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Distribution of ^{137}Cs and ^{90}Sr in various tissues and organs of freshwater fish in Finnish lakes

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The degree of radiocontamination in fish is usually analysed to estimate doses to fish consumers, for which the radionuclide contents in the edible parts of fish are needed. Recently increasing attention has been focused on radiation protection in plants and animals. To estimate the effects of radiation on fish, the distribution of radionuclides in various organs and radiosensitivity of the organs must be known. A step towards this was taken when the Radiation and Nuclear Safety Authority (STUK) of Finland determined the distribution of ^{137}Cs and ^{90}Sr in muscle tissue, skin + fins, and bones in perch samples, in muscle and bones or in muscle, skin + fins, and bones in pike samples and in muscle + skin + fins and bones in vendace samples. Accumulation of ^{137}Cs in fish liver, spawn and sperm was also studied and compared with respective values in the edible parts. The importance of skin and fins was evident as a source of ^{90}Sr to fish. Fish sperm showed somewhat higher activity concentrations of ^{137}Cs than muscle.

Introduction

Radionuclides in freshwater fish have usually been studied as part of the foodchain leading to man and causing internal radiation doses to man through fish consumption. Data on ^{137}Cs in freshwater fish concerning the use of fish as food and dose estimation for people via fish consumption, or concentration ratios used in modelling uptake and foodchain transport of radionuclides via fish to people have been widely published in Finland after the Chernobyl accident (Saxén and Rantavaara 1987, Saxén and Koskelainen 1996). Factors affecting accumulation of certain radionuclides in edible parts of fish were already thoroughly investigated during the period of nuclear weapon fallout (Kolehmainen *et al*. 1966) and after the unevenly distributed areal deposition from the Chernobyl accident (Särkkä *et al*. 1995, Jonsson *et al*. 1999). In addition to differences in deposition into the lakes other reasons for the variation are discussed, nutritional level of the lake being one of the most important factors.

To estimate radiation doses resulting from people eating fish, the radionuclide contents in the tissues eaten are important. However, increasing attention has been focused recently

1. Hirvijärvi ■
2. Hyrynjärvi ◇
3. Iso Valkjärvi ◇
4. Junkkarinjärvi ■
5. Kallavesi ◇
6. Kankarinjärvi ■
7. Katumajärvi ■
8. Keitele ◇■
9. Kemijärvi ●
10. Kertejärvi ■
11. Kivijärvi ◇
12. Konnevesi ■
13. Korpijärvi ■
14. Kyrösjärvi ◇■
15. Lentua ■
16. Lestijärvi ◇
17. Längelmävesi ■
18. Muurikaisjärvi ■
19. Naula-Meronen ■
20. Nilakka ◇●■□
21. Orivesi ■
22. Pieni Karakkajärvi ■□
23. Puulavesi ●■
24. Pyhäjärvi (Pieksämäen mlk) ■
25. Pyhäjärvi (Pirkkala) ◇●■
26. Pyhäjärvi (Säkylä) ◇
27. Päijänne ●■
28. Pälkänevesi ●■□
29. Rahtijärvi ●
30. Roine ■
31. Ruokojärvi ■
32. Saimaa ■
33. Summasjärvi ■
34. Suolijärvi ●■
35. Tarjanne ■
36. Uurajärvi ■□
37. Valkea Kotinen ◇
38. Valkeajärvi ◇
39. Valkeinen ■
40. Vehkajärvi ●■□

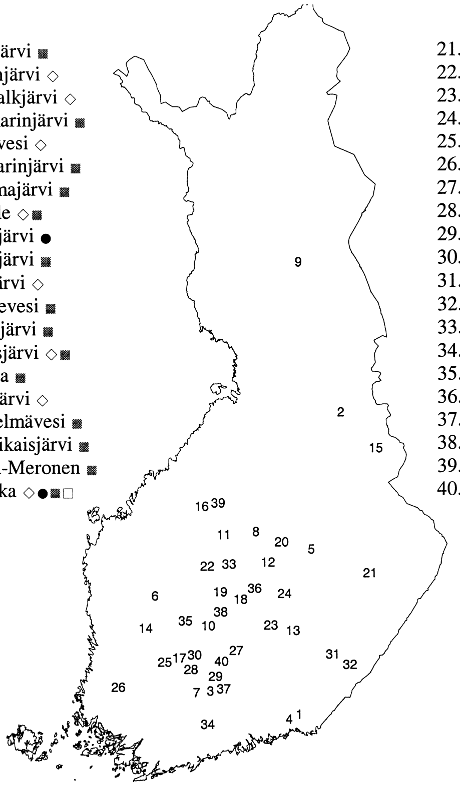

Fig. 1. Location of the lakes included in the study and tissues of fish analysed from various lakes (■ fish spawn, □ fish sperm, ● fish liver, ◇ muscle, bone, skin, fins).

