Technical University of Denmark

Environmental radioactivity in the North Atlantic Region. The Faroe Islands and Greenland included. 1983

Aarkrog, Asker; Boelskifte, S.; Buch, E.; Christensen, G.C.; Dahlgaard, Henning; Hallstadius, L.; Hansen, Heinz Johs. Max; Holm, Elis; Mattsson, S.; Meide, A.

Publication date:
1984

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Aarkrog, A., Boelskifte, S., Buch, E., Christensen, G. C., Dahlgaard, H., Hallstadius, L., ... Meide, A. (1984). Environmental radioactivity in the North Atlantic Region. The Faroe Islands and Greenland included. 1983. (Denmark. Forskningscenter Risoe. Risoe-R; No. 510).

DK8500096

Risø-R-510

RISØ

Risø-R-510

Environmental Radioactivity in the North Atlantic Region. The Faroe Islands and Greenland included. 1983

A. Aarkrog, S. Boelskifte, E. Buch, G.C. Christensen, H. Dahlgaard, L. Hallstadius, H. Hansen, E. Holm, S. Mattsson and A. Meide

Risø National Laboratory, DK-4000 Roskilde, Denmark
December 1984

Risø-R-510

ENVIRONMENTAL RADIOACTIVITY IN THE NORTH ATLANTIC REGION. THE FAROE ISLANDS AND GREENLAND INCLUDED. 1983

A. Aarkrog, S. Boelskifte, E. Buch[o], G. C. Christensen*, H. Dahlgaard, L. Hallstadius**, H. Hansen, E. Holm***, S. Mattsson**** and A. Meide.

o The Greenland Fisheries and Environmental Institute, Denmark
* Institute for Energy Technology, Kjeller, Norway
** University of Lund, Sweden
*** International Laboratory of Marine Radioactivity, Monaco
**** University of Gothenburg, Sweden

Abstract. Measurements of fallout radioactivity in the North Atlantic region including the Faroe Islands and Greenland are reported. Strontium-90 and cesium-137 was determined in samples of precipitation, sea water, vegetation, various foodstuffs (including milk in the Faroes) and drinking water. Estimates are given of the mean contents of ^{90}Sr and ^{137}Cs in human diet in the Faroes and Greenland in 1983. Results from samplings of surface sea water and seaweed in the Norwegian and Greenland Seas and along the Norwegian and Greenland west coasts are
(continued)

December 1984
Risø National Laboratory

reported. Beside radiocesium and ^{90}Sr some of these samples have also been analysed for tritium, plutonium and americium. Finally technetium-99 data on seaweed samples collected in the North Atlantic region since the beginning of the sixties are presented.

INIS Descriptors
ANIMALS; ATMOSPHERIC PRECIPITATIONS; AMERICIUM 241; ATMOSPHERIC PRECIPITATIONS; BONE TISSUES; CESIUM 137; DIET; DRINKING WATER; ENVIRONMENT; FAROE ISLANDS; FOOD CHAINS; GLOBAL FALLOUT; GREENLAND; MAN; MILK; PLANTS; PLUTONIUM 239; PLUTONIUM 240; RADIOACTIVITY; SEAWATER; SEAWEEDS; SEDIMENTS; STRONTIUM 90; TECHNETIUM 99.

UDC 614.73 (491.2)

ISBN 87-550-1036-9
ISSN 0106-2840

Risø Repro 1985

CONTENTS

ABBREVIATIONS AND UNITS

J: joule: the unit of energy; 1 J = 1 Nm (= 0.239 cal)
Gy: gray: the unit of absorbed dose = 1 J kg^{-1} (= 100 rad)
Sv: sievert: the unit of dose equivalent = 1 J kg^{-1} (= 100 rem)
Bq: becquerel: the unit of radioactivity = 1 s^{-1} (= 27 pCi)
ALI: annual limit of intake (according to ICRP)

cal: calorie = 4.186 J
rad: 0.01 Gy
rem: 0.01 Sv
Ci: curie: $3.7 \cdot 10^{10}$ Bq (= $2.22 \cdot 10^{12}$ dpm)
E: exa: 10^{18}
P: peta: 10^{15}
T: tera: 10^{12}
G: giga: 10^{9}
M: mega: 10^{6}
k: kilo: 10^{3}
m: milli: 10^{-3}
µ: mikro: 10^{-6}
n: nano: 10^{-9}
p: pico: 10^{-12}
f: femto: 10^{-15}
a: atto: 10^{-18}

pro capite: per individual
TNT: trinitrotoluol; 1 Mt TNT: nuclear explosives equivalent to 10^{9} kg TNT.

a^{-1}: per annum
OR: observed ratio
CF: concentration factor
µR: micro-roentgen, 10^{-6} roentgen
S.U.: pCi ^{90}Sr (g Ca)$^{-1}$
O.R.: observed ratio
M.U.: pCi ^{137}Cs (g K)$^{-1}$

V: vertebrae

m: male

f: female

nSr: natural (stable) Sr

eqv. mg KCl: equivalents mg KCl: activity as from 1 mg KCl (~ 0.88 dpm). 1 g K ~ 756 pCi ~ 28 Bq.

S.D.: standard deviation: $\sqrt{\frac{\Sigma(\bar{x}-x_i)^2}{(n-1)}}$

S.E.: standard error: $\sqrt{\frac{\Sigma(\bar{x}-x_i)^2}{n(n-1)}}$

U.C.L.: upper control level

L.C.L.: lower control level

Δ: one standard deviation due to counting

S.S.D.: sum of squares of deviation: $\Sigma(\bar{x}-x_i)^2$

f: degrees of freedom

s^2: variance

v^2: ratio between the variance in question and the residual variance

P: probability fractile of the distribution in question

η: coefficient of variation, relative standard deviation

anova: analysis of variance

Counting errors: given as relative standard deviation:

no indication: < 20%

A: 20-33%

B: >33%, such results are not considered significantly different from zero activity

B.D.L.: below detection limit

In the significance test the following symbols were used:

* : probably significant (P > 95%)

** : significant (P > 99%)

***: highly significant (P > 99.9%)

1. GENERAL INTRODUCTION

Since 1962 we have published separate annual reports for the Environmental Radioactivity in the Faroes[1] and in Greenland[2]. The reports on and after 1983 will be contained in the new series: "Environmental Radioactivity in the North Atlantic Region. The Faroe Islands and Greenland included" of which the present report is the first.

Chapter 2 in this report corresponds to the earlier report for the Faroes and Chapter 3 to the Greenland report.

In Chapter 4 we report on marine environmental radioactivity studies from other parts of the North Atlantic region and, furthermore, include sea water data from the Faroe Islands and Greenland. Chapter 4 also includes results from samplings carried out in earlier years.

2. ENVIRONMENTAL RADIOACTIVITY IN THE FAROE ISLANDS IN 1983

2.1. Introduction

2.1.1.

The fallout programme for the Faroes, which was initiated in 1962[1)] in close co-operation with the National Health Service and the chief physician of the Faroes, was continued in 1983. Samples of human bone were obtained in 1983 from Dronning Alexandrine's Hospital in Thorshavn.

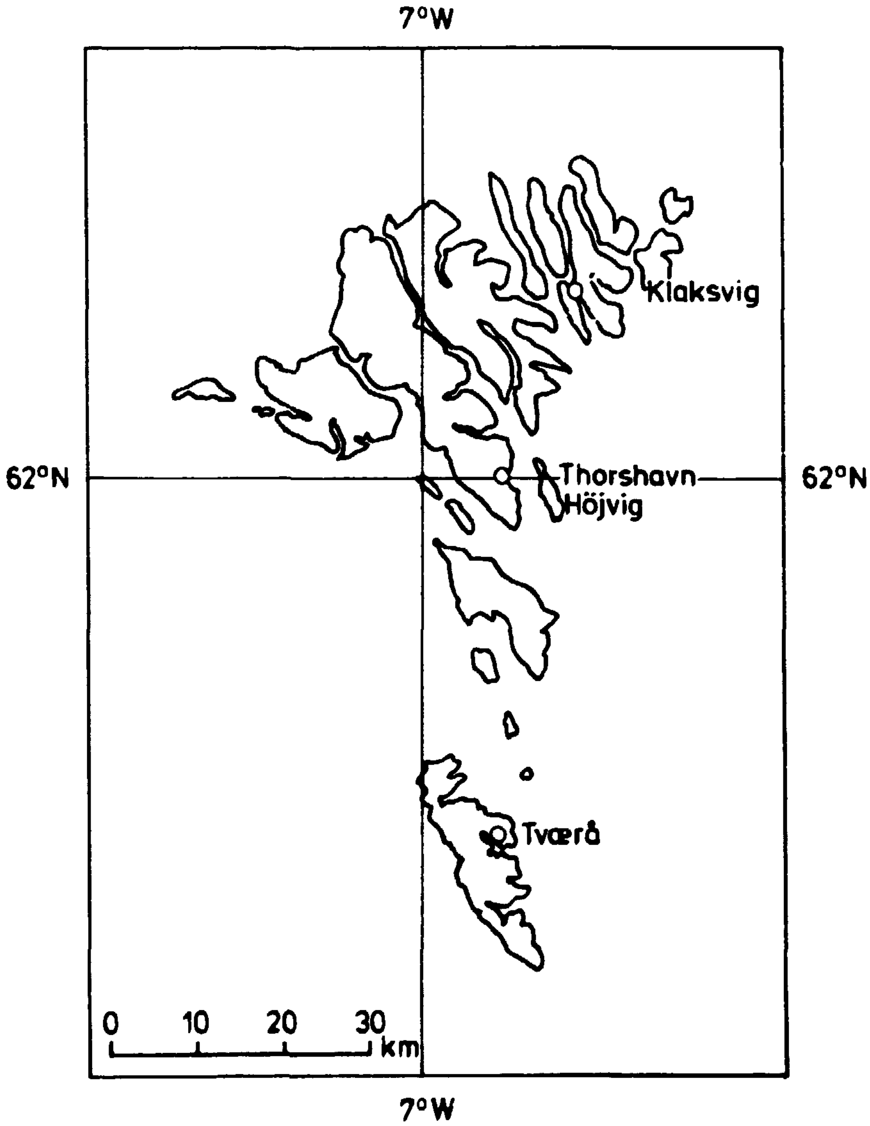


Fig. 2.1. The Faroese Islands.

2.1.2.

The present report will not repeat information concerning sample collection and analysis already given in Risø Reports Nos. 64, 86, 108, 131, 155, 181, 202, 221, 246, 266, 292, 306, 324, 346, 361, 387, 4C4, 422, 448, 470 and 488[1).

2.1.3.

The estimated mean diet of the Faroese as used in this report is still mased on the estimate given by the late Professor E. Hoff-Jørgensen, Ph.D., in 1962.

2.1.4.

The present investigation was carried out together with corresponding examinations of fallout levels in Denmark and Greenland, described in Risø Report No. 509 and in Chapter 3 of this report, respectively.

2.2. Results and discussion

2.2.1. Strontium-90 in Faroese precipitation

Table 2.1 shows the ^{90}Sr content in precipitation collected at Højvig (near Thorshavn) and Klaksvig in 1983. The amount of fallout at Højvig was a factor of 1.2 greater than that found at Klaksvig.

The ^{90}Sr fallout in 1983 was approximately 0.5 times of the 1982 levels in the Faroes. In Denmark the 1983 levels were 0.8 times the 1982 levels[2).

Table 2.2.1.1. Strontium-90 in precipitation in the Faroes in 1983 (sampling area = 0.02 m^2)

	Höjvig		Klaksvig	
	Bq m^{-3}	Bq m^{-2}	Bq m^{-3}	Bq m^{-2}
Jan-April	2.0	0.91	1.50	1.20
May-June	4.1 A	0.43 A	3.2	0.70
July-Aug	6.4	0.63	12.0	0.42
Sept-Dec	1.96	1.40	0.45 B	0.43 B
1983	2.5	Σ 3.37 Σ_m 1.363	1.36	Σ 2.75 Σ_m 2.020
1983	0.067 pCi l^{-1}	Σ 0.091 mCi km^{-2}	0.037 pCi l^{-1}	Σ 0.074 mCi km^{-2}

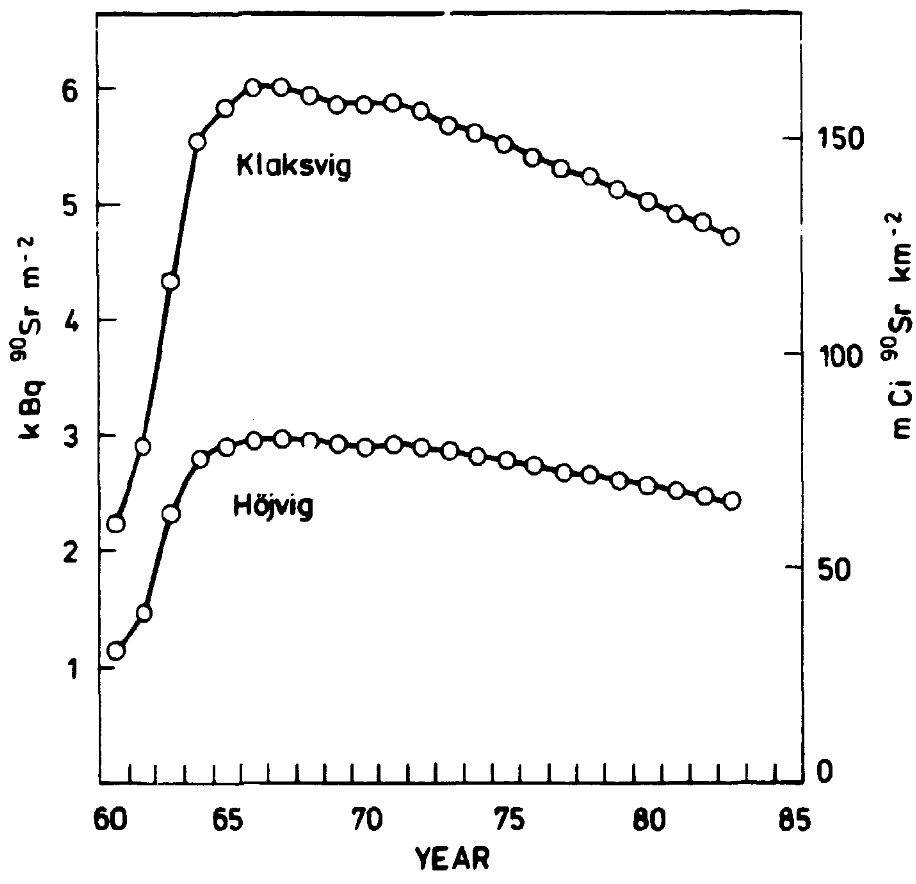


Fig. 2.2.1. Accumulated ^{90}Sr at Klaksvig and Højvig calculated from precipitation measurements since 1962. The accumulated fallout by 1962 was estimated from the Danish fallout data (cf. Risø Report No. 509[3]), Appendix D) and from the ratio between the ^{90}Sr fallout at the Faroese stations and the fallout in Denmark in the period 1962-1983 (cf. Table 2.2.1.2).

Table 2.2.1.2. Fallout rates and accumulated fallout (Bq ^{90}Sr m^{-2}) in the Faroes 1950-1983

	Höjvig		Klaksvig	
	d_i	$A_{i(29)}$	d_i	$A_{i(29)}$
1950	1.08	1.06	2.15	2.10
1951	5.21	6.12	10.34	12.14
1952	10.21	15.94	20.27	31.64
1953	25.78	40.74	51.18	80.87
1954	98.02	135.48	194.58	268.94
1955	128.96	258.20	256.00	512.54
1956	159.90	408.22	317.41	810.34
1957	159.90	554.70	317.41	1101.12
1958	221.82	758.18	440.34	1505.05
1959	314.64	1047.48	624.58	2079.33
1960	58.78	1080.14	116.69	2144.16
1961	76.36	1129.19	151.59	2241.52
1962	383.01	1476.48	760.31	2930.93
1963	9[illegible]3.00	2333.05	1503.00	4329.21
1964	544.00	2809.10	1363.00	5557.77
1965	181.00	2919.48	436.00	5852.21
1966	112.00	2959.88	289.00	5996.17
1967	94.70	2982.44	182.00	6032.25
1968	44.00	2954.96	55.50	5943.97
1969	41.10	2925.30	65.10	5867.15
1970	53.60	2908.54	141.00	5866.25
1971	101.00	2938.46	156.00	5880.02
1972	34.40	2902.65	55.10	5794.94
1973	24.20	2857.73	26.50	5683.95
1974	33.80	2823.23	58.80	5607.12
1975	34.40	2790.14	47.80	5521.36
1976	8.88	2732.91	21.60	5412.05
1977	27.40	2695.12	34.40	5317.81
1978	37.30	2667.89	47.60	5238.69
1979	13.90	2618.45	22.20	5136.64
1980	11.70	2568.03	12.60	5027.63
1981	22.50	2529.35	26.70	4934.95
1982	7.75	2477.18	4.79	4823.08
1983	3.37	2421.96	2.75	4711.95

1950-1961: are estimated values based upon HASL data (HASL Appendix 291, 1975) considering that the mean ratio between ^{90}Sr fallout in Denmark and New York was 0.7 in the period 1962-1974 and that the mean ratios between ^{90}Sr fallout in Höjvig and Denmark and between Klaksvig and Denmark are 1.39 and 2.76, respectively[5].

2.2.2. Strontium-90 and Cesium-137 in Faroese grass

Grass samples were collected near Thorshavn in 1983. Table 2.2.2 shows the results. The 1983 ^{137}Cs mean level in grass was 0.95 times the 1982 level. As compared with Danish grass in 1983[3] we found the ^{90}Sr level (Bq (kg Ca)$^{-1}$) in the Faroese grass to be higher by a factor of approximately 8.4 in the summer months.

Table 2.2.2. Strontium-90 and Cesium-137 in grass from Thorshavn 1983

Month	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	$^{137}Cs/^{90}Sr$
June	1.45	5300	8.7	2100	6.0
August	1.45	5200	9.1	2500	6.3

2.2.3. Strontium-90 and Cesium-137 in Faroese milk

As in previous years[1], weekly samples of fresh milk were optained from Thorshavn, Klaksvig, and Tværå. Strontium-90 and ^{137}Cs were determined in bulked monthly samples.

Table 2.2.3.1 shows the results and Tables 2.2.3.2, 2.2.3.3 and 2.2.3.4 the analysis of variance of the Bq ^{90}Sr (kg Ca)$^{-1}$, Bq ^{137}Cs (kg K)$^{-1}$, and Bq ^{137}Cs m^{-3} figures, respectively. As also observed in previous years, the variation between locations was significant for ^{137}Cs as well as for ^{90}Sr. The highest levels were found in the milk from Klaksvig, and the lowest in Thorshavn milk.

Figure 2.2.3.1 shows the quarterly Bq ^{90}Sr (kg Ca)$^{-1}$ values and Fig. 2.2.3.2 the quarterly Bq ^{137}Cs m^{-3} levels since 1962. The annual mean values for 1983 were 197 Bq ^{90}Sr (kg Ca)$^{-1}$ (5.3 S.U.) and 4300 Bq ^{137}Cs m^{-3} (116 pCi ^{137}Cs l^{-1}), i.e. the ^{90}Sr levels in 1983 were 90% of the 1982 concentration, while the ^{137}Cs levels were approximately 98% of the 1982 mean levels. In Danish milk the ^{90}Sr concentration in 1983 was 80% of the 1982 level, and the ^{137}Cs 1983 level was 73% of the 1982 content.

The annual mean values of the ratio: Bq ^{137}Cs (kg K)$^{-1}$/Bq ^{90}Sr (kg Ca)$^{-1}$ in Faroese milk are shown in Fig. 2.2.3.3. The annual mean ratio in 1983 for the three locations was 12.3±2.2 (1 S.E.).

Table 2.2.3.1. Strontium-90 and Cesium-137 in milk from the Faroes in 1983

Month	Thorshavn			Klaksvig			Tvarå			Mean		
	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs m^{-3}	Bq ^{137}Cs (kg K)$^{-1}$	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs m^{-3}	Bq ^{137}Cs (kg K)$^{-1}$	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs m^{-3}	Bq ^{137}Cs (kg K)$^{-1}$	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs m^{-3}	Bq ^{137}Cs (kg K)$^{-1}$
Jan	125±5	2040	1210	194±35	5300	2900	119	1240	790	146	2900	1630
Feb	116±6	1740	1090	159±34	3800	2040	164±21	4500	2600	146	3300	1910
March	103±1	1850	1110	244±43	8300	5100	225±20	4900	2900	191	5000	3000
April	117±8	1630	1000	333±53	7700	4300	266±66	4300	2700	139	4500	2700
May	123	1340	790	201	7900	4400	205	5400	3100	176	4900	2800
June	130	1440	890	300	6500	4200	188	3800	2200	206	3900	2400
July	176	2010	1390	276	6500	4200	234	5100	3000	229	4500	2900
Aug	194	2180	1510	279	6700	4400	302	7100	4100	258	5300	3[illegible]00
Sept	152	1990	1350	225	5500	3300	267	6700	4000	215	4700	2900
Oct	118	1300	1060	228	6700	4300	184	4900	3100	177	4300	2800
Nov	84	1000	610	268	8200	4400	244	4000	2200	193	4400	2400
Dec	128	1570	910	264	7200	3500	148	3700	2300	180	4200	2200
Mean	130	1670	1080	248	6700	3900	212	4600	2700	197	4300	2600

Table 2.2.3.2. Analysis of variance of ln Bq ^{90}Sr (kg Ca)$^{-1}$ in Faroese milk in 1983 (from Table 2.2.3.1)

Variation	SSD	f	s^2	v^2	P
Between months	1.278	11	0.116	2.359	> 95%
Between locations	3.613	2	1.807	36.679	> 99.95%
Month × loc.	1.084	22	1.155	58.375	-
Remainder	0.469	11	0.043		

Table 2.2.3.3. Analysis of variance of ln Bq ^{137}Cs (kg K)$^{-1}$ in Faroese milk in 1983 (from Table 2.2.3.1)

Variation	SSD	f	s^2	v^2	P
Between months	1.235	11	0.112	1.114	-
Between locations	10.585	2	5.293	52.498	> 99.95%
Remainder	2.218	22	0.101		

Table 2.2.3.4. Analysis of variance of ln Bq ^{137}Cs m^{-3} in Faroese milk in 1983 (from Table 2.2.3.1)

Variation	SSD	f	s^2	v^2	P
Between months	0.857	11	0.078	0.692	-
Between locations	11.860	2	5.930	52.687	> 99.95%
Remainder	2.476	22	0.113		

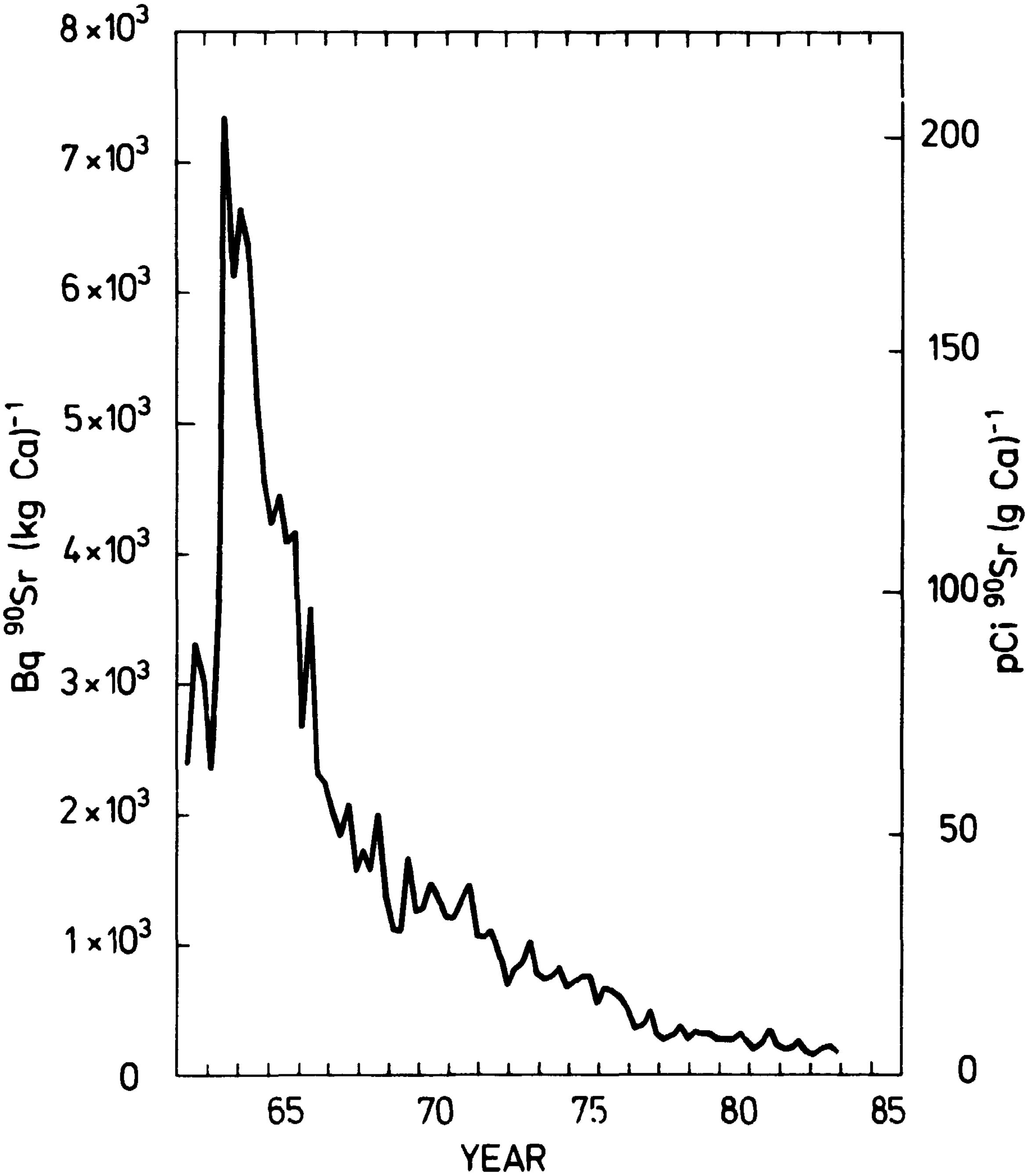


Fig. 2.2.3.1. Strontium-90 in Faroese milk, 1962-1983.

