

BIOACCUMULATION

DEFINING BIOACCUMULATION

An important process by which chemicals can affect living organisms is through bioaccumulation. Bioaccumulation means an increase in the concentration of a chemical over time in a biological organism compared to the chemical's concentration in the environment. Compounds accumulate in living things any time they are taken up and stored faster than they are broken down (metabolized) or excreted. Understanding the dynamic process of bioaccumulation is very important in protecting human beings and other organisms from the adverse effects of chemical exposure, and it has become a critical consideration in the regulation of chemicals.

A number of terms are used in conjunction with bioaccumulation:

Uptake

describes the entrance of a chemical into an organism -- such as by breathing, swallowing, or absorbing it through the skin -- without regard to its subsequent storage, metabolism, or excretion by that organism.

Storage

a term sometimes confused with bioaccumulation, means the temporary deposit of a chemical in body tissue or in an organ. Storage is just one facet of chemical bioaccumulation. (The term also applies to other natural processes, such as the storage of fat in hibernating animals or the storage of starch in seeds.)

Bioconcentration

is the specific bioaccumulation process by which the concentration of a chemical in an organism becomes higher than its concentration in the air or water around the organism. Although the process is the same for both natural and man-made chemicals, the term bioconcentration usually refers to chemicals foreign to the organism. For fish and other aquatic animals, bioconcentration after uptake through the gills (or sometimes the skin) is usually the most important bioaccumulation process.

Biomagnification

describes a process that results in the accumulation of a chemical in an organism at higher levels than are found in its own food. It occurs when a chemical becomes more and more concentrated as it moves up through a food chain -- the dietary linkages from single-celled plants to increasingly larger animal species.

A typical food chain includes algae eaten by a water flea eaten by a minnow eaten by a trout and finally consumed by an osprey (or human being). If each step results in increased bioaccumulation, that is, biomagnification, then an animal at the top of the food chain, through its regular diet, may accumulate a much greater concentration of chemical than was present in organisms lower in the food chain.

Biomagnification is illustrated by a study of DDT which showed that where soil levels were 10 parts per million (ppm), DDT reached a concentration of 141 ppm in earthworms and 444 ppm in robins. Through biomagnification, the concentration of a chemical in the animal at the top of the food chain may be high enough to cause death or adverse effects on behavior, reproduction, or disease resistance and thus endanger that species, even though contamination levels in the air, water, or soil are low. Fortunately, bioaccumulation does not always result in biomagnification.

THE BIOACCUMULATION PROCESS

Bioaccumulation is a normal and essential process for the growth and nurturing of organisms. All animals, including humans, daily bioaccumulate many vital nutrients, such as Vitamins A, D, and K, trace minerals, and essential fats and amino acids. What concerns toxicologists is the bioaccumulation of substances to levels in the body that can cause harm. Because bioaccumulation is the net result of the interaction of uptake, storage and elimination of a chemical, these parts of the process will be examined further.

Uptake

Bioaccumulation begins when a chemical passes from the environment into an organism's cells. Uptake is a complex process which is still not fully understood. Scientists have learned that chemicals tend to move, or diffuse, passively from a place of high concentration to one of low concentration. The force or pressure for diffusion is called the chemical potential, and it works to move a chemical from outside to inside an organism.

A number of factors may increase the chemical potential of certain substances. For example, some chemicals do not mix well with water. They are called lipophilic, meaning "fat loving", or hydrophobic, meaning "water hating". In either case, they tend to move out of water and into the cells of an organism, where there are lipophilic microenvironments.

Storage

The same factors affecting the uptake of a chemical continue to operate inside an organism, hindering a chemical's return to the outer environment. Some chemicals are attracted to certain sites, and by binding to proteins or dissolving in fats, they are temporarily stored. If uptake slows or is not continued, or if the chemical is not very tightly bound in the cell, the body can eventually eliminate the chemical.

One factor important in uptake and storage is water solubility which is the ability of a chemical to dissolve in water. Usually, compounds that are highly water soluble have a low potential to bioaccumulate and do not readily enter the cells of an organism. Once inside the organism, they are easily removed unless the cells have a specific mechanism for retaining them.

Heavy metals like mercury and certain other water-soluble chemicals are the exceptions, because they bind tightly to specific sites within the body. When binding occurs, even highly water-soluble chemicals can accumulate. This is illustrated by cobalt, which binds very tightly and specifically to sites in the liver and accumulates there despite its water solubility. Similar accumulation processes occur for mercury, copper, cadmium, and lead.

Many fat-loving (lipophilic) chemicals pass into organism's cells through the fatty layer of cell membranes more easily than water-soluble chemicals. Once inside the organism, these chemicals may move through numerous membranes until they are stored in fatty tissues and begin to accumulate.

