RAPPORTEUR PAPER
HYDROSPHERIC FOOD CHAINS

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THIS session contains papers on factors governing the uptake of radionuclides in the hydrospheric environment, marine or fresh water. In all these papers attempts are made to elucidate general factors, which make possible the prediction of the contamination level of different organisms, especially fish, in given pollution conditions.

The first of these papers is by Dr. Rinnosuke Fukai, from the International Laboratory of Marine Radioactivity, operated at Monaco by the International Atomic Energy Agency. It is titled "Some Biogeochemical Considerations on the Radioactive Contamination of Marine Biota and Environments". In this paper the author points out that if the over-all distribution of a given stable element in sea water and in marine organisms is known, the ultimate level of the radio isotopes of the same element in the same organisms can be predicted.

The author has determined the average concentrations of two stable elements, Co and Cr, in various biogeochemical phases. What the author calls "standard abundance" values (in μg/kg) are presented in his Table 1. As can be seen, considerable concentrations of these trace metals are found in several organisms and sediments, compared with those in sea water.

The author has also compiled from the literature and from his own studies, data on the dry weight as a percentage of the wet weight in representatives of four phylae (Fig. 1). As can be seen, the spread is quite large, in the case of algae, for instance, from less than 5% to 45%. Thus, the average values of "standard abundances" cannot be accurate, as the author himself points out, but they are useful in giving the first rough idea of the concentration of the element in representatives of different trophic levels.

To express the relationships between the concentration of a certain element in marine organisms and that in sea water, the term concentration factor or enrichment factor is in common use. The term is usually defined as the ratio

$$\frac{\text{amount of a nuclide or element in unit mass of a fresh organism}}{\text{amount of the same nuclide or element in unit mass of sea water}}.$$

Thus, for trace elements the ratio is usually expressed

$$\frac{\mu\text{g of element/kg fresh organism}}{\mu\text{g of element/l sea water}}.$$

According to the opinion of the author, the term concentration or enrichment factor implies that in the case of radionuclides the higher concentrations are more hazardous. He points out that this is not so, however, as it is a high specific activity (Ci per g stable element) of the radionuclide which is hazardous, not a high "absolute level" (Ci per g tissue). The author proposes the term "abundance ratio" to be used instead of concentration or enrichment factor, to avoid confusion.

Personally, I am not convinced that the introduction of a third name for this same ratio would decrease or increase the confusion, although it might be preferable from one point of view. The colourful term enrichment factor also has its advantages, at least for accuracy, as it need not be based on an average dry weight of a phylum.

The second paper, by Dr. W. Feldt, from the Isotope Laboratory of the Federal Research Institute of Fischery, in Hamburg, Germany, is titled "Radiation Protection Aspects in the Survey of Fish regarding their Radioactive Contamination". Dr. Feldt looks at the problem not only from the viewpoint of the radiation protection of man, but also that of fish. In addition he studies critically the factors affecting

the contamination levels in fish. The author states that the contamination level of fish in regard to ^{90}Sr is inversely proportional to the Ca concentration in the water and can be calculated from the ^{90}Sr and Ca concentrations in the water by the equation

$$K_F = D_{WF} \cdot \frac{^{90}\text{Sr/l.}}{\text{Ca/l.}}$$

D_{WF} is the discrimination factor water/fish, its value varying from 0.2 to 0.3 in various fish species.

The ^{90}Sr and ^{137}Cs contents of fish from limnologically widely different waters during 1964 are presented in the author's Table 1. As the fish species caught from fresh water and marine environments are different, direct comparison is not possible, but one can see that the radionuclide contents in the fresh water fish are generally 10 to 100 times higher than in the marine fish.

