Arch. Ryb. Pol.	Archives of Polish Fisheries	Vol. 4	Fasc. 2a	267 - 275	1996

RADIONUCLIDES ^{134}Cs AND ^{137}Cs IN EEL (*Anguilla anguilla* L.) IN FINNISH FRESHWATERS AFTER THE ACCIDENT AT CHERNOBYL NUCLEAR POWER STATION IN 1986

J. Tulonen, R. Saxén***

*Evo Fisheries Research and Aquaculture 16970 Evo, Finland
**Finnish Centre for Radiation and Nuclear Safety P.O. Box 14, FIN-00881 Helsinki, Finland

A B S T R A C T. The concentrations of ^{134}Cs and ^{137}Cs in eel after the Chernobyl accident in 1986 were analysed from nine lakes and two rivers during 1986-1992 in different parts of the country. The ratio of ^{134}Cs to ^{137}Cs was in 1986 about 0.5 but decreased gradually to 0.09 in 1992. In the same area the concentrations of ^{137}Cs increased slower in the eel than in the other fish species. The highest concentrations of ^{137}Cs (3580-3760 Bq/kg fresh weight) in eel were detected in small oligotrophic lakes in the area of the highest deposition four to five years after the accident.

Key words: ^{134}Cs, ^{137}Cs, CONCENTRATION IN EEL, FINNISH WATERS, CHERNOBYL ACCIDENT, *Anguilla anguilla*

INTRODUCTION

The accident at Chernobyl on 26th April 1986 raised the deposition levels of radioactive cesium in Finland, but areal deposition was uneven (Figure 1). The fall-out was greatest in the province of Häme in southern Finland, where also the Evo Fisheries Research and Aquaculture is situated. The average deposition of ^{137}Cs in this area was 45-78 kBq/m^2. As a result of this accident concentrations of radioactive cesium in water and fish increased in the whole country but especially in the areas of heavy deposition. Before the accident the concentrations of ^{137}Cs in water had reached low equilibrium values after the fallout period in the 1960s (Table 1). The concentrations of ^{137}Cs in freshwater fish in 1982, when the latest study before the accident was done, varied from 2.1 to 64 Bq/kg fresh weight (Saxén & Rantavaara 1987).

Finnish Centre for Radiation and Nuclear Safety (STUK) started a study on the radioactivity of freshwater fish, with a rather extensive monitoring programme in 1986. For this study Evo Fisheries Research and Aquaculture supplied a large number of fish samples. The aim of the study was to monitor fish as food, that is, to evaluate the importance of freshwater fish as a source of radiocesium to consumers in different

