocrine disruption poses challenges for toxicology

• Unconventional dose-response curves
  • Hard to study and set safety standards for these substances

• Theo Colburn’s *Our Stolen Future* (1996)
  • Describes how synthetic chemicals may be changing animals’ hormones

• Bisphenol A (BPA)
  • Suspected of causing reproductive harm (reduced sperm counts and quality, etc.)
The Science Behind the Story

• **Testing the Safety of Bisphenol A (BPA)**
  • Dr. Hunt at Case Western Reserve University in Ohio
    • Noticed that 40% developing mice eggs showed problems with their chromosomes
    • Investigated and found that a lab assistant had washed plastic cages and water bottles with a harsh soap
    • Cages contain BPA
• Testing the Safety of Bisphenol A (BPA)
  • Her lab researchers re-created the accidental cage-washing incident in controlled experiments
• Results
  • Developing eggs exposed to BPA through deliberately damaged plastic showed significant problems during meiosis
The Science Behind the Story (cont’d)

• Testing the Safety of Bisphenol A (BPA)
  • Additional testing
    • Females received daily oral doses of BPA over 3, 5, 7 days
    • Same meiotic abnormalities were observed but at lower levels
    • Mice given BPA for 7 days were most severely affected
  • These findings were published
    • Hundreds of other studies of BPA at low doses have documented harmful effects in lab animals
  • More and more scientists urge regulators to adopt the precautionary principle and restrict bisphenol A
Data Question

• Using the figure, predict the percentage of mice in the study that would likely suffer chromosomal problems when exposed to a BPA dosage of 70 ng/g.
We express risk in terms of probability

- Exposure to a threat doesn’t automatically produce an effect
  - Rather, it causes some probability (likelihood) of harm
- A substance’s threat depends on its identity and strength
  - Chance and frequency of an encounter
  - An organism’s exposure and sensitivity to the threat
- **Probability**
  - Describes the likelihood of a certain outcome
- **Risk**
  - The probability that some harm results from an action, event, or substance
Our perception of risk may not match reality

- Everything we do involves some level of risk
- We try to minimize risk
  - But perception may not match reality
  - Flying versus driving
- We feel more at risk when we do not control a situation
  - We fear nuclear power and toxic waste
  - But not smoking or overeating
Risk assessment analyzes risk quantitatively

- **Risk assessment**
  - The quantitative measurement of risk
  - Compares risks involved in different activities or substances
  - Identifies and outlines problems
  - Helps determine which substances and activities pose health threats to people or wildlife

- **Risk assessment has several steps**
  - The scientific study of toxicity
  - Assessing an individual or population’s exposure to the substance (frequency, concentrations, length)
Risk management combines science and other social factors

- Risk management
  - Decisions and strategies to minimize risk
- Federal agencies manage risk
  - The U.S. has the Centers for Disease Control and Prevention (CDC), the EPA, the Food and Drug Administration (FDA)
- Scientific assessments are considered with economic, social, and political needs and values
- Comparing costs and benefits is hard
  - Benefits are economic and easy to calculate
  - Health risks (costs) are hard-to-measure probabilities of a few people suffering and lots of people not
Risk assessment aids in risk management

• The end result of risk management is a policy decision that minimizes the risk of an environmental hazard

Scientific results and measurement of probability

Risk assessment

Political, social, economic, and ethical considerations

Risk management

Policy

Scientific data on

Hazard identification

Toxicity characterization

Extent of exposure

Information, opinion, and lobbying from

Private citizens

Industry and manufacturing

Nonprofit interest groups
Two approaches exist for testing the safety of new products

• “Innocent-until-proven-guilty” approach
  • Assumes a substance is harmless until it is shown to be harmful
  • Promotes technological innovation and economic activity
  • But allows dangerous substances to be used

• Precautionary principle
  • Assumes a substance is harmful until it is shown to be harmless
  • Identifies troublesome toxicants before they are released
  • But may impede the pace of technology and economic advancement
Two approaches exist for testing the safety of new products (cont’d)

- Who should have to prove a product is safe: the manufacturers or government/citizens?

<table>
<thead>
<tr>
<th>Sequence of events</th>
<th>“Innocent until proven guilty” approach</th>
<th>Precautionary principle approach</th>
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<tbody>
<tr>
<td>Industrial research and development</td>
<td>Limited testing; most products brought to market</td>
<td>Rigorous testing; only the safest products brought to market</td>
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<tr>
<td>Pre-market testing by industry, government, and academic</td>
<td>Some products harm human health</td>
<td>Minimal impact on human health</td>
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<td>Consumer use of products</td>
<td>Rigorous testing demanded</td>
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<td>Post-market testing by industry, government, and academic</td>
<td>Unsafe products recalled</td>
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<td>Regulations and bans of unsafe products</td>
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<tr>
<td>Consumer use of safe products</td>
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Weighing the Issues

• The Precautionary Principle
  • Industry’s critics say chemical manufactures should bear the burden of proof for the safety of their products before they hit the market
  • Industry’s supporters say that mandating more safety research will hamper the introduction of products that consumers want and will increase the price of products
  • What do you think? Should the government follow the precautionary principle and require proof of safety prior to a chemical’s introduction into the market?
Two approaches exist for testing the safety of new products (cont’d)

- Europe incorporates the precautionary principle
- The U.S. uses the innocent-until-proven-guilty approach
- Federal agencies involved in tracking and regulating synthetic chemicals include:
  - The FDA
    - Monitors food, food additives, cosmetics, drugs, medical devices
  - The EPA
    - Regulates pesticides and synthetic chemicals not covered by other laws
  - OSHA (Occupational Safety and Health Administration)
    - Regulates workplace hazards
EPA regulation is only partly effective

- The Toxic Substances Control Act (TSCA) (1976)
  - EPA monitors chemicals made in or imported into the U.S.
  - EPA can ban substances that pose excessive risk
- Many health advocates think the TSCA is too weak
  - Industry screening is minimal
  - To push for more testing, toxicity must already be proven, but testing is minimal
  - Only 10% of chemicals have been tested for toxicity
  - Fewer than 1% are regulated
  - Almost none have been tested for endocrine, nervous, or immune system damage
Frequently Asked Question

• If the government allows a product to be sold in stores, isn’t it safe?
Toxicants are regulated internationally

- The European Union’s REACH program (Registration, Evaluation, Authorization, and Restriction of Chemicals)
  - Shifts the burden of proof for safety to industry
  - 30,000 chemicals will have to be registered with the European Chemicals Agency
- The Stockholm Convention on Persistent Organic Pollutants (POPs)
  - Enacted in 2004 and ratified by over 150 nations
  - The “dirty dozen”: the 12 most dangerous POPs
  - Sets guidelines for phasing out these chemicals
  - Encourages transition to safer alternatives
Conclusion

• International agreements
  • Show that governments are working to protect society, wildlife, and ecosystems from toxic chemicals and environmental hazards
• But solutions need more than government regulations
  • Consumer choice affects industries
• Once scientific results are in, society’s approach to risk management determines what policies are enacted
• A safe and happy future depends on knowing the risks some hazards pose
  • Then replacing those substances with safer ones