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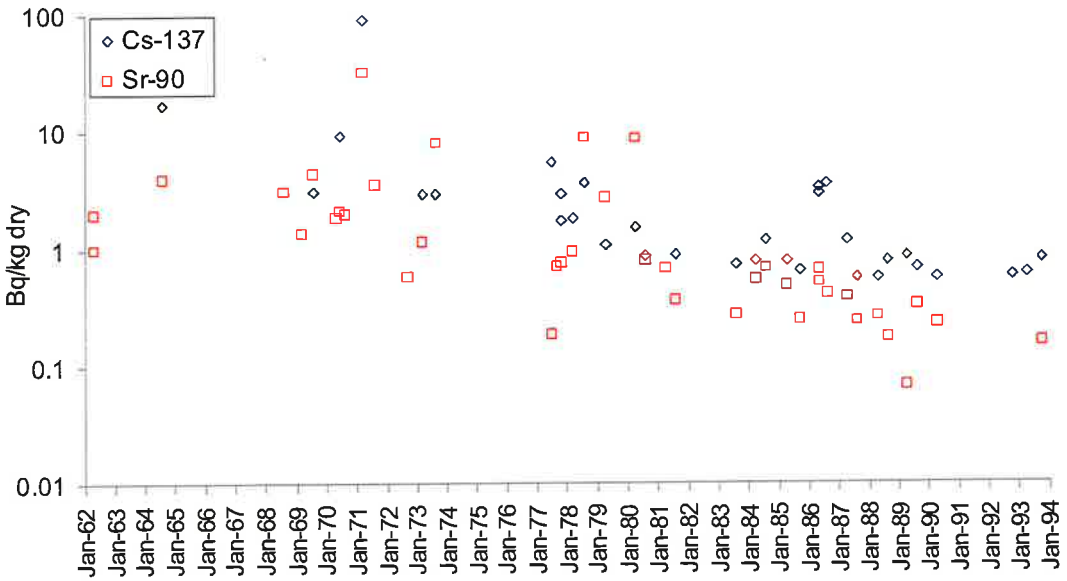
New indicator organisms for environmental radioactivity (INDOFERN).

NKS-B Status Report for the Faroe Islands October 2004

Hans Pauli Joensen



Measurements of ^{137}Cs and ^{90}Sr in *Laminaria sp.* from the Faroe Islands in the period 1962-1994.

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New indicator organisms for environmental radioactivity (INDOFERN). NKS-B Status Report, October 2004.

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1. Introduction

The INDOFERN project has continued in the Faroe Islands in 2004. The objective of the project is to identify organisms that can give information about dispersion of radionuclides, particularly in the early stage of an emergency situation.

The available data on indicator organisms in the Faroe Islands so far have been compiled into the present status report. The indicator value of the organisms is discussed, and a ranking list is given in some cases. New samplings have been carried out in 2004, but they have not been measured as yet.

2. Material and methods

Indicator organisms have been sampled in the years 2002, 2003 and 2004 at different locations in the Faroe Islands. Indicator organisms have also been sampled before the INDOFERN project. An overview can be found in Table 1.

Table 1. Samples related to the INDOFERN project.

Samples in 2002	**Samples in 2003**	**Samples in 2004**	**Earlier samplings**
Terrestrial • *Hylocomium splendens* • *Empetrum hermophroditum* • Soil • Grass Freshwater • Brown trout (*Salmo trutta)* • Water Marine • *Fucus vesiculosus* • Seawater	Terrestrial • *Hylocomium splendens* • *Empetrum hermophroditum* • *Empetrum nigrum* • *Erica cinerea L* • *Calluna vulgaris* • *Racomitrium laniginosum* Freshwater • Brown trout (*Salmo trutta)* Marine • *Fucus vesiculosus* • Seawater	Terrestrial • *Hylocomium splendens* • *Empetrum sp.* • *Calluna vulgaris* • *Racomitrium laniginosum* • *Parmelia Saxatilis* • *A. Alpino L.* Freshwater • Brown trout (*Salmo trutta)* Marine • *Fucus vesiculosus* • *Gadus morhua* • Seawater	Terrestrial • Moss sp. • Empetrum sp. • Lichen sp. Freshwater • Trout sp. • Water Marine • Fucus & laminaria sp. • Mytilus sp. • Ascophyllym sp. • Seawater

3. Results

The results are presented in the following paragraphs, sorted into a terrestrial, freshwater and marine part.

