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FRESHWATER ENVIRONMENT

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MASTER

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Introduction

The long-term effects of radionuclide deposition on freshwater environments depend on whether the ecosystem is a flowing-water or standing-water system. In the former are included streams and rivers which have water masses with relatively short residence times. In the latter are included ponds, reservoirs, and lakes which have residence times that range from several years to hundreds of years. For the purpose of this report, the discussion will be confined to standing-water systems, since radionuclide concentrations in flowing-water systems are minimized by the continuous natural flushing of water from the runoff from land of rain and melted snow. This water generally has been depleted of radionuclides by biological and physicochemical process.

The physical and chemical characteristics of standing-water systems are quite diverse. Ecosystems can differ by several orders of magnitude in the volume and depth of water they contain. Inorganic salts are present in widely different concentrations and composition. Nevertheless, those bodies of water that support the edible organisms of interest to man contain similar abiotic and biotic compartments as described earlier in this report for marine systems. Likewise, radionuclides introduced into the freshwater ecosystems are partitioned between the water and particulates and are accumulated by the biota in the various trophic levels.

Radionuclide Concentrations in the Biota

Concentrations of radionuclides in freshwater organisms are dependent on the amount of radioactivity the ecosystem receives, on the physicochemical characteristics of each radionuclide, on the chemical and physical properties of the ecosystem, and

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on the metabolic pathways in the organisms. The importance of these factors differs with the organism, the radionuclide, and the environment.

Amount of Radioactivity. The amount of radioactivity received by a freshwater ecosystem is determined primarily by the quantity of fallout deposited onto it and by the quantity contained in the inflowing water. The quantity of specific radionuclides deposited per unit area is latitude-dependent and has been evaluated by Volchok for this report. Through this inflowing water, a freshwater ecosystem can receive water from an area of land that is considerably greater than its own. However, only a part of the radioactivity deposited onto a drainage area may reach the standing-water system. Inflowing water can be depleted of radioactivity by sorbtion of radionuclides onto soil particles during its passage over land, by sorption onto natural materials present in rivers and streams, or by incorporation into the biota present in the ecosystems through which it flows.

Radionuclide Properties. After radionuclides are deposited in water, their behavior depends on their physical and chemical forms and on the chemical properties of their specific elements. These characteristics determine whether the material will be dispersed in the water or will settle to the bottom and whether it will be biologically available to organisms. Radioactive material deposited in the sediments may act as a continuing source to the water or be buried by continued sedimentation and effectively be removed from the biosphere.

Of the long-lived radionuclides under consideration ^{137}Cs and $^{238,239,240,241}Pu$ can be expected to be removed by sedimentation processes, whereas ^{3}H, ^{14}C, and ^{90}Sr can be expected to behave essentially as conservative substances in the water phase. Very little information is available on the distribution of ^{129}I and ^{241}Am in freshwater ecosystems. If it is assumed that ^{129}I behaves like ^{131}I, the distribution coefficients for ^{131}I indicate that ^{129}I would be present primarily in the water phase (Harrison, 1971; Petersen, 1975). If it is assumed that ^{241}Am behaves the same in freshwater as it does in seawater, most of it would be present in the sediments

(Noshkin, 1975). The differential behavior of radionuclides is evident from distributions reported for Lake Michigan and Lake Ontario: the water column contained almost all of the total inventory of the ^{90}Sr but less than 5 percent of the ^{137}Cs and even a smaller percentage of the ^{239}Pu (Wahlgren and Nelson, 1974; Bowen, 1975).

Ecosystem Properties. Physical properties can affect the dynamics of cycling and, in turn, the radionuclide concentrations in the water. Standing-water systems differ widely in area and in depth as well as in their ratios of surface area to volume and of sediment area to volume. In many temperate lakes, stratification of the water mass occurs during part of the season; the upper warm water is separated from the lower cold layer by an abrupt density gradient. The deep waters can become anaerobic and chemical changes occur that affect the radionuclide distribution and availability. In Lake Ontario, after several months of stratification the concentration of ^{239}Pu is higher in the deeper waters whereas ^{90}Sr profiles are uniform; this suggests remobilization of ^{239}Pu from the sediment (Bowen, 1975). The magnitude of the concentration gradients established and thus the concentrations of the radionuclides available to animals that differ in spatial distribution in the ecosystem can be expected to be dependent on the structure and hydrology of the specific system, on the climatic conditions, and on the radionuclide.

The amount of water in a lake or pond at any time is controlled by precipitation, by inflow and outflow, and by seepage and evaporative losses. Radionuclide concentrations in the water can increase depending on the magnitude of the evaporative effect in these processes. This increase may be considerable in shallow water systems.

Chemical properties of water and sediments are of major importance in determining radionuclide concentrations in aquatic organisms. Standing-water systems that are nutrient-poor (oligotrophic) are characterized by low productivity, those that are nutrient-rich (eutropic) by high productivity; the sedimentation rates of radionuclides are determined in part by productivity. Differences in the sedimentation rates of lakes can affect the size of the "effective" sediment compartment and the concentrations of radionuclides in it. These factors can result in lakes with similar physical properties having different rates of cycling of those radionuclides that are particulate-bound.