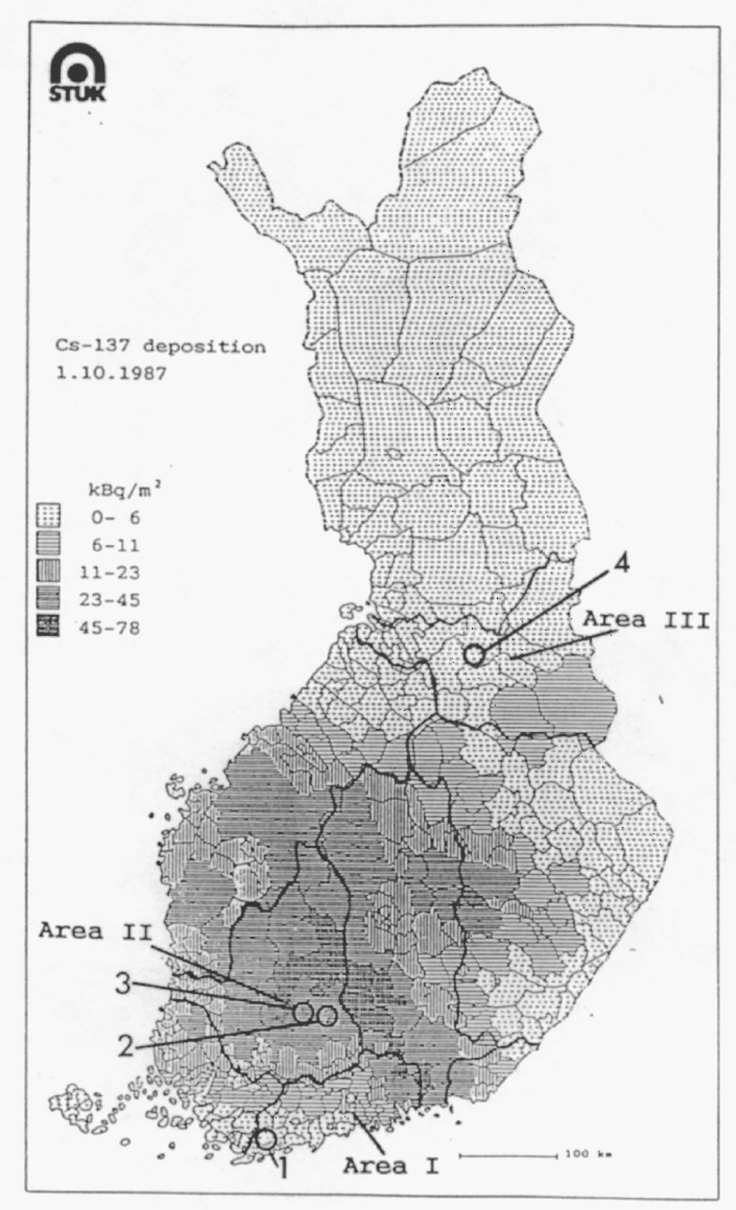

Fig. 1. The distribution of ^{137}Cs in Finland after the Chernobyl accident. The municipalities are divided into five categories according to their average ^{137}Cs deposition (Arvela et al. 1990), and the large drainage areas (Areas I-III) with locations of the lakes included in this study. Area I: 1. Lake Lohjanjärvi; Area II: 2. Evo district, Lakes: Ruuhijärvi, Hokajärvi, Onkimajärvi, Rahtijärvi, Valkea-Mustajärvi and Hautajärvi. Rivers: Kaukanen, Majajoki. 3. Lake Vanajavesi; Area III: 4. Lake Honkajärvi.

TABLE 1

Average activity concentrations (Bq/l) of ^{137}Cs in surface water in the large drainage areas, where the lakes included in this study are located (Saxén and Aaltonen 1987, Saxén 1990, Saxén and Koskelainen 1992). The areas are given in Fig. 1.

		1985	1986	1987	1988	1989
Area I	137Cs	0.0024	0.42	0.091	0.047	0.039
	134Cs	-	0.24	0.038	0.014	0.0086
Area II	137Cs	0.0013	1.3	0.12	0.084	0.061
	134Cs	-	0.78	0.050	0.025	0.014
Area III	137Cs	0.004	0.25	0.14	0.072	0.043
	134Cs	-	0.12	0.052	0.021	0.087

parts of the country. Attention was also paid to the differences in radioactivity between fish species and fish groups with different feeding habits. The characteristics of the lakes, such as area, water volume, flow rate and limnological type, and the characteristics of the catchment area also affect the contamination of fish by radioactive substances. The fish species analysed were those most commonly used for human consumption: perch, pike, vendace, bream, burbot, roach, whitefish, pike-perch and trout. Of these species, perch, pike and vendace each account for more than 20% of the total catch of freshwater fish in Finland (Saxén & Koskelainen 1992). Although eel catches in Finland are of minor importance (under 20 tonnes/year), eel samples were included in the study as well as some other species too.

