Radioprotection, Suppl. 1, vol. **40** (2005) S649-S654

DOI: 10.1051/radiopro:2005s1-095

^{137}Cs in fishes and water in Finnish lakes – considerations for radiological risk assessment

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Abstract. The deposition from Chernobyl in spring 1986 was most unevenly distributed in Finland and elevated the ^{137}Cs contents of fishes in Finnish lakes significantly. High activity concentrations of ^{137}Cs still occur in fish from certain lakes in the areas of the highest deposition. Activity concentrations of ^{137}Cs in perch varied from 20 to 7 800 and those in lake water from 4 to 330 Bq/m^3 in 1998 and 2002. Concentration factors (Bq/kg in perch / Bq/kg in lake water) ranged from 1 300 to 30 000 in the lakes studied. Ecological halftimes of ^{137}Cs in perch in certain lakes, monitored regularly since 1986, and representing different types in terms of environmental transfer, were estimated as examples. The longest halftimes of ^{137}Cs in perch were approximately 8 years and the shortest approximately 3 years determined for the time period of 1988-2002. Except for estimation of radiation doses to people eating fish, data on changes of activity concentrations in various parts of the aquatic system are also needed when estimating radiation doses to fish and other biota. Slow recovery of the habitat and feed from ^{137}Cs results in higher exposure of biota than in case of rapid activity decrease.

1. INTRODUCTION

Radiocesium in fishes has been regularly studied at STUK since the Chernobyl deposition in 1986 [1-3]. In this paper the results for perch, the most common fish species in Finnish lakes, are considered. In 1998 and 2002 also water of the lakes sampled for fishes were taken and analysed for ^{137}Cs to get a picture on the variation range of ^{137}Cs both in water and in fishes caused by the original deposition and several successive processes changing the distribution since the deposition. Lake specific concentration factors from water to fish 12-16 years after the deposition were also determined. A long-term purpose of our study is to find the most critical areas or lakes types or lakes in terms of high accumulation and/or slow recovery after the deposition. This is difficult because in Finland there are over 180 000 lakes larger than 500 m^2, and about 2 300 lakes larger than 1 km^2 [4].

2. SAMPLING LAKES

The lakes studied are located in southern and central parts of Finland (Figure 1). Both large lakes, being most important for freshwater fishing, and a few relatively small lakes were included in the study. The deposition of ^{137}Cs from the Chernobyl accident was most unevenly distributed in Finland. The country can be divided into five categories on the basis of the average deposition in each municipality [5] (Figure 1). Except fish samples, water samples from the lakes were taken and analysed for ^{137}Cs in 1998 and/or 2002.

3. RESULTS

3.1 ^{137}Cs in lake waters

Activity concentrations of ^{137}Cs in lake waters varied from 4 to 330 Bq/m^3 in 1998 and 2002 (Figure 2 and Table 1). ^{137}Cs was highest in Lakes Vehkajärvi and Siikajärvi, which are located in the area of the highest deposition in Finland, and lowest in lakes from eastern Finland with a low deposition. In two lakes located close to each other in the deposition area 5, the ^{137}Cs in lake water differed significantly, being 17 Bq/m^3 (Lake Oriselkä) and 260 Bq/m^3 (Lake Siikajärvi) in 2002. Deficiency of nutrients in water, abundance of humic substances and/or low sedimentation rate were recognized in certain lakes with relatively high ^{137}Cs concentrations in water in 2002.