In his Table 2 the author presents the concentration factor for ^{90}Sr and ^{137}Cs in waters having different Ca contents. In each column values for ^{90}Sr are on the left-hand, those for ^{137}Cs on the right-hand side. The concentration factor is defined in the usual way, for ^{90}Sr for instance

$$\frac{\text{pCi } ^{90}\text{Sr per kg fish (fresh wt)}}{\text{pCi } ^{90}\text{Sr per liter water}}$$

For ^{90}Sr the enrichment factor changes from 570 to 1 with increasing Ca content of the water (from 10 to 400 mg Ca/l). For ^{137}Cs the values change from 2000 to 23, with increasing Ca content. We shall see in a later paper of this session that it is really the potassium content of the water which determines the ^{137}Cs level in fish.

Dr. Feldt points out, that in order to evaluate the possible radiation risk to man from consumption of contaminated fish, one can use the specific activity of water and fish assuming that they must not exceed the maximum permissible specific activity (MPSA) in the human body, which has been set to 30 μCi/g Sr by the U.S. National Academy of Sciences National Research Council in its Publication No. 985 (1962), titled "Disposal of Low-Level Radioactive Wastes into Pacific Coastal Waters". Dr. Feldt presents in his Table 3 the specific activities of fish, μCi ^{90}Sr/g Sr. As can be seen, the most radioactive fish, pike from an oligotrophic fresh water lake, have an activity 0.14% of the MPSA, ocean fish having only 0.001% or less.

For ^{137}Cs the specific activity of North Sea fish is about 0.0001% of the MPSA. For freshwater fish it cannot be calculated as their content of inactive caesium is not known well enough.

Dr. Feldt has calculated the gonad doses for fish of two species, the contamination levels of which are presented in Table 4. The first species is typical of the Baltic Sea and the second represents the highest contamination level in the oligotrophic fresh waters. According to rather complicated calculations, the gonad dose of the Baltic Sea fish due to the two artificial nuclides ^{90}Sr and ^{137}Cs amounts to only 2% of the gonad dose caused by the natural radionuclide ^{40}K.

For the fresh water fish the dose from ^{40}K is 0.23 mrem/week and from ^{90}Sr plus ^{137}Cs is practically the same, i.e. 0.29 mrem/week, thus the latter together add about 100% to the natural dose.

The author concludes that the consumption of marine fish as human food does not constitute a radiation risk to man at present. The population of Northern Germany gets only about 5% of its body burden of ^{137}Cs through fish. Only fresh-water fish from the most calcium deficient lakes can play an important role in the dietary intake of ^{137}Cs to some population groups. The author emphasizes the need for increased monitoring of such critical waters. We shall see below that in Finland we have come to exactly similar conclusions in our studies.

The third and fourth papers report results of a research project carried out in our laboratory, The Department of Radiochemistry of the University of Helsinki, using a grant from the U.S. Department of Health, Education and Welfare. The third paper, by Drs. Häsänen, Kolehmainen and myself, is titled "Biological Half-times of ^{137}Cs and ^{22}Na in Different Fish Species, and Their Temperature Dependence". This paper summarizes our results on this subject obtained during the last two years. These studies became of real importance when

we found very high concentrations of ^{137}Cs in fresh water fish in 1962. The highest value observed hitherto is 26 nCi/kg fresh weight in the Finnish perch, measured in 1965. This is more than twice as high as Dr. Feldt's maximum value for the Kolksee pike. Fish flesh is the primary source of ^{137}Cs for Finnish population groups consuming fresh water fish, with the exception of reindeer herding Lapps and others consuming much reindeer or caribou meat, which contains even more ^{137}Cs than fresh water fish. The very laborious half-time determinations became necessary as very few papers have been published on excretion rates of ^{137}Cs in fish and none of these studies was made with species living in Finnish fresh waters.