MATERIAL AND METHODS

For STUK's monitoring programme almost 6000 fish samples from about 200 lakes all over the country were collected and analysed for gamma emitting radionuclides in 1986-1992. Of these 91 were eel samples from 9 lakes and two rivers. Both rivers (Kaukanen and Majajoki) and six lakes (Ruuhijärvi, Hokajärvi, Onkimajärvi, Rahtijärvi, Valkea-Mustajärvi and Hautajärvi) are near Evo Fisheries Research and Aquaculture (Evo district, point 2 in Fig. 1). All these lakes are small (6-20 ha) and oligotrophic. Except Lake Valkea-Mustajärvi, water of the lakes contains a lot of humic substances and in all lakes the pH-value of the water is low (5.8-6.5). The flow rates and retention time of water are also different in these lakes. In Lake Valkea-Mustajärvi the theoretical retention time is over 4 years but in the other lakes only from 1 to 3 years.

Ten samples are from Lake Vanajavesi (point 3 in Fig. 1) (10 000 ha) in the area of the highest fallout (45-78 kBq/m^2). Five samples are from Lake Lohjanjärvi (8 900 ha) in southern Finland (point 1 in Fig. 1) and three samples are from a small lake Honkajärvi (150 ha) in north-eastern Finland (point 4 in Fig. 1). The last two lakes lie in areas where the deposition was the lowest (0-6 kBq/m^2).

The samples consisted mostly of one eel each, but in the lakes Valkea-Mustajärvi and Hautajärvi three samples included of 87 small (16-29 cm) individuals in 1991 and 1992. These eels were young ones from stockings made in 1989. Eels in the other samples originated from the stockings made in 1978 and 1966. All the eels were females and their weight was between 600 and 1200 grammes.

The sampled eels were cleaned and gutted as normally in the kitchen. Their heads, entrails, skin and fins, backbone and other big bones were removed. Thus only edible parts were taken to analysis. All fish samples were preserved deep-frozen before gamma-spectrometric analyses. For the analyses the cleaned samples were cut into small pieces and packed into Marinelli beakers of about 560 ml (Saxén & Koskelainen 1992). The germanium detectors used for the analyses in STUK were either lithium drifted or high purity crystals with relative efficiencies of between 15% and 39%. The measurements were performed in background shields of 12 cm lead, lined with copper (2 mm) or cadmium (1 mm) and copper (0.5 mm) to reduce X-rays from the shields. The measuring times were between 15 minutes to about 15 hours. The activity concentrations of the samples were calculated using the computer program GAMMA-83 (Sinkko & Aaltonen 1985).

RESULTS

The radioactive substances detected by gammaspectrometric measurements on freshwater fish are the two cesium isotopes ^{134}Cs and ^{137}Cs. The average concentrations of both isotopes in eels are given in tables 2 and 3. As can be expected from the areal distribution of the deposition from Chernobyl (Fig. 1), the highest concentrations were detected in the samples from Evo district (point 2 in Fig. 1). In the lakes Lohjanjärvi and Honkajärvi, which were control lakes from the areas of lower deposition, the activity concentrations of both isotopes were low. Also in Lake Vanajavesi the concentrations were rather low although the lake is located in the area of the highest deposition. In 1986 the ratio of ^{134}Cs to ^{137}Cs was about 0.5. The ratio then gradually

TABLE 2

The average activity concentrations in ^{134}Cs (Bq/kg fresh weight) in eels in the studied lakes and rivers. The number of samples and variation is also given {n (min-max)}

Lake or river	1986	1987	1988	1989	1990	1991	1992
Lake Ruuhijärvi (stocked 1978)	190 4 (140-240)	849 1 (849-849)		195 2 (100-290)	101 5 (38-207)	157 2 (59-254)	70 7 (52-104)
Lake Hokajärvi (stocked 1978)		471 1 (471-471)			163 1 (163-163)		
Lake Onkimajärvi (stocked 1978)		606 3 (503-733)		286 1 (286-286)	195 2 (187-202)		75 3 (43-99)
Lake Rahtijärvi (stocked 1966)						204 1 (204-204)	
Lake Hautajärvi (stocked 1989)							53 6 (53-53)
Lake Valkea-Mustajärvi (stocked 1966) (stocked 1989)		848 2 (496-1200)		430 2 (377-483)	446 2 (393-499)	405 1 (405-405) 108 27 (108-108)	197 3 (71-266) 71 54 (71-71)
River Kaukanen (stocked 1967)		78 8 (25-117)			308 5 (103-628)	74 3 (23-118)	41 1 (41-41)
River Majajoki (stocked 1966)		256 3 (51-409)			381 4 (230-531)	173 3 (95-263)	
Lake Vanajavesi (stocked 1966-1979)					20 2 (5-35)	7 8 (6-21)	
Lake Lohjanjärvi (stocked 1966-1979)						0 5	
Lake Honkajärvi (stocked 1978)					3 3 (2-5)		