on radiation protection of plants and animals. When considering radiation doses in animals, data on the distribution of radionuclides in various tissues and organs is essential. It is known that different radionuclides accumulate in various organs in animals, e.g. ^{137}Cs in muscle tissue and ^{90}Sr in bones. The purpose of the present study was to determine the distribution of some radionuclides in various organs in fish. The activity concentrations in various tissues of freshwater fish was determined and the relative contributions of organs to the total activity analysed. Accumulation in other organs in addition to muscle and bones has not been widely reported. Apart from accumulation in certain organs the radiosensitivity of an organism affects the impact of radiation. Since gametes are usually the most sensitive to radiation, spawn and sperm of various fish species were analysed.

Material and methods

The distribution of ^{137}Cs and ^{90}Sr in muscle tissue, skin + fins and bones in perch (*Perca fluviatilis*), in muscle, bones and skin + fins in pike (*Esox lucius*) and in muscle + skin + fins and bones in vendace (*Coregonus albula*) was determined. The fish samples for these determinations were taken from 12 lakes in southern and central Finland (Fig. 1) in 1995. The tissues analysed and sample treatment varied slightly among species, depending mainly on the size of the fish in the sample. Skin and fins were removed from some pike samples and only muscle tissues and bones were analysed for ^{137}Cs and ^{90}Sr. Skin and fins were not separated from vendace samples, but were analysed together with the muscle tissue, because the fish were usually too small to enable easy separation of these parts. The parts to be analysed were separated as carefully as possible. In addition to the contents of ^{137}Cs and ^{90}Sr in various parts, such as muscle, bones, skin and fins, ^{137}Cs and ^{90}Sr were determined in gutted fish. Gutted perch included fish without heads, entrails and the spinous dorsal fin. From vendace samples only the heads and entrails were removed in gutting. Two pike samples were gutted so that the heads and entrails were removed, while from 6 pike samples the muscles and bones were separated. All the tissues separated were weighed to estimate the relative contribution of various organs or tissues to the total amount of ^{137}Cs and ^{90}Sr in the fish. Most samples consisted of several individuals; the perch and vendace samples included 8–74 fish and the pike samples 1–3 fish per sample. The total number of fish included in the study were 103 perch, 174 vendace and 15 pike.

Additionally, ^{137}Cs in livers, spawn and sperm of various fish species from several lakes were analysed (Fig. 1). Samples of liver were taken in 1986–1993, spawn in 1986–1989 and sperm in 1986. Livers of pike, pike-perch (*Stizostedion lucioperca*), burbot (*Lota lota*), whitefish (*Coregonus* sp.), bream (*Abramis brama*) and trout (*Salmo trutta*), spawn of perch, pike, burbot, vendace, whitefish, roach (*Rutilus rutilus*) and sperm of perch, burbot and whitefish were analysed for radiocaesium. The number of samples and individuals in the samples were as follows:

	Number of samples	Individuals in a sample
Liver		
Pike	12	1–5
Pike-perch	6	1–8
Bream	4	1
Burbot	14	1–10
Whitefish	13	1–21
Trout	5	1–6
Spawn		
Perch	9	3–81*
Pike	5	1
Burbot	2	1–3
Vendace	21	10–70*
Whitefish	10	1–30*
Roach	3	7–22*
Sperm		
Perch	3	3–81*
Whitefish	1	4
Burbot	1	1

* All individuals in the samples contained no spawn or sperm, but were included in the determination of ^{137}Cs in gutted fish.

The organ samples were cut into small pieces, dried at 105 °C, homogenized and packed into a small, cylindrical 30-ml canister for gammaspectrometric measurements. Some liver samples and all the spawn and sperm samples were measured fresh without drying. The gammaspectrometric analyses were performed using pure Ge or Ge(Li) detectors and the computer program GAMMA-83 (Sinkko 1981, Sinkko and Aaltonen 1985). The measuring times were usually 2–5 h, and the ^{137}Cs concentrations in all the samples were clearly above the detection limit. After the gammaspectrometric analyses the samples to be analysed for ^{90}Sr were ashed and the ash dissolved in nitric acid. ^{90}Sr was separated from the sample matrix using the nitric acid method (Bryant *et al.* 1959). Activity measurements were carried out using a liquid scintillation spectrometer (Quantulus; LKB Wallac Oy, Turku, Finland) or a low-background proportional counter (Risö National Laboratory, Denmark). Activity concentrations of ^{137}Cs and ^{90}Sr for all the samples were corrected for radioactive decay to sampling date.

