# BIOLOGICAL HALF-TIMES OF $^{137}Cs$ AND $^{22}Na$ IN DIFFERENT FISH SPECIES AND THEIR TEMPERATURE DEPENDENCE

**ERKKI HÄSÄNEN, SEPPO KOLEHMAINEN and J. K. MIETTINEN**
Department of Radiochemistry, University of Helsinki, Finland

**Abstract**—Biological half-times of $^{137}Cs$ in 5 species of fish were determined by giving *per os* a precisely known dose (usually *ca.* 250 nCi) of $^{137}Cs$ in a gelatine jelly or in a tiny gelatine capsule and by whole body counting the fish, first daily, then weekly, in the Institute's mobile whole body counter. Experiments were continued for up to 6 months. Twelve experiments were carried out in the field in summer (May–October) and 16 in the laboratory, where it was possible to keep a constant temperature (from 6 to 20°C) in the aquarium.

The excretion of $^{137}Cs$ from fish follows a two-differential equation: the fast component (usually 5 to 10% but in *Salmo* 25 and in *Cyprinus* 50% of the amount administered) has a half-time of a few days, the slow component is about one order of magnitude longer. At 15°C the long component is for perch (*Perca fluviatilis*) 200 days, roach (*Leuciscus rutilus*) from 100 days (age 11 years) to 57 days (3 years). For the rainbow trout (*Salmo iridaeus*) the long component varies from 20 to 80 days depending on the age of the fish. The value for young fish (1 year, 20 days at 20°C) is increased to 36 days at 7–8°C. Crucian carp (*Cyprinus carassius*) of about 5 years of age has a half-time of 55 days at 20°C, 120 days at 10°C.

The biological half-times of $^{22}Na$ are much shorter, but the temperature dependence seems to be very similar to that of $^{137}Cs$. For perch, half-times of $^{22}Na$ were 7 days at 20°C, 15 days at 10°C; for roach 7 days at 20°C, 11 days at 10°C; for burbot 30 days at 10°C, for the Crucian carp 10 days at 20°C, 25 days at 10°C.

Knowledge of the body burden and of the biological half-time make possible calculation of the daily intake of $^{137}Cs$ by fish in natural conditions.

## INTRODUCTION

The excretion rate of $^{137}Cs$ is known for a number of animal species.[1] It usually follows a two-exponential equation: a smaller fraction, typically 10 to 20% shows a short biological half-time ($TB_1$) varying from part of a day to a few days. Evidently, this fraction mainly represents $^{137}Cs$ in the extracellular space. The remaining bulk shows a biological half-time ($TB_2$) many times longer, varying from a few days to one hundred days. This fraction evidently represents $^{137}Cs$ in the intracellular space and especially within the muscle cells. Knowledge of the biological half-time(s) is necessary for the quantitative treatment of the behaviour of $^{137}Cs$ (and any other nuclide having an exponential excretion rate) in organisms, which again is necessary for clear understanding of the behaviour of the nuclide in a foodchain.

Except for $^{55}Fe$ which cannot be measured[2] by ordinary thick crystal gamma spectrometry, $^{137}Cs$ is the only artificial long-lived nuclide present in easily measurable amounts in the flesh of fish. $^{90}Sr$ is also present in fish in considerable concentrations but it is mainly located in the bones, which are not eaten by man. The presence of $^{55}Fe$ has been recently shown independently by Jaakkola[3] in fresh water fish and Palmer[2] in ocean fish. Ocean fish may contain it in high concentration (max. 2 $\mu$Ci/kg fresh wt. in salmon liver.[2] $^{137}Cs$ is found in fresh water fish in high concentrations, the highest value was in 1965 in the Finnish perch 26 nCi/kg fresh weight,[4] which is more than in any other food eaten by man except

reindeer meat. Fish flesh is the primary source of $^{137}Cs$ for population groups consuming fresh water fish, with the exception of reindeer-herding Lapps and other peoples consuming mainly reindeer or caribou meat having 2 to 4 times higher maximal $^{137}Cs$ contents than the fresh water fish. Even for these peoples fish is usually the second source of $^{137}Cs$ in importance.[5] $^{137}Cs$ content of lake fish varies greatly in different waters according to the limnological type of the water,[4] but even in the same water there exist great differences in the $^{137}Cs$ content between various species of fish. These are partly due to differences in the diets of the fish, but an equally important cause is a different excretion rate of $^{137}Cs$ in the various fish species, as will be shown in this paper.

