REMARKS ON THE ECOLOGICAL PROBLEMS IN CONNECTION WITH MARINE RADIOACTIVITY

by Michael BERNHARD

The concept of the food chain or food web and the theory of the trophic levels in an ecological system present a good model for the study of the movements of radioisotopes in the marine environment of man.

In figure 1 a general scheme of an ecological system is presented. This scheme shows that radioisotopes can be accumulated by the various organisms either directly from the surrounding seawater or through the food chain.

There are several ways of recycling into the inorganic pool, one by direct mineralization by the organism itself, another be decomposition and excretion of organic substances by the organism and the uptake of these organic substances by other organisms and yet a third by decomposition and excretion of organic substances followed by mineralization by saprophytes and microorganisms.

The evaluation of the transfer of radioisotopes from the inorganic environment to an organism or from an organism of one trophic level to one of different trophic level is greatly aided by the concept of the specific activity or the similar more general term of the specific isotopic content.

The specific isotopic content is defined as $Sp = \frac{A^*}{\Sigma A}$, A^* being the number of radioactive atoms and ΣA the sum of all atoms, whether radioactive or non-radioactive, of the same element per reference unit.

It easy to see that if ΣA is great in comparison to A^* in the environment, the organism taking up a given amount of an element will absorb less radioactive atoms than if A^* is of the same order of magnitude as A (the isotope effect is ignored here).

For exemple, let us compare strontium with zinc in seawater. Strontium is present in seawater in the amount of about 10 mg/l, while the zinc concentration is only about 10^{-3} mg/l. If the same amount of Zn^{65} and Sr^{90} is added to seawater the specific isotopic content of zinc will be 10,000 times as high as that of strontium and consequently, if the organism took up the same amount of both elements directly from the seawater, it will take up about 10,000 times more radioactive atoms of zinc than of strontium.

The theoretical distinction between essential and non-essential elements, although somewhat academic, since the function of many elements is not known, may, however, serve to illustrate the importance that trophic levels have for the entry of radioisotopes into the food chain.

In the case of the biological non-essential elements we have to keep in mind that these elements are taken up because the organisms can not absolutely effectively discriminate against them owing to chemical similarity to elements essential to their metabolic functions.