Results

The contents of ^{137}Cs in the fish examined showed a wide range in variation among several lakes (Table 1), which was dependent on the degree of deposition in the lakes in 1986 (Fig. 2). ^{137}Cs in muscle tissue of fishes from the lakes examined here varied by a factor of 100, from 43 to 4900 Bq kg^{-1}. Activity concentrations of ^{137}Cs in bones were in all fish species somewhat lower than half the respective concentration in muscle tissue. In skin + fins, ^{137}Cs concentration was lower than in muscle tissue but clearly higher than in bones. Variation in ^{90}Sr contents was not as high as in ^{137}Cs (Table 2). The activity concentrations of ^{90}Sr were highest in bones, while values for ^{137}Cs were highest in muscle tissue: ^{90}Sr in bones was on average 250 times and ^{90}Sr in skin and fins 130 times that in muscle tissue (Figs. 3 and 4).

The relative contributions of various tissues to the total weight of the 3 fish species: perch, pike and vendace, differ somewhat from each other (Fig. 5). Muscle tissue contributed from about 68% to 75% of the total weight of perch and pike, while that of bones was only 2%–4%. The relative contributions of various parts to the

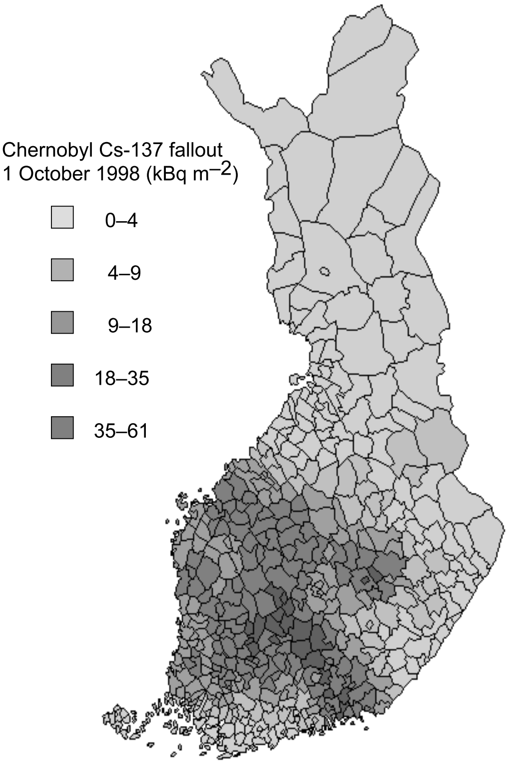

Fig. 2. Distribution of ^{137}Cs in Finland after the Chernobyl accident. The municipalities are divided into 5 categories according to their mean ^{137}Cs deposition (Arvela *et al.* 1990).

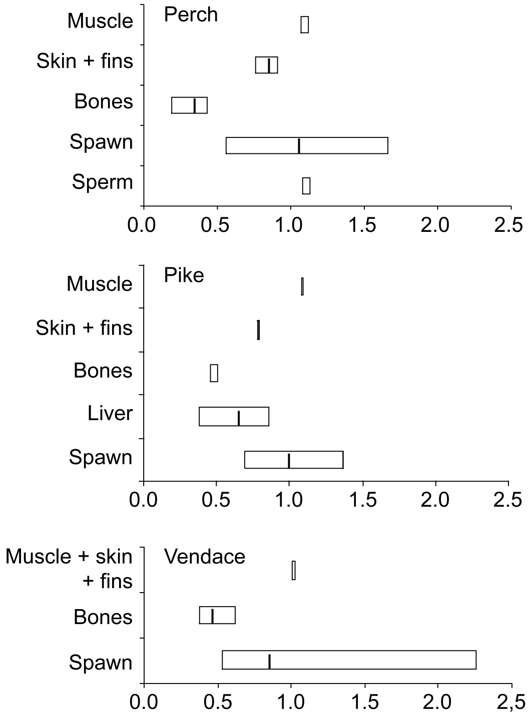

Fig. 3. Variation and mean of the ratio of ^{137}Cs activity concentration in a tissue to that in gutted fish (Bq kg^{-1} in a tissue/Bq kg^{-1} in gutted fish).