3.1. Terrestrial environment

The results from the terrestrial samplings during the INDOFERN project period are presented in Tables 2 and 3. Samples from 2004 have not been measured as yet.

Table 2. Cs-137 in terrestrial samples taken in 2002 on the shores of lakes Toftavatn and Leitisvatn. Values are given with 1 counting standard deviation. (NS: No Sample).

	Sampling date	Soil		Mixed Grass	*Empetrum hermaphroditum*	*Hyloconium splendens*
		0-5cm	5-10cm			
		Bq/m^2	Bq/m^2	Bq/kg dw	Bq/kg dw	Bq/kg dw
Toftavatn	9 Sept.	1514±74	1619±66	97.8±9.49	17.8±1.66	77.5±4.37
Leitisvatn	6 Sept.	2106±99	1940±112	75.4±4.90	NS	NS

Table 3. Cs-137 in terrestrial samples in 2003. All activity concentrations are given as Bq/kg dry weight, together with 1 counting standard deviation. The samples were collected on 4 August and 30 August, respectively, at the sites Norðoyri and Toftavatn. (NS: No Sample).

	Hyloconium splendens	*Empetrum nigrum*	*Erica cinerea L*	*Calluna vulgaris (L.) Hull*	*Racomitrium laniginosum*
Toftavatn	58.9 ± 4.16	26.3±2.31	NS	NS	NS
Norðoyri	NS	11.8±2.21	11.2 ±2.25	91.3 ± 5.33	31.9 ± 1.90

Measurements from previous data archives are presented in Tables 6-10. The measurements cover Cs-137 and ^{90}Sr in moss and lichen from 1967, 1987 and 1999. The particular moss and lichen species have not been registered in any case. The data show large differences between locations, which may be related to difference in soil conditions at the sites and difference in species. There exist, however, no data to support an explanation of the observed differences.

Cs-134 was measured in the moss sample from Tórshavn in 1987 with a $^{134}Cs/^{137}Cs$ ratio of 0.365, indicating that nearly all the radiocesium activity derived from the Chernobyl accident.

Table 6. Measurements of ^{137}Cs and ^{90}Sr in *moss* sampled in Tórshavn and Tvøroyri *1 April 1967*. The moss species are not identified.

Tórshavn				Tvøroyri	
^{137}Cs		^{90}Sr		^{137}Cs	^{90}Sr
Bq/kg fw	Bq/kg K	Bq/kg fw	Bq/kg Ca	Bq/kg fw	Bq/kg Ca
2479	410700	220	6808	363	1110

Table 7. Measurements of ^{137}Cs and ^{90}Sr in *moss* sampled in *Tórshavn* and "4-5km from Tórshavn" *1 July 1987*. The moss species are not identified.

Tórshavn		"4-5km from Tórshavn"		
^{134}Cs	^{137}Cs	^{90}Sr		
Bq/kg fw	Bq/kg fw	Bq/kg fw	Bq/kg dw	Bq/kg Ca
219	600	4.39	10.6	8745

Table 8. ^{137}Cs in *moss* sampled at lake *Toftavatn 1 September 1999*. The moss species are not identified.

Bq/kg fw	Bq/kg dw	Bq/kg K
270	300	134537

Table 9. Measurements of ^{137}Cs and ^{90}Sr in *lichen* sampled in Tórshavn and Tvøroyri *1 April 1967*. The lichen species are not identified.

Tórshavn				Tvøroyri			
^{137}Cs		^{90}Sr		^{137}Cs		^{90}Sr	
Bq/kg fw	Bq/kg K	Bq/kg fw	Bq/kg Ca	Bq/kg fw	Bq/kg K	Bq/kg fw	Bq/kg Ca
3352	210900	816	12173	1221	235320	89.0	7141

Table 10. Measurements of ^{137}Cs and ^{90}Sr in *lichen* sampled "4-5km from *Tórshavn*" *1 July 1987*. The lichen species are not identified.

^{134}Cs	^{137}Cs		^{90}Sr		
Bq/kg dw	Bq/kg dw	Bq/kg K	Bq/kg fw	Bq/kg dw	Bq/kg Ca
341	852	595804	3.44	4.48	10080

3.2. Freshwater environment

Three lakes have been selected for INDOFERN freshwater sampling: Toftavatn, Leitisvatn and Stóravatn in the islands Eysturoy, Vágoy and Sandoy, respectively. The results from 2002 and 2003 are presented in the tables 11-14. Trout samples have been taken from Toftavatn in 2004, but the measurements have not been carried out as yet.