Note: In 1991 and 1992 the small yellow eels were analysed as pooled samples

decreased as a result of shorter half-life of ^{134}Cs (1987 - 0.38; 1988 -; 1989 - 0.20; 1990 - 0.15; 1991 - 0.11 and 1992 - 0.09).

In general the contents of radiocesium in eels in the Evo district were not directly dependent on the size or age of the fish. Only in Lake Valkea-Mustajärvi there was a big difference in activity concentrations between the eels that were stocked in 1966 and 1989. The migration phase seemed to have some influence on the activity concentrations in eels. Silver eels which were caught in the rivers a year after the accident had much lower ^{134}Cs and ^{137}Cs activity concentrations than the yellow eels in lakes in the same year. A few years later the concentrations were almost equal in silver and yellow eels.

TABLE 3

The average activity concentrations in ^{137}Cs (Bq/kg fresh weight) in eels in the studied lakes and rivers. The number of samples and variation is also given {n (min-max)}

Lake or river	1986	1987	1988	1989	1990	1991	1992
Lake Ruuhijärvi (stocked 1978)	380 4 (280-480)	2356 1 (2356-2356)		901 2 (523-1278)	685 5 (255-1442)	1522 2 (684-2359)	888 7 (527-1334)
Lake Hokajärvi (stocked 1978)		1313 1 (1313-1313)			1004 1 (1004-1004)		
Lake Onkimajärvi (stocked 1978)		1546 3 (1213-1779)		1414 1 (1414-1414)	1392 2 (1319-1464)		828 3 (590-1127)
Lake Rahtijärvi (stocked 1966)						1985 1 (1985-1985)	
Lake Hautajärvi (stocked 1989)							628 6 (628-628)
Lake Valkea-Mustajärvi (stocked 1966)		2049 2 (1298-2800)		2181 2 (1859-2502)	3122 2 (2724-3520)	3579 1 (3579-3579)	2422 3 (1696-3129)
(stocked 1989)						927 27 (927-927)	903 54 (903-903)
River Kaukanen (stocked 1967)		206 8 (66-298)			1804 5 (589-3756)	624 3 (171-1040)	396 1 (396-396)
River Majajoki (stocked 1966)		644 3 (130-1093)			2240 4 (1335-3144)	1457 3 (766-2084)	
Lake Vanajavesi (stocked 1966-1979)					134 2 (35-233)	108 8 (56-174)	
Lake Lohjanjärvi (stocked 1966-1979)						10 5 (5-17)	
Lake Honkajärvi (stocked 1978)					39 3 (31-46)		

Note: In 1991 and 1992 the small yellow eels were analysed as pooled samples.

DISCUSSION

Although the concentrations of radiocesium in water after radioactive fallout normally decrease rather quickly, the concentrations in fish might increase as fish gets radiocesium mostly by feeding and not directly from water. The variation in the radiocesium content in fish in the same deposition area was due to different chemical and hydrological characteristics of the lakes and quality of their drainage basins, and to local differences in the amounts of radiocesium deposited within each deposition category. In a deposition area the amounts of cesium were the highest in the smallest lakes. In these lakes the amounts of cesium deposited were diluted less than in large la-