## EXPERIMENTAL

The experimental technique has varied to some extent. The first experiment was carried out with 150 small perch, 6 months of age, weighing 1–1.5 g each, in an aquarium in the laboratory. In this experiment labelling was given externally by keeping the fish for 1 hr in water (electrolytic conductivity 250 mho, potassium 5 mg/l) containing 860 $\mu$Ci carrier-free $^{137}Cs$ in 8 l. Each fish took up 1.8 nCi, 150 fish thus taking 0.27 $\mu$Ci or 0.03% of the amount given. The concentration factor was 0.012. Then the fish were grown with inactive food in a 200 l. aquarium (conductivity 250 mho, potassium content 5 mg/l.) in slowly changing inactive water. The experiment was continued for 6 months taking samples of 15 to 25 fish for measurement with intervals from 2 days to several weeks.

In most other experiments each fish has been labelled individually by giving it a precisely known amount of $^{137}Cs$ (usually 250 or 500 nCi) orally in a tiny gelatine capsule (4 × 8 mm). Each fish was then marked by clipping different fins and measured alive in the Institute's mobile whole body counter (Fig. 1), first at one-day intervals, later less frequently.

In field experiments the fish were kept in large cages made of Japanese nylon net and placed in the oligotrophic Suolijärvi lake.[4] They were regularly fed commercial fish food or milled inactive fish. In laboratory experiments they were kept in aquaria of different sizes, up to

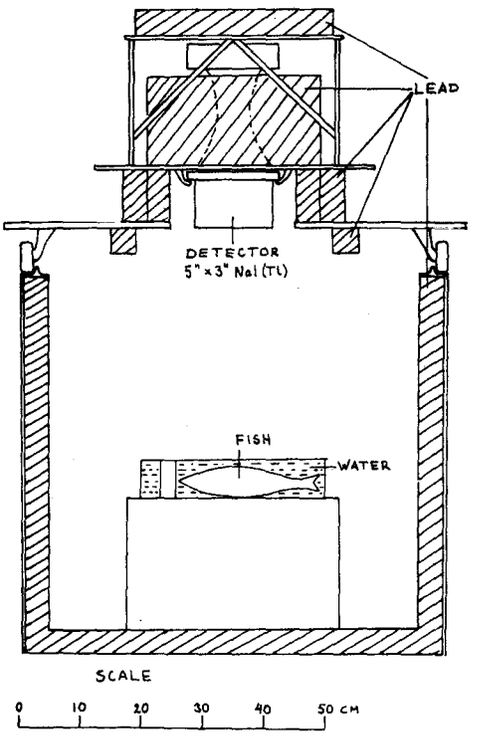


FIG. 1. Arrangement for whole body counting of live fish, initially labelled by an oral dose of 250 nCi $^{137}Cs$. This activity gives 1170 cpm net within the $^{137}Cs$ photopeak channel at a distance of 42 cm. BG is 200 cpm. The lead shield is 4 to 8 cm thick and weighs 1800 kg.

1 m × 2 m × 70 cm (depth). In some experiments, with quite young fish, the isotope was given orally by injecting an aliquot of $^{137}Cs$-containing gelatine jelly into the oesophagus. In one experiment the isotope was given by feeding labelled food to the fish.

As the fish in nature get the bulk of their $^{137}Cs$ in food, oral administration corresponds best to the natural conditions. In addition, a precise determination of the short component requires instantaneous administration of the isotope. Furthermore, the external labelling seems to give a higher percentage of the short component, probably due to partial adsorption on the surface of the fish (Table 1, line 1). Therefore, oral administration has been used in all experiments but the first.