Table 11. ^{137}Cs in Brown trout (*Salmo trutta*) and lake water from freshwater lakes Toftavatn and Leitisvatn in 2002. Trout were catched 15 August in both lakes. Lake water samples (each 200 liter) were collected 3 September from Toftavatn and 6 September from Leitisvatn.

Lakes in 2002	Salmo trutta					Water
	Number of trout	Mean	St. dev	Min	Max	
		Bq/kg ww	Bq/kg ww	Bq/kg ww	Bq/kg ww	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

Table 12. ^{137}Cs in Brown trout (*Salmo trutta*) from the lakes Stóravatn and Leitisvatn in 2003, one trout from each lake. ^{137}Cs activities are given with 1 counting standard deviation.

Lakes in 2003	Sampling time	Weight (g)	Length (cm)	^{137}Cs activity; Bq/kg fw
Leitisvatn	23 July 2003	181.81	26.5	1.26 ± 0.22
Stóravatn	1 June 2003	222.87	29.1	16.2 ± 1.00

Physical data concerning the lakes can be found in Table 13.

Table 13. Topographic data about the lakes.

	Altitude, m	Surface area, km^2	Max depth, m	Volume, m^3
Toftavatn	15	0.509	22	$2.11 \cdot 10^6$
Leitisvatn	32	3.42	59	$81.6 \cdot 10^6$
Stóravatn	26	0.160	1.8	$0.150 \cdot 10^6$

Physical statistics about the trout in Table 11 can be found in Table 14. The relationship between live weight and length of trout is given by the power function $W=K \cdot L^x$, where W is the live weight and L is the length. K is a proportionality constant. For trout from Leitisvatn we get $K=13.0 \cdot 10^{-3}$ and x=2.90. It was not possible to make the corresponding fit for trout from Toftavatn, as no intestines were included with the trout samples.

Table 14. Length and live weight of Brown trout (*Salmo trutta*) from lakes Toftavatn and Leitisvatn. The trout are the same as in Table 11. (*) Without intestines.

		Mean	St. dev	Min	Max
Toftavatn	Length (cm)	25.9	2.27	23.0	29.7
	Weight (g) (*)	148.9	42.7	97.7	216.0
Leitisvatn	Length (cm)	24.3	2.16	20.9	28.9
	Weight (g)	131.2	38.8	89.6	232.4

Earlier measurements of lake water can be found in the Tables 15. The $^{134}Cs/^{137}Cs$ ratio for lake water in 1987 was 0.161 and 0.241 in Leitisvatn and Leynavatn, respectively. The corresponding ratio was 0.101 in Leitisvatn in 1989.

Table 15. Measurements of radiocesium in lake water after the Chernobyl reactor accident. All values are given in Bq/m^3. (NS: No Samples).

	July 1987		July 1989		August 1991	June 1993	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	NS	1.84	2.60	2.30	1.26
Toftavatn	NS	NS	NS	NS	NS	NS	4.17

Earlier measurements of ^{137}Cs and ^{90}Sr in trout flesh are presented in Table 16. The trouts from 1987 were catched in Leitisvatn, and they contained almost only

radiocesium from the Chernobyl nuclear accident. The average $^{134}Cs/^{137}Cs$ ratio from 18 trouts was 0.377.

Table 16. Measurements of ^{137}Cs and ^{90}Sr in rainbow trout flesh (*Salmo irideus*) in the Faroe Islands (the site has not been registered). One trout from each of the years 1975 and 1976. In 1987, the data represent averages in flesh from 18 Brown trout (*Salmo trutta*) from the lake Leitisvatn.

1 August 1975				1 June 1976				July 1987	
^{137}Cs		^{90}Sr		^{137}Cs		^{90}Sr		^{134}Cs	^{137}Cs
Bq/ kg fw	Bq/ kg K	Bq/ kg fw	Bq/ kg Ca	Bq/ kg fw	Bq/ kg K	Bq/ kg fw	Bq/ kg Ca	Bq/ kg fw	Bq/ kg fw
0.78	196	0.17	207	0.45	126	0.22	207	42.4	115.4

3.3. Marine environment

Seawater and fucus have been sampled in 2002, 2003 and 2004. Measurements of ^{137}Cs are presented in Tables 17. Samples of cod, *Gadus morhua*, have been taken in 2004, but the samples are not measured.