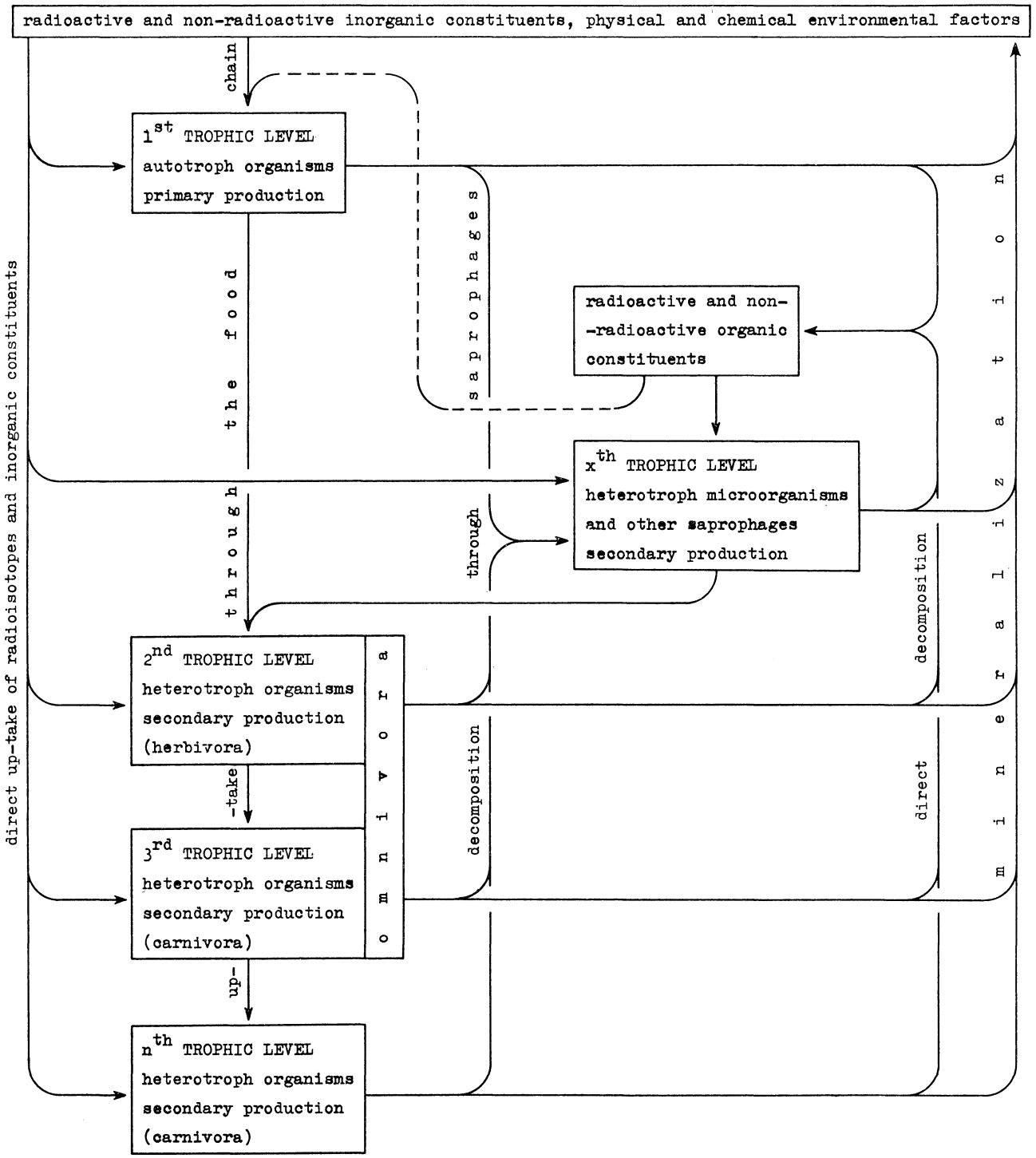

FIG. 1. — *Scheme of the paths of radioisotopes in a marine ecosystem.*

The best understood example of a pair of elements, of which one is an essential element and one apparently not, is that of Ca and Sr.

Since all animals, but not all plants, are able to discriminate against these « non-essential» or « substitution-elements » in favour of the biologically essential elements, the more levels in the food chain which have to be passed through by the substitution element, the smaller will be the amount of this radioisotope in the last level.

Or, in other words, the higher the level of entry of a substitution element into the food chain, the more dangerous will be the concentration in the last link.

For the biologically essential elements it is not possible to establish a general concept, since the uptake is, of course, closely related to its biological functions, which have to be investigated to make predictions about the amount of radioisotopes that are taken up.

According to the three mechanisms of radiocontamination, we might distinguish between :

Adsorption into the outer and inner surfaces of an organism,

Replacement of stable isotopes by radioactive ones in the already existing body tissues at the time t_0 of the exposure, owing to the energy, maintenance and regeneration metabolism *(replacement accumulation)*, and

Growth accumulation, i.e., the incorporation of radioisotopes during growth or other metabolic processes in which the organism increases the amount of the element in its body.

The mechanisms of adsorption are difficult to formulate. On the basis of a simple example taken from a culture of unicellular organisms, let us explain the growth accumulation in the first trophic level, on the assumption that the concentration of the element under consideration remains constant during the time interval under consideration.

At time t_0 an unicellular organism which multiplies by simple cell division and which was previously kept in a medium containing only the stable isotope is placed in a medium containing a radioisotope and its stable isotope with the specific isotopic content Sp_{env}.

During growth the cell has to take up the element from the environment in the same specific isotopic content as it is present there, and its newly formed cell substance will contain the element in the specific isotopic content of the medium (Sp_{env}).

After the cell has grown to double its original size it divides; each of the new cells will possess a specific isotopic content Sp_{org} which is 1/2 Sp_{env}.

After the next generation it will be $Sp_{org} = 3/4\ Sp_{env}$ and so on, or, more generally :

$$Sp_{org,gr} = Sp_{env}\ (1\text{-}2^{-G}) \qquad (1)$$

where G stands for the number of generations after t_0.

We then substitute $\frac{A}{A_0} = e^{kt}$ for $\frac{A}{A_0} = 2^{-G}$ in the equation (1), which becomes

$$Sp_{org,gr} = Sp_{env_0}\ (1 - e^{-kt})$$ k being the growth coefficient.

