Radioactivity in Marine Food Chains

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A few years ago the writer of a popular article on radioactivity in the oceans suggested that future historians will record that man began to reap the benefits of nuclear energy and the oceans almost simultaneously. Indeed, nuclear power may prove to be a major factor in the exploration, study, and rational use of the oceanic areas covering more than two-thirds of the earth. Most uses of nuclear energy result in the production of some unwanted radioactive wastes. Naturally, high-level wastes are very carefully controlled and stored; and low-level radioactive wastes and by-products are only permitted to enter the environment under the strictest precautions. Research on the fates of radioisotopes entering the marine environment is the province of marine radio-ecologists. This article will touch on some studies of radioecologists concerning the transfer of radioactive materials between water, plants, animals, and sediments in the oceans.

Artificial radioactivity finds its way into the oceans from many sources. Some of the principal means of input are the following: fallout from nuclear weapons tests, releases from nuclear powered vessels, input from fuel reprocessing and power plants to rivers and coastal areas, fallout of airborne radioisotopes released to the atmosphere from nuclear installations, and dumping of low-level packaged wastes on the seafloor. Once these radio-active elements enter the oceans, they may be dispersed and diluted by various physical and chemical processes. However, they can also be concentrated by some oceanic processes, notably biological processes. It is the study of the concentrating abilities of marine plants and animals that forms the research of many marine radioecologists.

If the concentrations of the elements present in sea-water are compared to their concentrations in marine organisms, some striking differences can be observed. For example, a gram of ocean water contains 3 billionths (3/1,000,000,000) grams of copper while a gram of phytoplankton, the single-celled plants forming the "grass of the sea", contains about 90 millionths (90/1,000,000) grams of copper. This 30,000-fold difference clearly shows that these tiny plant cells have the ability to extract the copper dissolved in large volumes of sea-water during their short lifespan. There are many other elements in the waters of the oceans that are concentrated by marine organisms 1,000 to 100,000-fold more. If plants and animals can concentrate some of the naturally-occurring elements in sea-water, it follows that artificial radioactive isotopes of these elements may also be concentrated. Although it has often been suggested that radionuclides are progressively concentrated in each higher step of marine food chains, this generalization has seldom been supported by scientific data from the laboratory or the field. Consequently, it is important to understand what radioisotopes are concentrated by marine organisms and how radioisotopes are passed up each step of marine food chains.