The ^{99}Tc activity concentration in the *Fucus vesiculosus* sample from 20 February 2003 was 1.68±0.08 Bq/kg dw.

Table 17. Measured activity concentration of ^{137}Cs in marine samples from Kirkjubø. Seawater activity is given with 1 counting standard deviation. (BDL: Below Detection Limit)

Seawater		*Fucus vesiculosus*	
Sampling date	Bq/m^3	*Fucus vesiculosus*	Bq/kg dw
27.06.2002	1.85±0.14	27.06.2002	BDL
20.02.2003	1.70±0.23	20.02.2003	<0.3
12.05.2003	2.04±0.16	12.05.2003	BDL
25.09.2003	Not measured	25.09.2003	BDL
05.03.2004	Not measured	05.03.2004	Not measured
26.05.2004	Not measured	15.06.2004	Not measured
24.09.2004	Not measured	24.09.2004	Not measured

Results from earlier marine samplings are presented in the following paragraphs. The bio-indicators are *Fucus sp., Laminaria sp., Mytilus edulis* and *Ascophyllum nodosum.* The longest time series exist for Fucus sp. The samples have been collected at different sites in the Faroe Islands, but they do all refer to the same water mass.

3.3.1. Fucus sp.

Measurement of ^{137}Cs and ^{90}Sr in *Fucus sp.* is presented in Figure 1. Both isotopes are, however, not reported in every case. The highest ^{90}Sr activity concentration is 186 $Bq \cdot kg^{-1}$dw, recorded in March 1968, while the second highest value is 15 $Bq \cdot kg^{-1}$dw, recorded for March 1966; i.e. about a factor of 10 below the maximum. Cs-137 is not recorded for March 1966. The maximum ^{90}Sr value has been cross-checked with Aarkrog & Lippert (1969) who state that "the extreme value in March is difficult to explain. August was in agreement with last year's observations." It has still not been possible to find an explanation for the recorded maximum.

Cs-134 has been measured in four Fucus samples after the Chernobyl accident, showing $^{134}Cs/^{137}Cs$ ratios of 0.453, 0.346, 0.480, 0.176 for samples collected 1 August 1986, 1 April 1987, 1 June 1987 and 17 July 1989, respectively.

The particular Fucus species have been recorded as *Fucus vesiculosus* since 1972, except for 1986 and for September 1972 and April 1987, when it was registered as *Fucus serratus* and *Fucus distichus*, respectively. The species are recorded as just *Fucus sp.* until 1968.