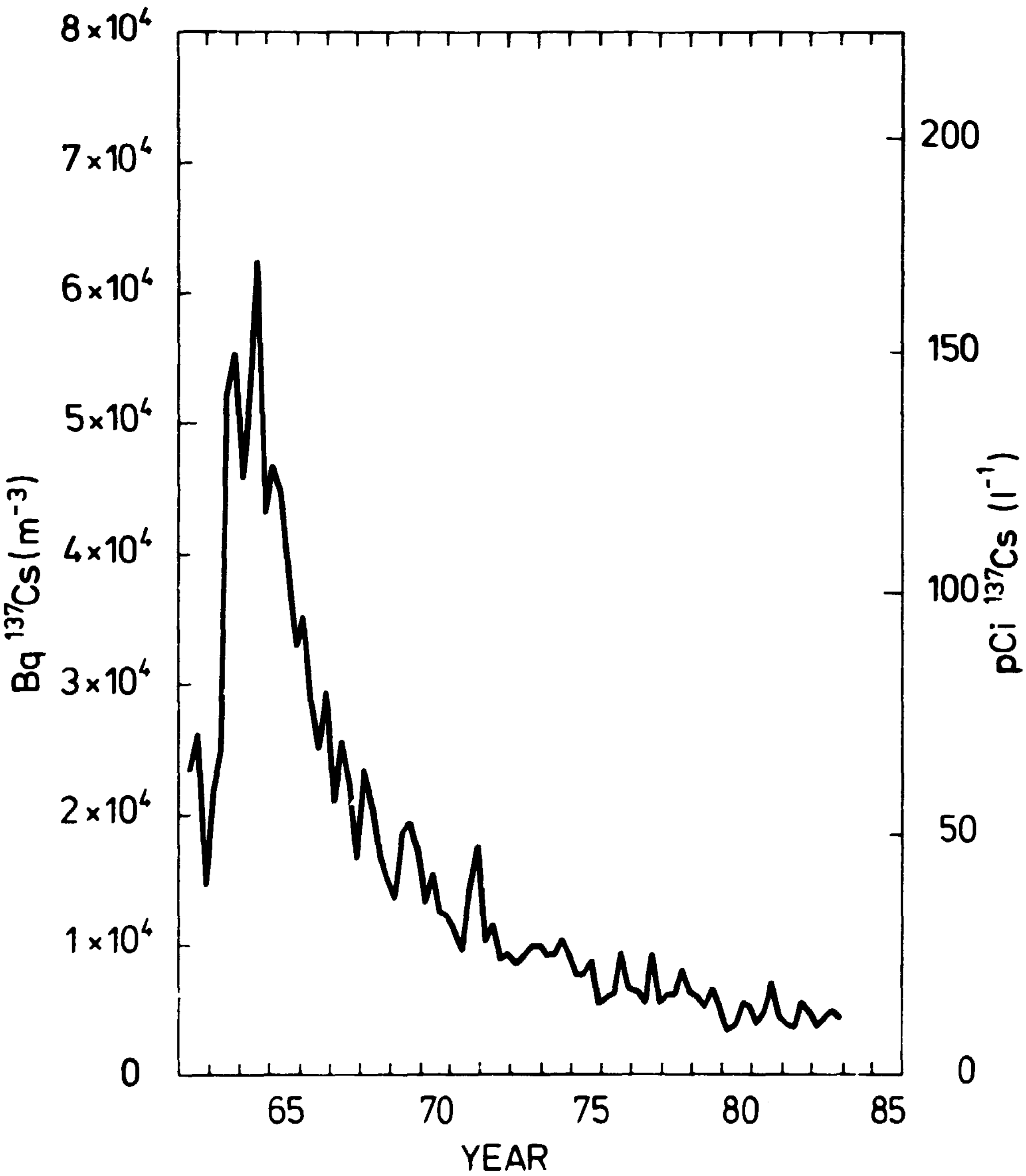


Fig. 2.2.3.2. Cesium-137 in Faroese milk, 1962-1983.

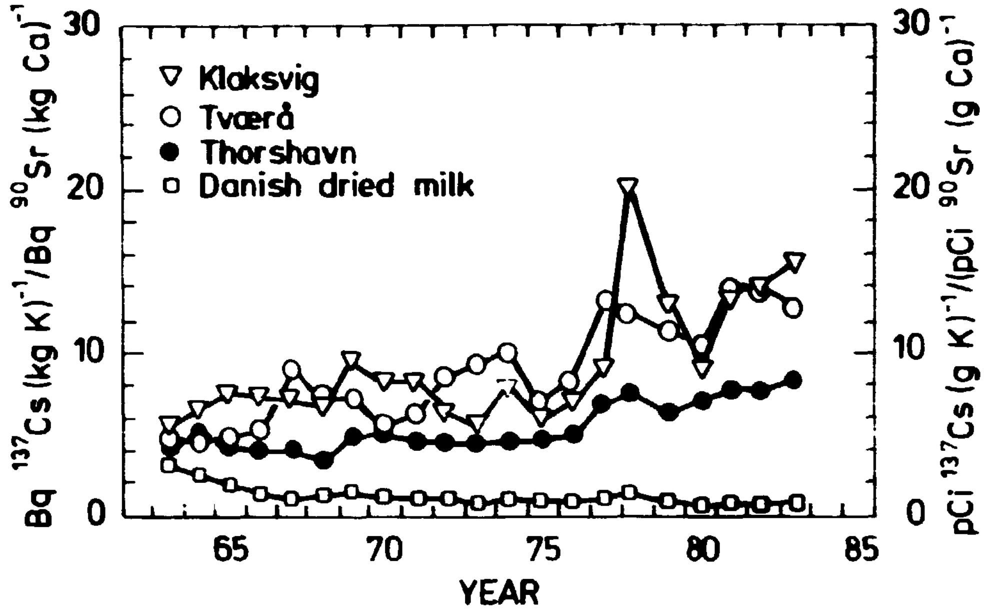


Fig. 2.2.3.3. $\frac{M.U.}{S.U.}$ ratios in Faroese and Danish milk, 1963-1983.

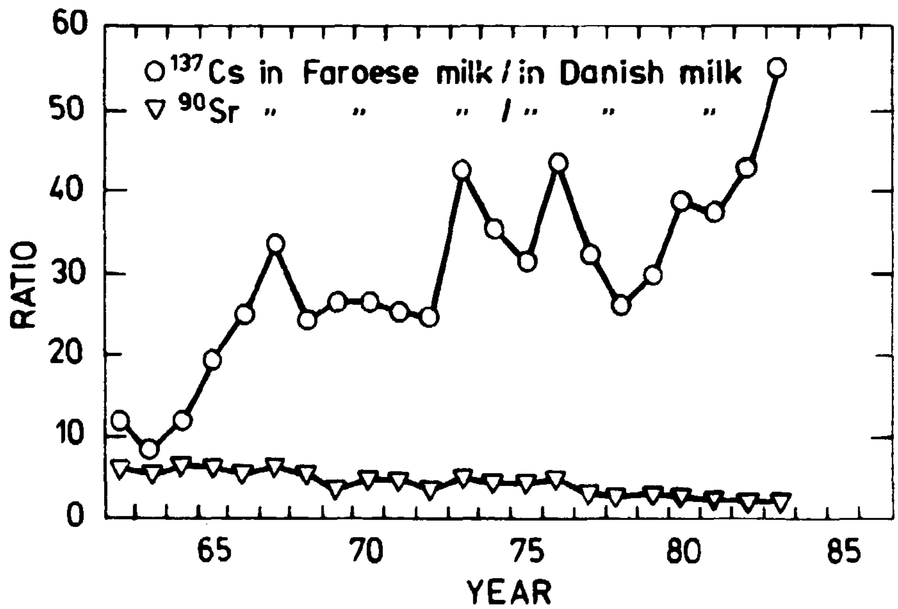


Fig. 2.2.3.4. A comparison between Faroese and Danish milk levels, 1962-1983.

Figure 2.2.3.4 shows a comparison between the ^{90}Sr and ^{137}Cs levels in Faroese- and Danish-produced milk. It is evident that indirect contamination plays an important role for the ^{137}Cs levels in the Faroes, because the ratio between ^{137}Cs in Faroese and Danish milk increases when the fallout rate decreases. The ratios between the ^{90}Sr levels in Faroese and Danisk milk have shown a slight tendency to decrease through the years.

2.2.4. Strontium-90 and Cesium-137 in Faroese terrestrial animals

The mean concentration in lamb meat was 6.43 Bq ^{137}Cs kg^{-1} in 1983, but as Table 2.2.4 shows the levels from the three locations varied by a factor of 24. The ^{90}Sr mean level in bone was 1360 Bq ^{90}Sr (kg Ca)$^{-1}$ and in meat we found 0.07 Bq ^{90}Sr kg^{-1}. As it appears from Figs. 2.2.4.1 and 2.2.4.2 the 1983 concentrations followed the decreasing trend seen in the previous years.

A sample of puffins contained less than 0.18 Bq ^{137}Cs kg^{-1} meat and 0.8 (B) Bq ^{90}Sr (kg Ca)$^{-1}$ in the bones. In meat the concentration was 0.008 Bq ^{90}Sr kg^{-1} (B).

The lamb meat was also analysed for ^{210}Po. The mean content was 0.36 Bq ^{210}Po kg^{-1} (±0.15, 1 S.D.). As the ALI value for ^{137}Cs is 40 times that of ^{210}Po, the radiological hazard from ^{210}Po in lamb meat was greater than that of ^{137}Cs.

Table 2.2.4. Strontium-90 and Cesium-137 in lamb collected in the Faroes in October 1983

Location	Sample type	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	Bq ^{210}Po kg^{-1}
Thorshavn	Meat	0.14	2300 (2000)	14.5	180	0.49
Tvarå	Meat	0.03	563 (990)	0.6	4400	0.19
Klaksvig	Meat	0.04	750 (1080)	4.2	1500	0.40

Bone levels are shown in brackets.

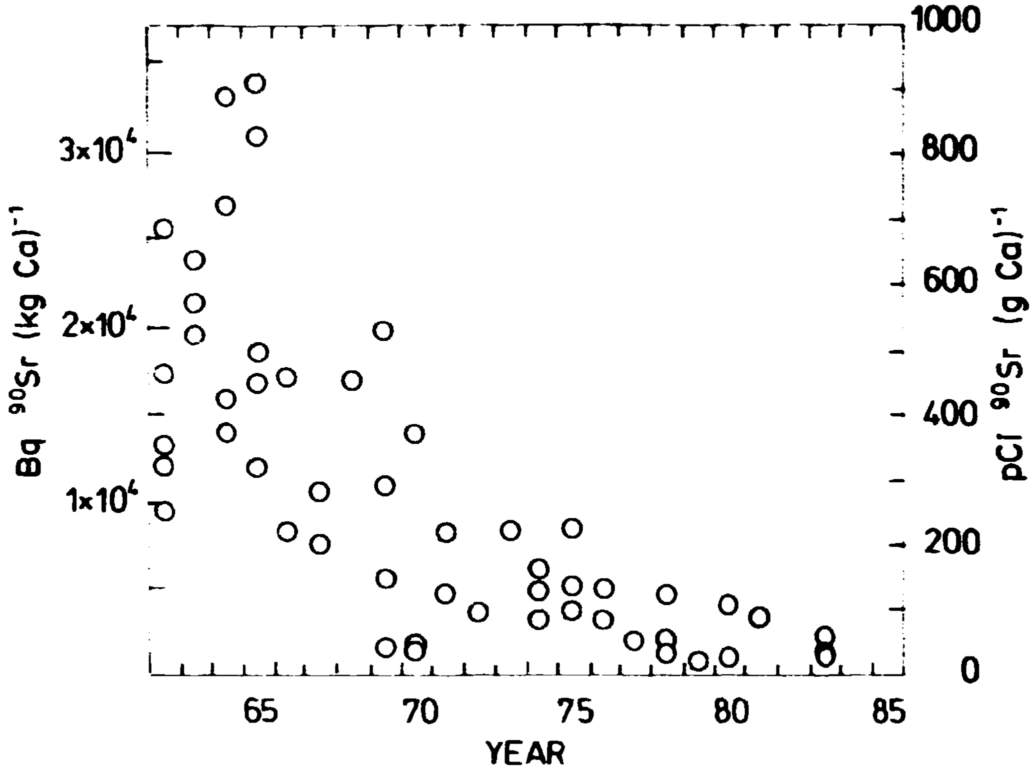


Fig. 2.2.4.1. Strontium-90 (Bq (kg Ca)$^{-1}$) in lamb bone collected in the Faroes, 1962-1983.

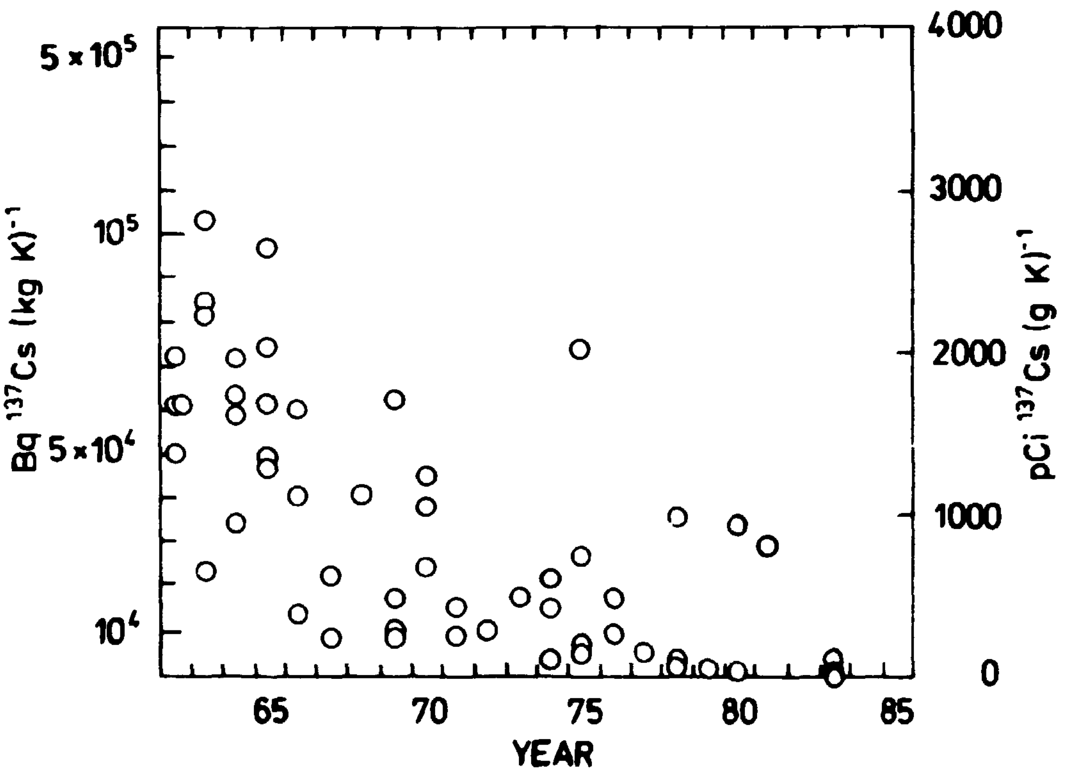


Fig. 2.2.4.2. Cesium-137 (Bq (kg K)$^{-1}$) in lamb bone collected in the Faroes, 1962-1983.

2.2.5. Strontium-90 and Cesium-137 in Faroese sea animals

Table 2.2.5.1 shows the ^{137}Cs levels in fish collected in 1983 in the Faroes. The mean levels in Gadus aeglefinus and Gadus callarias were 0.25 Bq ^{137}Cs kg^{-1} and 0.003 Bq ^{90}Sr kg^{-1}.

Whale meat from 1983 contained 0.004 Bq ^{90}Sr kg^{-1} (B) and 0.25 Bq ^{137}Cs kg^{-1} (85 Bq ^{137}Cs (Kg K)$^{-1}$). A whiting contained 0.25 Bq ^{137}Cs kg^{-1}, i.e. in agreement with the other Gadus species.

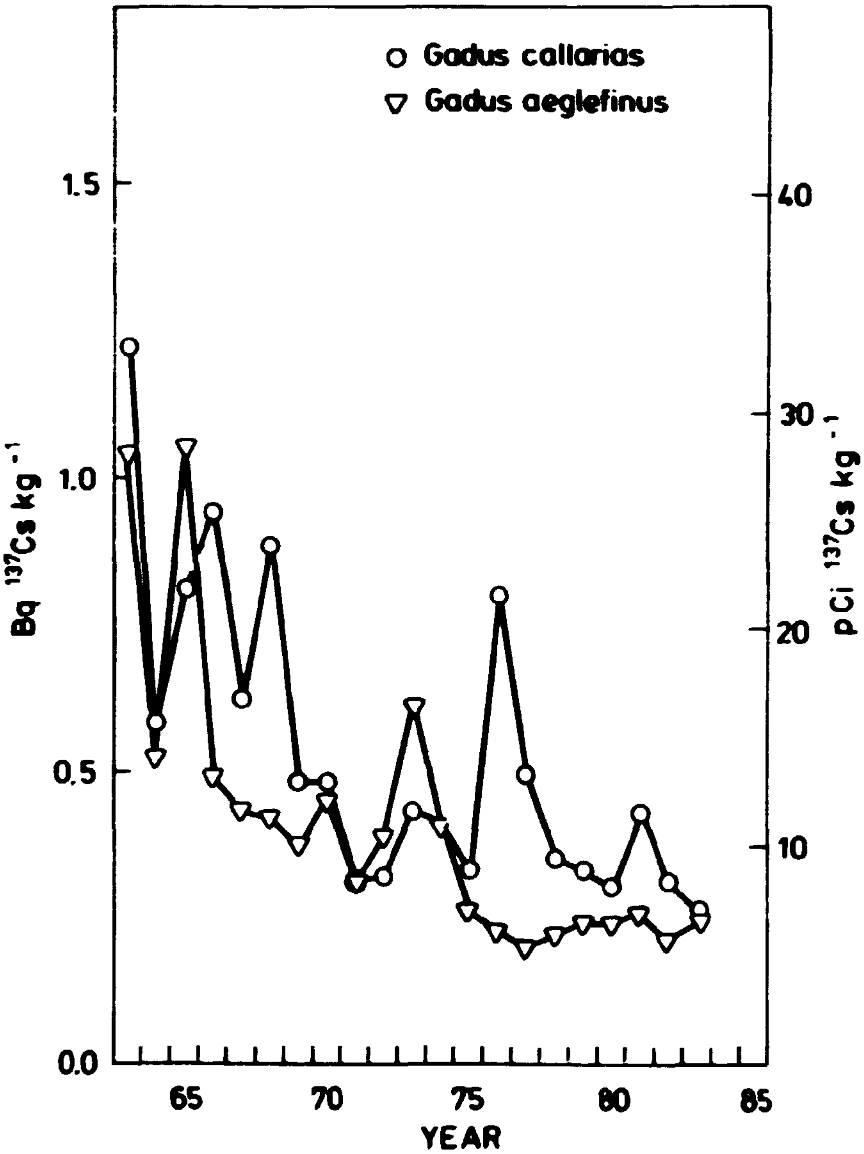


Fig. 2.2.5.1. Cesium-137 levels in meat of cod (Gadus callarias) and Haddock (Gadus aeglefinus) collected in the Faroes, 1962-1983.

Table 2.2.5.1. Strontium-90 and Cesium-137 in fish flesh from the Faroes in 1983

Sampling month	Species	Sample type	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr $(kg\ Ca)^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs $(kg\ K)^{-1}$
March	Gadus callarias	Cod flesh	0.003 B	26 B	0.29	74
June	- " -	- " -	0.002 B	29 B	0.29	71
Sept	- " -	- " -	0.005	44	0.21	62
Dec	- " -	- " -	0.009 A	120 A	0.25	61
March	Gadus aeglefinus	Haddock flesh	0.001 B	7 B	0.18	52
June	- " -	- " -	0.003 B	25 B	0.29	86
Sept	- " -	- " -	0.003 B	37 B	0.26	69
Dec	- " -	- " -	0.001 B	15 B	0.22	60

2.2.6. Strontium-90 in Faroese drinking water

Drinking-water samples were collected as previously but the samples were combined before the analysis as shown in Table 2.2.6.1. As in previous years, drinking water from Thorshavn contained more ^{90}Sr than that from Klaksvig and Tværå (cf. the explanation in Risø Report No. 181[1]). The mean level in 1983 was 5.1 Bq ^{90}Sr m^{-3} (0.14 pCi l^{-1}), i.e. a little lower than in 1982.

Figure 2.2.6.1 shows the annual mean levels of ^{90}Sr in drinking water from the three locations since 1962.

