Impacts on the Environment and Human Health

CHAPTER 10

Health, learning and virtue will ensure your happiness; they will give you a quiet conscience, private esteem and public honour.

—Thomas Jefferson

HAZARDS TO HUMAN HEALTH

Environmental risk analysis is the comparing of the risk of a situation to its related benefits. It is the overall process that allows one to evaluate and deal with the consequences of events, based on their probability. There are four classes of risk:

1. High risk—such as smoking or driving while intoxicated
2. Low risk—infrequent events that may have a large consequence, such as an earthquake on the East Coast of the United States
3. Very low risk—events that have never occurred in recorded history, such as a major meteor striking the North American continent
4. Mixed risk—outcomes that increase in frequency against a background of occurrences, such as additional cases of cancer beyond that normally expected

Understanding how people accept risk requires an understanding of how preferences are accepted and measured. The three types of preferences are revealed, expressed, and natural standards. Revealed preferences are observations on the risks people actually take. Expressed preferences are often measured through public opinion polls. Natural standards are levels of risk humans have lived with in the past.

Risk estimation is a scientific question, while acceptability of a given level of risk is a political question. We can see this distinction by comparing the risk of smoking with working in a coal mine. If the United States spent as much money on premature deaths and illnesses caused by smoking tobacco as we do on coal mine safety, there would be little money left in the United States for any other purpose. This is the political reality of risk acceptance that goes beyond risk estimation.

Three problems arise in risk analysis. First, lack of information leads to uncertainty and is known as a default option. Next, complexity of the information often leads to confusion. Finally, the failure to interpret uncertainty and complexity.

External influences are factored into decisions regarding risk. These influences include public concern, economic interest, and legislative actions that affect the possible choices available.

Risk analysis is divided into risk assessment and risk management. Risk assessment is an objective estimation of risk. It includes the identification of hazards, dose-response assessment, exposure assessment, and risk characterization.

Risk management is the process of determining what to do about risk. This includes risk identification and use of mitigating measures to reduce risk. Risk management has a scientific basis and uses inference to the extent possible that is free of policy implications. Once a risk has been characterized, risk management can be used either to prevent or to mitigate the risk. Risk prevention focuses on not doing or not allowing the risk to occur. In contrast, risk mitigation focuses on subsequent activity to limit the consequences. Risk management should take into consideration societal, economic, and political factors when weighing strategies for risk management. It is this dimension that many times causes tension between the scientific community and the decision makers.

RISK MANAGEMENT STRATEGY

- **Market-based method**—Relies on market forces to provide indirect controls. Usually the response from industry.
- **Hierarchical method**—Relies on explicit controls and top-down management styles (government, laws, etc.). Usually the response from lawmakers.
- **Sectarian method**—Relies on emotions. Usually the response from citizens.
- **Rational method**—Relies on logic and facts in decision making. Usually the response from researchers.

Acute and Chronic Effects

Acute health effects are characterized by sudden and severe exposure and rapid absorption of the substance. Normally, a single large exposure is involved. Acute health effects are often reversible, such as carbon monoxide poisoning.

Chronic health effects are characterized by prolonged or repeated exposures over many days, months, or years. Symptoms may not be immediately apparent. Chronic health effects are often irreversible. Examples include lead or mercury poisoning, asbestosis, or cancer.

Dose-Response Relationships

Dose-response relationships describe the change in effect on an organism or a population caused by differing levels of exposures to a substance. These relationships are used to determine whether various environmental risks are safe or hazardous.

A dose-response curve is a graph that relates the amount of drug or toxin given (plotted on the x-axis and usually the logarithm of the dose) compared with the response (plotted on the y-axis and usually provided in percentages). The point on the graph where the response is first observed is known as the threshold dose. For most drugs, the desired effect is found slightly above the threshold dose. When past this point, negative side effects begin to appear.

LD_{50} (lethal dose, 50%) is the median lethal dose of a pollutant or drug that kills half the members of a tested population within 14 days and is the most common indicator of toxicity. EC_{50} is the concentration of a compound where 50% of its effect is observed.