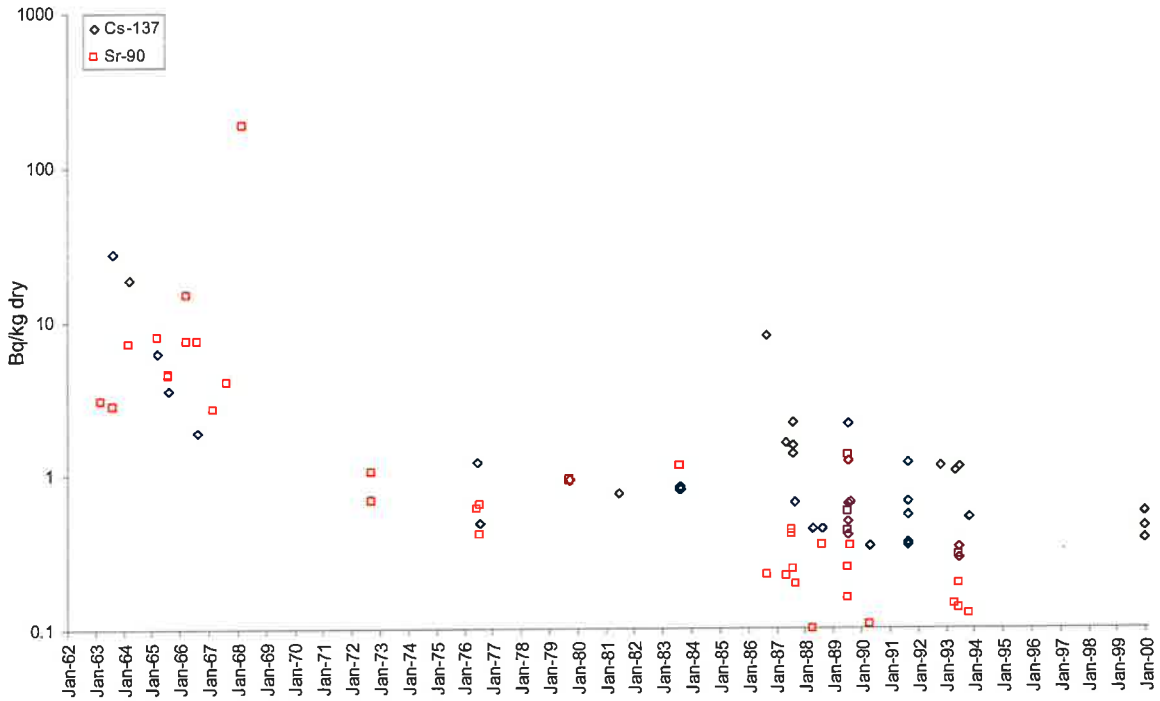

Figure 1. Measurements of ^{137}Cs and ^{90}Sr in *Fucus sp.* from the Faroe Islands in the period 1962-2000.

3.3.2. Laminaria sp.

Data on ^{137}Cs and ^{90}Sr in Laminaria species are presented in Figure 2. An increase in the activity concentration is observed from 1962 to 1965, but maximum values are recorded for 1971. It has not been possible to explain these maxima.

Cs-134 was measured in three samples collected 1 May 1986, 1 August 1986 and 1 April 1989, and the $^{134}Cs/^{137}Cs$ ratio was 0.555, 0.351 and 0.058, respectively.

The measurements of ^{137}Cs have been reported as $Bq{\cdot}kg^{-1}K$ until 1981. After 1981, the values have been given as both $Bq{\cdot}kg^{-1}K$ and $Bq{\cdot}kg^{-1}dw$, from which the ratio $(Bq{\cdot}kg^{-1}dw)/(Bq{\cdot}kg^{-1}K)$ was determined to 0.0558±0.0157. The ^{137}Cs values in Figure 2 prior to 1983 have been calculated by using this ratio.

The ^{90}Sr values are reported in the database as $Bq{\cdot}kg^{-1}Ca$ until 1983, where-after they are given as both $Bq{\cdot}kg^{-1}Ca$ and $Bq{\cdot}kg^{-1}dw$. Based on this last period, the ratio $(Bq{\cdot}kg^{-}$

^{1}dw)/(Bq·kg^{-1}Ca) was calculated to 0.1355±0.0020. The ^{90}Sr data in Figure 2 prior to 1984 have been calculated by using this ratio.

The Laminaria species have been *Laminaria digitata* in April 1980 and since 1985 except for 1992, when it is recorded as just *Laminaria sp.* For the three years 1977-79 it was recorded as *Laminaria hyperboria.* In 1981 it was *Laminaria saccharina.* All other cases have been reported as just *Laminaria sp.*