Table 2.2.6.1. Strontium-90 in drinking water from the Faroes in 1983 (Unit: Bq m^{-3})

	Thorshavn	Klaksvig	Tværå
Jan-June	8.8	1.7	6.1
July-Dec	6.0	2.7	5.2
1982	7.4	2.2	5.7

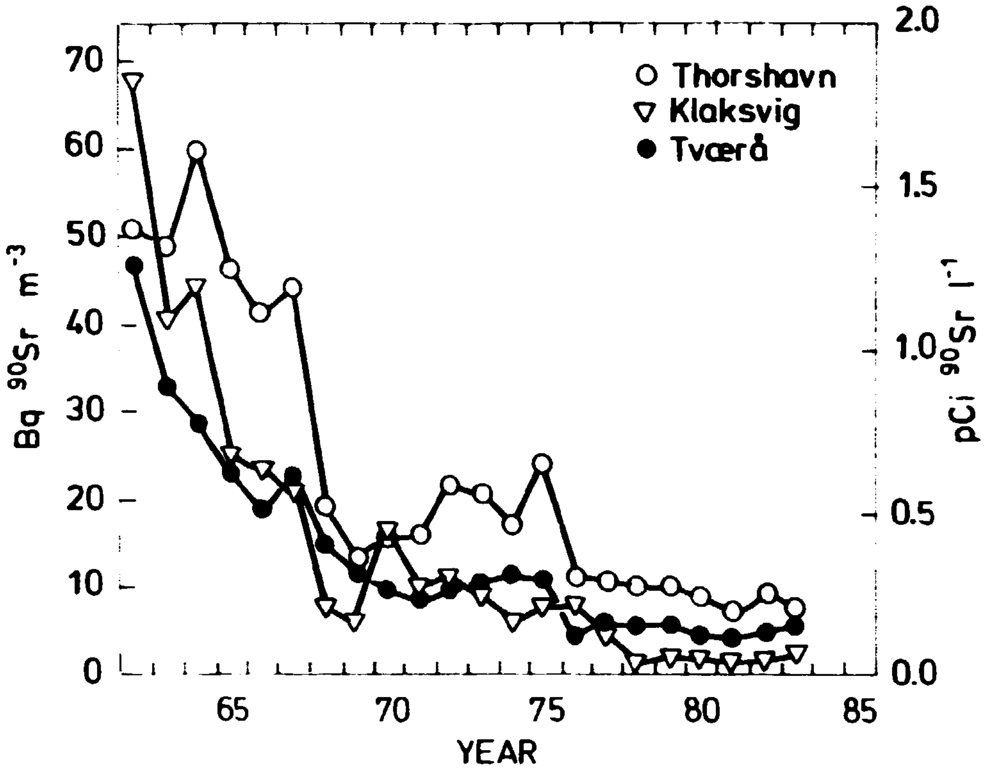


Fig. 2.2.6.1. Strontium-90 in drinking water from the Faroes, 1962-1983.

2.2.7. Strontium-90 and Cesium-137 in miscellaneous Faroese samples

2.2.7.1. Faroese soil

No samples in 1983.

2.2.7.2. Faroese sea water

Cf. Chapter 4 and Fig. 2.2.7.2.

2.2.7.3. Faroese sea plants

Table 2.2.7.3. shows the ^{90}Sr and ^{137}Cs contents in Laminaria and Fucus collected in 1983.

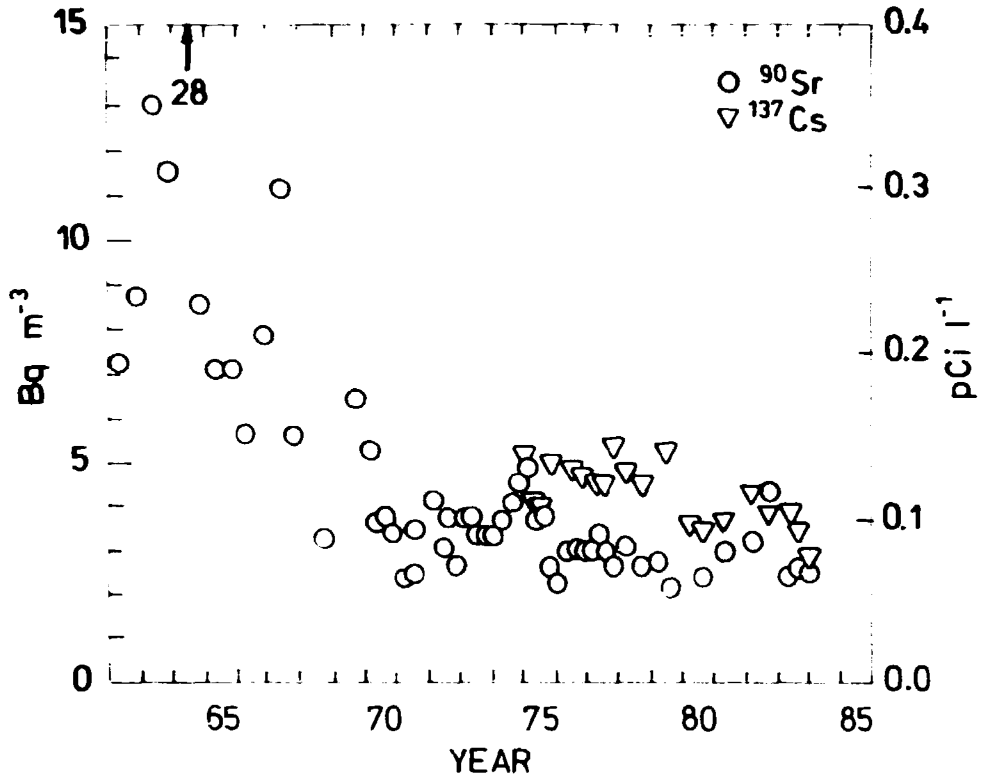


Fig. 2.2.7.2. Strontium-90 and Cesium-137 in Faroese sea water, 1962-1983.

Table 2.2.7.2. Strontium-90 and Cesium-137 in surface sea water from the Faroes in 1983

Sampling month	Bq ^{90}Sr m^{-3}	Bq ^{137}Cs m^{-3}	Salinity o/oo
April	2.4	3.9	35.3
August	2.6	3.4	35.2
December	2.5	2.9	34.7
1983	2.5	3.4	35.1

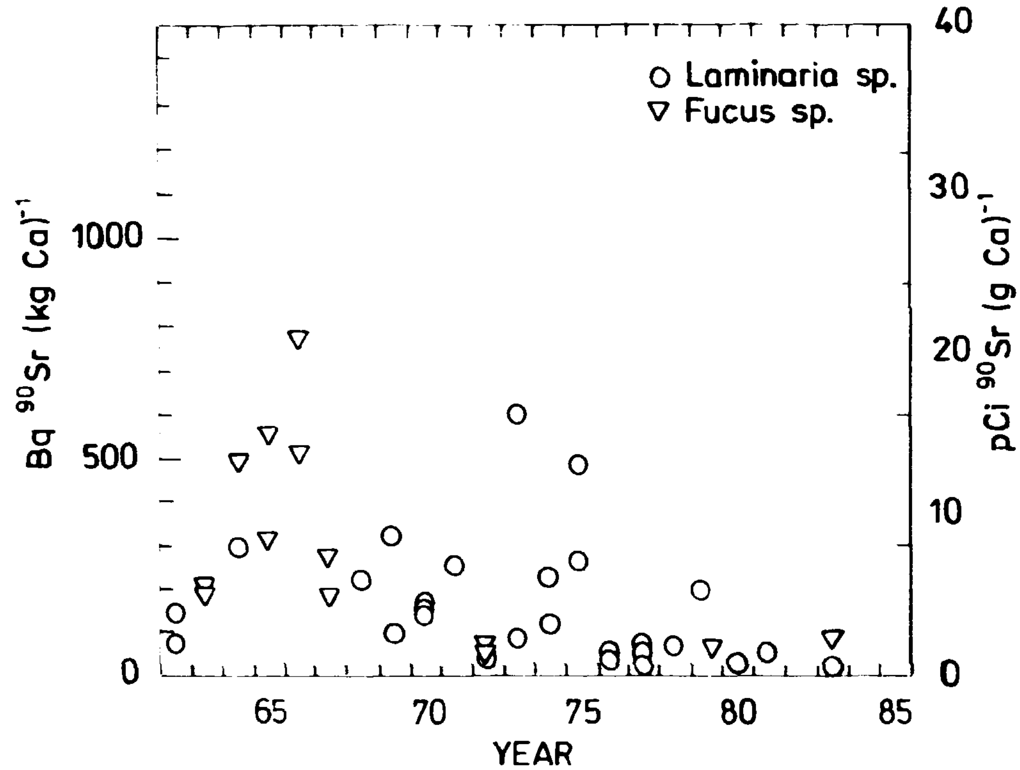


Fig. 2.2.7.3. Strontium-90 (Bq (kg Ca)$^{-1}$) in sea plants collected at Thorshavn, 1962-1983.

Table 2.2.7.3. Radionuclides in Faroese seaweed collected in August 1983

	Laminaria	Fucus
Bq ^{90}Sr kg^{-1} dry	0.49	-
Bq ^{90}Sr (kg Ca)$^{-1}$	25	98
Bq ^{137}Cs kg^{-1} dry	0.73 A	0.83
Bq ^{137}Cs (kg K)$^{-1}$	15 A	26
Fresh weight/dry weight	6.42	5.33

2.2.7.4. Faroese vegetables

Three samples of potatoes were analysed in 1983. The mean content was 0.22 Bq ^{90}Sr kg^{-1} (6700 Bq ^{90}Sr (kg Ca)$^{-1}$) and 12.1 Bq ^{137}Cs kg^{-1} (2900 Bq ^{137}Cs (kg K)$^{-1}$). Potatoes from Tværå contained nearly 100 times higher ^{137}Cs levels than those from Thorshavn.

Table 2.2.7.4. Radionuclides in Faroese potatoes collected in November 1983

	Thorshavn	Klaksvig	Tværå
Bq ^{90}Sr kg^{-1}	0.08	0.39	0.19
Bq ^{90}Sr (kg Ca)$^{-1}$	1280	13200	5700
Bq ^{137}Cs kg^{-1}	0.36	3.3	32.6
Bq ^{137}Cs (kg K)$^{-1}$	94	810	7900

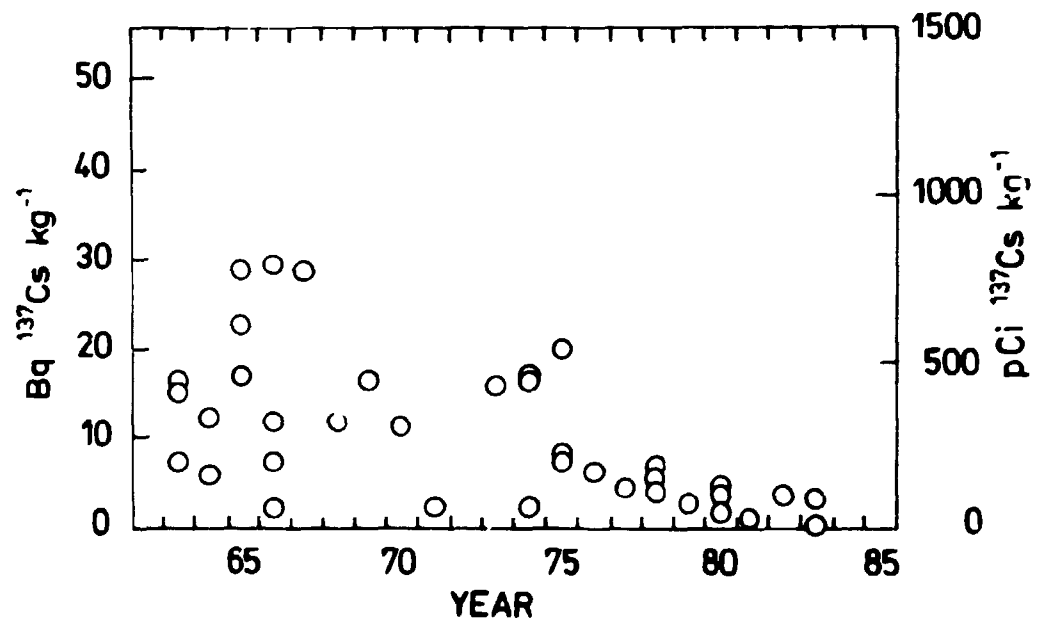


Fig. 2.2.7.4.1. Cesium-137 in Faroese potatoes, 1962-1983.

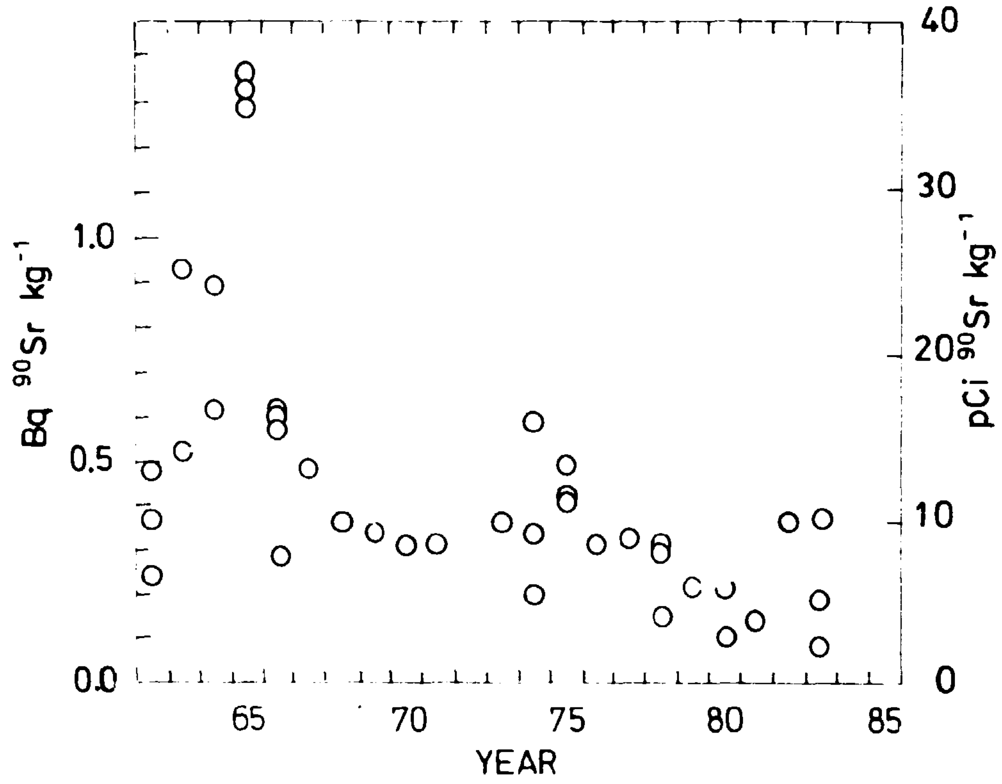


Fig. 2.2.7.4.2. Strontium-90 in Faroese potatoes, 1962-1983.

2.2.7.5. Faroese bread

Rye bread and white bread were collected at Thorshavn in June. The levels in white bread were 0.14 Bq ^{90}Sr kg^{-1} and 0.04 Bq ^{137}Cs kg^{-1}. The rye bread collected in 1983 contained 0.24 Bq ^{90}Sr kg^{-1} and 0.10 Bq ^{137}Cs kg^{-1}. The bread levels were thus significantly lower than those in 1982.

The ^{137}Cs and ^{90}Sr (kg^{-1}) levels in Faroese rye bread were generally lower than the corresponding Danish[3)], but the white bread concentrations were similar.

Table 2.2.7.5. Strontium-90 and Cesium-137 in Faroese bread in June 1983

Sort	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr $(kg\ Ca)^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs $(kg\ K)^{-1}$
White bread	0.14	109	0.04 A	24 A
Rye bread	0.24	110	0.10	43

2.2.7.6. Faroese eggs

Eggs were collected from Thorshavn in June 1983. The levels of hens eggs were 0.091 Bq ^{90}Sr kg^{-1} (164 Bq (kg Ca)$^{-1}$ and 0.22 Bq ^{137}Cs kg^{-1}.

2.2.8. Humans from the Faroes

2.2.8.1. Strontium-90 in human bone

In 1983 three human bone samples were obtained from Dronning Alexandrine's Hospital in Thorshavn. Table 2.2.8.1 shows the results.

The mean content of femur samples was 67 Bq ^{90}Sr (kg Ca)$^{-1}$ (1.8 pCi ^{90}Sr (g Ca)$^{-1}$).

Compared to Danish vertebrae in 1983[2)] the Faroese samples of femur contained approximately 2-3 times as much ^{90}Sr.

Table 2.2.8.1. Strontium-90 in human bone collected in the Faroes in 1983

Age	Bone type		Sex	Bq ^{90}Sr (kg Ca)$^{-1}$	S.U.
84 years	Femur	Amputation	F	50	1.35
89 years	Femur	- " -	F	84	2.27
85 years	Femur	- " -	F	68	1.84

2.3. Estimate of the mean contents of ^{90}Sr and ^{137}Cs in the Faroese human diet in 1983

2.3.1. Annual quantities

The annual quantities are still based on the estimate made by the late Professor E. Hoff-Jørgensen, Ph.D., in 1962[1] assuming a daily pro capite intake of approximately 3000 calories (12.6 MJ).

2.3.2. Milk and cream

75% of the milk consumed in the Faroes is assumed to be of local origin, and 25% comes from Denmark. Hence the ^{90}Sr content in milk consumed in the Faroes in 1983 was $1.2 \cdot (0.75 \cdot 0.197 + 0.25 \cdot 0.080) = 0.201$ Bq ^{90}Sr kg^{-1}, and the ^{137}Cs content was $0.75 \cdot 4.3 + 0.25 \cdot 0.076 = 3.24$ Bq ^{137}Cs kg^{-1} (cf. 2.2.3 and Ref. 3). 1 kg milk contains 1.2 g Ca.

2.3.3. Cheese

Nearly all cheese consumed in the Faroes is of Danish origin, and the Danish figures from ref. 3 were used: 0.68 Bq ^{90}Sr kg^{-1} and 0.055 Bq ^{137}Cs kg^{-1}.

2.3.4. Grain products

As most grain products are imported from Denmark, the Danish figures for 1983[3] were used in the calculation of the Faroese levels. The mean daily consumption of grain products in the Faroes is, as in Denmark, 80 g rye flour, 120 g wheat flour, and 20 g grits. Hence the mean concentration of ^{90}Sr in grain products consumed in the Faroes in 1983 is 0.29 Bq ^{90}Sr kg^{-1} and 0.091 Bq ^{137}Cs kg^{-1}.

2.3.5. Potatoes

All potatoes consumed in the Faroes are assumed to be of local origin. The values from 2.2.7.4 were used, i.e. 0.22 Bq ^{90}Sr kg^{-1} and 12.1 Bq ^{137}Cs kg^{-1}.

2.3.6. Other vegetables and fruit

As the amount of vegetables and fruit grown in the Faroes is limited, the Danish figures from 1983[3] were used. Thus the mean contents in vegetables other than potatoes were 0.36 Bq ^{90}Sr kg^{-1} and 0.11 Bq ^{137}Cs kg^{-1}, and the mean contents in fruit were 0.075 Bq ^{90}Sr kg^{-1} and 0.029 Bq ^{137}Cs kg^{-1}.

2.3.7. Meat and eggs

Meat and egg consumption in the Faroes is estimated to consist of 50% locally produced mutton (or lamb), 25% local whale meat, and 25% sea birds and eggs.

For lamb we use the mean of the samples obtained in 1983, i.e. 0.07 Bq ^{90}Sr kg^{-1} and 6.43 Bq ^{137}Cs kg^{-1}. Whale meat contained 0.004 Bq ^{90}Sr kg^{-1} and 0.25 Bq ^{137}Cs kg^{-1}, sea birds contained 0.008 Bq ^{90}Sr kg^{-1} and $<$ 0.18 Bq ^{137}Cs kg^{-1}, and eggs (cf. 2.2.4 and 2.2.7.6): 0.091 Bq ^{90}Sr kg^{-1} and 0.22 Bq ^{137}Cs kg^{-1}. Hence we estimate the mean content of ^{90}Sr in meat and eggs consumed in 1983 to be

$$0.50 \cdot 0.07 + 0.25 \cdot 0.004 + 0.25 \cdot \left(\frac{0.008+0.091}{2}\right) = 0.048 \text{ Bq } ^{90}\text{Sr kg}^{-1}$$

and the ^{137}Cs content to be

$$0.50 \cdot 6.43 + 0.25 \cdot 0.25 + 0.25 \cdot \left(\frac{0.18+0.22}{2}\right) = 3.33 \text{ Bq } ^{137}\text{Cs kg}^{-1}.$$

2.3.8. Fish

All fish consumed in the Faroes is of local origin, and the mean contents in fish, obtained from subsection 2.2.5, were 0.003 Bq ^{90}Sr kg^{-1} and 0.25 Bq ^{137}Cs kg^{-1}.

2.3.9. Coffee and tea

The Danish figures for 1983[3] were used, i.e. 0.87 Bq ^{90}Sr kg^{-1} and 2.53 Bq ^{137}Cs kg^{-1}.

2.3.10. Drinking water

The mean value found in Table 2.2.6.1 was used, i.e. 0.0051 Bq ^{90}Sr kg^{-1}. The ^{137}Cs content was estimated to be approximately one fourth (the ratio found in New York tap water in 1964[4]) of the ^{90}Sr content, i.e. 0.0013 Bq ^{137}Cs kg^{-1}.

Tables 2.3.1 and 2.3.2 show the diet estimates of ^{90}Sr and ^{137}Cs, respectively.

Table 2.3.1. Estimate of the mean content of ^{90}Sr in the human diet in the Faroe Islands in 1983

Type of food	Annual quantity in kg	Bq ^{90}Sr per kg	Total Bq ^{90}Sr	Percentage of total Bq ^{90}Sr in food
Milk and cream	146	0.201	29.35	30.2
Cheese	7.3	0.68	4.96	5.1
Grain products	80	0.29	23.20	23.8
Potatoes	91	0.22	20.02	20.6
Vegetables	20	0.36	7.20	7.4
Fruit	18	0.075	1.35	1.4
Meat and eggs	37	0.048	1.78	1.8
Fish	91	0.003	0.27	0.3
Coffee and tea	7.3	0.87	6.35	6.5
Drinking water	548	0.0051	2.79	2.9
Total			97.27	

The mean annual calcium intake is estimated to be 0.6 kg (approx. 200-250 g of creta praeparata). Hence the ratio: Bq ^{90}Sr $(kg\ Ca)^{-1}$ in total Faroese diet was 162 (4.4 pCi ^{90}Sr $(g\ Ca)^{-1}$).

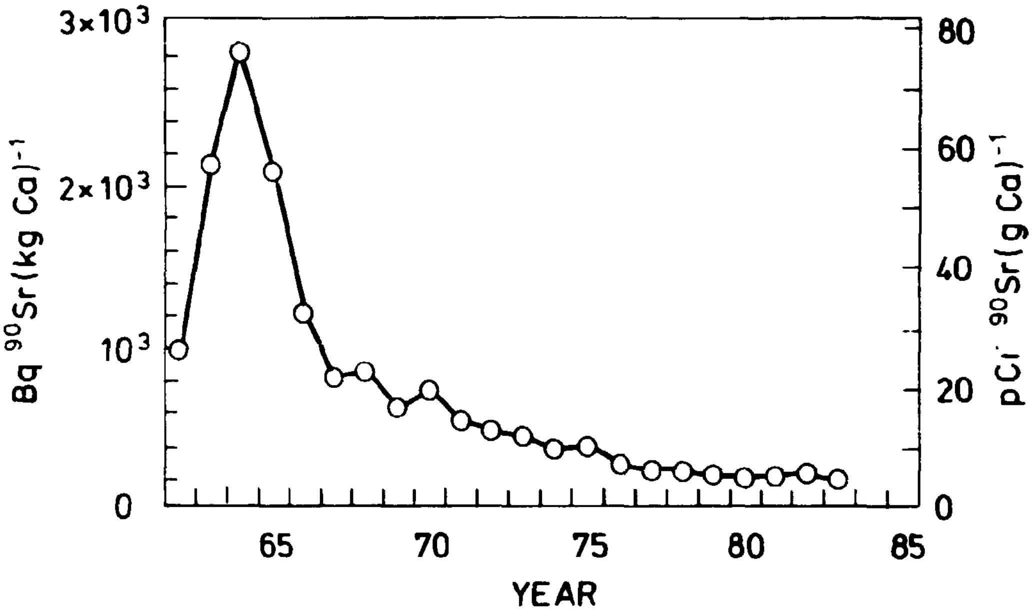


Fig. 2.3.1. Strontium-90 in Faroese diet, 1962-1983.