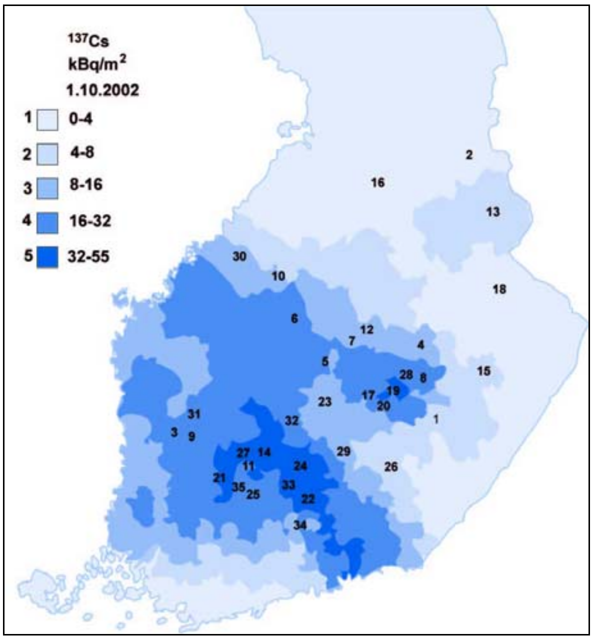

Figure 1. Location of the lakes sampled for water and fishes in 1998 and/or 2002 and the five deposition areas of ^{137}Cs in Finland [5], corrected for radioactive decay to October 1, 2002. Areas of the lakes are taken from [4].

	km^2		km^2		km^2
1. Haukivesi	620	13. Ontojärvi	95	25. Pälkänevesi	45,9
2. Hyrynjärvi	18,3	14. Oriselkä	<10	26. Saimaa (Mikk.mlk)	1147
3. Jämijärvi	9,2	15. Orivesi	536	27. Siikajärvi	0,96
4. Kallavesi	513	16. Oulujärvi	893	28. Sorsavesi	50,8
5. Keitele	500	17. Pieksänjärvi	25	29. Suontee	149
6. Kivijärvi	155	18. Pielinen	868	30. Ullavanjärvi	13,3
7. Konnevesi	187	19. Pieni Ahveninen	<1	31. Vahojärvi	<10
8. Kuore-Kaita	<1	20. Pyhäjärvi (Pieks.mlk)	10,9	32. Valkeajärvi	<10
9. Kyrösjärvi	96,2	21. Pyhäjärvi (Pirkkala)	124	33. Vehkajärvi	24,6
10. Lestijärvi	65	22. Päijänne (Asikkala)	1054	34. Vesijärvi (Hollola)	108
11. Längelmävesi	178	23. Päijänne (Jyväsk. mlk)	1054	35. Vesijärvi (Kangasala)	40,2
12. Nilakka	163	24. Päijänne (Kuhmoinen)	1054		

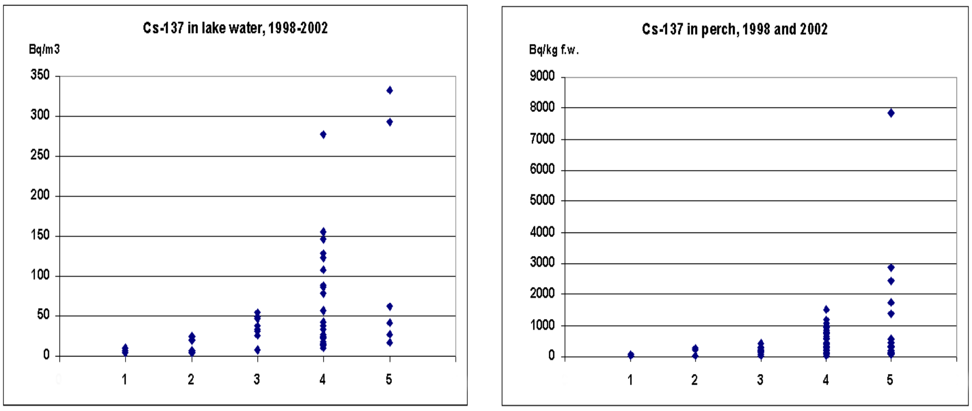

Figure 2. ^{137}Cs in lake water (n=47) and in perch *(Perca fluviatilis)* (n=86) in the five deposition areas of Finland in 1998 and 2002. Numbers on the x-axis refer to the deposition areas given in Figure 1.

Table 1. Activity concentrations of ^{137}Cs in lake water (Bq/m^3), in perch *(Perca fluviatilis)* (Bq/kg fresh weight), and concentration factors (Bq/kg in perch/Bq/kg in water) in the lakes studied in 1998 and 2002.