*Table* 1. *Biological Half-time of* $^{137}Cs$ *in Five Species of Fresh-water Fish*
(*F, Field experiment; L, Laboratory experiment*)

| Fish species | Type of expt. | Age of fish yr. | No of fish in expt. | Temp. °C | Fast comp. ($TB_1$) days | Fast comp. ($TB_1$) % | Slow comp. ($TB_2$) days | Slow comp. ($TB_2$) % |
|---|---|---|---|---|---|---|---|---|
| Perch | L | 0.5–1* | 150 | 18 ± 2 | | 17 | 200 | 83 |
| (*Perca fluviatilis*) | F | 2–3 | 16 | 15 ± 5 | 12 | 6 | 175 | 94 |
| | F | 2–3 | 6 | 15 ± 5 | | 6 | 220 | 94 |
| | F | 3–6 | 12 | 15 ± 5 | | 4 | 200 | 96 |
| | F | 6–8 | 3 | 15 ± 5 | | 10 | 220 | 90 |
| Roach | F | 2–3 | 11 | 15 ± 5 | | 6 | 57 | 94 |
| (*Leuciscus rutilus*) | F | 4–6 | 4 | 15 ± 5 | | 6 | 85 | 94 |
| | F | 9–12 | 3 | 15 ± 5 | | 10 | 150 | 90 |
| | F | 2–3 | 11 | 5 ± 2 | | | 340 | |
| Rainbow trout | L | 0.5–1 | 7 | 20 ± 0.2 | | | 20 | 94 |
| (*Salmo iridaeus*) | L | 0.5–1 | 11 | 14 ± 1 | | | 19 | 90 |
| | L | 0.5–1 | 10 | 7 ± 1 | 3 | 26 | 34 | 74 |
| | F | 0.3–0.5 | 50 | 15 ± 5 | 5 | 25 | 25 | 75 |
| | F | 1–2 | 18 | 15 ± 5 | 5 | 34 | 55 | 66 |
| | F | 2–3 | 15 | 15 ± 5 | 7 | 24 | 80 | 76 |
| | F | 1–2 | 17 | 4 ± 1 | | | ≃ 150 | |
| | F | 2–3 | 15 | 4 ± 1 | | | ≃ 230 | |
| Crusian carp | L | 5 | 29 | 20 ± 0.2 | 2 | 50 | 55 | 50 |
| (*Cyprinus carassius*) | L | 5 | 28 | 8 ± 3 | 3 | 55 | 120 | 45 |
| Burbot | L | 5 | 1 | 8 ± 3 | 8 | 14 | 110 | 86 |
| (*Lota vulgaris*) | | | | | | | | |

* Labelling given externally.

The *measurement* has been made with a multichannel analyzer at 42 cm distance from the 5 × 3 NaI(Tl) crystal (Fig. 1). With 250 nCi 1170 cpm net are obtained within the $^{137}Cs$ photopeak channel. With 250 to 500 nCi initial labelling and 2 to 4 min counting time a statistical accuracy (1 $\sigma$) better than 3% is obtained throughout the experiment of 2 × $TB_2$. This statistical error is small compared with the *biological* variance which is for individual fish 25%, and for a group of 15 fish 6% (1 $\sigma$) after external labelling and one $TB_2$ (unpublished). This is mainly due to differences of $TB_2$ between individuals of the same species.

## RESULTS

The results for $^{137}Cs$ are presented in Table 1. Those for rainbow trout are also illustrated in

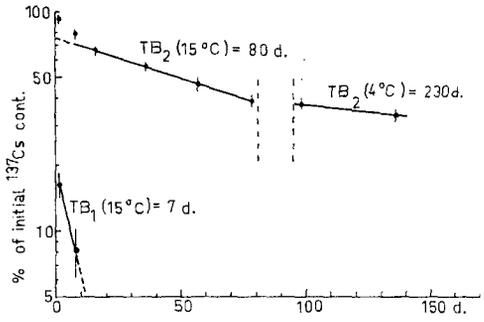


FIG. 2. $^{137}Cs$ retention in rainbow trout (15 fish) with biological variance (two $\sigma$) marked. At least two components are noticeable in the retention at 15°C: a "short" one having a half-time 7 ± 3 days ($TB_1$), and a "long" one, 80 ± 4 days ($TB_2$). At 4°C the value of $TB_2$ is 230 ± 10 days.

Fig. 2. The points for $TB_1$, the fast component of the biological half-time, have been obtained by subtracting from the total retention the part due to the slow component, $TB_2$, obtained by extrapolating to zero in the usual way. At the beginning of October the water temperature decreased in 2 weeks from 13°C to 5°C; the value of $TB_2$ then increased to about 230 days.