Table 2.3.2. Estimate of the mean content of ^{137}Cs in the human diet in the Faroe Islands in 1983

Type of food	Annual quantity in kg	Bq ^{137}Cs per kg	Total Bq ^{137}Cs	Percentage of total Bq ^{137}Cs in food
Milk and cream	146	3.24	473.0	27.0
Cheese	7.3	0.055	0.4	0
Grain products	80	0.091	7.3	0.4
Potatoes	91	12.1	1101.1	62.9
Vegetables	20	0.11	2.2	0.1
Fruit	18	0.029	0.5	0
Meat and eggs	37	3.33	123.2	7.1
Fish	91	0.25	22.8	1.3
Coffee and tea	7.3	2.53	18.5	1.1
Drinking water	548	0.0013	0.7	0.1
Total			1749.7	

The mean annual intake of potassium is estimated to be approx. 1.2 kg. Hence the ratio: Bq ^{137}Cs (kg K)$^{-1}$ becomes 1458 (39.4 pCi ^{137}Cs (g K)$^{-1}$).

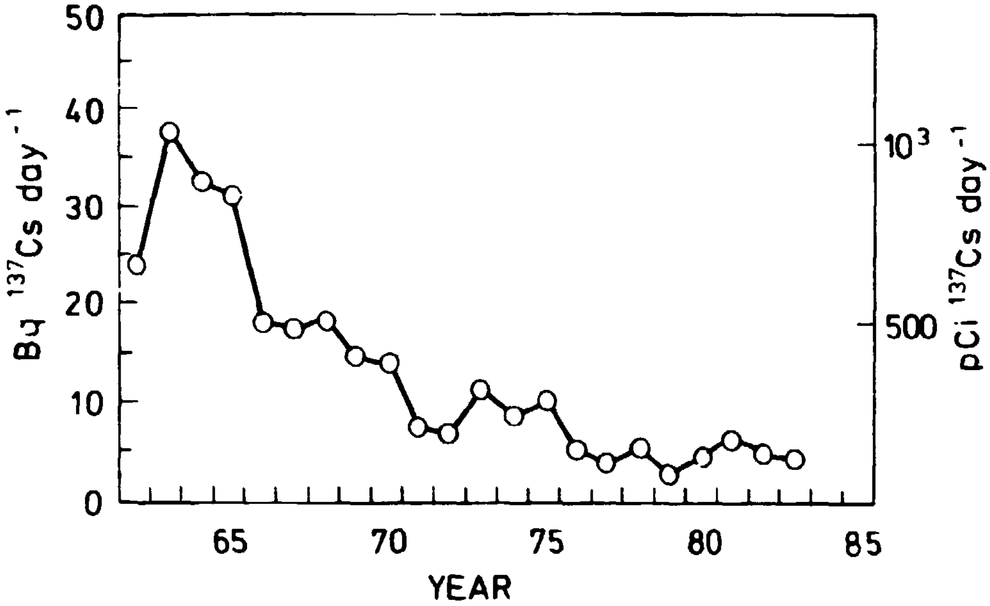


Fig. 2.3.2. Cesium-137 in Faroese diet, 1962-1983.

2.3.11. Discussion

Figures 2.3.1 and 2.3.2 show the Faroese diet levels since 1962.

The 1983 ^{90}Sr level in the total Faroese diet was 72% of the 1982 concentration, and the ^{137}Cs level was 93% of that observed in 1982.

The main contributors to the ^{90}Sr content in the Faroese diet were milk products, cereals and potatoes, which together accounted for appeoximately 80% of the total ^{90}Sr content in the diet in 1983. As regards ^{137}Cs, potatoes, milk products and meat (lamb) were the most important contributors. In 1983, 97% of the total ^{137}Cs content in the diet originated from these products.

The Faroese mean diet contained 1.3 times as much ^{90}Sr and approximately 17 times as much ^{137}Cs as the Danish diet in 1983[3].

As earlier[1] mentioned, the year-to-year variations in the ^{137}Cs estimates for Faroese diet are markedly influenced by the mutton and potatoe samples obtained for analysis.

2.4. Conclusion

2.4.1.

The ^{90}Sr fallout rate in the Faroes in 1983 was approximately 3 Bq ^{90}Sr m^{-2} (0.08 mCi km^{-2}). The accumulated fallout by the end of 1983 was estimated at approximately 3600 Bq ^{90}Sr m^{-2} (96 mCi km^{-2}) (the mean at Thorshavn and Klaksvig).

2.4.2.

The mean level of ^{90}Sr in Faroese milk was 197 Bq (kg Ca)$^{-1}$ (5.3 pCi (g Ca)$^{-1}$). The ^{137}Cs concentration was 4300 Bq ^{137}Cs m^{-3} (116 pCi l^{-1}).

Lamb contained 6.4 Bq ^{137}Cs kg^{-1} (174 pCi kg^{-1}) in 1983. Fish showed a mean level of 0.25 Bq ^{137}Cs kg^{-1} (6.8 pCi kg^{-1}).

The mean content of ^{90}Sr in drinking water was 5.1 Bq m^{-3} (0.14 pCi l^{-1}).

The mean daily pro capite intakes resulting from the Faroese diet in 1983 were estimated at 0.27 Bq ^{90}Sr (7.2 pCi d^{-1}) and 4.8 Bq ^{137}Cs (129 pCi d^{-1}).

2.4.3.

From the measurements on Faroese human bones (only femur), the Faroese bone level in 1983 was estimated at 67 Bq ^{90}Sr (kg Ca)$^{-1}$ (1.8 pCi (g Ca)$^{-1}$).

The mean content of ^{137}Cs in the Faroese adult was estimated at approximately 4400 Bq ^{137}Cs (kg K)$^{-1}$ (118 pCi (g K)$^{-1}$). This estimate is based on the diet estimate.

APPENDIX 2A

Predictions and observations of ^{90}Sr and ^{137}Cs in Faroese samples in 1983

The models used for the predictions shown in Table 2A were based on data collected 1962-1976[5]. If the predictions for previous years 1977-1982[1] were considered too, we conclude that the model for ^{90}Sr in milk overestimates the level and so do the model for ^{137}Cs in milk from Tværå. The following models underestimate the concentrations: ^{90}Sr in cod fish and ^{137}Cs in milk from Klaksvig.

Table 2A. Comparison between observed and predicted ^{90}Sr and ^{137}Cs concentrations in Faroese samples collected in 1983

Sample	Unit	Observed ±1 S.E.	Number of samples	Predicted	Obs./pre. ±1 S.E.	Model in ref. 5
Drinking water, Thorshavn	Bq ^{90}Sr m^{-3}	7.4 ±1.4	2	16.1	0.46±0.09	C.1.4.1 No. 9
- " - , Klaksvig	- " -	2.2 ±0.5	2	2.2	1.00±0.23	- " - No. 10
- " - , Tværå	- " -	5.7 ±0.5	2	4.3	1.33±0.12	- " - No. 11
Sea water	- " -	2.5 ±0.06	3	2.2	1.14±0.03	C.1.5.1 No. 3
Rye bread	Bq ^{90}Sr kg^{-1}	0.24	1	0.33	0.73	C.2.3.1 No. 6
White bread	- " -	0.14	1	0.12	1.17	- " - No. 7
Rye bread	Bq ^{137}Cs kg^{-1}	0.10	1	0.09	1.11	- " - No. 8
White bread	- " -	0.04	1	0.08	0.50	- " - No. 9
Grass	Bq ^{90}Sr (kg Ca)$^{-1}$	5300 ±100	2	5800	0.91±0.02	C.2.4.1 No. 4
- " -	Bq ^{137}Cs (kg K)$^{-1}$	2300 ±200	2	2300	1.00±0.09	C.2.4.2 No. 3
Potatoes	Bq ^{90}Sr kg^{-1}	0.22 ±0.09	3	0.23	0.96±0.39	C.2.5.1 No. 11
- " -	Bq ^{137}Cs kg^{-1}	12.1 ±10.3	3	6.8	1.78±1.52	C.2.5.3 No. 8
Milk	Bq ^{90}Sr (kg Ca)$^{-1}$	197 ±10	12	346	0.57±0.03	C.3.3.1 No. 1
Milk Thorshavn	Bq ^{137}Cs m^{-3}	1670 ±100	12	1800	0.93±0.06	C.3.3.2 No. 7
Milk Klaksvig	- " -	6700 ±400	12	2000	3.35±0.20	- " - No. 9
Milk Tværå	- " -	4600 ±400	12	11900	0.39±0.03	- " - No. 11
Cod fish	Bq ^{90}Sr (kg Ca)$^{-1}$	38 ±12	8	19	0.50±0.16	C.3.5.1 No. 3
- " -	Bq ^{137}Cs kg^{-1}	0.25 ±0.01	8	0.21	1.19±0.05	C.3.5.2 No. 2
Lamb meat	Bq ^{90}Sr (kg Ca)$^{-1}$	1200 ± 600	3	1550	0.77±0.39	C.3.4.1 No. 5
- " -	Bq ^{137}Cs (kg K)$^{-1}$	2030 ± 1250	3	4000	0.51±0.31	C.3.4.2 No. 5
Lamb bone	Bq ^{90}Sr (kg Ca)$^{-1}$	1360 ± 300	3	2400	0.57±0.13	C.3.4.3 No. 1
Whale	Bq ^{90}Sr kg^{-1}	0.004	1	0.0134	0.29	C.3.6.1 No. 3
- " -	Bq ^{137}Cs kg^{-1}	0.25	1	0.42	[illegible].60	C.3.6.2 No. 2
Sea birds	- " -	<0.18	1	0.11	<1.6	C.3.6.2 No. 8

3. ENVIRONMENTAL RADIOACTIVITY IN GREENLAND IN 1983

3.1. Introduction

3.1.1.

In 1983 the sampling programme was similar to that used in previous years bur for a few minor modifications.

3.1.2.

As hitherto, samples were collected through the local district physicians and the head of the telestations. However, we have also obtained samples collected by the Fishery Investigations of Greenland (GFU).

3.1.3.

The estimated mean diet in Grenland was the same as that in 1962, i.e., it agreed with the estimate given by the late Professor E. Hoff-Jørgensen, Ph.D.

3.1.4.

The environmental studies in Greenland were carried out together with corresponding investigations in Denmark (cf. Risø Report No. 509[3]) and in the Faroes (cf. Chapter 2 in this report).

3.1.5.

The present report does not repeat information concerning sample collection and analysis already given in ref. 2.

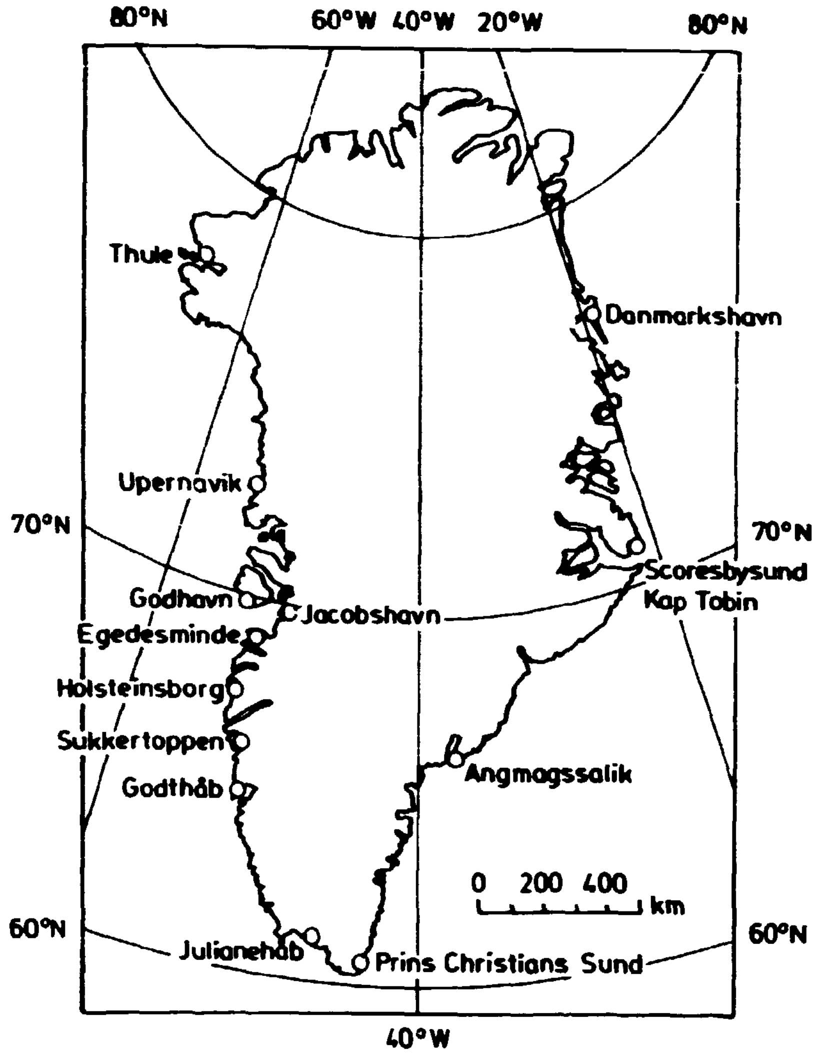


Fig. 3.1. Greenland.

3.2. Results and discussion

3.2.1. Strontium-90 in Greenland precipitation

Table 3.2.1.1 shows the results of the measurements.

The ^{90}Sr fallout in 1983 at the Greenland stations were nearly unchanged as compared with 1982. In Denmark[3] and the Faroes (cf. 2.2.1) the fallout decreased by a factor of 0.8 and 1.2, respectively.

Figure 3.2.1 shows the accumulated ^{90}Sr at the various stations in Greenland, since measurements began in 1962. (Prins Christians Sund in 1983 was calculated from the di values at the other three stations assuming that the fallout rate at Prins Christians Sund was proportional to the accumulated fallout.)

Table 3.2.1.1. Strontium-90 in precipitation in Greenland in 1983. (Sampling area: 0.02 m^2)

Location m precipitation	Unit	Jan-March	April-June	July-Sept	Oct-Dec	1983
Upernavik	Bq m^{-3}	8.5 A	10.4	10.6	7.5 B	9.1
Σ 0.207	Bq m^{-2}	0.28	0.55	0.49	0.56 B	1.88
Godthåb	Bq m^{-3}	4.1	4.2	2.8	2.4	3.3
Σ 1.122	Bq m^{-2}	1.36	0.86	1.11	0.62	3.65
Prins Chr. Sund	Bq m^{-3}	no samples in 1983				
	Bq m^{-2}					
Scoresbysund	Bq m^{-3}	1.7 (Jan-June)		10.0 A	4.4	2.7
Σ 0.534	Bq m^{-2}	0.68 (Jan-June)		0.30 A	0.46	1.44
Danmarkshavn	Bq m^{-3}	6.5 A	29.9 A	10.3	30.2 A	12.2
Σ 0.189	Bq m^{-2}	0.30 A	0.58 A	1.18	0.25 A	2.3[illegible]

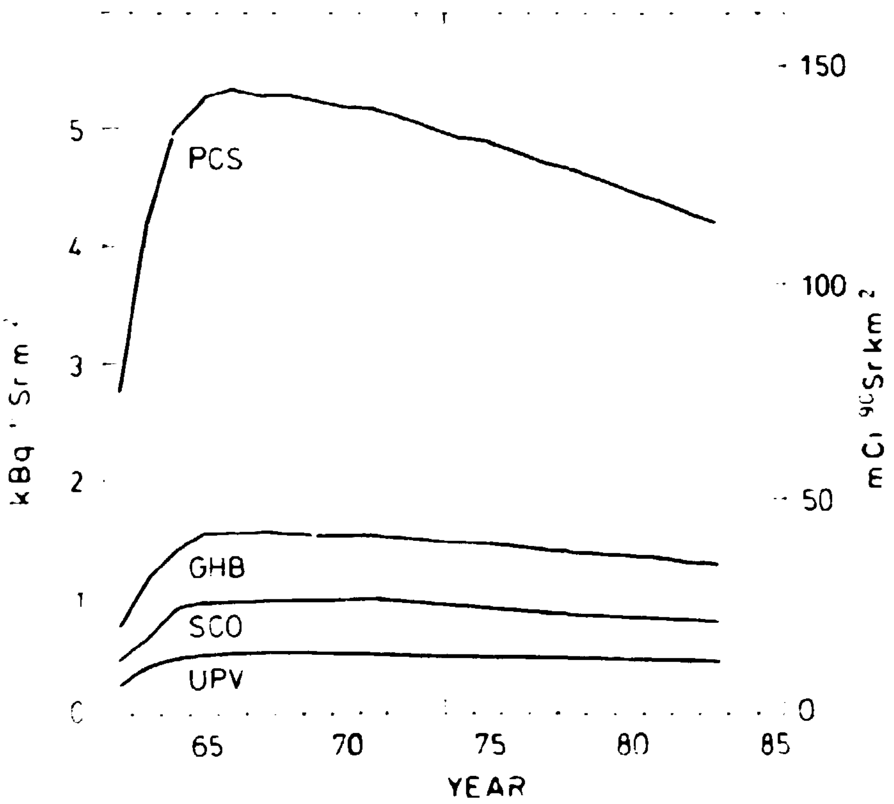


Fig. 3.2.1. Accumulated ^{90}Sr at Prins Chr. Sund, Godthåb, Scoresbysund (Kap Tobin) and Upernavik calculated from precipitation measurements since 1962. The accumulated fall-out by 1962 was estimated from the Danish data (cf. Risø Report No. [illegible], Appendix [illegible]) and from the ratio between the ^{90}Sr fall-out at the [illegible]

Table 3.2.1.2. Fallout rates and accumulated fallout (Bq m^{-2}) in Greenland 1950-1983

	Scoresbysund (Kap Tobin)		Pr.Chr.Sund		Godthåb		Upernavik	
	di	$Ai_{(29)}$	di	$Ai_{(29)}$	di	$Ai_{(29)}$	di	$Ai_{(29)}$
1950	0.37	0.36	2.04	1.99	0.57	0.56	0.20	0.20
1951	1.76	2.06	9.79	11.50	2.77	3.25	0.97	1.14
1952	3.44	5.38	19.19	29.97	5.42	8.46	1.90	2.97
1953	8.70	13.74	48.47	76.59	13.69	21.63	4.81	7.60
1954	33.06	45.69	184.28	254.71	52.05	71.94	18.29	25.28
1955	43.49	87.08	242.45	485.41	68.48	137.10	24.06	48.17
1956	53.93	137.67	300.61	767.46	84.91	216.76	29.83	76.16
1957	53.93	187.08	300.61	1042.85	84.91	294.54	29.83	103.49
1958	74.81	255.70	417.04	1425.40	117.79	402.59	41.39	141.45
1959	106.11	353.27	591.53	1969.29	167.07	556.21	58.70	195.43
1960	19.82	364.28	110.51	2030.68	31.21	573.55	10.97	201.52
1961	25.75	380.83	143.57	2122.90	40.55	599.60	14.25	210.67
1962	129.17	497.95	720.07	2775.83	203.38	784.01	71.46	275.46
1963	290.45	769.78	1545.12	4218.89	475.45	1229.72	160.58	425.75
1964	180.93	928.26	929.07	5026.38	258.63	1453.19	100.27	513.59
1965	68.82	973.53	383.32	5281.93	166.50	1581.44	38.11	538.67
1966	37.37	987.02	207.94	5360.21	43.29	1586.36	20.72	546.18
1967	18.13	981.41	73.63	5305.51	32.56	1580.68	12.21	545.20
1968	24.42	982.08	136.16	5313.15	37.00	1579.48	13.32	545.33
1969	18.13	976.59	72.89	5258.83	22.20	1563.85	6.73	539.03
1970	33.30	986.03	59.20	5192.43	34.41	1560.51	12.58	538.58
1971	15.17	977.56	122.84	5189.73	32.56	1555.44	8.14	533.81
1972	12.58	966.75	55.50	5121.35	15.17	1533.52	4.07	525.17
1973	3.40	947.24	17.91	5017.88	6.92	1504.06	2.78	515.48
1974	12.21	936.79	45.88	4944.16	18.83	1486.92	13.14	516.13
1975	4.48	919.04	86.21	4911.57	19.57	1470.91	8.44	512.18
1976	3.00	900.26	11.17	4806.47	4.85	1440.91	2.44	502.46
1977	5.18	884.06	34.78	4726.91	14.06	1420.60	7.03	497.46
1978	10.36	873.29	54.39	4668.38	14.43	1401.14	7.77	493.30
1979	2.81	855.41	10.36	4568.24	9.99	1377.80	3.70	485.26
1980	3.15	838.28	7.03	4467.21	4.74	1349.89	3.70	477.41
1981	5.51	823.86	34.04	4394.94	12.95	1330.65	5.55	471.55
1982	2.41	806.75	6.36	4297.35	2.63	1301.79	1.55	461.93
1983	1.44	791.36	(12.4)	(4204.37)	3.65	1273.52	1.88	452.47

3.2.2. Radionuclides in Greenland sea water

The detailed results are shown in Chapter 4. Table 3.2.2 shows the samplings carried out from land by local people in 1983.

Table 3.2.2. Radionuclides in surface sea water collected in Greenland in August 1983

Location	Bq ^{90}Sr m^{-3}	Bq ^{137}Cs m^{-3}	Salinity in o/oo
Angmaqssalik	5.78	6.98	30.1
Godthåb	4.32	4.98	31.2

3.2.3. Strontium-90 and Cesium-137 in Greenland terrestrial animals

Lamb samples were obtained from Greenland in 1983. The mean levels in lamb meat were 0.23 Bq ^{90}Sr kg^{-1} and 68.7 Bq ^{137}Cs kg^{-1}.

As it appears from Fig. 3.2.3 the ^{137}Cs levels were similar to those observed in previous years.

Table 3.2.3. Radionuclides in terrestrial animals in Greenland in 1983

		Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$
Lamb I	Meat	0.25	2400 (3400)	74	27000
Lamb II	Meat	0.19	2900 (3200)	101	32000
Lamb III	Meat	0.26	2600 (2800)	31	13000

Bone levels are shown in brackets.