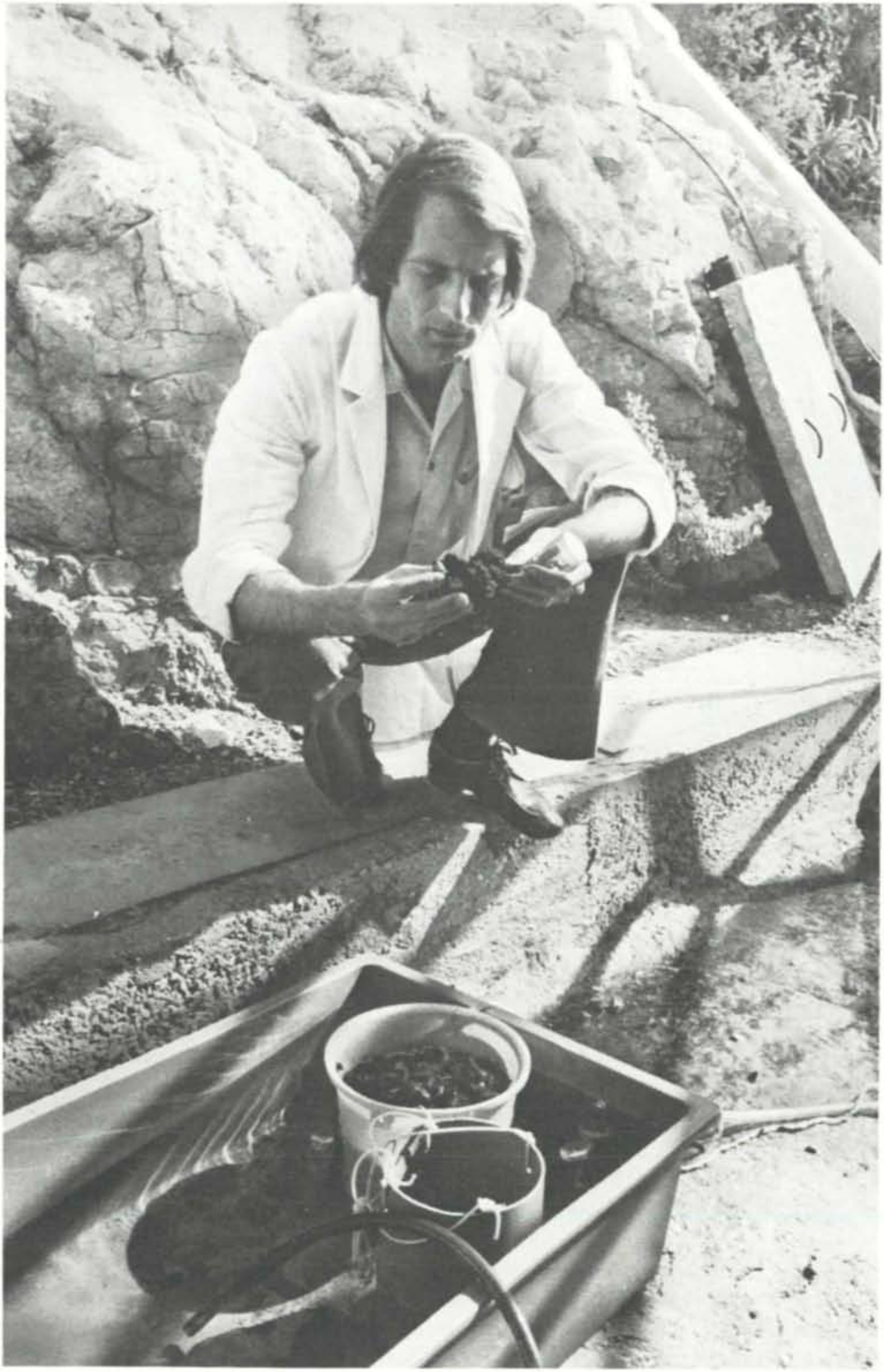
The source of all energy for marine plants and animals is the radiation from the sun. Single-celled plants floating in the upper layer of the ocean transform the electromagnetic energy of sunlight into chemical energy within the cell by a process termed photosynthesis. The microscopic plant cells are grazed upon by numerous organisms such as tiny crustaceans, molluscs, larval fishes, and other animals. These herbivorous animals are, in turn, eaten by carnivorous animals such as larger crustaceans and fishes. At the end of all marine food chains (or, more accurately, food webs) are the large carnivorous fishes and mammals, and, in some cases, man.

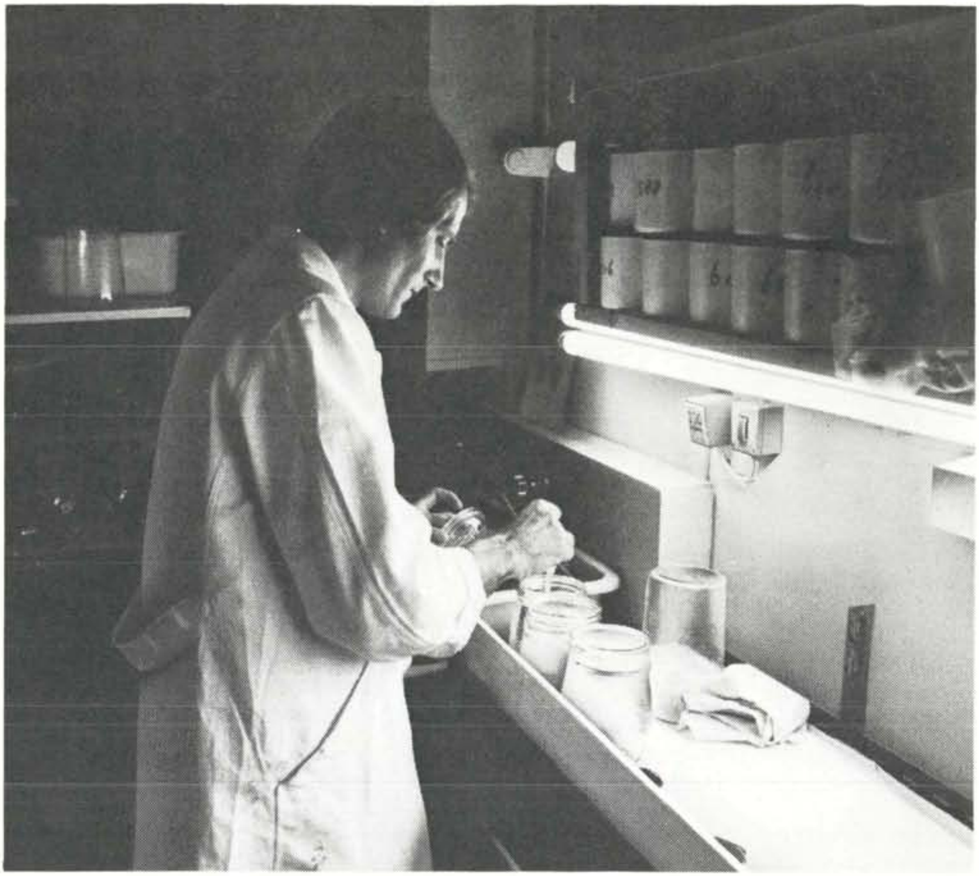
If food chains were simple and easy to describe quantitatively and if only the single-celled plants were able to extract dissolved elements from sea-water, it would be a relatively simple task to understand the biological cycling of radioactivity. It would only be necessary to measure the extent to which various radionuclides were accumulated by the plant cells and to follow the concentrations of these radionuclides at successive steps up the food chains supported by the plant cells. This work could be done both in natural environments receiving radioisotopes or under the controlled conditions of the laboratory. However, the situation is not nearly so simple, for animals, like plants, can obtain at least a part of their body burdens of radionuclides directly from the water. In addition, marine food chains, when studied closely, usually prove to be very complex. A particular animal species may prey on a large variety of other animals and may change its food habits with increasing age, with the changing seasons, with changes in the abundance of prey, or by migration to another environment. Clearly, there is much to be learned about the transfer of radionuclides between the various organisms comprising marine food chains.

