chemically or permanently sequestered so that they can cause no further harm to any life form.

Assimilation in the real world occurs in three general ways: nuclear disintegration, deposition, and degradation. Radioactive materials disintegrate; particulates and chemicals absorbed on soil particles may be deposited where they cause no harm; and chemicals and solid waste may be degraded through a chemical reaction, such as oxidation, or by some natural biochemical process. A useful measure of the rate at which a material disappears from the environment is the material's assimilation half-life, which is the period of time required for half of the initial amount of the material to disappear from the environment.

The half-life of any material assimilated by disintegration or deposition is essentially constant and a function of the material and the physical processes involved. The half-life of a chemically or biologically degraded material may, however, depend upon the quantity of the material present. In biological or chemical degradation, some substrate plays the role of initiating the breakdown of a pollutant. Chemical kinetic considerations can be used to show that the degradation half-life of a material may increase with its concentration. This effect is compounded if increases in the pollutant actually poison the degradative system, decreasing the effectiveness of the degrading substrates.

The Function of Technology in the Persistent Pollution Sector

The amount of pollution present in the ecosystem can be altered by changing the persistent pollution generation, appearance, or assimilation rate. The harm caused by persistent materials can be altered by changing the composition or the location of pollutants in the environment. New technical capabilities can be expected to affect each of these factors in varying degrees, depending upon the mix of pollutants present. Any technology developed in response to observed environmental damage will presumably decrease the rate of generation, increase the transmission delay, and decrease the effective assimilation half-life. Technologies developed for other purposes, such as increased food production or resource extraction, may inadvertently have the opposite effects. In analyzing the persistent pollution sector of the world model, we examined the effects of the possible results of different technological advances:

1. Decreasing the amount of pollution generated at any level of industrial and agricultural output. This change would correspond to a change in production processes or to improved emission controls.
2. Increasing the delay between the time the pollution is generated and the time its full impact is felt in the biosphere. This change could be brought about by, for example, transferring industrial operations to remote localities or by improving the storage facilities for nuclear and other wastes.
3. Increasing the rate at which the pollution is assimilated. This change represents the impact of such measures as the oxygenation of waste-bearing water or the substitution of shorter-lived chemicals for persistent pesticides.

4. Reducing the effects of persistent pollution on land fertility or on the average life expectancy of the population. This change represents a decrease in the average toxicity of effluents.

6.4 CAUSAL STRUCTURE

The preceding sections have described several concepts that appear to be important in governing the amount of persistent materials present in the environment over the long term. In the persistent pollution sector of World3 we employed the following set of assumptions to interrelate these concepts:

1. Persistent pollution is generated as a result of industrial and agricultural activities—the greater the per capita use of nonrenewable resources by industry, the greater the pollution generated each year per capita; the greater the capital intensity of agricultural production, the greater the persistent pollution generated per cultivated hectare per year.
2. There is a delay between the time a persistent material is generated and the time its full impact is exerted on the biosphere. A "transmission delay" contains materials that have been generated but have not yet fully affected the biosphere. As materials are transferred from the transmission delay to the level of accumulated pollution, they begin to affect plant and animal life.
3. The amount of accumulated pollution is determined by the integration of the difference between past rates of pollution appearance and pollution assimilation.
4. The amount of pollution assimilated per time period is directly proportional to the total accumulated level of pollution and inversely proportional to the assimilation half-life. Materials destined to be assimilated before they affect the biosphere are simply not counted in the calculation of the pollution generation rate.
5. The assimilation half-life of pollution may increase as the total level of pollution increases.

These assumptions are represented in the causal-loop structure shown in Figure 6-10. The causal links connecting the persistent pollution sector with the other sectors of World3 are represented by dashed arrows in that figure. The equations describing the generation and flow of persistent pollution are presented in this chapter; the equations describing the effects of accumulated persistent pollution on the human population and on agricultural productivity are presented in Chapters 2 and 4, respectively.

The causal relationships influencing persistent pollution generation are not involved in any feedback loop internal to this sector. Pollution generation is assumed to increase if population, agricultural inputs per hectare, arable land, or per capita resource usage increases (see Chapters 2, 4, and 5 for descriptions of these variables). The effects of these four variables are modified by a set of five parameters that represents the fractions of industrial resources and of capital inputs to agriculture that are persistent materials, the toxicity of the industrial and agricultural materials