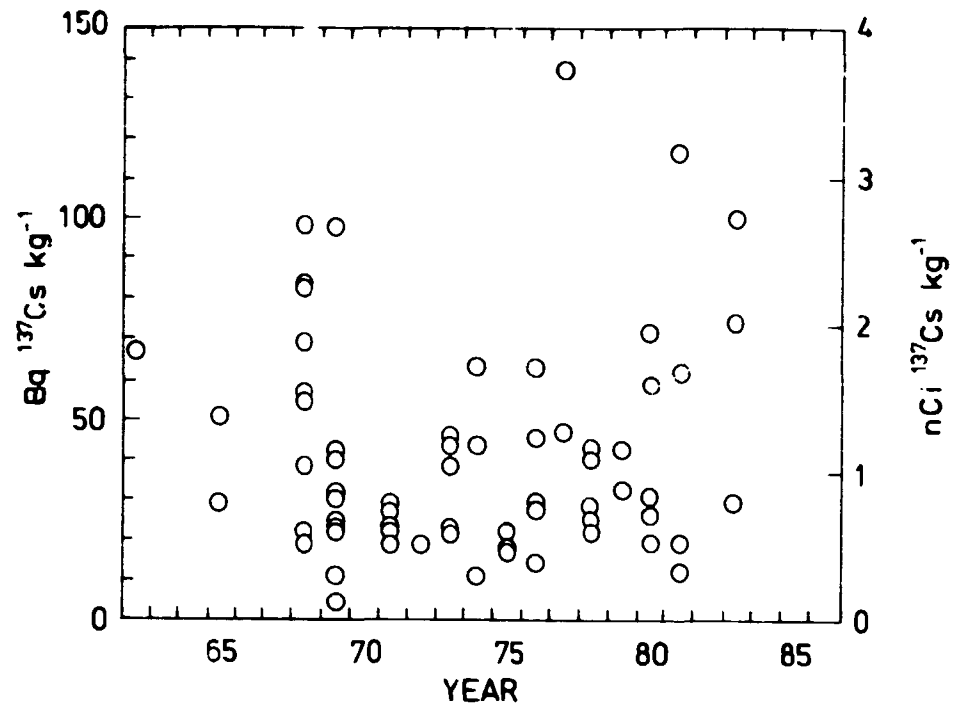


Fig. 3.2.3. Cesium-137 in Greenlandic mutton, 1962-1983.

3.2.4. Strontium-90 and Cesium-137 in Greenland sea animals

The mean levels in fish meat (cod and salmon) were: 0.015 Bq ^{90}Sr kg^{-1}, 0.28 Bq ^{137}Cs kg^{-1}. The mean levels in shrimps were 0.044 Bq ^{90}Sr kg^{-1} flesh and 0.070 Bq ^{137}Cs kg^{-1}.

Table 3.2.4.1. Strontium-90 and Cesium-137 in sea animals collected in Greenland in 1983

Location	Sample	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$
West Greenland	Cod meat I	0.017 A	14 A (3.8)	0.38	108
- " -	" " II	0.022 A	15.A (5.9)	0.37	106
- " -	Salmon meat I	0.009 A	88 A (8.2)	0.18	47
- " -	" " II	0.012	130 (6.0)	0.20	56
Jacobshavn	Shrimps flesh I	0.058	96	0.05 A	59 A
- " -	Shrimps flesh II	0.030	40	0.09	76

Bone levels are shown in brackets.

3.2.5. Radionuclides in Greenland vegetation

The Greenland Fisheries and Environmental Research Institute collected Fucus vesiculosus on the Greenland west coast in 1982 and 1983. Table 3.2.5 shows that the ^{90}Sr concentrations were half of those found at Angmagssalik in 1982 (Risø R-489, Table A.2)[3] (2.47 Bq ^{90}Sr kg$^{-1}{}_{d.w}$ ±0.8, 1 S.E., n = 4). The ^{137}Cs level was 3 times lower and the ^{99}Tc concentration on the west coast was 2.3 times lower than that found at Angmagssalik in 1982.

Table 3.2.5. Radionuclides in Fucuids collected in West Greenland in 1982-1983

Location	Date	Bq ^{90}Sr $kg^{-1}_{d.w.}$	Bq ^{99}Tc $kg^{-1}_{d.w.}$	Bq ^{137}Cs $kg^{-1}_{d.w.}$
Godthåb	7 Aug 1982	1.31 (146)	3.79	-
Ivigtut	June 1982	1.36 (144)	3.71	-
Umanak (71°07'N 52°19'W)	Sept 1983	0.57 (37)	3.65	0.77

In brackets: Bq ^{90}Sr (kg Ca)$^{-1}$

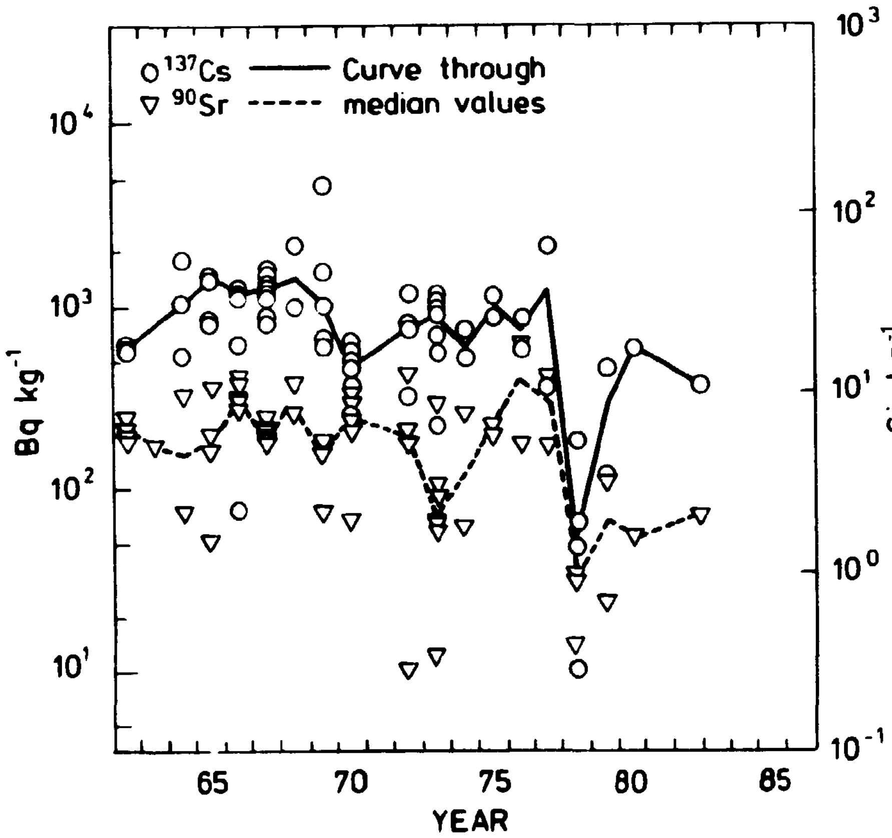


Fig. 3.2.5. Cesium-137 and Strontium-90 in lichen (fresh weight) collected along the Greenlandic coast, 1962-1983.

3.2.6. Strontium-90 and Tritium in Greenland drinking water

Quarterly samples of drinking water were collected from a number of locations in Greenland. Table 3.2.6.1 shows the results from 1983, and Fig. 3.2.6 the geometric annual means of all samples for the period 1962-1983.

As in previous years, we found it most expedient to choose the geometric mean of all figures, i.e. 12 Bq ^{90}Sr m^{-3} (0.33 pCi l^{-1}) as representative of the mean level of ^{90}Sr in Greenland drinking water in 1983, this level was lower than that observed in 1982, but in agreement with the previous years (Fig. 3.2.6). The levels in drinking water are still surprisingly high as compared to present rain concentrations (cf. Table 3.2.1.1). We have suggested that evaporation from the drinking water reservoirs was responsible for the higher ^{90}Sr levels. Tritium measurements show (Table 3.2.6.2) that the Greenland drinking water shows similar tritium levels as rain from Denmark[3], hence evaporation seems to be a possible explanation. The high ^{90}Sr levels may, however, also be due to extraction of old deposited ^{90}Sr activity from the soil by the water collected for drinking. This would also be compatible with "normal" tritium concentrations.

Table 3.2.6.1. Strontium-90 in drinking water collected in Greenland in 1983. (Unit: Bq m^{-3})

Location	Jan-March	April-June	July-Sept	Oct-Dec
Danmarkshavn	42	27		32
Scoresbysund	9.0	9.8	3.8	5.7
Godthåb				9.8
Upernavik				8.3

Table 3.2.6.2. Tritium in drinking water collected in Greenland in 1983. (Unit: kBq m^{-3})

Location	Jan-March	Oct-Dec
Danmarkshavn	1	
Scorebysund	4	
Godthåb		0.4
Upernavik		1

An empirically found tritium background of 1.2 kBq has been subtracted from all results (cf. the discussion in Risø-R-509, Chapter 7)[3].

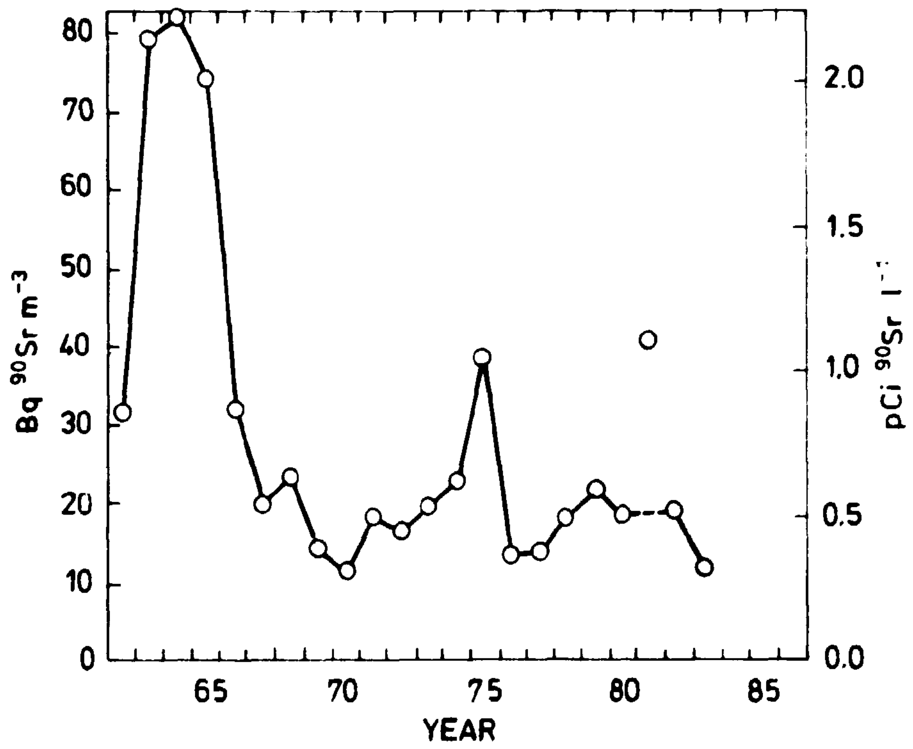


Fig. 3.2.6. Strontium-90 in Greenlandic drinking water (Geometric mean), 1962-1983.

3.3. Estimate of the mean contents of ^{90}Sr and ^{137}Cs in the human diet in Greenland in 1983

3.3.1. The annual quantities

The estimate of the daily pro capite intake of the different foods in Greenland is still based on the figures given in 1962 by the late Professor E. Hoff-Jørgensen, Ph.D., in Risø Report No. 65[2].

3.3.2. Milk products

All milk consumed in Greenland was imported as milk powder from Denmark. The mean radioactivity content in milk prepared from Danish dried milk produced in 1983 was 0.096 Bq ^{90}Sr kg^{-1} and 0.076 Bq ^{137}Cs kg^{-1} [3]).

Cheese was also imported from Denmark and contained 0.68 Bq ^{90}Sr kg^{-1} and 0.055 Bq ^{137}Cs kg^{-1}.

3.3.3. Grain products

All grain was imported from Denmark. It is assumed that only grain from the harvest of 1982 was consumed in Greenland during 1983. The daily pro capite consumption was: rye flour (100% extraction): 80 g, wheat flour (75% extraction): 110 g, rye flour (70% extraction): 20 g, biscuits (rye, 100% extraction): 27 g, and grits: 25 g. The content of ^{90}Sr in these five products was 0.65, 0.10, 0.13, 0.48 and 0.20 Bq kg^{-1}, respectively. Hence the mean content of ^{90}Sr in grain products was 0.32 Bq kg^{-1}. The content of ^{137}Cs in the five products was 0.18, 0.05, 0.09, 0.13 and 0.05 Bq kg^{-1}. Hence the mean content of ^{137}Cs in grain products was 0.10 Bg kg^{-1}.

The activity levels in rye flour (100% extraction), wheat flour (75% extraction), and grits were all taken from Tables 5.9.1 and 5.9.2 in Risø Report No. 509[3]. The ^{90}Sr level in rye flour (70% extraction) was calculated analogously with the level in wheat flour (75% extraction), i.e. as one-fifth of the wholegrain activity. The ^{137}Cs content in rye flour (70% extraction) was calculated as one half of the whole-grain level in rye in analogy with the ratio between ^{137}Cs in whole wheat grain and in wheat flour (75% extraction)[3]. The ^{90}Sr and ^{137}Cs contents in biscuits were calculated by dividing the levels of the rye flour (100% extraction) by 1.35, since 1 kg flour yields 1.35 kg bread[3].

3.3.4. Potatoes, other vegetables, and fruit

The Danish mean levels for 1983 were used[3] since the local production is insignificant compared with imports from Denmark.

The Danish mean levels were: in potatoes 0.066 Bq ^{90}Sr kg^{-1} and 0.048 Bq ^{137}Cs kg^{-1}, in other vegetables 0.36 Bq ^{90}Sr kg^{-1} and 0.11 Bq ^{137}Cs kg^{-1}, and in fruit 0.075 Bq ^{90}Sr kg^{-1} and 0.029 Bq ^{137}Cs kg^{-1}.

3.3.5. Meat

Nearly all meat consumed in Greenland is assumed to be of local origin. Approximately 10% comes from sheep, 5% from reindeer, 60% from seals, 5% from whales, and 20% from sea birds and eggs.

The activities in lamb were estimated from 3.2.3. Reindeer, seal and whale were estimated from the 1982 data[2]. The levels of sea birds and eggs were taken from the 1978 analyses[2]. Hence the mean levels in Greenland meat from 1983 were 0.034 Bq ^{90}Sr kg^{-1} and 11.4 Bq ^{137}Cs kg^{-1}.

(^{90}Sr: $0.1 \times 0.23 + 0.05 \times 0.19 + 0.6 \times \sim 0 + 0.05 \times 0.003 + 0.2 \times 0.007 = 0.034$ Bq kg^{-1})

(^{137}Cs: $0.1 \times 68.7 + 0.05 \times 83 + 0.6 \times 0.51 + 0.05 \times 0.75 + 0.2 \times 0.35 = 11.4$ Bq kg^{-1})

3.3.6. Fish

All fish consumed was of local origin, and the mean levels (cod and salmon meat) from 3.2.4 were used, i.e. 0.015 Bq ^{90}Sr kg^{-1} and 0.28 Bq ^{137}Cs kg^{-1}.

3.3.7. Coffee and tea

The Danish figures for 1983[3] were used for coffee and tea, i.e. 0.87 Bq ^{90}Sr kg^{-1} and 2.53 Bq ^{137}Cs kg^{-1}.

3.3.8. Drinking water

The geometric mean calculated in 3.2.6 was used as the mean level of ^{90}Sr in drinking water, i.e. 12 Bq ^{90}Sr m^{-3}. The ^{137}Cs content was as previously[2] estimated at 1/4 of the ^{90}Sr content, i.e. approximately 3 Bq ^{137}Cs m^{-3}.

Tables 3.3.1 and 3.3.2 show the diet estimates of ^{90}Sr and ^{137}Cs, respectively.

3.3.9. Discussion

The most important ^{90}Sr source in the Greenland diet is still grain products, which contribute 50% of the total ^{90}Sr content in the diet. Approximately 85% of the ^{90}Sr in the food consumed in Greenland in 1983 originated from imported (Danish) food.

Meat is still the most important ^{137}Cs source in the Greenland diet, contributing 88% of the total content in 1983. Approximately 94% of the ^{137}Cs in the Greenland diet in 1983 came from local products.

The ^{90}Sr contents in the total diet in 1983 was approximately 70% of the 1982 level.

The ^{137}Cs level was 91% of that found in 1982. As earlier discussed[2] the great variations from year to year are primarily due to the variations in the ^{137}Cs levels in the meat samples obtained.

Table 3.3.1. Estimate of the mean content of ^{90}Sr in the human diet in Greenland in 1983

Type of food	Annual quantity in kg	Bq ^{90}Sr per kg	Total Bq ^{90}Sr	Percentage of total Bq ^{90}Sr in food
Milk and cream	78	0.096	7.49	12.2
Cheese	2.5	0.68	1.70	2.8
Grain products	95.6	0.32	30.59	49.9
Potatoes	32.8	0.066	2.16	3.5
Vegetables	5.5	0.36	1.98	3.2
Fruit	13.5	0.075	1.01	1.7
Meat and eggs	45.6	0.034	1.55	2.5
Fish	127.6	0.015	1.91	3.1
Coffee and tea	7.3	0.87	6.35	10.4
Drinking water	548	0.012	6.58	10.7
Total			61.32	

The mean annual calcium intake is estimated to be 0.56 kg (approx. 0.2-0.25 kg creta praeparata). Hence the $^{90}Sr/Ca$ ratio in Greenland total diet in 1983 was 110 Bq ^{90}Sr (kg Ca)$^{-1}$ or 3.0 pCi ^{90}Sr (g Ca)$^{-1}$ and the daily intake was 0.17 Bq ^{90}Sr or 4.5 pCi ^{90}Sr.

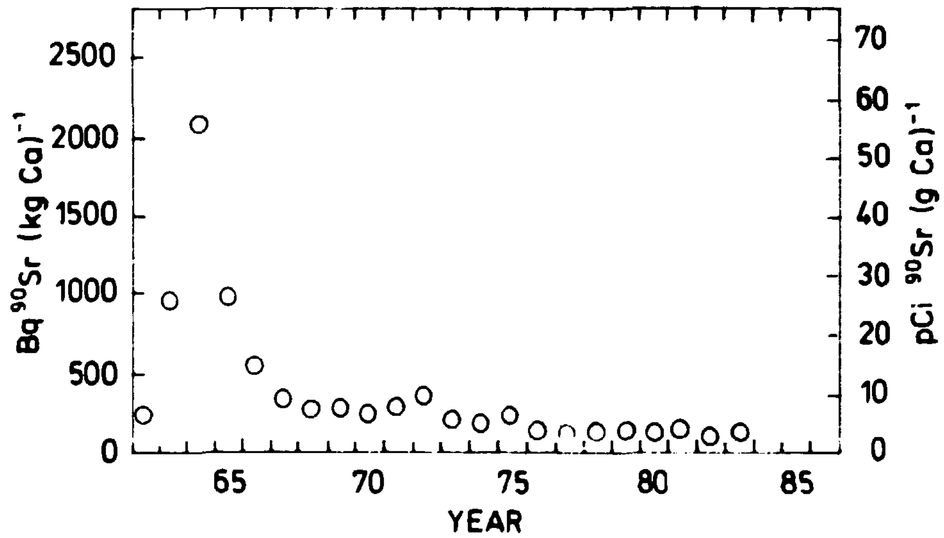


Fig. 3.3.1. Strontium-90 in Greenlandic diet, 1962-1983.

Table 3.3.2. Estimate of the mean content of ^{137}Cs in the human diet in Greenland in 1983

Type of food	Annual quantity in kg	Bq ^{137}Cs per kg	Total Bq ^{137}Cs	Percentage of total Bq ^{137}Cs in food
Milk and cream	78	0.076	5.93	1.0
Cheese	2.5	0.055	0.14	0.0
Grain products	95.6	0.10	9.56	1.6
Potatoes	32.8	0.048	1.57	0.3
Vegetables	5.5	0.11	0.61	0.1
Fruit	13.5	0.029	0.39	0.1
Meat and eggs	45.6	11.4	519.84	87.5
Fish	127.6	0.28	35.73	6.0
Coffee and tea	7.3	2.53	18.47	3.1
Drinking water	548	0.003	1.64	0.3
Total			593.88	

The mean annual potassium intake is estimated to be approx. 1.2 kg. Hence the $^{137}Cs/K$ ratio becomes 495 Bq ^{137}Cs (kg K)$^{-1}$ or 13.4 pCi ^{137}Cs (g K)$^{-1}$. The daily intake in 1983 from food was 1.63 Bq ^{137}Cs or 44 pCi ^{137}Cs.

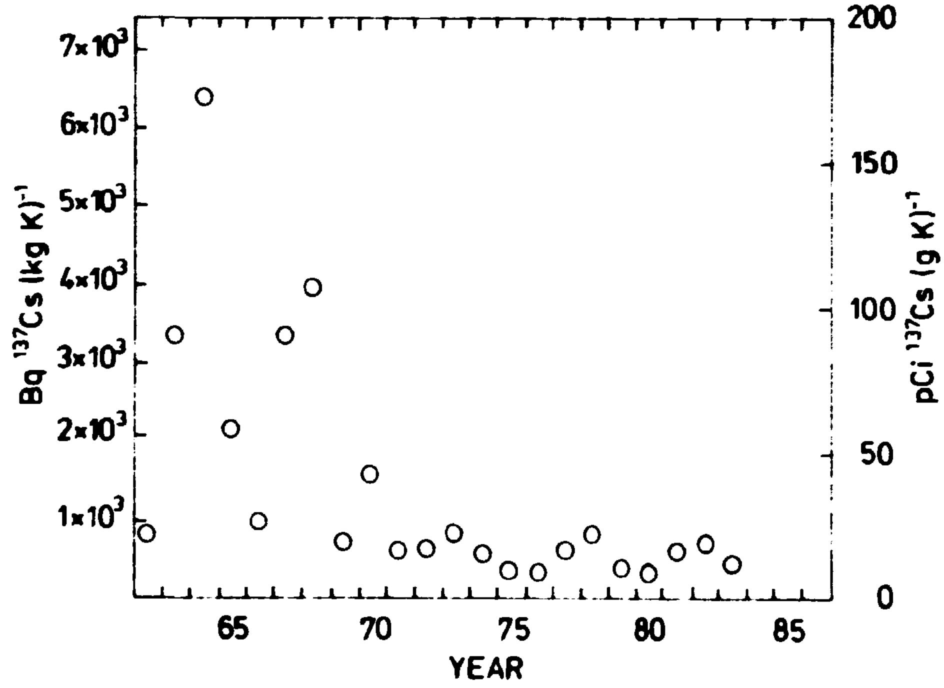


Fig. 3.3.2. Cesium-137 in Greenlandic diet, 1962-1983.

To estimate the maximum pro capite intakes of ^{90}Sr and ^{137}Cs in Greenland in 1983 we assume[2)] that the only grain product consumed by a person is dark rye bread, and that he only eats reindeer meat. His daily intake of ^{90}Sr is thus 0.27 Bq and his ^{137}Cs intake 10.6 Bq day^{-1} (using the quantities in Tables 3.3.1 and 3.3.2). At the lower limit we can imagine a person eating white bread and seal and drinking water with hardly any activity (e.g. water formed by the melting of old ice). In this case the daily intakes are 0.08 Bq ^{90}Sr and 0.25 Bq ^{137}Cs. Hence the ratios between the levels in the maximum and minimum diets become 3 for ^{90}Sr and 42 for ^{137}Cs.

The ^{90}Sr content of the Greenland diet in 1983 was 79% of the estimated Danish mean content[3)], and 63% of the Faroese level[1)]. The ^{137}Cs level in the total diet in Greenland was 5.8 times that of the Danish diet and 34% of the Faroese diet level.

3.4. Conclusion

3.4.1.

The ^{90}Sr fallout rates in 1983 were the following: Prins Chr. Sund: missing; Godthåb: approximately 3.6 Bq m^{-2}; Scoresby Sund: 1.4 Bq m^{-2}; Upernavik: 1.9 Bq ^{90}Sr m^{-2} and Danmarkshavn: 2.3 Bq m^{-2}. The accumulated fallout levels by the end of 1983 were estimated at approximately 1270 Bq ^{90}Sr m^{-2} at Godthåb, 4200 Bq ^{90}Sr m^{-2} at Prins Chr. Sund, and 450 Bq ^{90}Sr m^{-2} at Upernavik.

3.4.2.