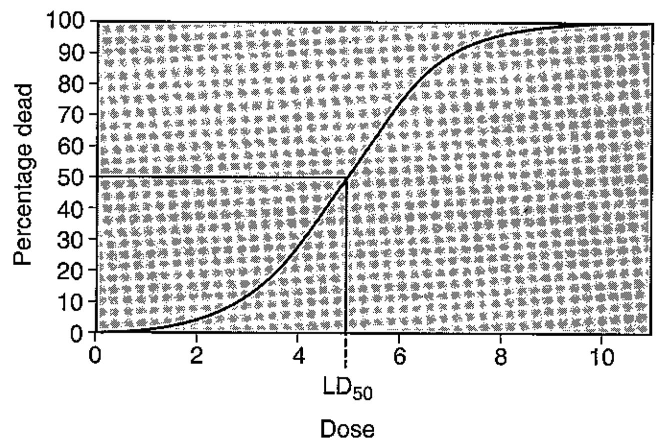

Figure 10.1 A dose-response curve

Air Pollutants and Their Effect on Human Health

AIR TOXICS

Air toxics are a group of air pollutants that are known or suspected to cause serious health problems. Examples of air toxics include asbestos, benzene, chloroform, formaldehyde, lead, mercury and nickel compounds, and perchloroethylene. People exposed to air toxics at sufficient concentrations and durations may have an increased chance of developing cancer or other serious health problems. These include damage to the immune system as well as neurological, reproductive (reduced fertility), developmental, and respiratory problems.

ASBESTOS

Studies of people who were exposed to asbestos in factories and shipyards have shown that breathing high levels of asbestos fibers can lead to an increased risk of lung cancer, mesothelioma (a cancer of the lining of the chest and the abdominal cavity), and asbestosis (the lungs become scarred with fibrous tissue). Researchers have not yet determined a safe level of exposure. However, they know that the greater and longer the exposure, the greater the risk of contracting an asbestos-related disease. Risks of lung cancer and mesothelioma increase with the number of fibers inhaled. The risk of lung cancer from inhaling asbestos fibers is also greater for smokers. People who develop asbestosis have usually been exposed to high levels of asbestos for a long time. The symptoms of these diseases do not usually appear until about 20 to 30 years after the first exposure.

CARBON MONOXIDE (CO)

Carbon monoxide enters the bloodstream through the lungs and binds chemically to hemoglobin, the substance in blood that carries oxygen to cells. In this way, CO interferes with the ability of the blood to transport oxygen to organs and tissue throughout the body. This can cause slower reflexes, confusion, and drowsiness. It can also reduce visual perception and coordination and can decrease the ability to learn. People with cardiovascular disease, such as angina, are most at risk from exposure to CO. These individuals may experience chest pain and other cardiovascular symptoms if they are exposed to CO, particularly while exercising.

INDOOR AIR POLLUTANTS

Remember

Environmental problems have a cultural and social context. Understanding the role of cultural, social, and economic factors is vital to the development of solutions.

Health effects from indoor air pollutants may be acute and experienced soon after exposure or may be chronic. Immediate effects may show up after a single exposure or repeated exposures. These include headaches, dizziness, fatigue, and irritation of the eyes, nose, and throat. Such immediate effects are usually short term and treatable. The likelihood of immediate reactions to indoor air pollutants depends on several factors: age, preexisting medical conditions, and individual sensitivity. Certain immediate effects are similar to those from colds or other viral diseases. Other health effects from exposure to indoor air pollutants may show up either years after exposure has occurred or only after long or repeated periods of exposure. These effects, which include some respiratory diseases, heart disease, and cancer, can be severely debilitating or fatal.

LEAD (Pb)

Exposure to lead can occur through inhalation of air and ingestion of lead in food, water, soil, or dust. Excessive lead exposure can cause seizures, brain and kidney damage, mental retardation, and/or behavioral disorders. Children six and under are most at risk because their bodies are growing quickly.

NITROGEN DIOXIDE (NO_2)

Health effects of exposure to nitrogen dioxide include coughing, wheezing, and shortness of breath in children and adults with respiratory disease such as asthma. Even short exposures to nitrogen dioxide can affect lung function and may cause permanent structural changes in the lungs.

OZONE (O_3)

The reactivity of ozone causes health problems because it damages lung tissue, reduces lung function, and sensitizes the lungs to other irritants. Exposure to ozone for several hours at relatively low concentrations has been found to reduce lung function significantly and to induce respiratory inflammation in normal, healthy people during exercise. This decrease in lung function is generally accompanied by symptoms including chest pain and pulmonary congestion.