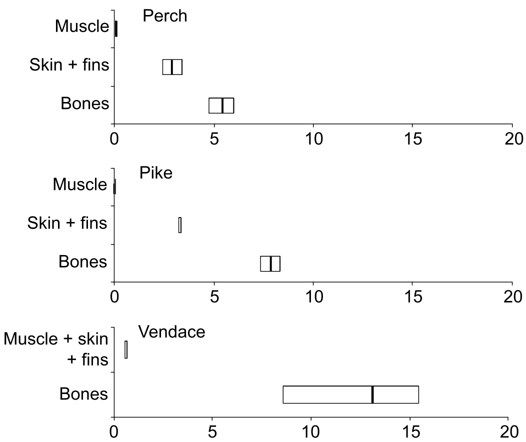

Fig. 4. Variation and mean of the ratio of ^{90}Sr activity concentration in a tissue to that in gutted fish (Bq kg^{-1} in a tissue/Bq kg^{-1} in gutted fish).

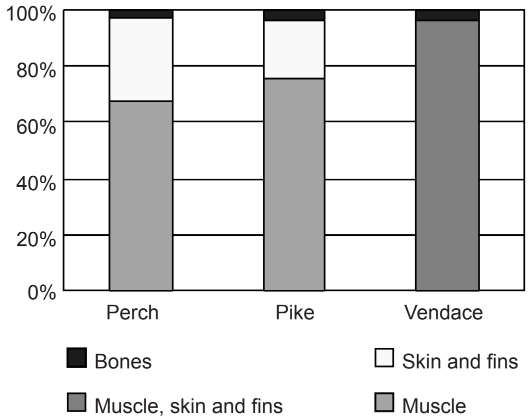

Fig. 5. Relative weights of various parts of 3 freshwater fish species: perch (*Perca fluviatilis*), pike (*Esox lucius*) and vendace (*Coregonus albula*).

total contents of ^{137}Cs and ^{90}Sr in gutted fishes were calculated, based on the weight distribution and activity concentrations of radionuclides in various tissues of fish. The contributions of

Table 1. Contents of ^{137}Cs (Bq kg^{-1} fresh weight) in various tissues of perch, pike and vendace samples from various lakes. The samples were taken in 1995. Each perch, pike and vendace sample included 8–53, 1–3 and 17–74 individuals, respectively. Locations of the lakes are shown in Fig. 1.

Species/Lake	Muscle Bq kg^{-1}	Skin and fins Bq kg^{-1}	Muscle, skin and fins Bq kg^{-1}	Bones Bq kg^{-1}
Perch, *Perca fluviatilis*				
Hyrynjärvi	68	47	–	26
Pyhäjärvi (Pirkkala)	88	74	–	16
Pyhäjärvi (Säkylä)	104	80	–	41
Valkeajärvi	1440	1178	–	450
Pike, *Esox lucius*			–	
Valkeajärvi	2102	1517	–	882
Keitele	611	441	–	284
Kallavesi	43	–	–	17
Kyrösjärvi	184	–	–	63
Lestijärvi	312	–	–	122
Nilakka	232	–	–	114
Iso-Valkjärvi	4940	–	–	2460
Valkea-Kotinen	2152	–	–	960
Vendace, *Coregonus albula*				
Kallavesi	–	–	13	5
Kivijärvi	–	–	133	63
Lestijärvi	–	–	140	51
Nilakka	–	–	69	31
Pyhäjärvi (Säkylä)	–	–	25	15

Table 2. Contents of ^{90}Sr (Bq kg^{-1} fresh weight) in various parts of perch, pike and vendace samples from various lakes. The samples were taken in 1995. Each perch, pike and vendace sample included 8–53, 1–3 and 17–74 individuals, respectively. Locations of the lakes are shown in Fig. 1.