The food consumed in Greenland in 1983 contained on the average 110 Bq ^{90}Sr $(kg\ Ca)^{-1}$, and the daily mean intake of ^{137}Cs was estimated at 1.63 Bq. The most important ^{90}Sr contributor to the diet were grain products accounting for approximately 50% of the total ^{90}Sr content of the diet. Cesium-137 originated mainly from meat (reindeer and lamb) and fish, contributing approximately 94% of the total ^{137}Cs content of the diet.

3.4.3.

No ^{90}Sr analyses of human bone samples have hitherto been carried out on the population of Greenland. Considering the estimated ^{90}Sr levels in the diet, it seems probable[4)], however, that the 1983 ^{90}Sr levels of humans in Greenland were on the average rather similar to those found in Denmark, i.e. the mean levels in human bone in Greenland were approximately 30 Bq ^{90}Sr $(kg\ Ca)^{-1}$ (vertebrae). From diet measurements the ^{137}Cs content in Greenlanders was estimated at 1500 Bq ^{137}Cs $(kg\ K)^{-1}$.

4. MARINE ENVIRONMENTAL RADIOACTIVITY IN THE NORTH ATLANTIC REGION

4.1. Radionuclides in sea water samples collected on the "Polarstern" cruise to the Fram Strait in July 1983

4.1.1. Surface water

A more detailed interpretation of the results shown in Table 4.1.1 have been given elsewhere[6,7]. All samples were analysed for ^{3}H too, however, an intercomparison with G. Ostlund, showed that we have had problems with our tritium background and our tritium data have consequently been deleted. West ot 0^{o} longitude in the Fram Strait we are in the polar water. We have estimated the fallout backgrounds in this part of the East Greenland Current to 6.86 Bq ^{137}Cs m^{-3} and 5.72 Bq ^{90}Sr m^{-3}.[6]

In the Atlantic water (east of 0^{o} in the Fram Strait) the fallout concentrations are 3 Bq ^{137}Cs m^{-3} and 2 Bq ^{90}Sr m^{-3}, and the mean contributions from Sellafield become 11.38-3 = 8.38 Bq ^{137}Cs m^{-3} and 4.00-2 = 2.00 Bq ^{90}Sr m^{-3}.

Melted sea ice (cf. Table 4.1.2) in the Fram Strait contained 8 times lower ^{90}Sr and 4 times lower ^{137}Cs levels than the corresponding sea water. The ^{90}Sr activity in the snow was much lower than that in precipitation from Danmarkshavn in 1983 (cf. Table 3.2.1.1)

4.1.2. Deepwater samples

Table 4.1.3 and Figs. 4.1.2 and 4.1.3 show the distribution of activity concentrations with depth at one of the "Atlantic" stations and at two of the "Polar" stations (combined in Fig. 4.1.3) in the Fram Strait. All activities decrease with depth. At the eastern, "Atlantic" station the decrease for ^{137}Cs is more pronounced than that at the two western, "Polar" stations; ^{90}Sr shows in general a less pronounced variation with depth than ^{137}Cs. This is compatible with the relatively greater con-

Table 6.1.1. Radionuclide concentrations in surface sea water collected on the "Polarstern" cruise to the Fram Strait in 1983

Position North	East	Date	Salinity o/oo	Temp. °C	^{90}Sr Bq m^{-3}	^{134}Cs Bq m^{-3}	^{137}Cs Bq m^{-3}	$^{239,240}Pu$ mBq m^{-3}	^{238}Pu / $^{239,240}Pu$	^{241}Am / $^{239,240}Pu$
57°54'	4°07'	June 30	32.7	12.2	18.8	2.8 A	62	17.1	0.18	0.10
60°33'	4°00'	- " -	30.2	-	19.7	2.0 A	53	-	-	-
63°21'	5°43'	July 1	31.2	12.8	-	1.6	53	11.8	-	0.05
65°33'	8°36'	- " -	33.7	11.0	10.2	-	35	-	-	-
68°30'	12°55'	July 2	34.4	10.0	-	1.2	49	10.9	0.11	0.06
70°36'	19°27'	July 3	34.0	9.5	13.2	1.4	53	-	-	-
71°32'	25°03'	- " -	34.5	9.5	7.6	0.89	37	13.9	-	-
73°00'	22°00'	July 4	35.2	8.5	-	-	35	-	-	-
73°44'	20°24'	- " -	34.6	7.5	4.6	-	16.6	-	-	-
74°06'	19°36'	- " -	35.0	4.5	4.7	0.25	14.9	18.0	-	0.09 A
75°14'	18°02'	July 5	34.2	1.5	4.6	-	11.4	-	-	-
76°15'	16°52'	- " -	34.1	2.3	4.3	0.20	11.8	12.0	-	0.15 A
77°07'	12°03'	- " -	34.5	6.5	4.6	-	14.3	-	-	-
80°01'	7°49'	July 6	34.5	4.2	4.3	-	11.0	-	-	-
81°32'	5°41'	July 7	34.0	-1.8	4.4	0.19	11.7	-	-	-
81°13'	5°46'	- " -	33.0	-1.5	4.0	-	9.6	12.2	-	0.14 A
80°51'	5°45'	July 8	33.2	1.5	3.8	0.21	11.4	13.1	-	-
79°42'	2°06'	July 11	32.7	0.0	3.8	-	11.7	10.8	0.07	0.13
79°19'	3°36'	July 13	33.6	3.2	4.2	0.20	12.2	12.1	-	0.19 A
79°46'	3°56'	July 17	34.9	4.6	3.8	-	10.7	-	-	-
79°43'	5°20'	July 18	34.9	5.4	3.6	-	13.5	13.3	0.08	0.145
79°45'	8°12'	- " -	34.0	4.2	3.8	-	10.6	-	-	-
79°43'	10°25'	July 19	34.4	2.7	4.2	0.21	12.2	-	-	-
79°46'	0°05'	July 17	32.1	-1.2	4.5	0.061	9.1	12.4	-	0.10 A
North	West									
79°45'	12°05'***	July 15	31.4	-1.0	6.18±0.10	0.004	6.61±0.26	12.6	-	0.12 A
79°47'	9°47'	- " -	31.0	-0.7	6.7	rel.SD	7.3	9.9	-	-
79°46'	4°14'	July 16	31.2	-0.5	5.6	43%	7.5	11.8	-	0.16 A
79°56'	2°56'	- " -	31.4	-1.2	5.7	-	6.9	-	-	-
79°45'	1°09'	July 17	31.4	-1.5	4.6	-	7.0	-	-	-
65°36'	37°41'*	Aug	30.1	-	5.8	-	7.0	-	-	-
71°	8° **	Oct 13	34.1	-	3.4	-	9.1	-	-	-

* A coastal sample collected at Angmagssalik by local people.

** Collected by local people at Jan Mayen.

***50 l of this water was analysed for ^{99}Tc. It contained 0.08 Bq m^{-3} (rel. S.D. 32%).

Table 6.1.2. Cesium-137 and Strontium-90 in snow and melt water on ice floe from the Fram Strait collected in July 1983

Lattitude	Longitude	Sample size in l	Date	Salinity in o/oo	^{90}Sr Bq m^{-3}	^{137}Cs Bq m^{-3}	
78°47'N	9°47'W	50	July 15	0.22	0.80	1.7	Collected from a lake on an ice floe
- " -	- " -	10	- " -	0.04	0.8 B	-	Melted snow on the ice

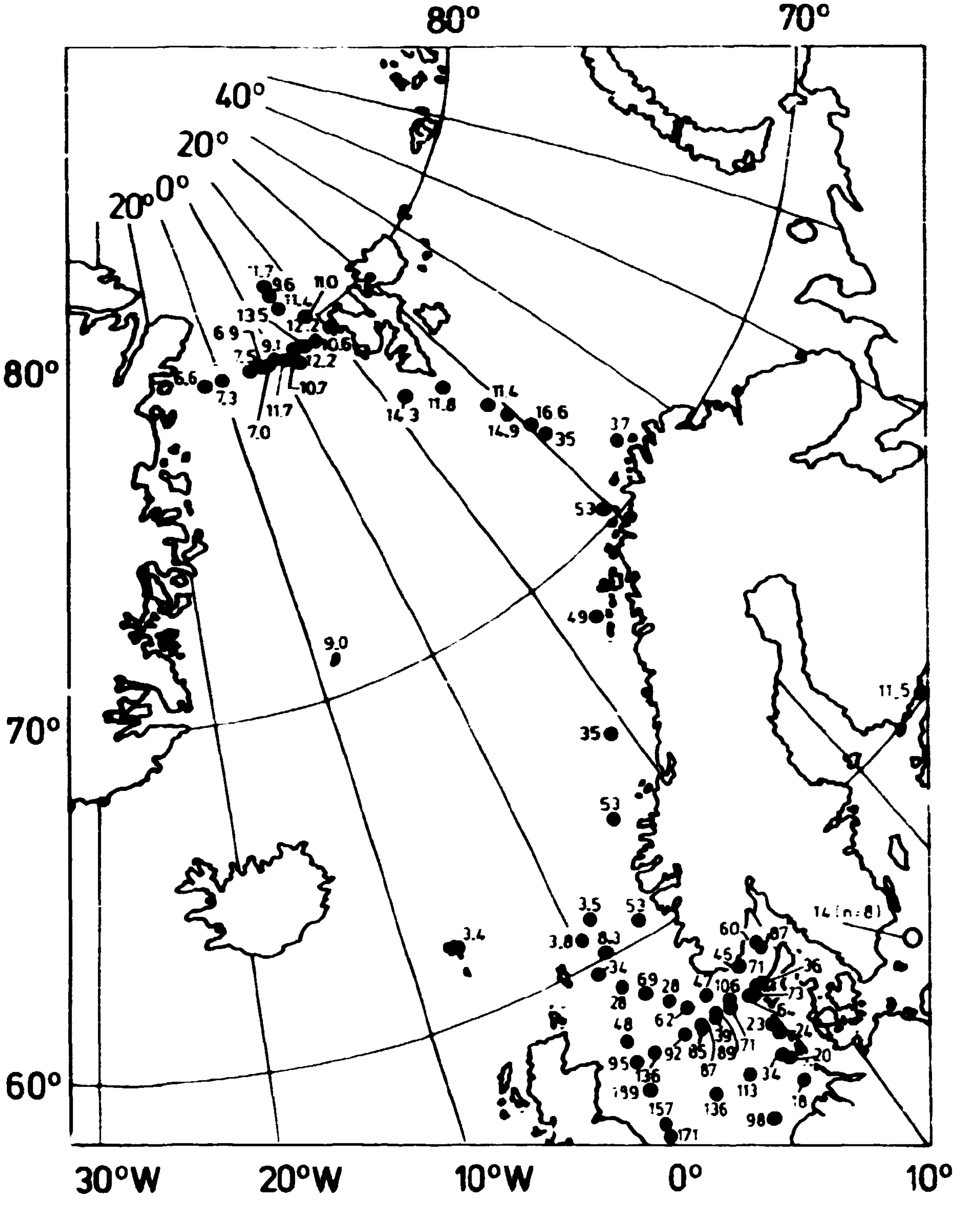


Fig. 4.1.1. Cesium-137 (Bq m^{-3}) in surface water samples collected in the North Atlantic in 1983.

Table 4.1.3. Strontium-90 and Cesium-137 concentrations in deep water samples collected in the Fram Strait in July 1983

Position Lattitude	Longitude	Depth in m	Date	Salinity in o/oo	^{90}Sr Bq m^{-3}	^{137}Cs Bq m^{-3}	$^{137}Cs/^{90}Sr$	Sample size in l
79°19'N	03°36'E	2	July 13	33.6	4.17	12.16	2.92	50
- " -	- " -	200	- " -	35.0	3.88	9.63	2.48	50
- " -	- " -	400	- " -	35.0	2.96	8.50	2.87	50
- " -	- " -	700	- " -	35.1	2.79	6.39	2.29	50
- " -	- " -	1000	- " -	36.2	1.52	2.37	1.56	150
79°45'N	12°05'W	2	July 15	31.4	6.18±0.07*	6.61±0.18*	1.07±0.02*	2 × 50*
- " -	- " -	50	- " -	32.1	6.92	6.37	1.09	50
- " -	- " -	200	- " -	34.4	3.63	5.07	1.40	100
79°46'N	04°14'W	2	July 16	31.2	5.56	7.46	1.34	50
- " -	- " -	300	- " -	34.9	2.44	4.01	1.64	50
- " -	- " -	600	- " -	34.4	1.11	2.31	2.08	50
- " -	- " -	1000	- " -	34.8	1.63	3.00	1.84	25

*Double analysis (± 1 S.E.)

tribution from Sellafield of ^{137}Cs than of ^{90}Sr as compared to the fallout, the latter having had the time to become better mixed in the water column than the Sellafield effluent. At 1000 m the ^{137}Cs concentrations were the same at the "Atlantic" and "Polar" stations, and so were the ^{90}Sr concentrations. We assume that at 100 metres at both sets of stations we have Atlantic water contaminated with fallout only. The ^{137}Cs and ^{90}Sr concentrations at this depth were actually nearly equal to our assumed fallout backgrounds in the Atlantic water.

The higher fallout levels in polarwater are detectable at the "Polar" stations down to approximately 300 m, but most of the fallout contaminated polar water seems to be in the upper 50 metres where the temperature is below 0°C.

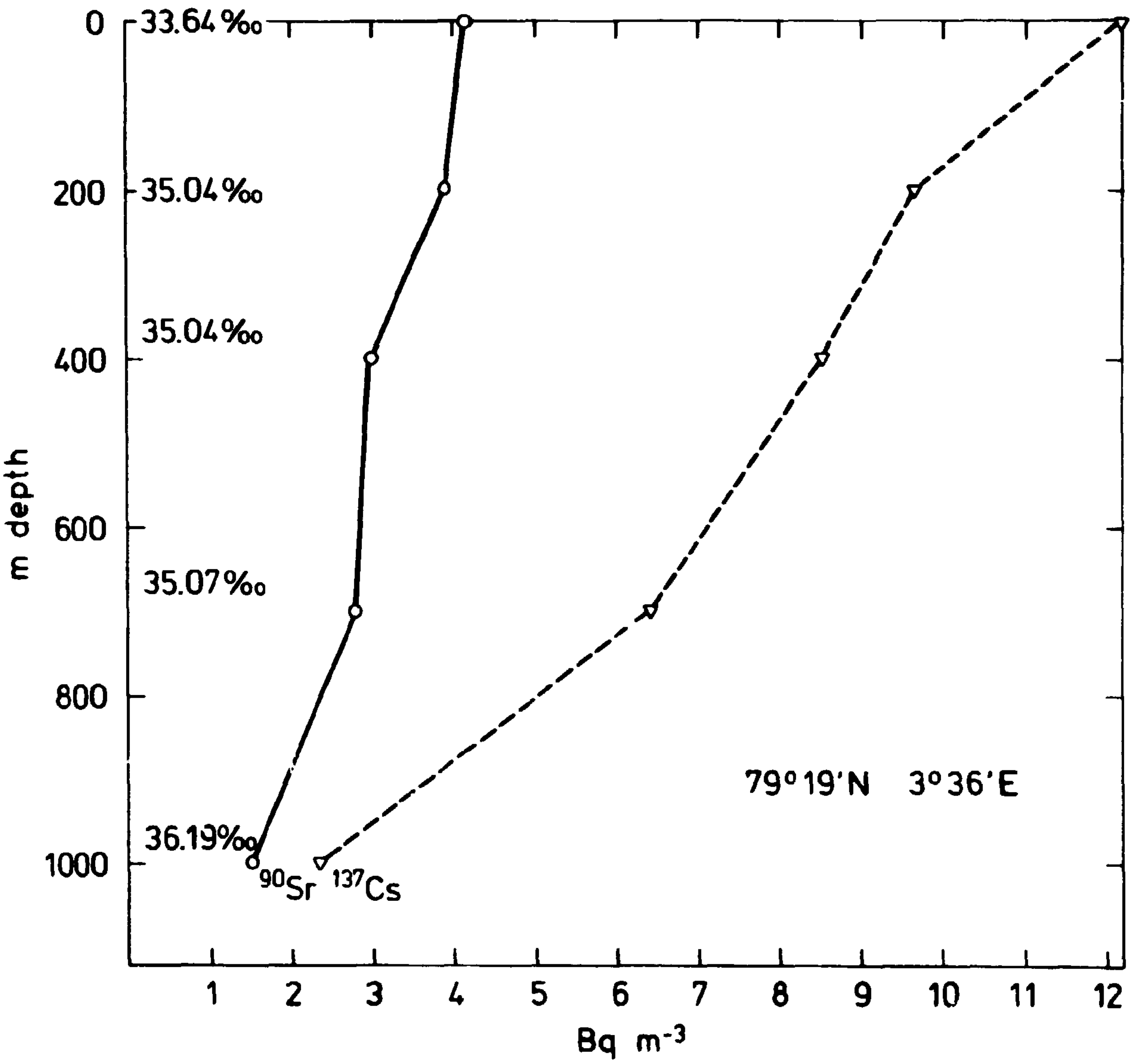


Fig. 4.1.2. Strontium-90 and Cesium-137 concentrations in a vertical profile in the eastern part of the Fram Strait in July 1983.

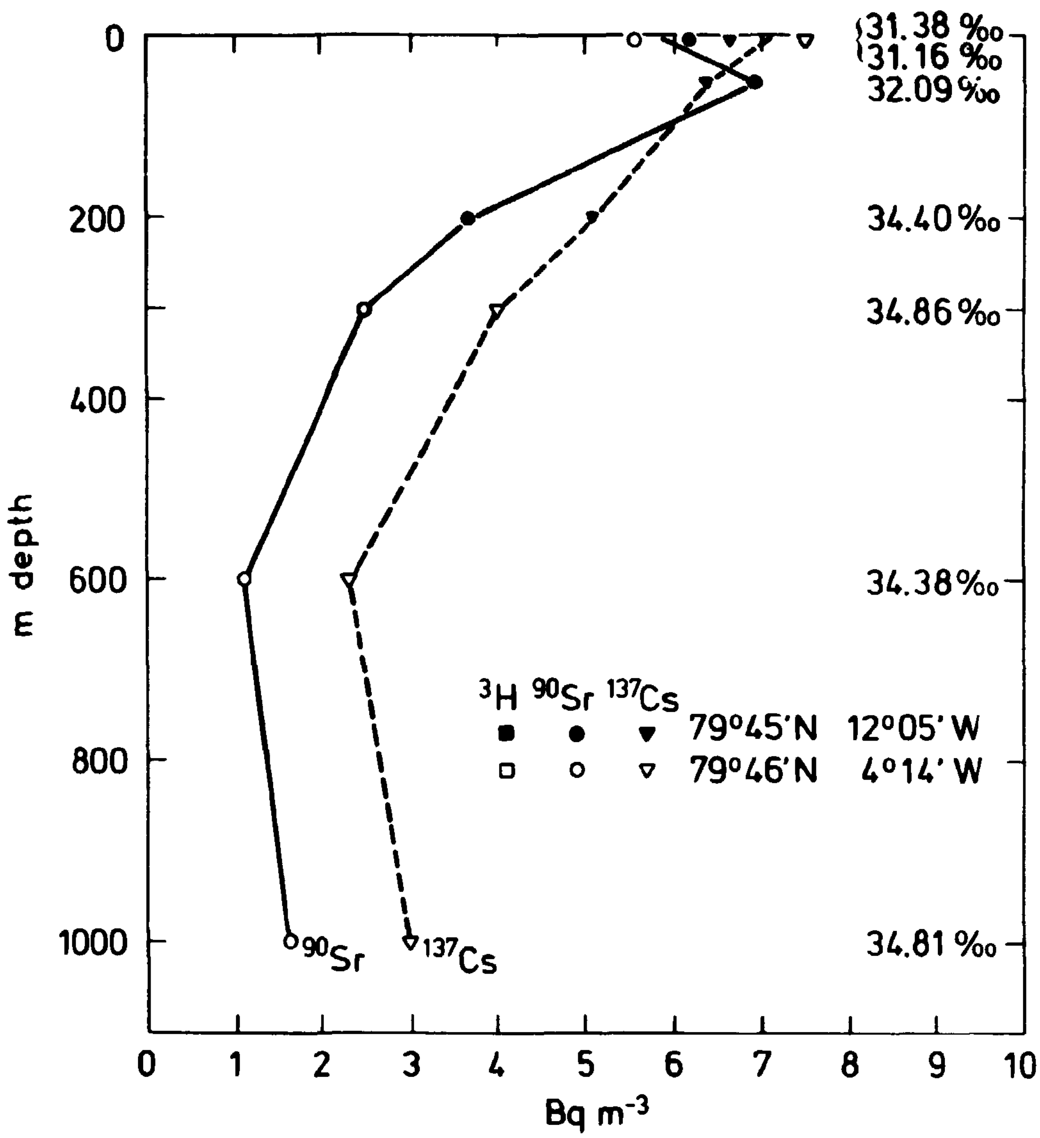


Fig. 4.1.3. Strontium-90 and Cesium-137 concentrations in a vertical profile in the western part of the Fram Strait in July 1983.

4.2. Radionuclides in West Greenland waters in 198?

Since 1963 sea water has been collected[2] at the Greenland west coast at Godthåb (~ 64°N) and at Godhavn (~ 69°N) the ^{90}Sr concentrations have from 1963 to 1980 approximately followed the equation:

$$\text{Bq } ^{90}\text{Sr m}^{-3} = 14\ e^{-0.095t} \qquad \text{(Eq. 1)}$$

where t is the time in years and t = 0 in 1963. We have measured ^{137}Cs since 1973 and have in this case got the equation:

$$\text{Bq }^{137}\text{Cs m}^{-3} = 8.7\ e^{-0.096(t-10)} \qquad \text{(Eq. 2)}$$

In a similar way we have for the east coast of Greenland from samples obtained from Danmarkshavn (~ 75°N) and Angmagssalik (~ 65°N) got the equations:

$$\text{Bq }^{90}\text{Sr m}^{-3} = 18.3\ e^{-0.080t} \qquad \text{(Eq. 3)}$$

and

$$\text{Bq }^{137}\text{Cs m}^{-3} = 11.4\ e^{-0.085(t-10)} \qquad \text{(Eq. 4)}$$

If we use the above equations we would in 1982 and 1983 have expected 2.3 Bq ^{90}Sr m^{-3}, 3.7 Bq ^{137}Cs m^{-3} and 2.1 Bq ^{90}Sr, 3.3 Bq ^{137}Cs m^{-3}, respectively, at the Greenland west coast. At the east coast the concentrations would have been 4.0 Bq ^{90}Sr m^{-3}, 5.3 Bq ^{137}Cs m^{-3} and 3.7 Bq ^{90}Sr m^{-3}, 4.9 Bq ^{137}Cs m^{-3}, respectively.

In 1983 the observed mean ^{137}Cs level at the west coast was 5.4±0.77 (n = 41, ± 1 S.D.) Bq m^{-3} and the ^{90}Sr concentration was 4.5±0.9 (n = 41, ± 1 S.D.) Bq m^{-3}, in 1982 we found 5.5±0.79 (n = 10, ± 1 S.D.) Bq ^{137}Cs m^{-3} and 4.2±0.1 (n = 3, ± 1 S.D.) Bq ^{90}Sr m^{-3} (Risø-R-489[2]).

The observed levels were thus higher than those expected for West Greenland and closer in agreement with the predicted levels for East Greenland. The two years were both characterised by great amounts of sea ice along the west coast. This suggests that the East Greenland Current has passed relatively undiluted by Atlantic water from East to West Greenland waters in 1982 and 1983.