Our experimental technique has varied slightly, but in most cases we have labelled each fish individually by giving it a precisely known amount of ^{137}Cs—usually 250 or 500 nCi—orally in a tiny gelatine capsule. The capsule has been applied by small forceps through the oesophagus of the fish. Each fish has been marked by clipping different fins and measured alive in the Institute's mobile whole body counter, first daily, later less frequently (Fig. 1). In laboratory experiments the fish were kept alive in thermostated aquaria. In field experiments they were placed in large cages made of Japanese nylon net suspended in an oligotrophic lake. The fish were regularly fed with either commercial inactive fish food, or milled inactive fish. The counting was performed by using a multichannel analyzer and the statistical error was smaller than 3%. Such a statistical error is small compared with the biological variance, which we have found to be 25% for individual fish, and 6% (1σ) for a group of 15 fish of the same species and age after one half-time from the labelling.

The results of a typical experiment are illustrated in Fig. 2. We can see that, as in many mammalia, the excretion rate follows a double-exponential function. A smaller fraction, typically 10 to 20%, shows a short biological half-time marked TB_1, usually varying from a part of a day to a few days (in this case it is 7 days at 15°C). Evidently this fraction mainly represents ^{137}Cs in the extracellular space. The remaining amount shows a biological half-time (TB_2) many times longer, varying from a few days to hundreds of days (in this case 80 days at 15°C). This fraction evidently represents ^{137}Cs in the intracellular space and especially within the muscle cells. In fish and other cold blooded animals the half-time is sharply dependent on temperature. When, in this experiment, at the beginning of October, the water temperature decreased within 2 weeks from 13° to 5°C, the value of the slow component increased to about 230 days.

The other results are summarized in Table 1. After the fish species, the type of experiment is mentioned. In the third column the age of the fish is given since in most species the half-time increases with increasing age of the fish (e.g. see roach). The next column gives the number of fish in the experiment. We attempted to have at least 15 similar fish in each experiment, but it was not always practicable. In the next column is the temperature, which in the field experiments varied more than in the aquaria, which could be thermostated. The last two columns contain figures for the fast and slow components of excretion: the half-times in days and the percentage of the component.

As can be seen, perch have the longest half-time, 200 ± 20 days at 15°C. There may be some increase in the value of the slow component with the ageing of the fish but the change is not definite. In roach the half-time in young fish (57 days) is about half that in the old fish (105 days). The age dependance is also clear in the rainbow trout, also the temperature dependance in all cases when determined. The half-time is about doubled when the water temperature decreases from 15° to 5°C, i.e. by 10 degrees.

The results on ^{22}Na are presented in Table 2. Only the long component is recorded since for sodium the presence of a short component in the excretion curve is not always certain. From perch and roach a small amount ($5 \pm 3\%$) was consistently excreted very rapidly, and from rainbow trout 20% at 6°C, but none was observed at the higher temperature. Temperature dependance seems to be similar to the case of the ^{137}Cs excretion: reduction to about one-half, with a temperature decrease from 15° to 5°C.

Also in this paper there is mentioned all of the similar studies that we have found in the literature. Unfortunately, most

cases are of little interest as a different species was studied and it is not clear whether the fast or slow component is given. Also the age of the fish and the temperature were not mentioned, but in two cases results rather similar to ours are reported. Scott reports for the brook trout (*Salvelinus fontialis*) a half-time of 47 days which corresponds to our 25 to 80 days in rainbow trout (*Salmo iridaeus*) of different ages at 15°C. Kevern, Griffith and Grizzard report for the carp (*Cyprinus carpio*) 98 days at 20°C, and 174 days at 12.5°C, values which are rather similar to those we found for the closely related Crusian carp (*Cyprinus carassius*). It may be mentioned also that Williams and Pickering, and Nelson and Early, in two different studies, report for the blue gills (*Lepomis machrochirus*) a half-time of 40 days for the ^{137}Cs excretion.

It can be concluded from these studies that: (1) the biological half time of ^{137}Cs in different fish species varies greatly, up to 10-fold, being one of the main factors causing different body burdens of this nuclide in different fish species; (2) in winter the half-times are much longer than in summer, for instance in perch well over one year.

