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Transfer of anthropogenic radionuclides to organisms in the Faroe Islands

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Abstract. The ^{137}Cs activity has been measured in organisms from the Faroese terrestrial, aquatic and marine environments in the years 2002, 2003 and 2004. The aim of the study was to point out organisms that can be useful indicator organisms for radioactive contamination of the environment. Measurements are available back to the early 1960's for some organisms, and the variation with time is considered for these organisms.

1. INTRODUCTION

Anthropogenic radionuclides from the nuclear weapons tests in the 1950's and 1960's and the Chernobyl nuclear accident on the 26th of April 1986 did also reach the Faroe Islands. Radioactive discharges from reprocessing plants in Sellafield and La Hague are potential sources for radioactive contamination of the Faroese marine environment.

The paper presents measurements of radioactivity in organisms from the terrestrial, freshwater and marine environments in the Faroe Islands. The sampling was carried out in 2002, 2003 and 2004. Some results can be compared with earlier measurements, mainly published in annual data reports on environmental radioactivity in the Faroe Islands [1].

2. MATERIAL AND METHODS

The terrestrial samples constitute individual plants, mixed grass and soil. The plant species were picked by hand within about 200 m^2, while grass and soil were sampled from four randomly chosen 50 cm × 50 cm plots in the same area. The grass was cut from the plots, where after three soil cores were taken with a length of 10 cm and a diameter of 5.7 cm. The soil samples from the individual plots were divided into an upper and a lower 5 cm layer, and the material from the respective layers was mixed and dried at room temperature before measurement. Plant samples were dried at 105°C before measurement.

Trout and water were sampled from freshwater lakes, and seaweed, haddock and seawater were sampled from the marine environment. Trout and haddock samples constitute flesh that was kept frozen before measurement.

Gamma radioactivity in the samples was measured with a lead shielded Germanium detector, and the spectral analyses were based on the GammaVision software from Ortec. Samples of seawater, seaweed, haddock and water from freshwater lakes were measured by Risø DTU National Laboratory for Sustainable Energy, Roskilde, Denmark. Samples collected before 2002, except for *Salmo trutta*, were also measured by Risø.

All ^{134}Cs/^{137}Cs ratios in the paper are date corrected to the 26th of April 1986.

Table 1. ^{137}Cs activity in terrestrial samples collected at the shores of the lakes Leitisvatn and Toftavatn on the islands Vágoy and Eysturoy, respectively. Values are given with 1 counting standard deviation. *: *Empetrum hermaphroditum*. **: *Empetrum nigrum*. NS: No Sample.

	Sampling date	Soil		Mixed Grass	*Empetrum sp.*	*Hyloconium splendens*
		0–5 cm	5–10 cm			
		Bq m^{-2}	Bq m^{-2}	Bq kg^{-1}dw	Bqkg^{-1}dw	Bqkg^{-1}dw
Toftavatn	9 Sept. 2002	1514 ± 74	1619 ± 66	97.8 ± 9.49	17.8 ± 1.66 *	77.5 ± 4.37
Leitisvatn	6 Sept. 2002	2106 ± 99	1940 ± 112	75.4 ± 4.90	NS	NS
Toftavatn	30 Aug. 2003	NS	NS	NS	26.3 ± 2.31 **	58.9 ± 4.16

Table 2. ^{137}Cs activity concentration (Bqkg^{-1}dw) in samples collected near the village Norðoyri on the island Borðoy the 4th of August 2003 and the 4th of August 2004. The results are presented with 1 counting standard deviation. NS: No Sample.

Year	*Empetrum hermaphroditum*	*Empetrum nigrum*	*Erica cinerea*	*Calluna vulgaris*	*Racomitrium laniginosum*	*Potentella eracta*
	Bqkg^{-1}dw	Bqkg^{-1}dw	Bqkg^{-1}dw	Bq kg^{-1}dw	Bq kg^{-1}dw	Bq kg^{-1}dw
2003	NS	11.8 ± 2.21	11.2 ± 2.25	91.3 ± 5.33	31.9 ± 1.90	NS
2004	6.13 ± 0.34	NS	10.2 ± 0.86	29.3 ± 0.82	46.1 ± 0.78	14.1 ± .76

Table 3. Activity concentration of ^{137}Cs and ^{134}Cs in moss and lichen sampled in 1987 near the capital Tórshavn (unspecified species).