However, to complete the picture we also have to take into consideration the replacement accumulation in the tissues already existing at the time t_0, and to remember that the relative portion of the «old part» will decrease in a cell with each generation, so that after G generations the «old part» is $\frac{1}{2^{-G}}$ or, expressed in a more general dependance of time t and the growth coefficient k, the old part is equal to $\frac{1}{e^{kt}}$.

Let the replacement rate of all atoms of the same species be $\frac{dA_{repl}}{dt} = Ex\ A_{non}$

where A_{non} are the non-replaced atoms and Ex the relative exchange coefficient; the specific isotopic content then becomes:

$$Sp_{org,gr + Ex} = Sp_{env}\ (1 - e^{-kt}) + e^{-kt}\ (1 - e^{-Ext})$$

$$\text{or} = Sp_{env}\ (1 - e^{-t\,(k + Ex)}) \qquad (2)$$

Let us consider the decay of the radioisotope ($A^* = A^*\ e^{-\lambda t}$), for $A \gg A^*$.

Then the Sp_{org} at any time is:

$$Sp_{org} = Sp_{env_o}\ .\ e^{-1t}\ (1 - e^{-t\,(k + Ex)}) \qquad (3)$$

From the specific isotopic content Sp_{org} of the organism it is then easy to calculate the amount of radioisotope (R) in an organism, if we know the concentration of the element (C_{org}) in question in the organism, since

$$R = C_{org}\ .\ Sp_{org} \qquad (4)$$

Therefore substituting (3) in (4) we obtain (BERNHARD 1963):

$$R = C_{org}\ .\ Sp_{env_o}\ .\ e^{-\lambda t}\ (1 - e^{-t\,(k + Ex)}) \qquad (5)$$

On the assumption that the concentration of the element in question (C_{org}) expressed jointly in grams per such reference units as dry weight, ash weight, carbon content, etc., is constant, the two biological parameters k and Ex allow us to make predictions about the degree (R) of radiocontamination. The value of R has, of course, the same dimension as C_{org} and the same reference units.

On the other hand, in order to make these predictions, k, Ex, Sp_{env} and C_{org} must be known from experimental data under different ecological conditions and in the various stages of the life cycle of an organism.

Ex is closely related to the maintenance metabolism. Since an organism's maintenance needs will generally have priority to growth, under limited energy supply Ex will only become smaller when k approaches zero. During the life cycle the relation between Ex and k will change.

In organisms with limited growth, after a certain stage in the life cycle k will become zero and consequently only exchange, i.e., replacement accumulation, will contribute to the radio-contamination of the organism.

Ex further depends very much on the function of the element under consideration. If the element take part in the energy metabolism (e.g., phosphate) Ex will have very high values. If, on the other hand, the element is incorporated into supporting tissue (e.g., strontium), Ex will have a very low value.

k, the growth coefficient, may vary according to nutrient supply, available foods (i.e., energy supply), food composition, the position in the food chain, stage in the life cycle, temperature, light and other ecological factors.

Since growth requires energy in the form of the combustible organic substance for the construction of new organic substance, it will increase the exchange of atoms with the environment, which in turn will result in a higher value of Ex.

Strictly speaking, k is not identical with the normal growth coefficient, since there may be an increase in the total amount of an element which is not proportional to the actual increase in organic matter of the organism.

Per exemple, the zinc content of a fish's liver may vary without an accompanying growth increase in the liver itself (in dry weight) or even of the whole organism. But in many cases

when the time period under consideration includes several generations, especially in small organisms with short generation times, early stages in the life cycle, etc., a k-value derived from the general growth coefficient may be used without too great an error of approximation.

On the other hand, if the values of k and/or Ex are relatively large and the time period under consideration is long, then the value of the expression $(1 - e^{-t\,(k + Ex)})$ may be so close to 1 that one can approximate equation (5) by

$$R = C_{org} \cdot Sp_{env_0} \cdot e^{-\lambda t} \qquad (6)$$

However, under these circumstances care should be taken that the assumption C_{org} = constant is still valid.

These few generalizations, still based on many restricting assumptions, show, however, even now that it should be possible to make predictions on the hazard presented by certain radioisotopes, provided that certain biological and ecological parameters such as the life cycle, the growth rate and element exchange rate due to maintenance and growth in relation to environmental factors, the position of the organisms in the food web, the concentration of elements in the organism, the specific isotope content in the environment including the food, etc., can be determined in nature and effectively simulated under experimental conditions in the laboratory.

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REFERENCE

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