As can be seen from Table 1, perch has the longest half-time ($TB_2$), 200 ± 20 days at 15°C. There may be some increase in the value of $TB_2$ with the ageing of the fish, but the change is not clear. As the youngest age group (0.5 to 1 year) was labelled externally the results are not strictly comparable with the others.

In roach the half-time (50 days) in young fish is about half of that in old fish (100 days). The age dependence is clear also in rainbow trout as is the temperature dependence in rainbow trout and in the crusian carp. The table is incomplete in many respects due to technical difficulties. In laboratory experiments these include lack of space, presence of impurities in tap water, malfunction of thermostats and occasional infectious diseases. The field experiments have the advantage of more natural conditions, but the disadvantage that the water temperature cannot be kept constant. It was concluded from parallel determinations and parallel experiments that the accuracy of the data presented is better than 10%. Because the biological variance is rather large (see above) it is for most purposes not meaningful to have the average value determined with much higher accuracy; and in any case this would be very cumbersome.

In experiments made with oral labelling of perch and roach the percentage of the short component was 4 to 10%. In rainbow trout it was 25 ± 1% in three experiments, but 34% in one experiment. A large percentage is understandable in salmon which have rapid metabolism and short half-time ($TB_2$). The high percentage in the crucian carp is exceptional. There was no excretion during the first 24 hr, then about 50% of intake was suddenly excreted during the next 24 hr, and after that a very slow excretion rate ($TB_2$ 55–120 days) was observed.

The results for $^{22}Na$ are presented in Table 2. The presence of a short component in the excretion curve for sodium is not always clear. From perch and roach a small amount (5 ± 3%) was consistently excreted very rapidly, and from rainbow trout 20% at 6°C but none was observed at the higher temperatures. As the long component was only 2.2 to 2.5 days it would have needed measurements at 1 hr intervals to notice the short one, but these were not made. No signs of a third component were noticed although most of the experiments were continued for several half-times (30 to 40 days).

*Table 2. Biological Half-time of $^{22}Na$ in Five Species of Freshwater Fish*

| Fish | Age, yr. | No. of fish in expt. | Temp. °C | Biol. half-time of $^{22}Na$, days |
|---|---|---|---|---|
| Perch | 1–2 | 6 | 20 ± 0.2 | 7 |
| | | 5 | 8 ± 3 | 15 |
| Roach | 1–2 | 5 | 20 ± 0.2 | 7 |
| | | 5 | 8 ± 3 | 11 |
| Rainbow trout | 0.5–1 | 7 | 20 ± 0.2 | 2.2 |
| | | 11 | 14 ± 1 | 2.5 |
| | | 10 | 7 ± 1 | 7 |
| Crusian carp | 5 | 30 | 20 ± 0.2 | 10 |
| | | 30 | 8 ± 3 | 25 |
| Burbot | 5 | 1 | 8 ± 3 | 30 |

Temperature dependence seems to be similar to $^{137}Cs$-excretion: a 10° temperature decrease (from 15 to 5°C) reduces the excretion rate to about one-half.

## CONCLUSIONS AND DISCUSSION

It is of interest to compare the above results with those obtained elsewhere, although the species are evidently different in all cases. Dean *et al.*[6] have studied the uptake and excretion of $^{137}Cs$ in different tissues of another species of rainbow trout, *Salmo gairdneri*. By injecting 10 $\mu$Ci intravenously into yearling fish they found the "effective half-time" ($TB_2$) of $^{137}Cs$ in red muscle 5½ days, in white muscle 13 days. The curves published also suggest the existence of a short component of less than a day in most tissues (heart, gills, blood, liver, kidney). Temperature was not given, but if it was around 20°C and the whole body burden was determined by the white muscle, 13 days corresponds approximately to our value of 19 days at 14°C in *Salmo iridaeus*. Scott[7] reports 47 days for the brook trout (*Salvelinus fontialis*) and Ichikawa[8] 5 to 10 days for salmon (*Salmo salar*). Rudakov[9] has studied Crusian carp (*Cyprinus* sp.) and reports 10 to 15 days, but this value may represent the short component. Our values for $TB_2$ in the Crusian carp are 55 and 120 days at 20 and 8°C, respectively, but there may be a different species in question. Kevern *et al.*[10] report for the carp (*Cyprinus carpio*) 98 days at 20°C and 174 days at 12.5°C, i.e. about similar temperature dependence as found in this work. From the data of Williams and Pickering[11] we can estimate for very young bluegills (2 g each) the fast component to be about 3 to 4 days, the slow one 40 days. Nelson and Early[12] report the same value, 40 days, for blue gills (*Lepomis macrochirus*). Baptist and Price[13] studied retention of $^{137}Cs$ in skin, muscle, liver and gonad of the Atlantic croaker fish (*Micropogon undulatus*) finding that each tissue required multiple rate functions involving two or four exponents. Muscle had the longest retention time and it evidently governed the whole body retention. In most of the above studies the age of the fish and the water temperature are not given.