Species/Lake	Muscle Bq kg^{-1}	Skin and fins Bq kg^{-1}	Muscle, skin and fins Bq kg^{-1}	Bones Bq kg^{-1}
Perch, *Perca fluviatilis*				
Hyrynjärvi	0.2	33	–	56
Pyhäjärvi (Pirkkala)	0.1	14	–	27
Pyhäjärvi (Säkylä)	0.2	23	–	46
Valkeajärvi	0.8	133	–	236
Pike, *Esox lucius*				
Valkeajärvi	0.6	61	–	139
Keitele	0.3	35	–	88
Kallavesi	0.2	–	–	25
Kyrösjärvi	0.4	–	–	75
Lestijärvi	0.3	–	–	62
Nilakka	0.2	–	–	49
Iso-Valkjärvi	0.6	–	–	222
Valkea-Kotinen	0.4	–	–	97
Vendace, *Coregonus albula*				
Kallavesi	–	–	2.1	26
Kivijärvi	–	–	3.6	89
Lestijärvi	–	–	3.3	82
Nilakka	–	–	4.2	75
Pyhäjärvi (Säkylä)	–	–	2.1	54

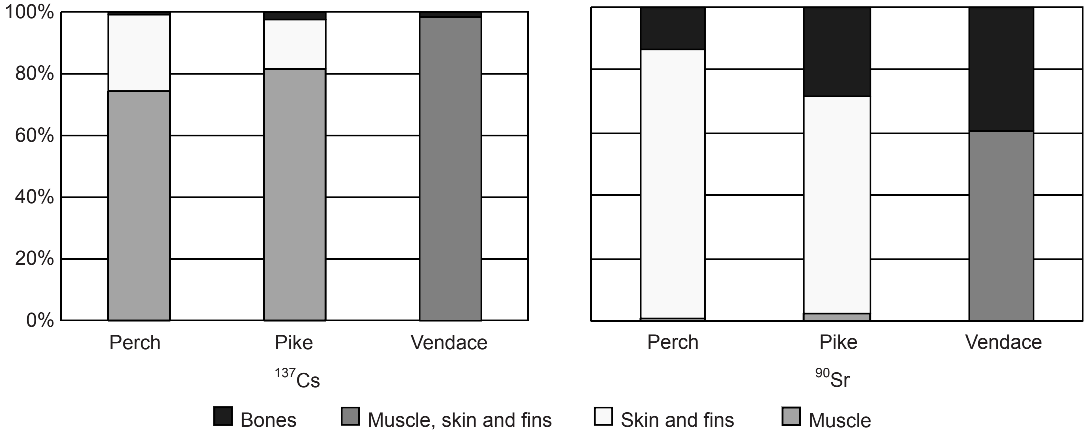

Fig. 6. Relative distribution of ^{137}Cs and ^{90}Sr in various tissues of perch, pike and vendace.

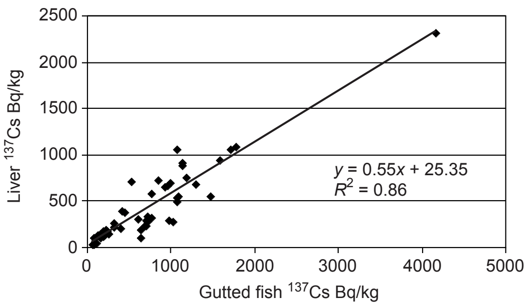

Fig. 7. Correlation of ^{137}Cs in fish liver with ^{137}Cs in gutted fish (muscle). Livers of pike (*Esox lucius*), pike-perch (*Stizostedion lucioperca*), burbot (*Lota lota*), whitefish (*Coregonus* sp.), bream (*Abramis brama*) and trout (*Salmo trutta*) were analysed. Sampling lakes are shown in Fig. 1.

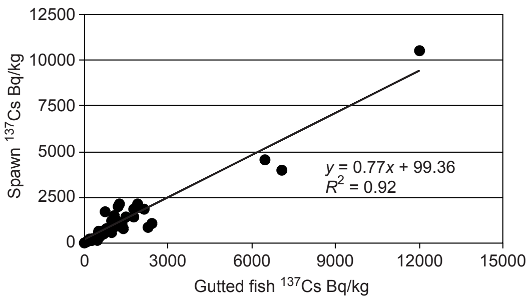

Fig. 8. Correlation of ^{137}Cs in fish spawn with ^{137}Cs in gutted fish. Spawn of perch (*Perca fluviatilis*), pike (*Esox lucius*), burbot (*Lota lota*), vendace (*Coregonus albula*), whitefish (*Coregonus* sp.) and roach (*Rutilus rutilus*) were analysed. Sampling lakes are shown in Fig. 1.