PM_{10}

Coarse particles can aggravate respiratory conditions such as asthma. Exposure to fine particles is associated with several serious health effects, including premature death. When exposed to PM_{10}, people with existing heart or lung diseases such as asthma, chronic obstructive pulmonary disease, and congestive or ischemic heart disease are at increased risk of premature death. Older persons are especially sensitive to PM_{10} exposure. When exposed to PM_{10}, children and people with existing lung disease may not be able to breathe as deeply or as vigorously as they normally would. They may also experience symptoms such as coughing and shortness of breath. PM_{10} can increase susceptibility to respiratory infections and can aggravate existing respiratory diseases, such as asthma and chronic bronchitis.

SULFUR DIOXIDE (SO_2)

High concentrations of sulfur dioxide affect breathing and may aggravate existing respiratory and cardiovascular disease. Sensitive populations include asthmatics, individuals with bronchitis or emphysema, children, and the elderly.

Smoking and Other Risks

Cigarette smoke contains over 4,700 chemical compounds including 60 known carcinogens. No threshold level of exposure to cigarette smoke has been defined. However, conclusive evidence indicates that long-term smoking greatly increases the likelihood of developing numerous fatal conditions.

Cigarette smoking is responsible for more than 85% of lung cancers and is also associated with cancers of the mouth, pharynx, larynx, esophagus, stomach, pancreas, kidney, bladder, and colon. Cigarette smoking has also been linked to leukemia. Apart from the carcinogenic aspects of cigarette smoking, links to increased risks of cardiovascular diseases (including stroke), sudden death, cardiac arrest, peripheral vascular disease, and aortic aneurysm have also been established. Many components of cigarette smoke have also been characterized as ciliotoxic materials. These irritate the lining of the respiratory system, resulting in increased bronchial mucus secretion and chronic decreases in pulmonary and mucociliary function.

RELEVANT LAWS

Federal Hazardous Substances Act (1960): Required that certain hazardous household products bear cautionary labels to alert consumers to the potential hazards of these products.

Federal Environmental Pesticides Control Act (1972): Required registration of all pesticides in the United States.

Hazardous Materials Transportation Act (HAZMAT) (1975): Governs the transportation of hazardous materials and wastes. Covers containers, labeling, and marking standards.

Toxic Substances Control Act (1976): Gives the Environmental Protection Agency (EPA) the ability to track the 75,000 industrial chemicals currently produced in or imported into the United States.

Comprehensive Environmental Response, Compensation and Liability (CERCLA or SUPERFUND) (1980): Established federal authority for emergency response and cleanup of hazardous substances that have been spilled, improperly disposed of, or released into the environment.

Low-Level Radioactive Policy Act (1980): Made states responsible for disposing of their own low-level radioactive wastes.

Nuclear Waste Policy Act (1982): Established a study to find a suitable site for disposal of spent fuel from nuclear reactors. Yucca Mountain, Nevada, seems most feasible at this time.

HAZARDOUS CHEMICALS IN THE ENVIRONMENT

A hazardous waste is a waste with properties that make it dangerous or potentially harmful to human health or the environment. Hazardous wastes can be liquids, solids, contained gases, or sludges. The Environmental Protection Agency has separated hazardous wastes into the following categories:

CORROSIVE

Corrosive wastes are strong acids or strong bases that are capable of corroding metal containers, such as storage tanks, drums, or barrels. Battery acid is an example.

DISCARDED COMMERCIAL PRODUCTS

These are specific commercial chemical products in an unused form. Some pesticides and some pharmaceutical products become hazardous wastes when discarded.

IGNITABLE

Ignitable wastes can create fires under certain conditions, are spontaneously combustible, or have a flash point less than 140°F (60°C). Examples include waste oils and used solvents.

MUTAGENS

A mutagen is a physical or chemical agent that changes the genetic material, usually DNA, of an organism and thus increases the frequency of mutations above the natural background level. Many mutations cause cancer, as mutagens are typically also carcinogens. Examples of common mutagens include nitrous acid, bromine and bromine-containing compounds, sodium azide (as found in car safety air bag systems), and benzene.

NONSPECIFIC SOURCE

These include wastes from common manufacturing and industrial processes, such as solvents that have been used in cleaning or degreasing operations.