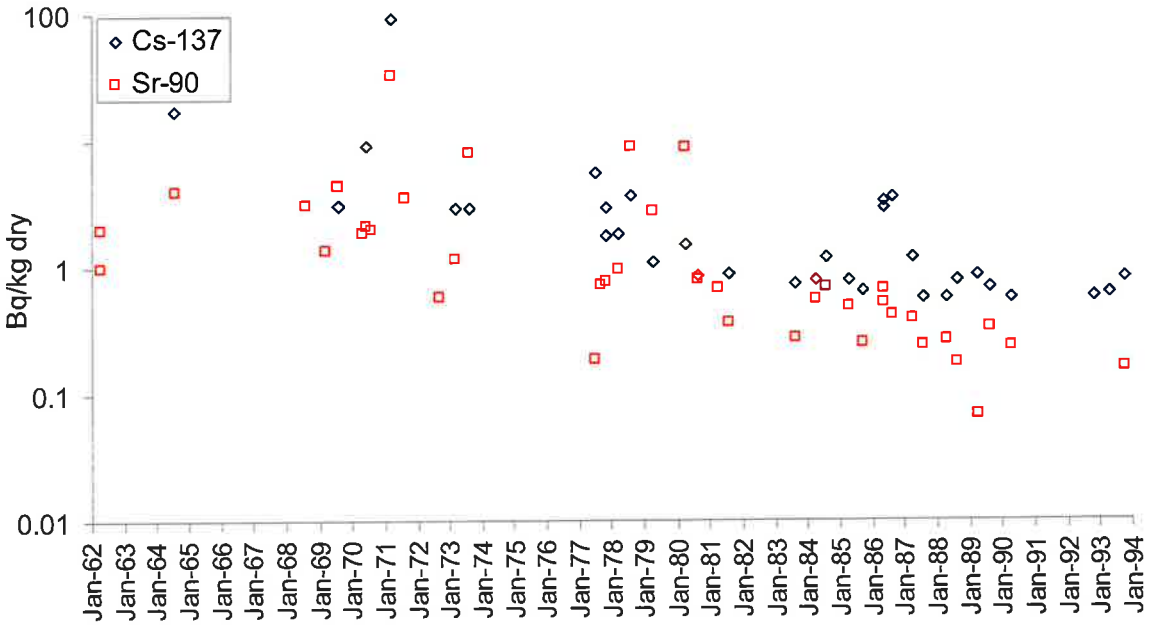

Figure 2. Measurements of ^{137}Cs and ^{90}Sr in *Laminaria sp.* from the Faroe Islands in the period 1962-1994.

3.3.3. Ascophyllum nodosum

Ascophyllum nodosum has been sampled in 1972, 1989 and 1991. The measurements are presented in Table 18. It has not been possible to explain the increasing trends in the activity concentrations.

Table 18. ^{137}Cs and ^{90}Sr in *Ascophyllum nodosum.* Values are given with 1 counting standard deviation if available. (ND: No Data)

	^{137}Cs		^{90}Sr	
	Bq/kg dw	Bq/kg K	Bq/kg dw	Bq/kg Ca
1 Sept. 1972	ND	ND	0.68	50.0±16.5
1 April 1989	0.39±0.14	16.2	0.11±0.03	8.3±2.1
1 August 1989	0.60±0.09	23.8±3.40	ND	ND
1 May 1991	1.36±0.14	61.2	2.34±0.05	165.4±3.47

3.3.4. Mytilus edulis

Soft tissue from *Mytilus edulis* has been measured on three occasions, as presented in Table 19. The relatively high activity concentration of ^{137}Cs in July 1987 is due to input from the Chernobyl accident. Cs-134 was measured to 0.160 Bq·kg^{-1}dw in this particular sample, giving a ^{134}Cs/^{137}Cs ratio of 0.235.

Table 19. ^{137}Cs and ^{90}Sr in *Mytilus edulis* soft tissue. Values are given with 1 counting standard deviation if available. (ND: No Data)

	^{137}Cs			^{90}Sr		
	Bq/kg fw	Bq/kg dw	Bq/kg K	Bq/kg fw	Bq/kg dw	Bq/kgCa
14 June 1981	0.0568±0.0170	ND	23.0	ND	ND	ND
1 July 1987	ND	0.6804±0.0782	86.2	0.0083±0.0035	0.0048±0.0020	5.68±2.39
7 Dec. 1999	0.0521±0.0164	0.1326±0.0418	21.6±6.79	ND	ND	ND

3.4. Discussion

3.4.1. Terrestrial environment

Measurements of ^{137}Cs and ^{90}Sr from April 1967 indicate a significant geographical variation of the activity concentrations in Moss sp. and Lichen sp. with lower activity in the southern part of the country (Tvøroyri) as compared with the central area (Tórshavn). The moss and lichen species are, however, not identified in the old data files, and there is neither any information about soil characteristics from the respective sampling sites that could assist to explain the observed differences. Measurements of radiocesium in moss and lichen from July 1987 show a pronounced signal from the Chernobyl nuclear accident in both bio-indicators. The ^{137}Cs measurements in moss at lake Toftavatn show a decrease from 600Bq/kg dw in July 1987 to 300 Bq/kg dw in September 1999 and further to 78 Bq/kg dw in September 2002 and 59 Bq/kg dw in August 2003.

The results for *Empetrum nigrum* in 2003 indicate also a geographic variation of the ^{137}Cs concentration. The variability of the concentration within the pastures may be expected to be similar to the variation between the sites. The results indicate that *Holoconium splendens* and *Calluna vulgaris* are most suitable bio-indicators among the five selected indicators in 2003.