The sediments represent a pool of particulate-bound radionuclides that may control the concentration in the overlying waters. Exchange rates between water and sediment can be affected by physical and chemical factors (Lee, 1970). Important physical factors are the hydrodynamics of the system, the fluidity of the sediments, and the reworking of the sediments by larger benthic organisms. Important chemical factors are attributable to microorganisms in the sediment. The metabolic activities of these organisms can alter directly the chemical form of the radionuclides or can alter indirectly their availability by reactions with the byproducts released in biochemical reactions.

Metabolism in organisms. Concentrations of radionuclides in organisms are determined by their physiological roles and specific chemical properties. When the concentration of a radionuclide in the water is known or can be predicted, concentration factors can be used to approximate its concentration in organisms. Concentration factors are typically more variable in freshwater than in marine organisms. (Polikarpov, 1966; Jinks and Eisenbud, 1972). In fishes, concentration factors for ^{90}Sr have been found to vary by more than three orders of magnitude and to be inversely correlated with calcium concentrations in the water (Fig. 1). A similar inverse correlation has been reported for ^{137}Cs and potassium (Preston, 1972). Of the radionuclides of interest in this report, the concentration factors for ^{90}Sr and ^{137}Cs are typically higher in freshwater than marine organisms. In freshwater fish, the average value for ^{137}Cs is reported to be 3680 (range 120 to 22,000) whereas for marine fish it is 48 (range 5 to 244) (Jinks and Eisenbud, 1972). Because of the high concentration value for ^{137}Cs in fish flesh, the contribution to the dose to man from ^{137}Cs deposition in a freshwater ecosystem may be greater from the consumption of the fish than from the drinking of the water. For a given species, differences in radionuclide concentration factors are attributable in part to the chemical properties of lakes. Other factors, both ecological and physiological, have been reported to affect concentration factors (Polikarpov, 1966; National Academy of Sciences, 1972; Jinks and Eisenbud, 1972). In freshwater ecosystems, however, these are generally less significant than the chemical composition of the water.

In an organism, concentrations of radionuclides are determined in part by their rates of influx and efflux. Turnover rates have been found to differ with radionuclide and with species, and are generally more rapid for ^{3}H, ^{14}C, ^{129}I and ^{137}Cs than for ^{90}Sr and the transuranic elements. The consideration of turnover effects on radionuclide concentrations in organisms is appropriate only for those ecosystems having water masses with residence times considerably less than 10 years. In such ecosystems, the concentrations of a radionuclide such as ^{239}Pu that is turned over very slowly in organisms would decrease more rapidly in the water than in the organism. The use of concentration factors and water concentrations for approximation of ^{239}Pu levels in adult organisms would result in underestimation of the actual values.

Research needs:

1. For many radionuclides, insufficient information is available currently on sediment/water exchange to predict the extent and net direction of exchange. Since sediments appear to be very important in the control of radionuclide concentrations, data on sediment/water exchange are needed for the calculation of temporal changes in water concentrations.
2. More information is needed also on chemical process occurring in sediments and how they affect the availability of the radionuclides to the biota. Changes in availability can result in different quantities of the radionuclides being accumulated and changes in the predicted doses to the organism and to man.
3. Additional information is needed on the behavior of transuranic elements in freshwater organisms. Because of the long half-times and the types of emission of some of these isotopes, data on amounts accumulated, on tissue distribution, and on turnover rates are needed for better understanding of the potential effects on the organism and for the evaluation of quantities that could be transferred to man.

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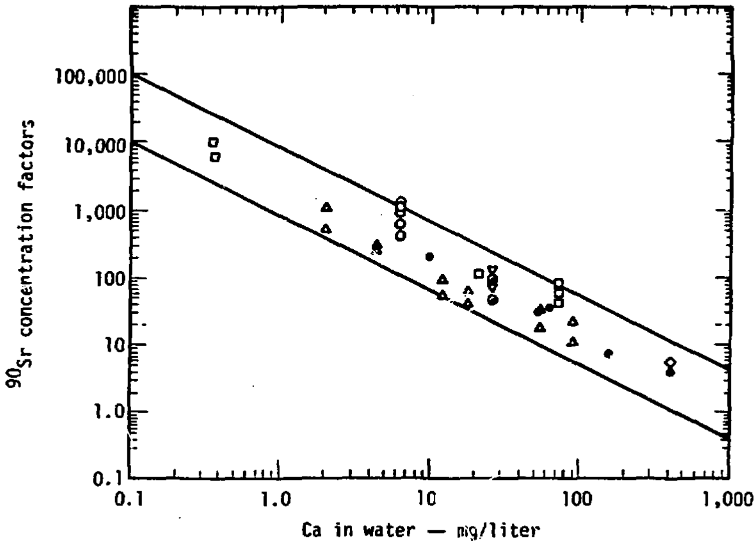
FIGURE LEGEND

Figure 1. Relationship between the concentration factors for ^{90}Sr in whole fish (wet weight basis) and the concentration of calcium in the water. □ Templeton and Brown (1964), △ calculated from Agnedal (1967), ▽ calculated from Nelson (1967), ● Feldt (1970), ○ Ophel and Fraser (1970), ◇ Templeton (1959), ⊙ Ophel and Judd (1969).


100,000
10,000
1,000
100
10
1.0
0.1
^{90}Sr concentration factors
0.1
1.0
10
100
1,000
Ca in water — mg/liter