Lake	Sampling municipality	Water Bq/m^3 1998	Water Bq/m^3 2002	Perch Bq/kg 1998	Perch Bq/kg 2002	CF 1998	CF 2002
1. Haukivesi	Rantasalmi	19		61		3 200	
2. Hyrynjärvi	Hyrynsalmi	6		59		9 800	
3. Jämijärvi	Jämijärvi	18					
4. Kallavesi	Kuopio	7		21		2 800	
5. Keitele	Äänekoski	38		624		16 400	
6. Kivijärvi	Kannonkoski	57	42				
7. Konnevesi	Vesanto	54		326		6000	
8. Kuorekaita	Leppävirta		78		314		4 000
9. Kyrösjärvi	Ikaalinen	22	13	134	106	6 100	8 200
10. Lestijärvi	Lestijärvi	49	30	254	207	5 200	6 900
11.Längelmävesi	Kangasala	16	24	126	165		6 900
12. Nilakka	Tervo	25		267		10 700	
13. Ontojärvi	Kuhmo		24		244		10 200
14. Oriselkä	Orivesi		17		117		6 900
15. Orivesi	Liperi	4		37		9 200	
16. Oulujärvi	Vaala	10		40		4 000	
17. Pieksänjärvi	Pieksäm. mlk	277		932		3 400	
18. Pielinen	Lieksa	4		34		8 500	
19. Pieniahveninen	Pieksäm. mlk		128		439		3 400
20. Pyhäjärvi	Pieksäm. mlk	123	155	956	1082	7 800	7 000
21. Pyhäjärvi	Pirkkala	27	16	106	75	3 900	4 700
22. Päijänne	Asikkala	41		396		9 700	
23. Päijänne	Jyväskylä mlk	37		240		6 500	
24. Päijänne	Kuhmoinen	61	41	247	102	4 000	2 500
25. Pälkänevesi	Pälkäne	14	10	66	42	4 700	4 200
26. Saimaa	Mikkeli mlk	7		21		3 000	
27. Siikajärvi	Orivesi		259		7 836		30 300
28. Sorsavesi	Leppävirta	107	88	806	545	7 500	6 200
29. Suontee	Joutsa	33		303		9 100	
30. Ullavanjärvi	Ullava		47		143		3 000
31. Vahojärvi	Parkano	86		452		5 300	
32. Valkeajärvi	Jämsänkoski	147		1011		6 900	
33. Vehkajärvi	Padasjoki	332	292	1558	2657	4 700	9 100
34. Vesijärvi	Hollola	26		34		1 300	
35. Vesijärvi	Kangasala	33	25	237	155	7 200	6 200

3.2 ^{137}Cs in perch

Contents of ^{137}Cs in perches *(Perca fluviatilis)* from various lakes varied from 19 to 1 700 and from 38 to 7 800 Bq/kg in 1998 and 2002, respectively (Figure 2 and Table 1). Each sample consisted of several individual fishes. ^{137}Cs in perches in 2002 varied by a factor of 200, although the original amount deposited in the sampling municipalities varied by a factor of 50. In a single lake the contents in fishes varied generally by a factor of two, but in the first years after the deposition even by a factor of six.