REACTIVE

Reactive wastes are unstable under normal conditions. They can cause explosions, toxic fumes, gases, or vapors when heated, compressed, or mixed with water. Examples include lithium batteries and explosives.

SOURCE SPECIFIC

These are wastes from specific industries, such as petroleum refining or pesticide manufacturing. Examples include certain sludges and wastewaters from treatment and production processes.

TERATOGENS

Teratogens are substances found in the environment that can cause a birth defect. Examples of teratogens include drinking alcohol (ethanol), radioactive compounds, dioxin, certain pharmaceuticals (e.g., Dilantin, which is used to treat seizures and certain heart arrhythmias), lithium, mercury, tetracyclines, ethers, tobacco, and excessive caffeine.

TOXIC

Toxic wastes are harmful or fatal when ingested or absorbed. They may contain mercury or lead for example. When toxic wastes are disposed of on land, contaminated liquid may leach from the waste and pollute groundwater.

Treatment, Disposal, and Cleanup of Contaminated Sites

Reduction and cleanup of hazardous wastes can occur by producing less waste, converting the hazardous material to less hazardous or nonhazardous substances, and placing the toxic material into perpetual storage.

PRODUCE LESS WASTE

- **Recycle**—Improved technology seeks ways of collecting hazardous wastes and using them as raw materials for new products.
- **Reduce or eliminate toxicity**—Improved technology seeks substitutes for hazardous chemicals. For example, Puron replaced Freon.

CONVERSION TO LESS HAZARDOUS OR NONHAZARDOUS SUBSTANCES

Chemical, physical, and biological treatment

Bioremediation is the use of bacteria and enzymes to break down hazardous materials. Phytoremediation involves rhizofiltration (using sunflowers to absorb radioactive wastes), phytostabilization (using willow and poplar trees to absorb organic contaminants), phytodegradation (using poplars to absorb and break down contaminants), and phytoextraction (using Indian mustard and brake ferns to absorb inorganic metal contaminants). Pros: inexpensive, low energy use, little to no air pollution, easy to build. Cons: slow, effective only as far down as roots will reach, some toxic materials can evaporate through plants. Plants would be toxic and need to be properly disposed. Chemical methods involve use of cyclodextrin.

Incineration

Can release air pollutants and toxic ash (such as lead, mercury, and dioxins).

Thermal Treatment

Plasma arcs. Pros: small, mobile, no toxic ash. Cons: expensive and can release particulates, chlorine gas, toxic metals, and radioactive wastes.

PERPETUAL STORAGE

Arid Region Unsaturated Zone

The unsaturated zone is the subsurface between the land surface and underlying aquifers. It includes sites in the arid western United States that are being relied upon to isolate a significant portion of the nation's radioactive and other hazardous wastes for thousands of years.

Capping

Capping, often used in combination with other cleanup methods, covers buried wastes to prevent contaminants from spreading. Spreading or migration of buried wastes can be caused by rainwater or surface water moving through the site or by wind blowing dust off the site. The primary purpose of a cap is to minimize contact between rain or surface water and the buried waste. Caps: (a) minimize water movement through the wastes by using efficient drainage; (b) resist damage caused by settling; and (c) prevent standing water by funneling away as much water as the underlying filter or soils can handle. Capping is used when the underground contamination is so extensive that excavating and removing it isn't practical, or when removing wastes would be more dangerous to human health and the environment than leaving them in place. Wells are often used to monitor groundwater where a cap has been installed to detect any movement of the wastes.

Landfill

Pros: inexpensive. Cons: groundwater seepage and contamination.

Salt Formations

Toxic wastes are deposited in deep salt formations. The absence of flowing water within natural salt formations prevents dissolution and subsequent spreading of the waste products. Rooms and caverns in the salt can be sealed, thus isolating the waste from the biosphere.

Surface Impoundments

Excavated ponds, pits, or lagoons. Pros: low cost, low operating cost, built quickly, wastes can be retrieved and, if lined, can store wastes for long periods. Cons: groundwater contamination, VOC pollution, overflow if flooding occurs, earthquake issues, promotes waste production.

Underground Injection

Pros: low cost, wastes can be retrieved, simple technology. Cons: leaks, earthquake issues, groundwater contamination.