The storage of toxic chemicals in fat reserves serves to detoxify the chemical, by removing it from contact with other organs. However, when fat reserves are utilized to provide energy for an organism, the materials stored in the fat may be remobilized within the organism and may again be potentially toxic. If appreciable amounts of a toxicant are stored in fat and fat reserves are quickly used, significant toxic effects may be seen from the remobilization of the chemical.

Elimination

Another factor affecting bioaccumulation is whether an organism can break down and/or excrete a chemical. The biological breakdown of chemicals is called metabolism. This ability varies among individual organisms and species and also depends on the chemical's characteristics.

Chemicals that dissolve readily in fat but not in water tend to be more slowly eliminated by the body and thus have a greater potential to accumulate. Many metabolic reactions alter a chemical into more water soluble metabolites, which are more readily excreted.

However, there are exceptions. Natural pyrethrins, insecticides that are derived from the chrysanthemum plant, are highly fat-soluble pesticides, but they are easily degraded and do not accumulate. The insecticide chlorpyrifos, which is less fat-soluble but more poorly degraded, tends to bioaccumulate. Factors affecting metabolism often determine whether a chemical achieves its bioaccumulation potential in a given organism.

A DYNAMIC EQUILIBRIUM

When a chemical enters the cells of an organism, it is distributed and then excreted, stored or metabolized. Excretion, storage, and metabolism decrease the concentration of the chemical inside the organism, increasing the potential of the chemical in the outer environment to move into the organism. During constant environmental exposure to a chemical, the amount of a chemical accumulated inside the organism, and the amount leaving reach a state of dynamic equilibrium.

To understand this concept of dynamic equilibrium, imagine a tub filling with water from a faucet at the top and draining out through a pipe of smaller size at the bottom. When the water level in the tub is low, little pressure is exerted on the outflow at the bottom of the tub. As the water level rises, the pressure on the outflow increases. Eventually, the amount of the water flowing out will equal the amount flowing in, and the level of the tub will not change. If the input or outflow is changed, the water in the tub adjusts to a different level.

So it is with living organisms. An environmental chemical will at first move into an organism more rapidly than it is stored, degraded, and excreted. With constant exposure, the concentration inside the organism gradually increases. Eventually, the concentration of the chemical inside the organism will reach an equilibrium with the concentration of the chemical outside the organism, and the amount of chemical entering the organism will be the same as the amount leaving. Although the amount inside the organism remains constant, the chemical continues to be taken up, stored, degraded, and excreted.

If the environmental concentration of the chemical increases, the amount inside the organism will increase until it reaches a new equilibrium. Exposure to large amounts of a chemical for a long period of time, however, may overwhelm the equilibrium (for example, overflowing the tub) and potentially cause harmful effects.

Likewise, if the concentration in the environment decreases, the amount inside the organism will also decline. If the organism moves to a clean environment, in which there is no exposure, then the chemical eventually will be eliminated from the body.

BIOACCUMULATION FACTORS

This simplified explanation does not take into account all of the many factors that affect the ability of chemicals to be bioaccumulated. Some chemicals bind to specific sites in the body, prolonging their stay, whereas others move freely in and out. The time between uptake and eventual elimination of a chemical directly affects bioaccumulation. Chemicals that are immediately eliminated, for example, do not bioaccumulate.

Similarly, the duration of exposure is also a factor in bioaccumulation. Most exposures to chemicals in the environment vary continually in concentration and duration, sometimes including periods of no exposure. In these cases, an equilibrium is never achieved and the accumulation is less than expected.

Bioaccumulation varies between individual organisms as well as between species. Large, fat, long-lived individuals or species with low rates of metabolism or excretion of a chemical will tend to bioaccumulate more than small, thin, short-lived organisms. Thus, an old lake trout may bioaccumulate much more than a young bluegill in the same lake.

SUMMARY

Bioaccumulation results from a dynamic equilibrium between exposure from the outside environment and uptake, excretion, storage, and degradation within an organism. The extent of bioaccumulation depends on the concentration of a chemical in the environment, the amount of chemical coming into an organism from the food, air or water, and the time it takes for the organism to acquire the chemical and then excrete, store, and/or degrade it. The nature of the chemical itself, such as its solubility in water and fat, affects its uptake and storage. Equally important is the ability of the organism to degrade and excrete a particular chemical. When exposure ceases, the body gradually metabolizes and excretes the chemical.

Bioaccumulation is a normal process that can result in injury to an organism only when the equilibrium between exposure and bioaccumulation is overwhelmed. Sometimes bioaccumulation can be a protective mechanism in which the body accumulates needed chemicals.