In the IAEA International Laboratory of Marine Radioactivity at Monaco marine food chain research has been in progress for more than 10 years. These studies have been concerned with the mechanisms and rates of radioactivity accumulation and loss by marine organisms at various levels in oceanic food chains. For example, not all radioactive elements are concentrated equally by marine organisms. Those elements required by living plants and animals to form body structures, to produce energy, and to be involved in various biochemical reactions are concentrated to high levels. Thus, radioisotopes of such biologically important elements as iron, manganese, and zinc are concentrated by organisms and passed along to animals higher in the food web. Although many elements have no real metabolic function, they may be concentrated because they are chemically similar to biologically-important elements. Finally, some radioactive elements are concentrated due to their tendency to become sorbed to the surfaces of particles, particularly, fine clay particles and microscopic plant cells which have large surface to volume ratios.

It is not only the biological importance of the radioisotope that determines the degree to which an organism will accumulate it. Other factors also influence radioactivity uptake. For example, recent research in the Monaco Laboratory has shown that the physical and chemical form of the radionuclide is important. This effect was shown in experiments with ruthenium-106 which was concentrated from sea-water more rapidly and to higher levels by marine crustaceans when added as chloride compounds than when added as

Mussels and crabs to be used in laboratory experiments are maintained in outdoor tanks floating in the sea water of the Mediterranean, at the foot of the Monaco Institute. ▶





Experimental marine organisms (shrimp, clams, crabs) undergo various tests with radioactive tracers in the constant temperature room at the Laboratory. The flowing sea water, on tap, comes from the acquarium system of the Musée Océanographique, an important feature of the Lab. facilities.

a nitrogen compound. Earlier experiments had shown that the presence of other dissolved substances in sea-water also influence the accumulation of radionuclides by organisms. The rate of accumulation of zinc-65 by a marine clam is depressed when dissolved calcium is added to the sea-water but is increased when ferric iron is added. The increased iron content of the sea-water results in formation of particles enriched with zinc-65 which are readily filtered from the water by the clam. Other experiments showed that some radionuclides, which are normally concentrated to high levels by marine organisms, are not biologically available when present as a part of organic molecules in the sea-water. Some radionuclides, although tightly bound to bottom sediments, are taken up in limited amounts by worms and other benthic organisms.

Research on the concentration of radioactive wastes in marine organisms and studies on the mechanisms by which these materials are cycled through marine food webs continue in the Monaco Laboratory. **To summarize in a single sentence the most important general conclusion of this work, it could be said that "the more closely the processes of biological concentration of radionuclides are investigated, the more complicated they prove to be".**