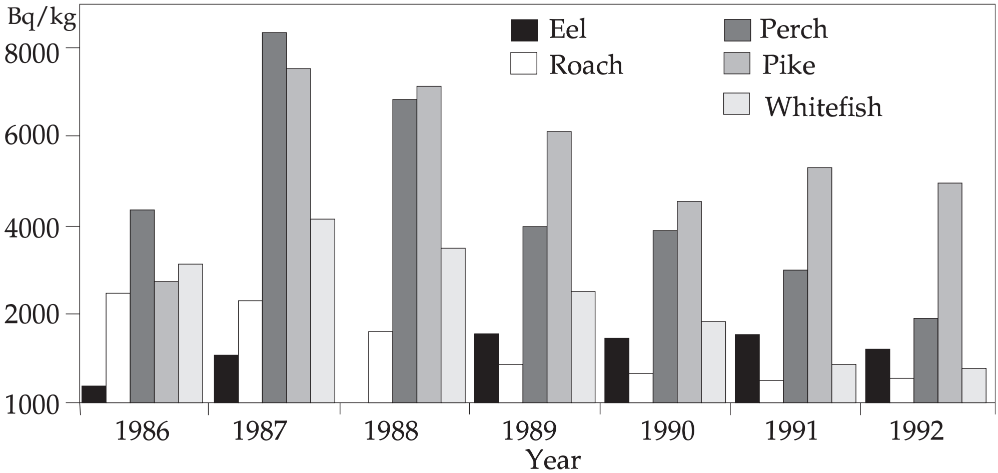

Fig. 2. Temporal variation in ^{137}Cs (Bq/kg fresh weight) concentrations in different fish species in some small lakes in the Evo distric.

kes, and the proportion of runoff was higher than in large lakes. Moreover, most of the small lakes in STUK's study were oligotrophic, thus representing conditions of maximum accumulation of radiocesium in fish. The flow rate and retention time of water in a lake also affect the transport of radiocesium to fish, causing differences between lakes even when the deposition in the area is otherwise the same. In a lake, the feeding habits of fish affect their radiocesium level. This causes variations between different fish species with different feeding habits and between fish of different sizes of the same species (Saxén & Koskelainen 1992).

The same pattern was also seen with eels, the highest concentrations of ^{134}Cs and ^{137}Cs in eels were in small, oligotrophic lakes in the area of the highest deposition (E-vo district). Maximum values were observed in lake with the longest water residence time (Lake Valkea-Mustajärvi). In a much bigger lake (Lake Vanajavesi) in the same area the concentrations were only slightly increased. Those eels which were feeding actively (yellow eels) had higher concentrations of radiocesium than the eels which were in the migrative phase and were not eating much. Compared to other fish species in the same lakes in Evo district, the eels had much lower concentrations of ^{134}Cs and ^{137}Cs in 1986 and 1987 (Figure 2). This must be because eels in Finland are in their north-eastern limit of natural geographical distribution. In summer water temperature is over 15^{o}C only for a few months and for a few weeks over 20^{o}C, so there is not too much time for eels to eat and grow. Other species (pike, roach, perch, whitefish) have much lower temperature optimum for feeding than eels and that's why they have also got more radiocesium. During 1989-1992 contents of radiocesium in roach and in 1991 and 1992 also in whitefish were clearly lower than in eel. Feeding habits of these three species are quite different. Whitefish feeds mainly on zooplankton. Roach feeds on zooplankton, bottom fauna and detritus, but eel is more omnivorous, being also an effective predator on small fish. Thus, it can accumulate more radiocesium through food chain than the two other species.

According to the information given by Dr. Håkan Wickström (Institute of Freshwater Research, Drottningholm Sweden) the ^{137}Cs concentrations in eel in Sweden in a few analysed samples have been higher than in Finland. In 1986 a few months after the accident, the concentrations in eel were still low in both countries, but already next year the two analysed samples in Sweden had ^{137}Cs concentrations over 5000 Bq/kg. In 1992 the concentrations in three samples were between 1380 Bq/kg and 6200 Bq/kg.