The ^{137}Cs concentrations were not related to the salinity while ^{90}Sr were inversely related to salinity:

$$\text{Bq }^{90}\text{Sr} = 11.9 - 0.237 \times (\text{salinity in o/oo}) \qquad \text{(Eq. 5)}$$

Table 4.2. Strontium-90 and Cesium-137 in surface sea water off W-Greenland in 1983

Lattitude N	Longitude W	Name of location	July 1983 ^{90}Sr Bq m^{-3}	July 1983 ^{137}Cs Bq m^{-3}	July 1983 Salinity in o/oo	Nov 1983 ^{90}Sr Bq m^{-3}	Nov 1983 ^{137}Cs Bq m^{-3}	Nov 1983 Salinity in o/oo	GFU* Salinity July/Oct
64°07'	51°53'	Fylla Bank (Nuuk)	5.28	6.44	29.1	-	-	-	32.8/ -
63°58'	52°44'	- " -	-	-	-	4.77	6.09	28.3	- /32.0
63°55'	53°07'	- " -	6.27	6.18	29.5	4.65	6.45	31.4	32.9/32.2
63°48'	53°56'	- " -	5.18	4.80	23.8	4.59	5.55	31.9	33.0/32.8
65°06'	53°00'	Sukkertoppen (Manitsoq)	4.25	6.68	33.3	4.02	6.74	32.1	33.2/31.8
65°06'	53°59'	- " -	4.45	5.44	32.9	5.08	6.60	31.7	33.3/32.4
65°06'	54°58'	- " -	5.91	4.47	24.[illegible]	3.81	5.68	30.3	33.2/32.3
66°53'	54°10'	Holsteinsborg (Sisimiut)	3.94	5.05	33.2	4.23	5.70	31.8	33.6/32.1
66°46'	55°36'	- " -	4.05	5.36	33.5	3.77	6.66	31.8	33.7/31.8
66°43'	56°07'	- " -	4.90	3.99	31.9	-	-	-	33.7/ -
66°41'	56°38'	- " -	-	-	-	3.46	6.13	32.0	- /32.3
67°34'	57°10'	Intermediate station	6.46	3.94	25.2	-	-	-	32.2/ -
68°00'	55°00'	Egedesminde (Ausiait)	4.46	4.99	32.2	3.72	6.40	31.4	33.6/32.6
68°04'	56°00'	- " -	5.49	5.14	31.3	4.42	5.83	31.9	33.1/32.3
68°08'	57°17'	- " -	7.64	5.46	25.7	3.68	5.08	32.6	32.6/33.0
68°14'	58°40'	- " -	-	-	-	3.83	4.25	32.8	- /33.2
68°43'	55°03'	Disko Rende	4.45	5.45	33.1	5.30	4.72	31.7	32.7/33.6
68°54'	55°54'	- " -	4.02	4.8[illegible]	32.1	3.90	5.79	3[illegible].4	33.1/33.1
69°08'	58°24'	- " -	5.28	3.70	32.0	-	-	-	31.7/ -
69°30'	58°20'	Disko Fjord	-	-	-	2.99	4.93	32.8	- /33.2
70°20'	55°10'	Hareø south	4.43	4.28	26.8	3.94	4.49	32.9	33.0/33.5
70°34'	54°47'	Hareø north	4.88	4.51	32.7	3.44	5.12	33.3	33.1/33.2
69°42'	51°38'	Arveprinsen Ejland	4.03	4.43	32.7	3.94	5.10	31.2	32.7/33.2
69°03'	52°26'	Skansen - Akunaq	3.66	4.59	32.6	4.85	5.60	32.5	32.5/33.2

*The salinities determined at Risø were in some cases significantly lower than those found by GFU (The Greenland Fisheries and Environmental Research Institute). We assume that the GFU values are the correct ones for the water masses but cannot completely dismiss that the 50 l samples, which we analysed have had a higher content of fresh water perhaps due to melt water in the surface layer (cf. the text also).

For zero salinity (Eq. 5) predicts a fresh water (run-off) concentration of 11.9 Bq m^{-3}. This is what we see as mean concentration in Greenland drinking water (cf. 3.2.6). A few samples from July 1983 showed salinities about 25 o/oo, these low salinities could not be confirmed by the hydrographic samples collected by Erik Buch (GFU); however, the low salinity samples contained relatively high ^{90}Sr concentrations and low ^{137}Cs levels. Hence we assume that these samples have contained run-off from land, which we will assume to be high in ^{90}Sr and low in ^{137}Cs.

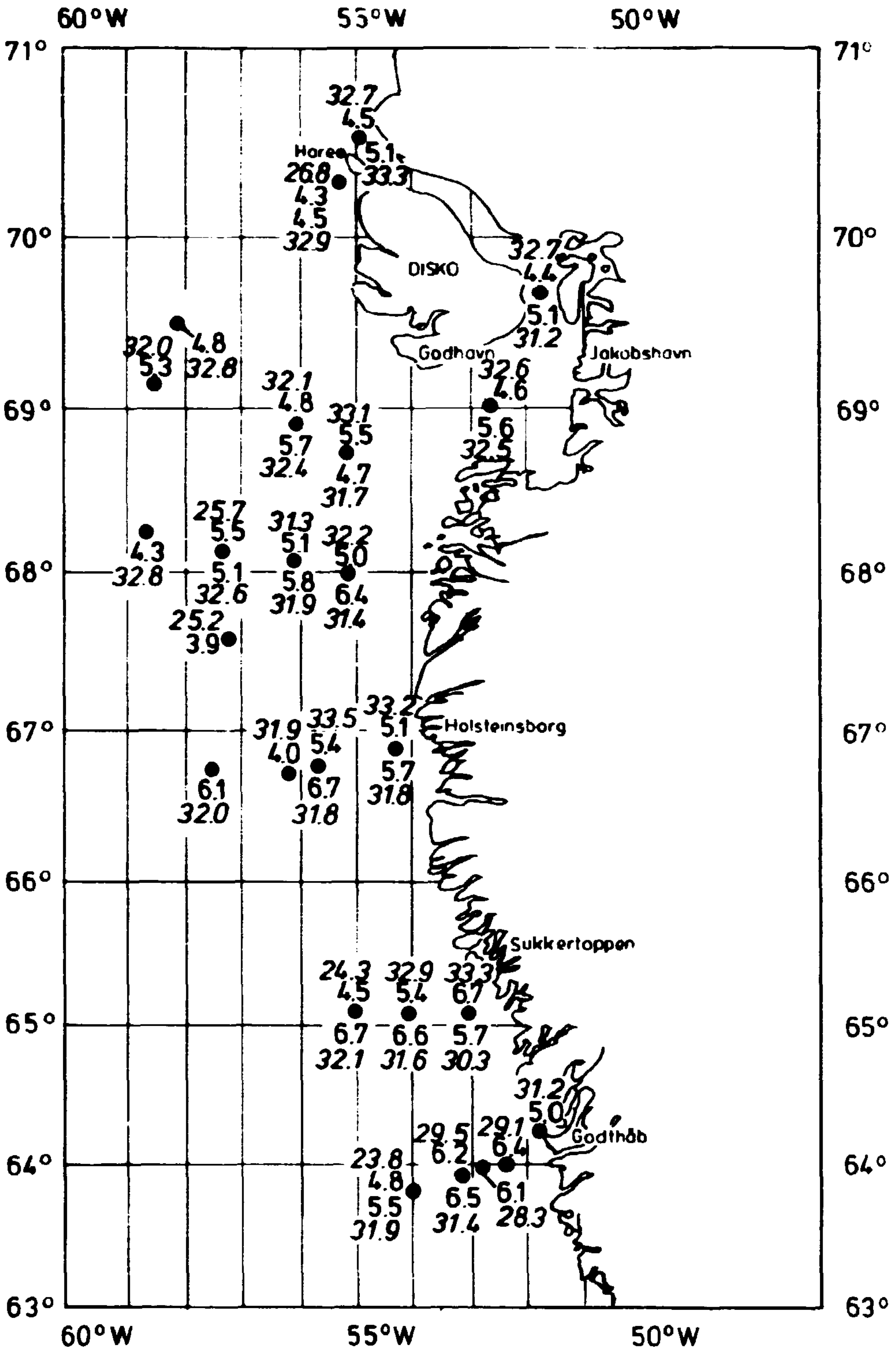
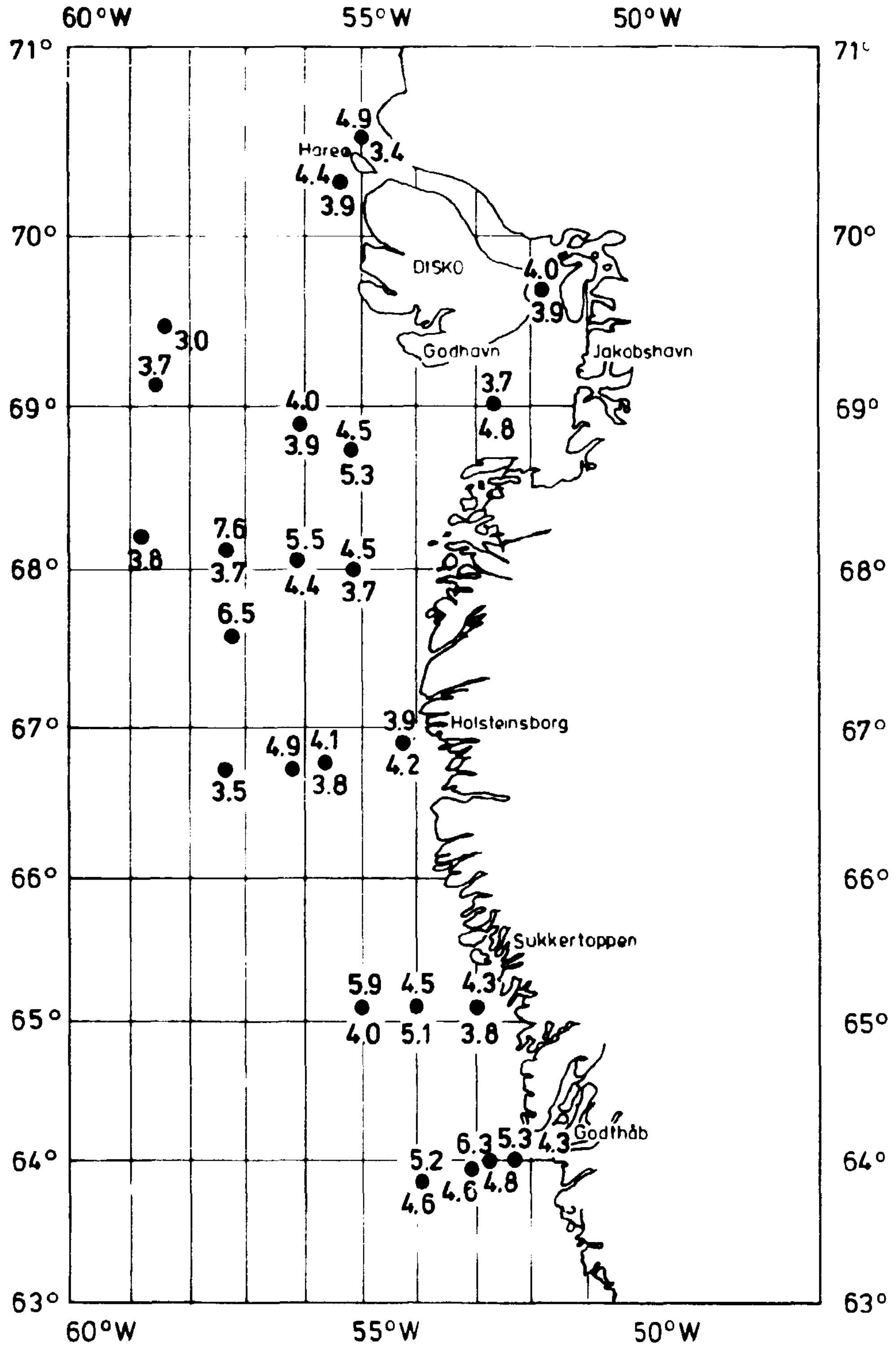


Fig. 4.2.1. Cesium-137 (Bq m^{-3}) in surface water collected off West Greenland in July 1983 (upper figures) and in October-November 1983 (lower figures). The salinities in o/oo are shown in italics.



<u>Fig. 4.2.2.</u> Strontium-90 in surface water collected off West Greenland in July 1983 (upper figures) and in October-November 1983 (lower figures).

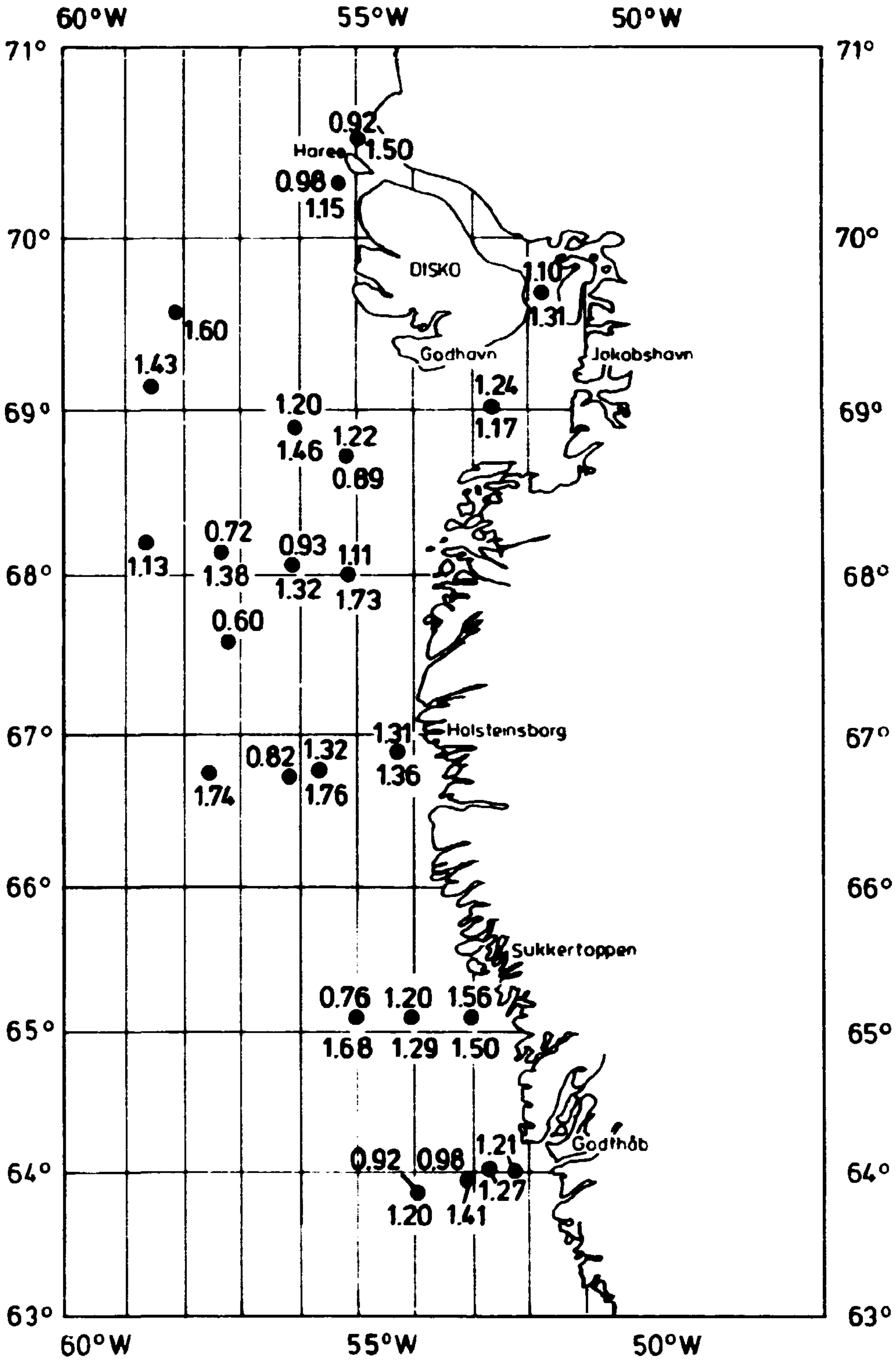


Fig. 4.2.3. The $^{137}Cs/^{90}Sr$ ratio in surface water collected off West Greenland in July 1983 (upper figures) and in October-November 1983 (lower figures).

The high salinity Atlantic water, which is low in ^{90}Sr and ^{137}Cs will dilute the higher activities in the polar water and at the same time increase its salinity.

If we consider the situation from July to October-November 1983 we notice that a tongue of high ^{137}Cs concentrations have moved northward from approximately 65°N to 68°N and furthermore have spread westward from 53°W to 58°W. At the same time there seems to be a southward movement of low activity water entering the Greenland coastal water with the Canadian Polar Current. This water apparently shows a higher $^{137}Cs/^{90}Sr$ ratio than the Polar water carried by the East Greenland Current (cf. Fig. 4.2.3).

4.3. Radionuclides in seaweed collected 1980-1983 in Northern Europe

Table 4.3.1 show the ^{99}Tc data in seaweed samples collected in Denmark, The Faroe Islands, Iceland, Svalbard and Holland in recent years. Some of these results are summarized in Table 4.6.2. It is in particular interesting that the samples from the outlet of the Shelde river in Holland contained relatively high levels of ^{99}Tc. This may indicate a contribution from another source than Sellafield, probably Cap de la Hague in France.

The ^{137}Cs data from Bodø in Table 4.3.2 are in agreement the results found in Norwegian studies[8]. The sample from the Gulf of Finland was collected along with a sea water sample, which contained 11.5 Bq ^{137}Cs m^{-3} (salinity 5.8 o/oo). The observed concentration ratio of Fucus to water was thus 580, which is in agreement with observations in the Baltic Sea[3]. The sample from Bremerhafen is in agreement with those found in the south western part of Denmark (cf. Risø-R-509, Table 5.11.2.2)[3].

Table 4.3.1. Technetium-99 in various samples of sea weed collected 1980-1982

Location	Sampling date		Species	^{99}Tc Bq kg^{-1} dry weight	
Eastern Shelde*	June	1982	As.no.	169	Holland
Western Shelde*	June	1982	Fu.ve.	105	Holland
Thorshavn	June 14	1981	Fu.sp.	2.6	Faroes
Gjógv	June	1981	Fu.di.	2.1	Faroes
- " -	June	1981	La.di.	-	Faroes
Arnanæs	June	1981	Fu.ve.	1.25	Iceland
Grindavik	June	1981	Fu.ve.	0.28	Iceland
Raufarhöfn	June	1981	Fu.ve.	1.53	Iceland
Hnifsdalur	June	1981	Fu.ve.	1.08	Iceland
Isfjord	August	1980	Fu.se.	8.3	Svalbard
Rødbyhavn	Dec	1982	Fu.se.	38	Denmark
Esbjerg, N.V.	Dec	1982	Fu.ve.	110	Denmark
Bornholm	Nov	1982	Fu.ve.	2.6	Denmark
Fornæs Fyr	Sep	1982	Fu.ve.	64	Denmark
Frederikshavn	Sep	1982	Fu.ve.	233	Denmark

Fu.ve.: Fucus vesiculosus, Fu.se.: Fucus serratus, Fu.sp.: Fucus spiralis, Fu.di.: Fucus disticus, As.no.: Ascophyllum nodosum, La.di.: Laminaria digitata.

*These samples were obtained from Dr. Duursma.

Table 4.3.2. Cesium-137 in sea weed collected at various locations in 1983

Location	Position		Sampling date	Species	Bq ^{137}Cs kg^{-1} dry weight	Bq ^{137}Cs (kg K)$^{-1}$	% dry matter
Finnish Bay	60°15'N	25°49'E	Oct 23	Fu.ve.	6.7	230	19.5
Bodø, Norway	67°17'N	14°25'E	June 6	Fu.ve.	11.8	340	15.0
- " -	- " -	- " -	- " -	Fu.se.	7.8	220	17.1
- " -	- " -	- " -	- " -	As.no.	5.6	250	18.0
Bremerhafen	53°33'N	08°35'E	June 28	Fe.ve.	3.5	125	-

Fu.ve.: Fucus vesiculosus, Fu.se.: Fucus serratus, As.no.: Ascophyllum nodosum.

4.4. Technetium-99 in Greenland fucoids collected 1963-1983

The material used in this study have been Fucus vesiculosus and Fucus disticus collected in Greenland since 1963[2]. The samples have been kept at Risø as ashed or dried samples. We have found that the ^{99}Tc content of ashed samples is 0.92±0.05 (n = 4, 1 S.D.) times that of dried samples, and that 100 g dry matter yields 26 g ash . Furthermore, we have seen the Fucus vesiculosus and Fucus disticus does not differ significantly with respect to ^{99}Tc concentrations[10].

The results of Table 4.4.1 and Fig. 4.4.1 are discussed in details elsewhere[9].

The anova in Table 4.4.2 shows that there was no significant difference between the various locations in East Greenland.

The important observation is the significant increase that occurred in 1976-1977 in the ^{99}Tc levels in fucoids collected along the East Greenland coast. This increase is supposed to be due to an enhanced discharge of ^{99}Tc with liquid waste from Sellafield in 1970. This assumption is based upon a transit time from Sellafield to the East Greenland Current of approximately 7 years estimated from radiocesium tracer studies[11] and from studying the so-called "salt anomaly" in the North Atlantic[12]. From studies of ^{99}Tc in fucoids collected in the Danish Strait we also conclude that enhanced discharges of ^{99}Tc began in 1970 (cf. 4.5).

A possible increase of ^{99}Tc in fucoids from the Greenland west coast is less evident. However, if we consider the $^{99}Tc/^{90}Sr$ ratios, we observe that the mean ratio in 1965-1979 was 0.63±0.06 (n = 2, ± 1 S.E.), but in 1981-1983 it had increased to 2.60±0.54 (n = 4, ± 1 S.E.). In these calculations all ^{90}Sr data were decay corrected to 1983. The relation to ^{90}Sr was used in order to correct for any variations in the contributions of fallout-produced ^{99}Tc, which might influence the ^{99}Tc levels in the Greenland waters. Hence we conclude that fucoids collected since 1981 from the Greenland west coast have shown

Table 4.4.1. Technetium-99 in Fucus vesiculosus/disticus collected in Greenland and coastal waters 1963-1983 (summer period). Unit: Bq ^{99}Tc kg^{-1} dry weight.

Year	East Greenland coastal waters				West Greenland coastal waters		
	Danmarkshavn	Scoresby Sund	Angmagssalik	Prins Chr. Sund	Narssaq-Godthåb	Godhavn-Upernavik	Thule
1963			3.62±0.18				
1964							2.00±0.03
1965					2.16±0.11		
1966			2.13±0.04		2.42±0.05		
1967				2.99±0.07;2.24±0.05	2.92±0.06		
1968	1.95±0.05			1.84±0.05			
1969	1.34±0.11	2.06±0.16;1.93±0.13		1.34±0.14			
1970	2.39±0.36			1.58±0.04			
1971	2.05±0.16						
1972	1.07±0.10;1.64±0.13		2.23±0.11				
1973	2.79±0.07;1.87±0.09			2.16±0.09			
1974				2.28±0.12			
1975				2.48±0.24			
1976							
1977			6.17±0.24	5.21±0.15			
1978		3.60±0.27;3.11±0.15					
1979		6.85±0.22		8.04±0.31	1.86±0.10		0.73±0.29;0.50±0.14
1980				5.59±0.15			
1981						1.72±0.10	
1982	6.42±0.26	7.29±0.28;9.65±0.14	7.43±0.37;9.37±0.56 8.66±0.52		3.78±0.09;3.71±0.11		
1983						3.65±0.14	

*The error term is 1 S.D. due to counting statistics.