3.4.2. Freshwater environment

There are no pre-Chernobyl data for lake water in the Faroe Islands. The ^{137}Cs activity concentration in water from Leitisvatn decreased from 9.94 Bq/m^3 in 1987 to 3.45 Bq/m^3 in 2002. The ^{137}Cs activity concentration in water from Leynavatn decreased from 3.74 Bq/m^3 in 1987 to 1.26 Bq/m^3 in 1999; no other data are available from this lake. Lake water from Toftavatn has only been sampled in September 1999 and August 2002, showing ^{137}Cs activity concentrations of 4.17±0.11 Bq/m^3 and 5.51±0.32 Bq/m^3, respectively. An explanation factor for the unexpected trend in water from Toftavatn may be that the water has been sampled from different parts of the lake the respective years, as the lake consists of a deeper and a shallower part that are relatively separated. The higher ^{137}Cs concentration in water from Toftavatn as compared with Leitisvatn may be explained by higher resuspension from sediments in Toftavatn, as this lake is much shallower and smaller than Leitisvatn.

There exists only two pre-Chernobyl samples of trout, but the specific sampling location has not been registered, making it impossible to compare the data with new

measurements. Radioactivity measurements of trout from July 1987 showed a pronounced signal from Chernobyl in trout flesh. The radiocaesium content in trout from August 2002 was higher in Toftavatn than in Leitisvatn, which coincide with the activity concentrations in the lake water.

The results from 2003 showed that the activity in the trout from Stóravatn has significant higher ^{137}Cs concentration than the trout from Leitisvatn. This may be a reflection of feeding habit of the trout, as trout in Stóravatn would be expected to feed more on benthic fauna than trout in Leitisvatn. The stomach contents in the trout were, however, not studied. But a study in July 1987 and July 1988 showed that trout from Stóravatn feed mainly on benthic fauna followed by diptera, while trout from Leitisvatn feed almost equally on dipteria and benthic animals.

3.4.1. Marine environment

The ^{137}Cs activity concentration in *Fucus sp.* decreased with short effective ecological half-life during the first tree years of measurements in the 1960's. The level was constant from the mid 1970's until 1986 when input from the Chernobyl nuclear accident caused the activity concentration to exceed the level from the mid 1960's. 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, in *Fucus sp.* 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 ^{90}Sr data do not show trends similar to ^{137}Cs in the early 1960's and after the Chernobyl nuclear accident, although the general decreasing pattern is similar (except for the beginning of the 1960's and a maximum ^{90}Sr value in March 1968). There was no ^{90}Sr input from Chernobyl.

As for *Fucus sp.*, the ^{137}Cs level in *Laminaria sp.* increased in 1986 due to input from the Chernobyl accident. The pre-Chernobyl ^{137}Cs activity concentration decreased with a half-life of 4.9 years (R^2=0.794). As mentioned earlier, there was no input of ^{90}Sr from the Chernobyl accident, and the ^{90}Sr activity concentration decreased with a half-life of 6.3 years (R^2=0.510) onwards from the early 1960's. The extreme activity concentrations for 1 March 1971 were excluded in the half-life estimation.

The ^{137}Cs concentration of 1.70±0.23 Bq/m^3 in seawater from February 2003 was not significantly different from the corresponding activity of 1.85±0.14 Bq/m^3 in June 2002. The ^{137}Cs concentration in *Fucus vesiculosus*, sampled at the same time and site as the seawater, was below the detection limit, although the samples corresponded to around 150 gram dry weight.

There are only few measurements of *Ascophyllum nodosum* and *Mytilus edulis*, and no time series exist for those species in Faroese waters. The measurements of soft tissue from *Mytilus edulis* suggest that it is a suitable bio-indicator organism for radiocesium. It is, however, not possible to make any such conclusion from existing radioactivity data on *Ascophyllum nodosum*, although it should be expected to be a suitable bio-indicator organism.

4. Conclusion

Calluna vulgaris, Hylocomium splendens and Empetrum hermaphroditum were, respectively, the most suitable bio-indicators among five selected species in the terrestrial environment.

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

Fucus vesiculosus was the most suitable indicator organism for the marine environment. It showed a soon reaction to ^{137}Cs input from the Chernobyl accident. It was also observed that the halftime for ^{137}Cs in *Fucus vesiculosus* was shorter after the Chernobyl accident as compared to the situation in the early 1960's.

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