	^{134}Cs	^{137}Cs	$^{134}Cs/^{137}Cs$
	Bq kg^{-1}fw	Bq kg^{-1}fw	Date: 26 April 1986
Moss	219	600	0.532
Lichen	262	654	0.585

3. RESULTS AND DISCUSSION

3.1 Terrestrial environment

Measurements of the terrestrial samples are presented in Tables 1–3. It is noted that the deposition is equally divided between the upper and lower 5 cm soil layer. There are only minor changes with time in the activity concentrations in the plants, although a decreasing trend is observed in some cases. It should be considered that the sampling stations were not at exactly the same locations every year. It is well known from other studies [2] that the ^{137}Cs activity concentration in mixed grass varies significantly within short distances, and this is presumably also the case for other vegetation.

^{134}Cs and ^{137}Cs were measured in moss and lichen in 1987 (Table 3). The $^{134}Cs/^{137}Cs$ ratios indicate that practically all the observed radiocaesium derived from the Chernobyl accident. The ^{137}Cs activities in 2002–2004 were an order of magnitude lower than in 1987.

3.2 Freshwater environment

Topographic information about the selected lakes is presented in Table 4. Stóravatn is a shallow lake with an almost uniform depth. Leitisvatn and Leynavatn are oblong relatively deep lakes gradually

Table 4. Topographic data for the selected lakes.

Lake	Island	Altitude, m, above sea level	Surface area, km^2	Max depth, m	Average depth, m
Toftavatn	Eysturoy	15	0.52	22	5.8
Leitisvatn	Vágoy	32	3.56	59	27.5
Stóravatn	Sandoy	26	0.160	1.8	No data
Leynavatn	Streymoy	63	0.18	33	13.7

Table 5. Measurements of radiocaesium ($Bq\,m^{-3}$) in lake water. NS: No Sample. ND: No Data.

	July 1987		July 1989		August 1991	June 1992	Sept. 1999
	^{134}Cs	^{137}Cs	^{134}Cs	^{137}Cs	^{137}Cs	^{137}Cs	^{137}Cs
Leitisvatn	1.60	9.94	0.63	6.23	6.24	6.24	NS
Leynavatn	0.90	3.74	ND	1.84	2.60	2.30	1.26
Toftavatn	NS	NS	NS	NS	NS	NS	4.17

Table 6. ^{137}Cs in *Salmo trutta* flesh and in lake water from Toftavatn and Leitisvatn in 2002. Trout were caught on the 15th of August in both lakes. Water samples (each 200 liter) were collected on the 3rd of September from Toftavatn and on the 6th of September from Leitisvatn.

Lakes in 2002	*Salmo trutta*					Water
	Number of trout	Mean	St. dev	Min	Max	
		$Bq\,kg^{-1}fw$	$Bq\,kg^{-1}fw$	$Bq\,kg^{-1}fw$	$Bq\,kg^{-1}fw$	$Bq\,m^{-3}$
Toftavatn	9	9.88	4.20	5.85	19.8	5.51±0.32
Leitisvatn	10	5.31	1.99	4.02	10.7	3.45±0.27

descending towards a centre line. Toftavatn consists of a shallow northern part with maximum depth of 3.5 m and a southern deeper part with almost circular isobaths and a maximum depth of 22 m. Further description of the lakes can be found in [3].

Measurements of radiocaesium in water from Leynavatn have been included in Table 5, although no biological samples were collected from the lake. In 1987, the $^{134}Cs/^{137}Cs$ ratio in water from Leitisvatn and Leynavatn was 0.235 and 0.351, respectively. In 1989, the $^{134}Cs/^{137}Cs$ ratio was 0.281in water from Leitisvatn.

Eighteen *Salmo trutta* were caught from Leitisvatn in July 1987. The average ^{134}Cs concentration was 42.4 $Bq\,kg^{-1}fw$ and the average ^{137}Cs concentration was 115.4 $Bq\,kg^{-1}fw$. The average $^{134}Cs/^{137}Cs$ ratio was 0.536, as calculated from single trout measurements, indicating that practically all radiocaesium in the trout derived from the Chernobyl accident.

Measurements of ^{137}Cs in water and *Salmo trutta* from Toftavatn and Leitisvatn in 2002 are presented in the Table 6. The activity is found to be higher in Toftavatn. Two trout were sampled in 2003, one from Leitisvatn (23th of July) and one from Stóravatn (1th of June). The ^{137}Cs activity concentrations were, respectively, 1.26 $Bq\,kg^{-1}fw$ and 16.2 $Bq\,kg^{-1}fw$. The higher activity concentration in the trout from the shallower lakes may partly be a reflection of feeding habits. Studies from July 1987 and July 1988 showed e.g. that trout from Stóravatn feed mainly on benthic fauna followed by Diptera, while trout from Leitisvatn feed almost equally on Diptera and benthic fauna [4].