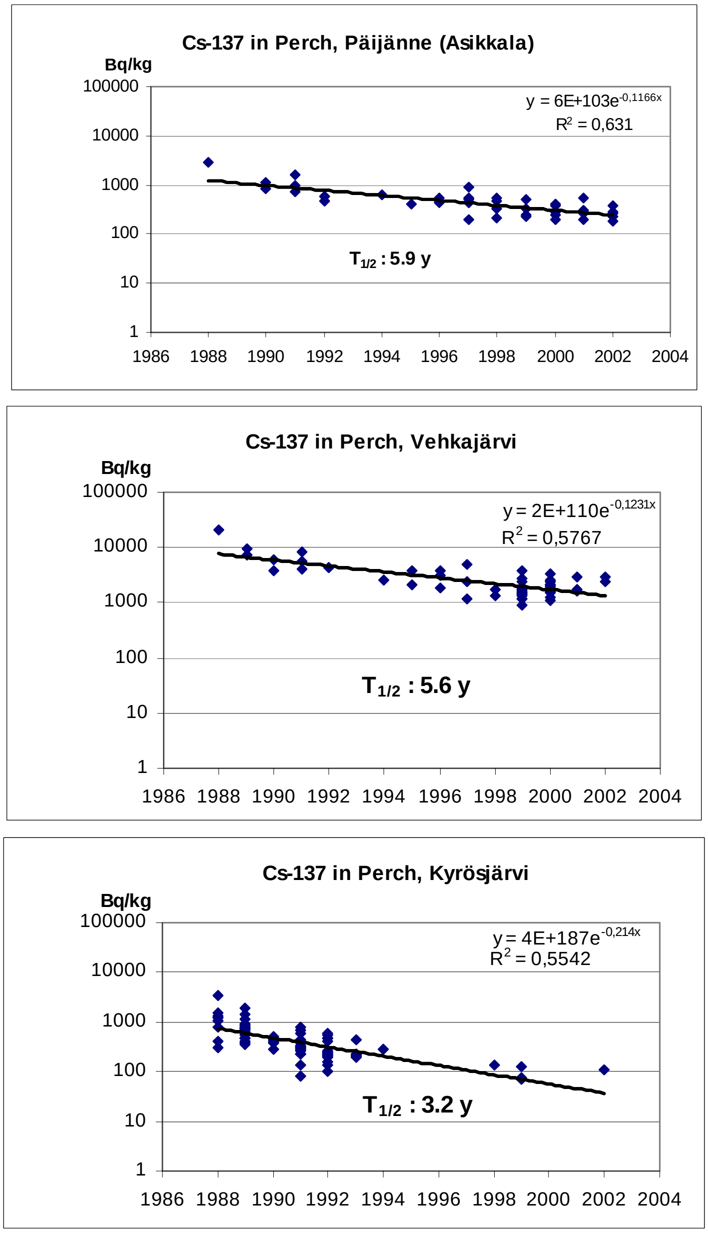

Figure 3. Decrease of ^{137}Cs in perch in three lakes (Päijänne, Asikkala), Vehkajärvi and Kyrösjärvi and the observed halftimes in 1988-2002. Päijänne (Asikkala) is the southern oligotrophic part of Lake Päijänne, Vehkajärvi is a clear water lake with a low sedimentation rate and Kyrösjärvi a eutrophic lake with colour value of about 100 mg Pt/l.

3.3 Concentration factors

Concentration factor is determined here as the following ratio:

$$CF = {}^{137}Cs \text{ in fish (Bq/kg f.w.)} / {}^{137}Cs \text{ in lake water (Bq/kg)}$$

Concentration factors for perches from various lakes varied between 1 300 and 30 000 in 1998 or 2002 (Table1). The lake with the lowest CF (Vesijärvi, Hollola) is a eutrophic lake and the lakes with the highest CFs (e.g. Nilakka, Päijänne (Asikkala), Siikajärvi, Vehkajärvi, Suontee) are oligotrophic; Siikajärvi and Vehkajärvi have additionally very low sedimentation rate, Ontojärvi is rich in humic substances. It is extremely difficult to name exactly the factors causing high or low concentration factors, because the conditions vary from lake to lake and even in various parts of a single lake. Besides the lake parameters, also the types of catchment that affect the secondary input to the lake during the years, vary from lake to lake. Furthermore, even the parameters that could presumably be significant in terms of radionuclide transfer are not easily available for all the lakes studied in order to perform more detailed analyses of the results.

