12.9: Biological Interaction with Environmental Chemicals

Organisms in the environment interact significantly with xenobiotic materials (those foreign to living systems) in their surroundings. The uptake of such materials by organisms is discussed in this section. The biodegradation of xenobiotic substances, primarily through the action of bacteria, is discussed in Section 12.10.

Bioaccumulation is the term given to the uptake and concentration of xenobiotic materials by living organisms. The materials may be present in water in streams or bodies of water, sediments in bodies of water, drinking water, soil, food, or even the atmosphere. Bioaccumulation can lead to **biomagnification** in which xenobiotic substances become successively more concentrated in the tissues of organisms higher in the food chain. This usually occurs with poorly degradable, lipid-soluble organic compounds. Suppose, for example, that such a compound contacts lake water, accumulates in solid detritus in the water, sinks to the sediment, is eaten by small burrowing creatures in the sediment, which are eaten by small fish. The small fish may be eaten by larger fish, which in turn are consumed as food by birds. At each step, the xenobiotic substance may become more concentrated in the organism and may reach harmful concentrations in the birds at the top of the food chain. This is basically what happened with DDT, which almost caused the extinction of eagles and hawks.

Fish that bioaccumulate poorly degradable, lipid-soluble organic compounds from water will lose them back to water if they are placed in an unpolluted environment. The process by which this occurs is called **depuration**. The time required to lose half of the bioaccumulated xenobiotic material is called the **half-life** of the substance.

The most straightforward case of bioaccumulation is **bioconcentration**, which occurs when a substance dissolved in water enters the body of a fish or other aquatic organism by passive processes (basically, just “dissolves” in the organism), and is carried to bodies of lipid in the organism in the blood flow. The model of bioconcentration assumes that the organism taking up the compound does not metabolize the compound, a good assumption for refractory organic compounds such as DDT or PCBs. It also assumes that uptake is by nondietary routes, including diffusion through the skin and especially through the gills of fish. The model of bioconcentration applies especially to substances that have low water solubilities (though high enough to make the compound available for uptake) and high lipid solubilities. This model of bioconcentration assumes a dynamic equilibrium between the xenobiotic substance dissolved in water and the same substance dissolved in lipid tissue. It is called the **hydrophobicity model** because of the hydrophobic (“water-hating”) nature of the substance being taken up.

The degree of bioconcentration depends upon a number of factors. The most important of these are the relative water and lipid solubility of the compound. The size and shape of the xenobiotic molecule also seem to be factors, as is temperature. In addition, bioconcentration depends upon the species of fish and their age, size, and lipid contents. Bioconcentration may be expressed by **bioconcentration factors** defined as

$$\text{Bioconcentration factor} = \frac{\text{Concentration of xenobiotic in lipid}}{\text{Concentration of xenobiotic in water}} \tag{12.9.1}$$

The bioconcentration factor can also be regarded as the ratio of the solubility of the compound in lipid to its solubility in water. Typical bioconcentration factors for PCBs and hexachlorobenzene in sunfish, trout, and minnows range from somewhat more than 1,000 to around 50,000, reflecting the high lipid solubility of these compounds.