Recommendations on using fish as food were issued by STUK for the first time in June 1986. People living in the main deposition area (45-78 kBq/m^2), were advised not to eat fish from small lakes as the main course more than 2-3 times a week. The recommendation was extended to include all lakes in the area of the highest deposition in autumn 1986. Inhabitants of the area were advised not to eat perch, pike or vendace more than 2-3 times a week as the main course. In addition, people were advised not to eat fish from small lakes in the areas of lower deposition (6-45 kBq/m^2) as the main course more than 2-3 times a week. The recommendation was mitigated in 1989 to concern only perch and predatory fish in areas where the deposition had been 23-78 kBq/m^2. No restrictions for the use of non-predatory fish were needed any more (Saxén & Koskelainen 1992). Nowadays all restrictions are withdrawn.

ACKNOWLEDGEMENT

We thank Dr Håkan Wickström for the information on Swedish analyses of radiocesium.

REFERENCES

Arvela H., Markkanen M. and Lemmelä H. 1990 - Mobile survey of environmental gamma radiation and fall-out levels in Finland after the Chernobyl accident - Radiation Protection Dosimetry Vol. 32 No. 3: 177-184.

Saxén R. 1987 - Studies on environmental radioactivity in Finland 1984-1985. Surface water, Report STU-K-A54, Annual Report, Finnish Centre for Radiation and Nuclear Safety, Helsinki, 1987.

Saxén R. 1990 - Radioactivity of surface water and freshwater fish in Finland in 1987 - Report STUK-A77, Suppl. 3 to Annual Report STUK-A74. Finnish Centre for Radiation and Nuclear Safety, Helsinki, 1990.

Saxén R. and Aaltonen H. 1987 - Radioactivity of surface water in Finland after the Chernobyl accident in 1986 - Report STUK-A60. Supplement 5 to Annual Report STUK-A55. Finnish Centre for Radiation and Nuclear Safety, Helsinki, 1987.

Saxén R. and Koskelainen U. 1992 - Radioactivity of surface water and freshwater fish in Finland in 198-8-1990 - Report STUK-A94. Supplement 6 to Annual Report STUK-A89. Helsinki, Finnish Centre for Radiation and Nuclear Safety, 1992.

Saxén R. and Rantavaara A. 1987 - Radioactivity of freshwater fish in Finland after the Chernobyl accident in 1986 - Report STUK-A61. Supplement 6 to Annual Report STUK-A55, Helsinki, Finnish Centre for Radiation and Nuclear Safety, 1987.

Sinkko K. 1981 - Computer analysis of gamma-ray spectra in sample measurements - Licenciate Thesis, Helsinki, University of Helsinki, Department of Physics (In Finnish).

Sinkko K. and Aaltonen H. 1985 - Calculation of the true coincidence summing correction for different sample geometries in gamma-ray spectroscopy - Helsinki, Finnish Centre for Radiation and Nuclear Safety, Surveillance Department, STUK-B-VALO 40.

STRESZCZENIE

ZAWARTOŚĆ RADIONUKLEIDÓW ^{134}Cs i ^{137}Cs W WĘGORZU W FIŃSKICH WODACH ŚRÓDLĄDOWYCH PO WYPADKU W CZERNOBYLSKIEJ ELEKTROWNI ATOMOWEJ W 1986 R.

Po wypadku w Czernobylskiej elektrowni atomowej analizowano w latach 1986-1992 stężenie radionukleidów cezu w mięsie węgorza pochodzącego z dziewięciu jezior i dwóch rzek położonych w różnych częściach Finlandii. Stosunek ^{134}Cs do ^{137}Cs w roku 1986 wynosił 0.5 a nastepnie ulegał stopniowemu spadkowi, dochodząc do 0.09 w roku 1992. Zawartość ^{137}Cs w mięsie węgorza wzrastała po wybuchu wolniej niż w mięsie innych ryb słodkowodnych. Najwyższe stężenia ^{137}Cs (w granicach 3579-3756 Bq/kg mokrej masy) w mięsie węgorza stwierdzono w małym dystroficznym jeziorku położonym na obszarze, który w okresie 5 lat po wypadku otrzymywał najwyższe opady radioaktywne.