The higher ^{137}Cs concentration in water from Toftavatn as compared with Leynavatn (Table 5) and Leitisvatn (Table 6) may partly be explained by higher resuspension from sediments in Toftavatn, because of the smaller depth of Toftavatn. The reason for the higher ^{137}Cs activity in water from

Table 7. ^{137}Cs in marine samples from Kirkjubøur. Concentrations are given with 1 counting standard deviation. (BDL: Below Detection Limit. NS: No Sample).

Sample	Unit	27 June 2002	20 Febr. 2003	12 May 2003	25 Sept. 2003	05 March 2004	15 June 2004
Seawater	Bq m^{-3}	1.85 ± 0.14	1.70 ± 0.23	2.04 ± 0.16	1.92 ± 0.34	NS	NS
Fucus vesiculosus	Bq kg^{-1} dw	BDL	BDL	BDL	0.262 ± 0.059	0.175 ± 0.053	0.300 ± 0.063
Ascophyllum nodosum	Bq kg^{-1} dw	NS	NS	NS	NS	0.22 ± 0.05	NS

Toftavatn in 2002 as compared to 1999 (Tables 5 and 6) may be that the sampling has been carried out in the deeper part of the lake in 1999 and in the shallow part in 2002. The highest activity concentration was, though, found in the biggest and deepest lake Leitisvatn.

3.3 Marine environment

Seawater and seaweed were sampled in 2002, 2003 and 2004 at the coast of the village Kirkjubøur on the island Streymoy. Measurements of ^{137}Cs in the samples are presented in Table 7. *Ascophyllum nodosum* and *Fucus vesiculosus* were sampled at the same location in Kirkjubøur on the 5th of March 2004 in order to compare their ^{137}Cs activity concentrations. The activity concentration in the two species was found to be the same within one counting standard deviation.

A haddock was caught on the 15th of March 2003 in the sea around the Faroe Islands. The ^{137}Cs activity in the haddock flesh (*Melanogrammus aeglefinus*) was 0.071 ± 0.007 Bq kg^{-1} fw, corresponding to 0.355 ± 0.035 Bq kg^{-1} dw.

3.3.1 Time series for seaweed

Long-term time series for ^{137}Cs and ^{90}Sr in seaweed are presented in Figure 1. The species has not been specified for all samples, but it has mainly been *Fucus vesiculosus* since 1972.

Exponential curve fitting to the ^{137}Cs data from March 1963 to August 1966 and from August 1986 to April 1988 resulted in half-lives of 271 days ($R^2 = 0.986$) and 142 days ($R^2 = 0.883$), respectively. The shorter post-Chernobyl half-life is explained by the fact that the input from Chernobyl came as a short pulse, while the input to the atmosphere in the 1960's was distributed over a longer time scale.

The maximum ^{90}Sr concentration of 186 Bq kg^{-1} dw in March 1968 has been checked with earlier reports [5] who state that "the extreme value in March is difficult to explain. August was in agreement with last year's observations." The maximum is still not explained.

The $^{134}Cs/^{137}Cs$ ratio in seaweed samples from the 1th of August 1986, 1th of April 1987, 1th of June 1987 and 17th of July 1989 were 0.491, 0.465, 0.681 and 0.497, respectively. The ratios show that practically all radiocaesium in seaweed originated from the Chernobyl nuclear accident.

3.4 Transfer factors and concentration ratios

The aggregated transfer factor for mixed grass at the shore of Toftavatn in 2002 was 31.2 $m^2 kg^{-1}$ dw. The transfer factor was calculated as the activity concentration, Bq kg^{-1}dw, in grass divided by the deposition in the top 10cm soil layer. The grass and soil samples were collected at the same place.