It is evident from the present results, and from those of the earlier workers, that the excretion rate of $^{137}Cs$ in fish varies greatly, by at least one order of magnitude. For instance, old perch has a two times longer half-time (200 days) than the old roach (100 days). $^{137}Cs$ body burdens in perch have been in most Finnish lakes 3 to 6 times higher than in roach.[4] Half of this difference is evidently due to different

food activity as perch eats mainly small perch, but roach plankton and bottom animals,[14] half to different half-times. As shown in the above paper by us,[14] if one knows the $^{137}Cs$ body burden in a fish species at intervals of one to two half-times, and the percentage and value of the long component, one can calculate very accurately the daily intake of $^{137}Cs$ by the fish. Direct intake of $^{137}Cs$ through gills is so small that it can be neglected.[4] If, in addition, the activity of the food of the fish is known, one can calculate the food intake by the fish, a factor which is of great interest to fish investigators, and otherwise difficult to determine. Food intake by roach was in this way estimated in 6 lakes and found to vary from 0.8 to 2.3% of the weight of the fish per day. The intake was lowest in eutrophic lakes where a large number of small fish evidently limited the amount of food available. The annual growth of the fish was greater in the oligotrophic lakes where the food intake was greater, too.[14]

These examples show that some benefit may be obtained from the worldwide fallout to ecology and limnology.

**ACKNOWLEDGEMENTS**

Financial support for this investigation was obtained from the U.S. Department of Health, Education and Welfare (Public Health Service Research Grant No. RH-00307).

We are much indebted to the Kalamiesten keskusliitto organization for allowing us to use in these studies their fish hatchery facilities at Kytäjä.

It is a pleasure to acknowledge skilful technical assistance by Mr. Seppo Takatalo, Cand. Sci., and Mr. I. Vöry.

**REFERENCES**

1. C. R. Richmond, J. E. Furchner and W. H. Langham. *Health Phys.* **8**, 201 (1962).
2. H. E. Palmer and T. M. Beasley. *Radioecological Concentration Processes*, p. 259. Pergamon Press, London (1967).
3. T. Jaakkola. Ibid., p. 247.
4. S. Kolehmainen, E. Häsänen and J. K. Miettinen. This volume, p. 407.
5. Aili Jokelainen. *Acta Agr. Fenn.* **103,** 1 (1965) (Ph.D. Thesis).
6. J. M. Dean, J. Eapen and R. E. Nakatani. Hanford Biology Research Annual Report for 1964, BNWL-122, 73–4 (1965).
7. D. P. Scott. *J. Fish. Red. Board. Can.* **19,** 194 (1962).
8. R. Ichikawa. *Jap. J. Rad. Res.* **1,** 107 (1965).
9. N. P. Rudakov. *Izv. Oos. Nauchn.—Issled. Inst. Ozern. i Rechn. Rybn. Khoz* **51,** 165 (1961).
10. N. R. Kevern, N. A. Griffith and T. Grizzard. ORNL-3697, 101 (1964).
11. L. G. Williams and Q. Pickering. *Ecology* **42,** 205 (1961).
12. D. J. Nelson and R. C. Early. ORNL-3347, 67 (1962).
13. J. P. Baptist and T. J. Price. *U.S. Fish Wildlife Serv., Fishery Bull.* **62** (206), 177 (1962).
14. S. Kolehmainen, E. Häsänen and J. K. Miettinen. *Radioecological Concentration Processes*, p. 913. Pergamon Press, London (1967).