4. EXAMPLES OF ECOLOGICAL HALFTIMES OF ^{137}CS IN PERCH FROM VARIOUS LAKES

The results of the lakes studied regularly for ^{137}Cs in fishes after the Chernobyl accident give a chance to estimate ecological halftimes of ^{137}Cs. The time describes recovery rates of the lakes after the accidental contamination. The ecological halftime is dependent on the time period. Here they were estimated for the time period of 1988-2002. The year 1988 was selected as a starting point because the peak contents had usually already passed by then. The shortest halftimes were approximately 3 years and the longest approximately 9 years. The longest halftime was found in a lake with high contents of humic substances (colour over 200 mg Pt/l) (Lake Pieni Ahveninen (Pieksämäki)), but in a clear water lake nearby the halftime was only a little shorter (Lake Pyhäjärvi (Pieksämäki)). The shortest halftime was found in a lake with rather high amounts of nutrients and colour number approximately 100 mgPt/l (Lake Kyrösjärvi). In clear water oligotrophic lakes the ecological halftimes of ^{137}Cs in perch were typically about 5-6 years, as in lake Vehkajärvi and Päijänne (Asikkala) in Figure 3.

5. CONSIDERATIONS FOR RADIOLOGICAL RISK ASSESSMENT

The data obtained shows that transfer parameters in freshwater environment vary in a large range although 12-16 years have elapsed since the deposition. Besides differences in the original deposition several environmental processes have changed the distribution of ^{137}Cs during the years in various compartments of the freshwater environment. Most of ^{137}Cs is now in the bottom sediments of the lakes. The recovery of fishes from ^{137}Cs in various lakes also takes different times, as shown by the examples on ecological halftimes. Empirical data is self-validating and cannot totally be substituted by modelling, as concluded in a previous study [6].

Except for estimation of radiation doses to people eating fish, data on temporal changes in various parts of the aquatic system are also needed when estimating radiation doses to fishes and other biota. Slow recovery of the habitat and feed results in higher exposure of biota than in case of rapid decrease. Our first attempt to estimate exposure to perch, a pelagic fish, from lake Päijänne after the Chernobyl accident showed that most of the exposure was caused by the internal beta radiation [7]. For fish species and other biota living close to the bottom, contents of radionuclides in bottom sediment play an important role.

References

[1] Saxén R. and Rantavaara A. Radioactivity of freshwater fish in Finland after the Chernobyl accident in 1986. Report STUK-A61. STUK-Radiation and Nuclear Safety Authority, Helsinki (1987).

[2] Saxén R., Koskelainen U. and Alatalo M., Transfer of Chernobyl-derived ^{137}Cs into fishes in some Finnish lakes, Report STUK-A170 (STUK-Radiation and Nuclear Safety Authority, Helsinki, 2000) pp. 5-55.

[3] Saxén R. and Koskelainen U. Regional variation of ^{137}Cs in freshwater fishes in Finland. Proceedings of the International Congress The Radioecology-Ecotoxicology of Continental and Estuarine Environments, ECORAD 2001, Aix-en-Provence, France, 3-7 September, 2001, F. Bréchignac Ed. Radioprotection-Colloques, **Volume** 37, C1(2002) pp. C1 617-C1 620.

[4] Raatikainen M. and Kuusisto E., The number and surface area of the lakes in Finland. *Terra* **Volume** 102 (1988) 97-110.

[5] Arvela H., Markkanen M. and Lemmelä H., Mobile survey of environmental gamma radiation and fall-out levels in Finland after the Chernobyl accident, *Radiation Protection Dosimetry* **Volume** 32 No. 3 (1990) 177-184.

[6] Sheppard S.C. Transfer parameters - when do we know enough? Proceedings of the International Symposium on Radioecology and Environmental Dosimetry, Rokkasho, Aomori, Japan, October 22-24, 2003, J. Inaba, H. Tsukada and A. Takeda Eds. (Institute for Environmental Sciences, Japan, 2003) pp. 3-12.

[7] Oksanen M., Niemistö H. and Saxén R., Estimation of radiation doses from ^{137}Cs to perch in a Finnish lake. IAEA-CN-109. International conference on the protection of the environment from the effects of ionizing radiation, Contributed papers, Stockholm, Sweden, 6-10 October, 2003, pp. 205-207.