Waste Piles

Storage of toxic materials in drums, underground vaults, or above-ground buildings. Pros: easy to identify leaks. Cons: shipping of materials to facilities results in accidents.

CASE STUDY

The first synthesized chlorinated organic pesticide was DDT. It appeared to have low toxicity and was broad spectrum. It did not break down, so it did not have to be reapplied often. Crop production increased and mosquitoes decreased. In 1962, Rachel Carson published *Silent Spring*, which made the connection between DDT and nontarget organisms by direct and indirect toxicity. DDT persisted in the environment through bioaccumulation (an increase in concentration up the food chain) and biomagnification (the tendency for a compound to accumulate in tissues). DDT was found to decrease the eggshell thickness of various species of birds, nearly wiping out bald eagles and peregrine falcons. DDT was beginning to show up in native people of the Arctic, seals, and human breast milk. It was pulled off the U.S. market and is now being manufactured in Indonesia.

Bioaccumulation

Bioaccumulation is the increase in concentration of a pollutant from the environment in an organism or part of an organism. It involves the biological sequestering of substances that enter the organism through respiration, food intake, or epidermal (skin) contact with the substance. The level at which a given substance is bioaccumulated depends on:

- Rate of uptake
- Mode of uptake (gills, ingested along with food, contact with skin, etc.)
- Rate the substance is eliminated from the organism
- Transformation of the substance by metabolic processes
- Lipid (fat) content of the organism
- Environmental factors

Biomagnification

Biomagnification is the increase in concentration of a pollutant from one link in a food chain to another. In order for biomagnification to occur, the pollutant must be long-lived, mobile, soluble in fats, and biologically active. If a pollutant is short-lived, it will be broken down before it can become dangerous. If it is not mobile, it will stay in one place and be less likely to be taken up by many organisms. If the pollutant is soluble in water, it will be excreted by the organism. Pollutants that dissolve in fats, however, may be retained for a long time. It is traditional to measure the amount of pollutants in fatty tissues of organisms such as fish. In mammals, milk produced by females is often tested since the milk is high in fat and because the young are often more susceptible to damage from toxins.

Bioaccumulation vs. Biomagnification

For example, methylmercury is taken up by bacteria and phytoplankton. Small fish eat the bacteria and phytoplankton and *accumulate* the mercury. The small fish are in turn eaten by larger fish, which can become food for humans and animals resulting in the buildup (*biomagnification*) of large concentrations of mercury in human and animal tissue. As a general rule, the more fat-like a substance is, the more likely it is to bioaccumulate in organisms, such as fish.

ECONOMIC IMPACTS

A cost-benefit analysis is a technique for deciding whether to make a change. To use the technique, one adds up the value of the benefits of a course of action and subtracts the costs associated with it.

Costs are either one time or ongoing. Benefits are most often received over time. Time is factored into a cost-benefit analysis by calculating a payback period—the time for the benefits of a change to repay its costs.

In its simple form, a cost-benefit analysis is carried out using only financial costs and benefits. For example, a simple cost-benefit analysis of a new road would measure the cost of building the road and subtract this from the economic benefit of improving transport links. It would not measure either the cost of environmental damage or the benefit of quicker and easier travel to work. A more sophisticated approach is to attempt to put a financial value on intangible costs and benefits, which is highly subjective.

A cost-benefit analysis applies to three economic situations: First, it can help judge whether public services provided by the private sector are adequate. Second, it can be used when judging and assessing inefficiencies (market failures) in the private sector and their impact on the health, safety, and environmental needs of the country. Third, it helps in determining how to meet societal needs in a cost-effective manner in areas that only government can address. These include defense, preservation of scenic areas, environmental protection, and so on.

A cost-benefit analysis can be used for evaluating policy alternatives, shaping regulatory strategies, and evaluating specific regulations. A cost-benefit analysis requires:

1. Gathering all information and data about a public issue, including history and background
2. Defining the possible solutions to solving the issue
3. Brainstorming the possible environmental and societal consequences of the alternatives
4. Quantifying the benefits and the costs
5. Making decisions and balancing concerns

Externalities or True Costs

Externality is a general term for a wide variety of costs and benefits that are not included in prices or the effects of an action on people who were not a part of the process. One example of environmental externalities is the cost of environmental damage associated with production and transportation activities such as species die-off or poisonings. Another example is the cost of flooding of low-elevation areas and the increase in home and property damage from extreme weather associated with climate change. A third example is air pollution generated by a local industry that affects others who had no choice or say in the matter.