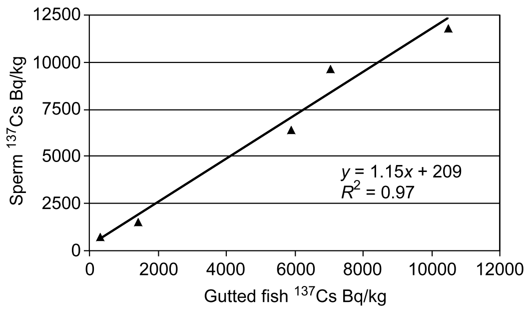

Fig. 9. Correlation of ^{137}Cs in fish sperm with ^{137}Cs in gutted fish. Sperm of perch (*Perca fluviatilis*), burbot (*Lota lota*) and whitefish (*Coregonus* sp.) was analysed. Sampling lakes are shown in Fig. 1.

^{137}Cs and ^{90}Sr differ greatly (Fig. 6); in pike and perch muscle tissue accounted for 74%–82% and bones only 1%–2% of the total amount of ^{137}Cs in the fishes. In vendace samples 99% of the ^{137}Cs was in muscle, skin and fins and about 1% in bones. Skin and fins contributed most to the amount of ^{90}Sr in perch and pike samples (70%–85%). The proportion shown by bones was 13%–28% and that of muscle tissue only 1%–2%. In vendace samples muscle together with skin and fins accounted for about 60% and bones for 40% of the amount of ^{90}Sr.

The contents of ^{137}Cs in fish livers, spawn and sperm showed high correlations (R^2 between 0.86 and 0.97) with the respective contents in gutted fishes (Figs. 7–9). Variation in the contents of

^{137}Cs in livers, spawn and sperm was high as it was also in gutted fishes, due to uneven distribution of Chernobyl deposition in Finland. In livers ^{137}Cs was clearly lower, in spawn nearly at the same level or somewhat lower and in sperm always higher than in the gutted fish. All the fish sperm samples were taken in 1986 only a few months after Chernobyl deposition.

Discussion

Few studies are available concerning distribution of radionuclides in various organs of freshwater fish and their contribution to the total amounts. More data on marine than on freshwater fish can be found (Ropes and Whicker 1985, Pyle and Clulow 1997a, 1997b). The distribution of radionuclides, such as ^{137}Cs, ^{60}Co, ^{207}Bi, ^{239,240}Pu in fish and invertebrates from Bikini Atoll was studied. The highest ^{137}Cs concentrations were found in muscle of all species and the lowest concentrations in bone or liver. ^{90}Sr was found to be associated with nonedible parts of fish, such as bone and viscera (Noshkin *et al*. 1988). The distribution of natural radionuclides such as Th, U, ^{226}Ra, ^{210}Pb and ^{210}Po in fish tissues from lakes and rivers in Canada were reported, as was tissue distribution of ^{137}Cs and ^{60}Co in fish from tropical waters (Atomic Energy Control Board 1987, Guimaraes 1988). The highest concentration of ^{137}Cs was found in the muscle, which accounted for 66% of the total body burden, while the highest concentration and greatest fraction (19%) of ^{60}Co was located in the liver. In silver carp (*Cyprinus carpio*) from the cooling pond of the Chernobyl nuclear power plant, the ^{137}Cs in muscle tissue increased almost linearly with fish weight in contrast to liver tissue, the specific activity of which remained independent of weight (Kulikov and Ryabov 1992).

A review on bioaccumulation factors of various radionuclides in freshwater biota (Vanderploeg *et al*. 1975) showed that different radionuclides accumulate in various amounts and in various organs of fish. The organs studied for ^{137}Cs and ^{90}Sr were muscle and bones. Accumulation of ^{137}Cs in muscle is dependent on the potassium content and that of ^{90}Sr in bones and muscle on the calcium content of water. The ^{60}Co concentration in kidney of some fish species was 20 times and in liver 3 times that occurring throughout the body.

Conclusions

To estimate the effects of radiation on biota, the radionuclide distribution and radiosensitivity of various organs must be known. The results of this study give new information on the distribution of ^{137}Cs and ^{90}Sr in various organs of freshwater fish. The activity concentrations of ^{137}Cs in fish liver were only about half of those occurring in edible parts of fish. In spawn ^{137}Cs was higher than in liver but somewhat lower than in gutted fish, while in fish sperm ^{137}Cs was somewhat higher than in gutted fish. Since gametes are generally the most sensitive of all cells to the effects of radiation, fish sperm must be considered when evaluating the effects of radiation on freshwater fish. However, due to the small number of sperm samples included in this study, additional data are needed. The study also showed that skin and fins are more important than bones in evaluating the effects of ^{90}Sr on fish, although the activity concentrations of bones are higher compared with those found in skin and fins.

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