The fourth paper, by Drs. Kolehmainen, Häsänen and myself, is titled "^{137}Cs in the Plants, Plankton and Fish of the Finnish Lakes and Factors affecting its Accumulation."

In this paper results from the years 1964 and 1965 are reported of an environmental investigation for 12 lakes of widely different limnological types, varying from eutrophic (rich in nutrients) to oligotrophic (nutrient deficient). Some limnological analyses of these lakes are presented in Table 1. The first lake is nutrient rich, the last ones extremely nutrient deficient. The potassium content in the first lake is 3.5 mg/l., in No. 10 only 0.2 mg/l. As can be seen in the last column the pollution level in these lakes from the global fallout varies very little, only about 2-fold, the extreme difference being 4-fold. This is, of course, one of the factors determining the contamination level of the organisms, but as can be seen, a minor one from the viewpoint of differences in the Finnish lakes.

Our results further show that the ^{137}Cs content of all organisms depends sharply on the potassium concentration of the water, which is the main factor determining the ^{137}Cs level. The contamination of the same organism varies more than 10-fold in different types of lakes as can be seen below.

In Table 2 some plankton analyses are presented, the lakes being in the same order as in the previous table, No. 1 being the most nutrient-rich. As can be seen, the ^{137}Cs content of the plankton varies about 10-fold, in one extreme case even 500-fold. The results represent mainly zooplankton, the percentage of phytoplankton being shown in the last column. Comparison between different years and lakes is difficult as the composition of the samples varies greatly, even from the same lake at different times. The approximate composition of the samples collected in 1965 is shown in Table 3.

The above tendency is also visible in the ^{137}Cs values of the higher plants, especially species rich in minerals like the horsetail (*Equisetum fluviatile*). Values for 2 higher plants are presented in Table 4. As can be seen, there is an approximately 20-fold difference in the ^{137}Cs content of plants grown in eutrophic and oligotrophic lakes. The values of higher plants do not always change regularly, but horsetail seems to be usable as an indicator species.

Relatively few samples of bottom animals have been obtained. Results of three samples are presented in Table 5. The values are practically the same as in plankton from the same lake.

Most clear-cut is the inverse relationship of the ^{137}Cs content of fish and the potassium content of the lake water. It is best illustrated in Fig. 1 of this paper. As can be seen, down to a K content of 1 mg/l. the ^{137}Cs content in pike remains low (< 3 nCi/kg), but with the K content 0.6 mg/l. it reaches the very high value of 21.3 nCi/kg fresh wt. The extreme differences within the same species are 100-fold. The deviating case is a lake polluted by wastes from the cellulose industry, mainly Na and Ca cations. The ^{137}Cs contents of other fish species are shown in Table 6.

A third factor determining the body burden of fish is the ^{137}Cs content of the food of the fish. Our results show that this is a minor factor effecting usually no more than 2- or 3-fold differences.

The fourth factor, and an important one, is

the biological half-time of ^{137}Cs which in the previous paper was shown to vary from 20 to 200 days at 15°C. The biological half-time of ^{137}Cs in perch and pike, for instance, is over a year in natural conditions, the annual mean temperature in the Finnish lakes being 4° to 6°C. This explains also why the ^{137}Cs values in many lakes, especially the oligotrophic ones, were still increasing in 1965.

To summarize, we can state that it is the potassium level of the lake water and the biological half-time of ^{137}Cs in the species which mainly determines the ^{137}Cs-level in the fish at a given pollution level. Especially in oligotrophic lakes, body burdens are fully determined by intake in the food. Our studies show that direct intake of the nuclide by an osmotic mechanism in the gills is negligible. Dr. Feldt's studies show that the ^{90}Sr level in fish is similarly determined by the Ca level in the water, and we can generalize that the contamination of fish in different waters is practically determined by the carrier ion levels in the water at a given pollution level.