If there are externalities, then there is overproduction of a good. The total cost of a good to society (called the social cost) includes the costs of production incurred by the industry as well as the external costs. The marginal cost is reached when the change in the total cost of a product changes with the production of just one more item. For example, it may cost a company the same price to produce 5 widgets as it does to produce 10 widgets. However, if the company has to pay more (and conse-

Framework of Cost-Benefit Analysis

Step	Description
Cost-benefit	Determine an action and levels of action that achieve the greatest net economic benefit. Exploring options and determining incremental levels of remediation provide the most benefit for the least cost.
Cost-effectiveness	Implementing a specific environmental, health, or safety objective at the least cost. Emphasis is on achieving the objective. Flexible regulatory guidelines are adapted to find the lowest cost to solve a problem.
Health or environmental protection standards	Reducing risk to the public whatever the cost.
Risk-benefit	Balancing health or environmental protection with the costs of providing the protection.
Technology	To achieve results that are predictable and certain.

quently charge more) to produce the 11th widget, then it has exceeded its marginal cost. The optimal level of an externality is found by equating the marginal benefit to the marginal cost. Negative externalities can be handled in three ways:

- Regulation prohibiting or limiting the activity
- Making the activity more costly through taxation—by setting the tax equal to the cost to others, the externality has been internalized
- A hybrid approach that includes tradable licenses, with the number of licenses set by regulation and the market determining the use of the licenses

Green Taxes

Green taxes, also known as ecotaxes, are taxes intended to promote ecologically sustainable activities through economic incentives. Such policies can complement or avert the need for regulatory or command and control approaches. Often, a green tax policy will attempt to maintain overall tax revenue by proportionately reducing other taxes (payroll, income, corporate taxes, and/or property taxes on building or infrastructure).

Cap and Trade

Cap and trade, also known as emissions trading, is a market approach used to control pollution by providing economic incentives for achieving reductions in the emissions of pollutants. With cap-and-trade policies, the government sets a limit or "cap" on the amount of a pollutant that can be emitted. Companies or other groups are then issued emission permits and are required to hold an equivalent number of allowances or credits, which represent the right to emit a specific amount of pollutants. The total amount of allowances and credits cannot exceed the cap, limiting total emissions to that level. Companies that need to increase their emission allowance must then buy credits from those who pollute less. The transfer of allowances is referred to as a "trade." In effect, the buyer is paying a charge for polluting, while the seller is being rewarded for having reduced emissions by more than was needed. Therefore, those who can reduce emissions more cheaply will do so, achieving pollution reduction at the lowest cost to society.

CASE STUDY

The European Union's Emission Trading Scheme (ETS) is the largest multinational emissions trading system in the world and is a major component of the European Union climate policy. The ETS currently covers more than 10,000 installations, which are collectively responsible for close to half of the EU's emissions of CO_2 and 40% of its total greenhouse gas emissions. Large emitters of carbon dioxide within the EU must monitor and annually report their CO_2 emissions and are obliged every year to return an amount of emission allowances to the government that is equivalent to their CO_2 emissions in that year.

Sustainability

Sustainability deals with the continuity of the economic, social, and institutional aspects of human society while at the same time preserving biodiversity and the environment. Sustainable activities seek to provide the best outcomes for both human societies and natural ecosystems. Several issues are common to both interests:

- Consideration of risk, uncertainty, and irreversibility
- Ensuring appropriate valuation, appreciation, and restoration of nature
- Integration of environmental, social, and economic goals in policies and activities
- Equal opportunity and community participation
- Conservation of biodiversity and ecological integrity
- A commitment to best practice
- No net loss to either human or natural capital
- Continuous improvement
- The need for good governance

Unlimited economic and population growth puts many demands on natural resources. Its effects on pollution and the carrying capacity of Earth are factors that impact sustainability. These are all analyzed using life cycle assessments and ecological footprint analyses.

QUICK REVIEW CHECKLIST

- ☐ **Hazards to Human Health**
  - ☐ types of risks
  - ☐ risk management strategies
  - ☐ acute and chronic effects
  - ☐ dose-response relationships
    - ☐ LD_{50}
    - ☐ EC_{50}
    - ☐ dose-response curves