The transfer factors for other species (Table 8) than grass must be considered as more rough estimates, as they were collected some 100 meters away from the soil sampling location. The estimates at Toftavatn in 2003 were calculated from the deposition in 2002 (Table 1), and the estimates at Norðoyri

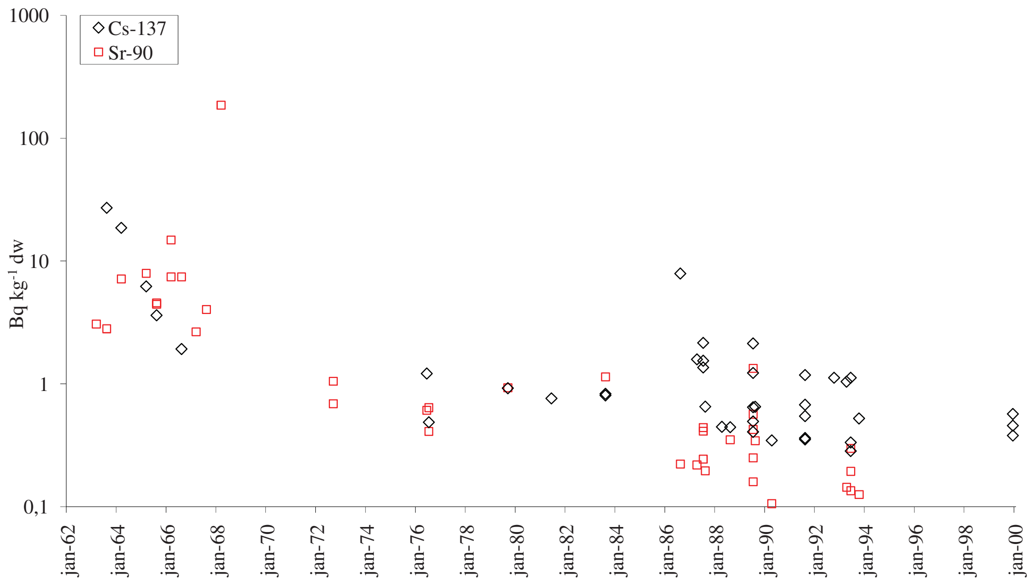

Figure 1. Measurements of ^{137}Cs and ^{90}Sr in seaweed from the Faroe Islands in the years 1963-2000.

Table 8. Transfer factors (m^2 10^{-3} kg dw) for ^{137}Cs.

	Empetrum herma-phroditum	*Empetr. nigrum*	*Hylocon. splend.*	*Erica cinerea*	*Calluna vulgaris*	*Racomitrium laniginosum*	*Potentella erecta*
Toftavatn 9 Sept. 2002	5.68		24.7				
Toftavatn 30 Aug. 2003		8.39	18.8				
Norðoyri 4 Aug. 2003		2.16		2.05	16.7	5.85	
Norðoyri 4 Aug. 2004	1.12			1.86	5.37	8.44	2.58

in 2003 and 2004 were both years based on the deposition measured in 2003 (5455 Bq m^{-2}). The results show differences between species regarding uptake of ^{137}Cs.

As based on transfer factors, mixed grass was found to be the best terrestrial indicator for radioactive contamination, followed by *Hyloconium splendens* and *Calluna vulgaris*. The transfer factors for *Racomitrium laniginosum* and *Calluna vulgaris* appear in opposite order in 2003 and 2004.

The concentration ratio [(Bq kg^{-1} dw)/(Bq m^{-3})] between the ^{137}Cs activity concentration in *Fucus vesiculosus* and seawater from Kirkjubøur on the 25th of September 2003 vas 0.136 $m^{3\cdot}$ kg^{-1} dw.

The concentration ratio [(Bq kg^{-1} ww)/(Bq m^{-3})] between the ^{137}Cs activity concentrations in haddock flesh (*Melanogrammus aeglefinus*) and seawater was 0.038 m^3 kg^{-1} ww, or 0.19 m^3 kg^{-1} dw. The value is calculated from the activity concentration in the haddock sample from the 15th of March

2003 and the average ^{137}Cs activity concentration in seawater samples from the 20^{th} of February 2003 and the 12^{th} of May 2003.

4. CONCLUSION

Among the selected species from the terrestrial environment, mixed grass was found to be the best indicator organism, followed by *Hyloconium splendens* and *Calluna vulgaris*.

Salmo trutta is a good indicator organism for the freshwater environment. It showed a pronounced ^{137}Cs signal soon after the Chernobyl accident.

Fucus vesiculosus is a good indicator organism for the marine environment. It showed a soon reaction to ^{137}Cs input from the Chernobyl accident. The half-life for ^{137}Cs in seaweed was observed to be shorter after the Chernobyl accident than after the bomb tests in the 1960's. The reason for the difference is to be found in the different deposition scenarios.

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