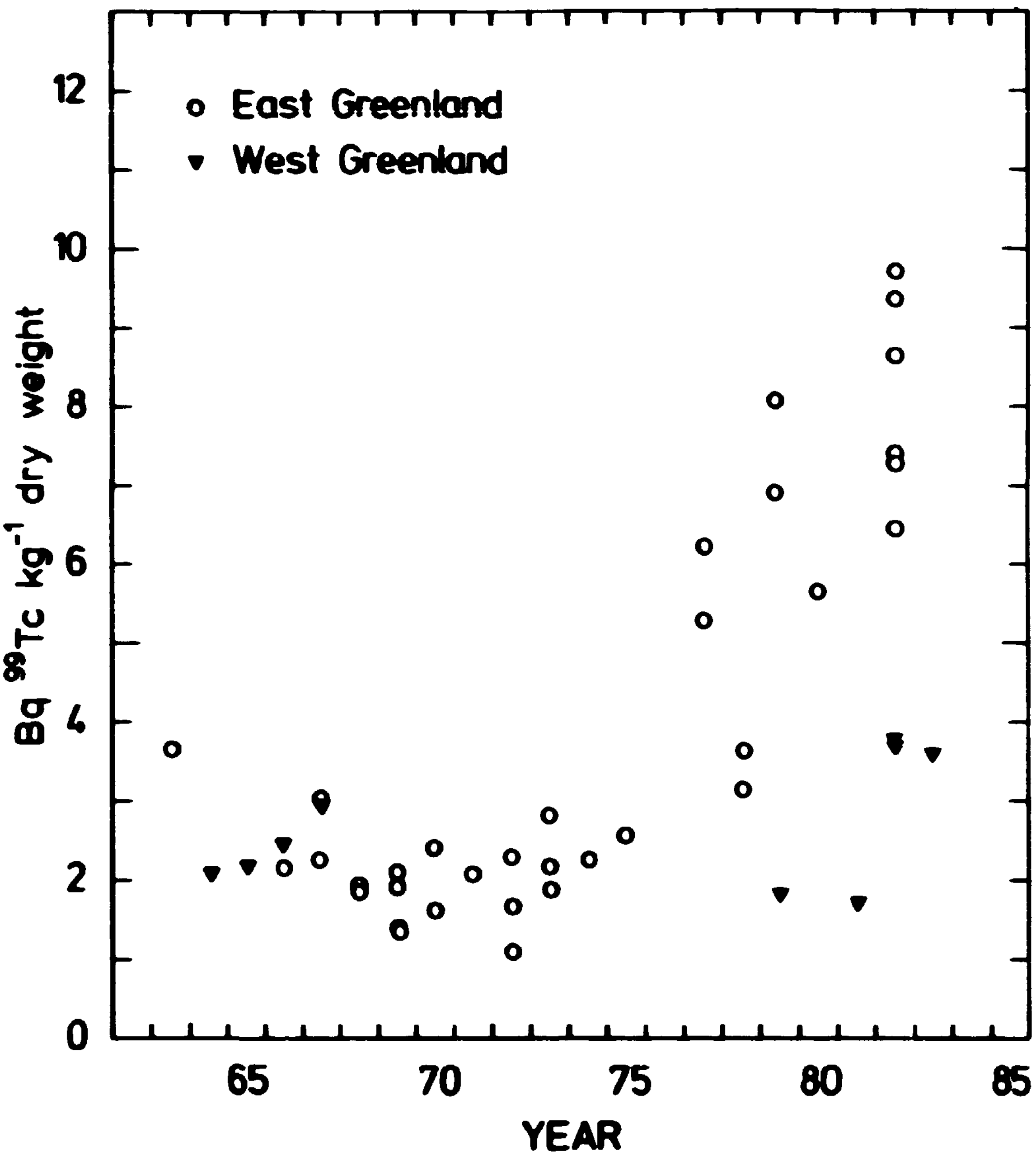


Fig. 4.4.1. Technetium-99 in Fucus vesiculosus/disticus collected in Greenland 1963-1983.

enhanced ^{99}Tc, which cannot be explained by an increase in fallout. If the expected ^{99}Tc/^{90}Sr ratio in fucoids from fallout was 0.63 and we find a ratio of 2.6 in 1983 we conclude that the ratio between Tc from Sellafield, and Tc from fallout in 1983 was

$$\frac{2.60 \pm 0.54}{0.63 \pm 0.06} - 1 = 3.13 \pm 0.94$$

or that 0.76±0.23 of the ^{99}Tc in fucoids from West Greenland were from Sellafield in 1983. If the ^{99}Tc level in fucoids from the west coast in 1983 (cf. Table 4.4.1) was 3.7 Bq kg^{-1}, the fallout background has been 0.9 Bq kg^{-1} in these samples. This background is compatible with the ^{99}Tc concentrations seen around Iceland (cf. 4.3.) in 1982, and for Iceland we can neglect any non-fallout contribution.

Table 4.4.2. Anova of Bq ^{99}Tc kg^{-1} dry weight in Fucoids collected in East Greenland: at Danmarkshavn, Scoresby Sund, Angmagssalik and Prins Christians Sund in 1963-1982

Variation	SSD	f	s^2	v^2	P
Between years	8.67	15	0.58	13.14	> 99.95%
Between locations	0.15	3	0.051	1.17	-
Interaction	0.24	7	0.035	0.66	-
Remainder	0.42	8	0.053	-	-

Table 4.4.3. Annual discharge rates of ^{99}Tc from Sellafield[13)]

Year	TBq ^{99}Tc a^{-1}
1978	179
1979	44
1980	57
1981	5.8
1982	3.6
1983	4.4

In a similar way we may estimate the fallout background of ^{99}Tc in East Greenland fucoids in 1983. The mean $^{99}Tc/^{90}Sr$ ratio in fucus[2] collected 1963-1975 in East Greenland was 1.01±0.11 (n = 16, ± 1 S.E.) and for the period 1977-1982 we found 4.57± 0.92 (n = 10, ± 1 S.E.). Hence the Sellafield contribution in 1983 was 0.78±0.23. From the 1982 ^{99}Tc data we calculate the fallout background in East Greenland fucus to: 8.63 × 0.22 = 1.9 Bq ^{99}Tc kg^{-1}. This background is as expected, higher than that of West Greenland fucus due to the enhanced fallout levels in the East Greenland Current[6].

If we want to calculate transfer factors to fucus in Greenland for liquid ^{99}Tc discharges from Sellafield we have to correct for the fallout background concentrations in the fucus. Furthermore, we must know the discharges from Sellafield. However, such information have been available only since 1978 (Table 4.4.2). In 4.5 we have tried to estimate the discharges in the years prior to 1978. According to these estimates, the mean discharge in the years 1970-76 was 44±22 TBq ^{99}Tc a^{-1}. If we use the average East Greenland fucus level for the years 1977-1982, i.e. 7.9±0.63 (n = 13, ± 1 S.E.) Bq ^{99}Tc kg^{-1}, the transfer factor becomes 7.9 × 0.78/0.044 = 140±80 Bq kg^{-1} per PBq a^{-1}. In a similar way the transfer factor to West Greenland fucus is calculated from the mean level found in 1981-1983, i.e. 3.35±0.37 (n = 4, ± 1 S.E.) Bq ^{99}Tc kg^{-1} and the transfer factor becomes 3.35 × 0.76/0.044 = 60±35 Bq kg^{-1} per PBq a^{-1}.

If the concentration factor between fucus and sea water in Greenland is 10^5 (the value we have found in the Danish Straits in 1984), the transfer factor to East Greenland waters becomes 1.4 Bq m^{-3} per PBq a^{-1} and to West Greenland waters 0.6 Bq m^{-3} per PBq a^{-1}.

This is more than estimated for ^{90}Sr and radiocesium in the western part of the Fram Strait but lower than that for the eastern part [6]. But the estimate is in good agreement with that from Jan Mayen[6] where the transfer factor was 1.3 Bq ^{137}Cs m^{-3} per PBq ^{137}Cs a^{-1}. We also determined ^{99}Tc in a single 50 l water sample from the western part of the Fram Strait in 1983. The concentration was 0.08±0.024 Bq m^{-3}. The transfer factors calculated from this sample becomes 0.08 × 0.78/0.042 = 1.5 Bq ^{99}Tc m^{-3} per PBq ^{99}Tc a^{-1}, which (by coincidence?) is in agreement with the factor based upon East Greenland fucus.

For the time being we conclude that the transfer factor of liquid effluents from Sellafield to East Greenland waters is on the order of 0.1-1 Bq m^{-3} per PBq a^{-1}. It should be recalled that the higher value is based upon Fucus samples assuming a concentration factor of 10^5. If, however, this factor is too low for arctic conditions we may approach the lower value of the transfer factor range.

4.5. Technetium-99 in Fucus vesiculosus collected in the Danish Straits 1967-1984

Four locations (cf. Fig. 4.5.1) have been used in this study, which was initiated in Sweden already in 1967.

The results (Table 4.5.1.) and the anova (Table 4.5.2.) are summarized in Figs. 4.5.2. and 4.5.3. and discussed in ref. 9. An evident increase in the ^{99}Tc levels occurred in 1974. We know that the transit time of water masses from Sellafield to the Danish Straits is approximately four years[3]. Hence the increase in 1974 must refer to an enhanced discharge in 1970, which was the same conclusion as that drawn from the East Greenland Fucus observations (cf. 4.4). The anova shows a significant seasonal variation, the ^{99}Tc concentrations were thus nearly two times higher in Oct-Dec than in July-Sept. It is remarkable that there is no interaction between years and locations. As it appears from Fig. 4.5.3 the ^{99}Tc concentration in Fucus from the Sound (Barsebäck) show a nearly constant ratio to the levels from the Cattegat (Ringhals, Klint and Särdal), the latter being 4.3 times higher than the former.

If we use the discharge data since 1978 (cf. Table 4.4.2) from Sellafield we may relate these data to the observed mean values (obtained from the anova) for the 3 locations from the Cattegat. The discharge period 1978-1980 is that seen in samples

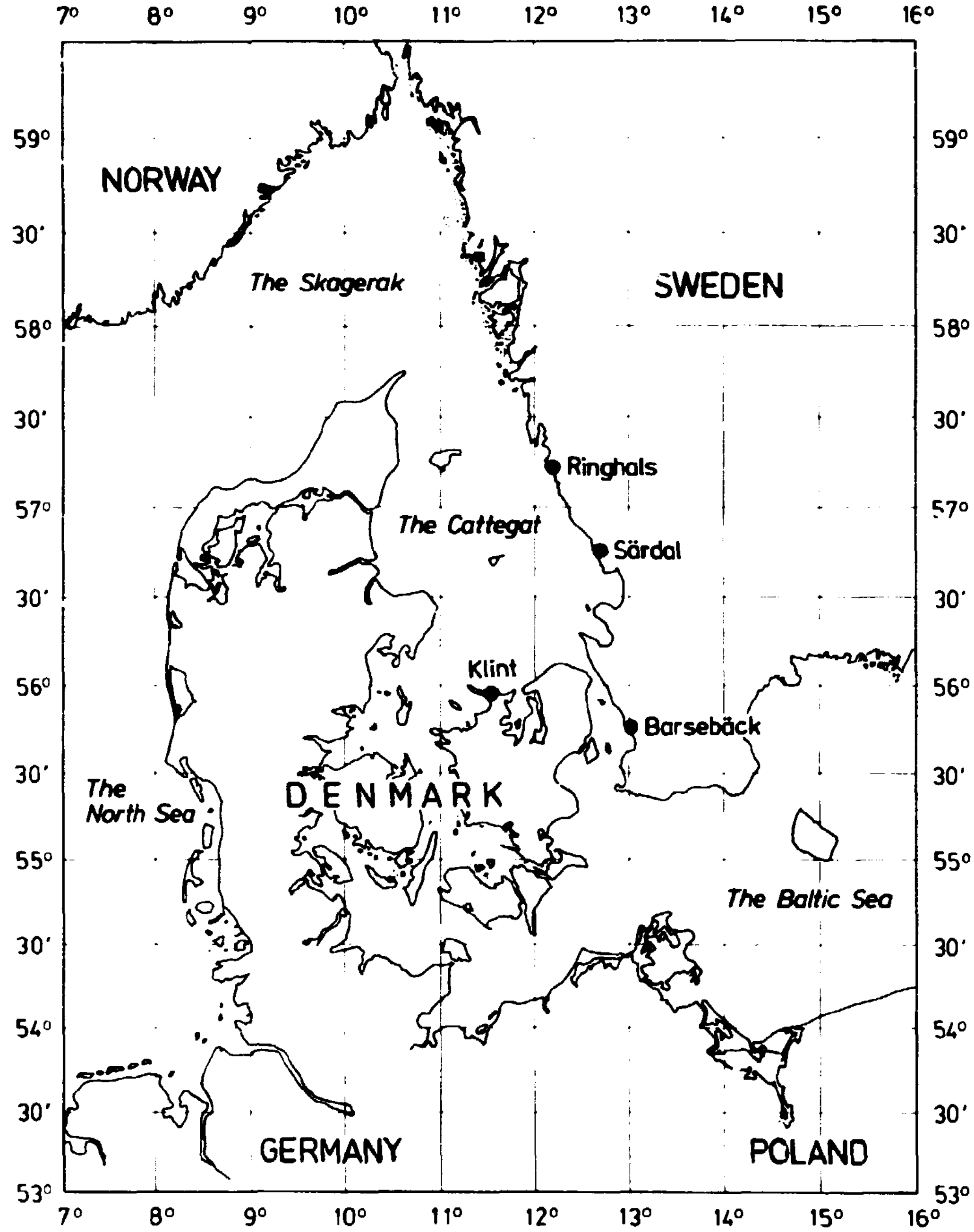


Fig. 4.5.1. Sampling locations for Fucus vesiculosus used for ^{99}Tc analysis in the Danish straits.

collected in 1982-1984. If these two periods are considered as a whole we get a transfer factor to Fucus vesiculosus from the Cattegat of 148.5±28.3/93±43 = 1.6±0.8 (n = 3, ± 1 S.E.) Bq ^{99}Tc kg^{-1} per TBq ^{99}Tc a^{-1} or approx. 10 times higher than that observed along East Greenland (cf. 4.4). There may be several uncertainties in this calculation. A serious one would be, if we should see other sources than Sellafield in the Danish Straits, e.g. discharges from Cap de la Hague. This cannot be dismissed, because we have indications for such a discharge from Dutch seaweed samples (cf. Table 4.3.1). Furthermore, it is difficult to explain why the concentrations in the samples from 1982 were lower than those from 1983-1984 as the corresponding discharges in 1978 were higher than those in 1979 and 1980 (cf. Table 4.4.2).

Table 4.5.1. Technetium-99 in Fucus vesiculosus collected in the Cattegat and the Sound in 1967-1984

Location	Ringhals				Särdal				Klint				Barsebäck			
Quarter	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Year																
1967							5.6									
1970							4.1									
"							3.9									
"							3.9									
"							1.3									
1972							3.0									
1973							6.9									
1974							30									
1975							37									
1976		78					40	55						14.1		
1977			81			72								16.8		
1978			41			34		48						12.4		
1979		59				30	16	44						11.0		
1980			34		57	59	27								9.9	
"					48	29										
"						53										
1981			78		83	90	35	101						21	13.6	
1982			71				39	117						11.1	23	
"			61				43							26	13.2	
"			103											10.1		
"			111											15.4		
"			29											21		
"			95													
1983		193	170			152	60		112					34	41	
"		197	72			50			150					26		
"		169	101						151					31		
"		233	142						180					26		
"		216	149						187					41		
"		155	164											25		
"			136													
1984		204							207	239	120		44			
"									223	179	120		64			
"									201		83					

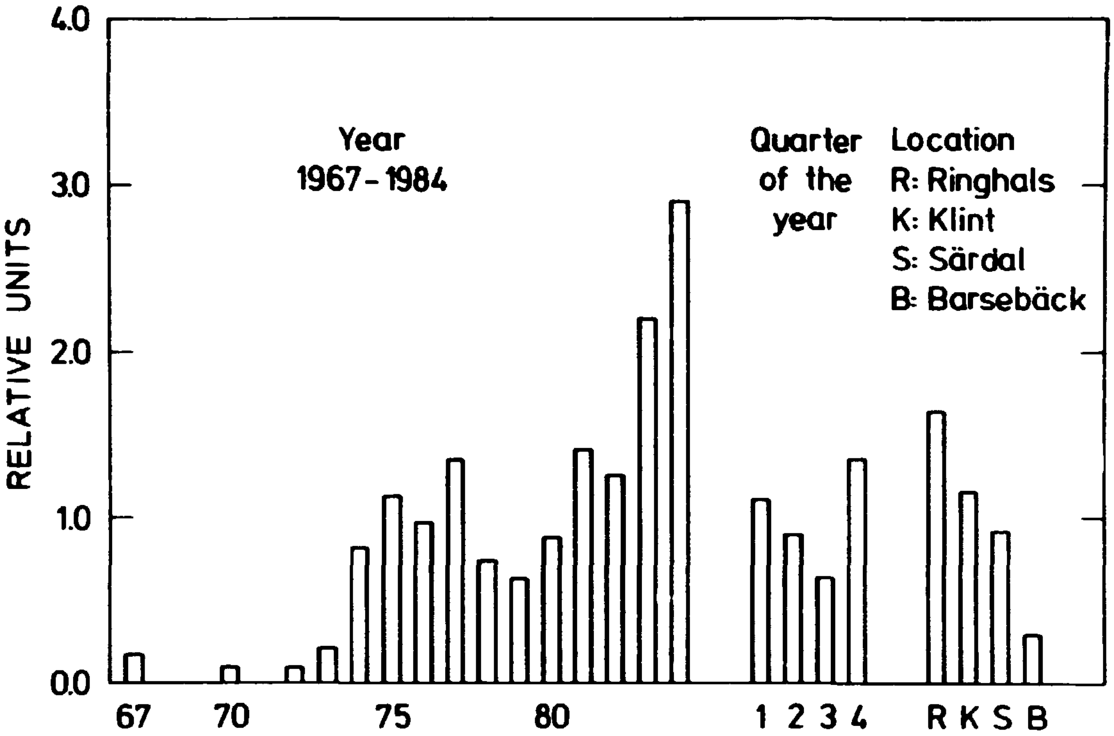


Fig. 4.5.2. The annual, quarterly and local variation of ^{99}Tc in Fucus vesiculosus collected in the Cattegat (Ringhals, Klint and Särdal) and in the Sound (Barsebäck) in 1967-1984. The columns show the concentrations relative to the grand mean 56 Bq kg^{-1} dry weight (= 1 at the relative scale) (cf. the anova in Table 4.5.2).

Table 4.5.2. Anova of Bq ^{99}Tc kg^{-1} dry weight in Fucus vesiculosus collected at Ringhals, Särdal, Klint and Barsebäck in 1967-1984 (cf. Table 4.5.1 and Fig. 4.5.2)

Variation	SSD	f	s^2	v^2	P
Between years	36.07	14	2.58	22.03	> 99.95%
Between quarters	3.68	3	1.23	10.51	> 99.95%
Between locations	31.58	3	10.53	90.00	> 99.95%
Interactions	1.51	30	0.05	0.43	-
Remainder	5.16	44	0.12	-	-

If, however, we use the above transfer factor we may estimate from Fig. 4.5.2 the annual mean discharges from Sellafield in 1970-1973 to 52 TBq ^{99}Tc, in 1974-1976 to 32 TBq and in 1977 to 65 TBq. The estimated error on these discharge rates is ±50%.

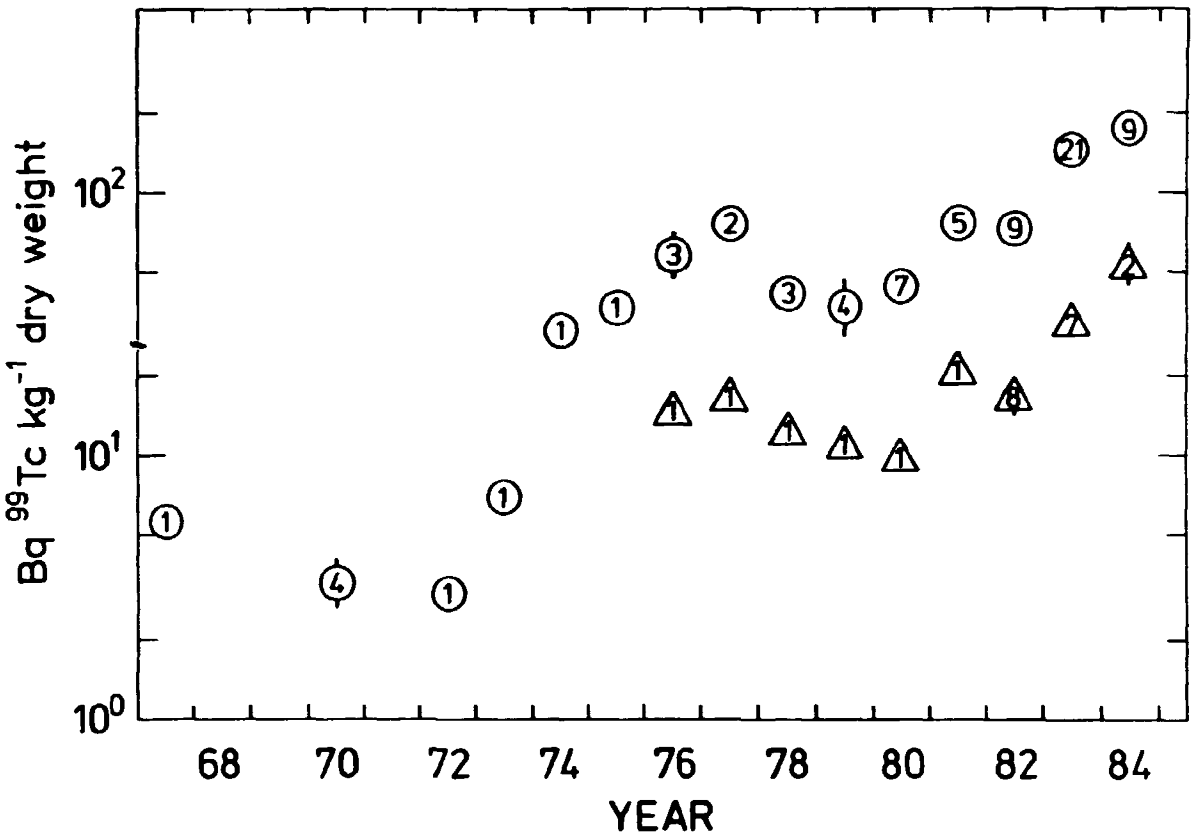


Fig. 4.5.3. Annual mean values of ^{99}Tc in Fucus vesiculosus calculated from Table 4.5.1. The number of samples and ± 1 S.E. is indicated. The circles represent the samples from the Cattegat (Ringhals, Klint and Särdal) and the triangles represent the Sound (Barsebäck).

Water samples were collected in 1984 at Klint and from these we determined the observed ratio between ^{99}Tc in Fucus vesiculosus and sea water. We have mutual observations of Fucus and water from February, April, July and August and we found a mean ratio of: $(155 \pm 54) \times 10^3$ (n = 4; ± 1 S.E.) Bq kg^{-1} Fucus vesiculosus/ Bq l^{-1} sea water. Holm[10] has estimated concentration ratios for ^{99}Tc in Fucus vesiculosus going from 25 000 to 85 000. Until more data are available we shall use 10^5 as the concentration ratio for ^{99}Tc in Fucus vesiculosus compared with sea water. If we use this ratio we can estimate the transfer factor from Sellafield discharges to the surface water of the Cattegat to 16 Bq ^{99}Tc m^{-3} per PBq ^{99}Tc a^{-1}. This factor is the same as that obtained for ^{90}Sr[14] in the Cattegat. It is likely that ^{90}Sr and ^{99}Tc should show similar transfer factors because neither of these radionuclides are carried to the sediments to any appreciable extent.

4.6. Technetium-99 in seaweed samples collected in northern U.K. in 1982

The results from this cooperative study between the University of Lund and Risø have been reported in Risø-R-488 Appendix B[1].

However, in that report no ^{99}Tc data were given. These are now presented in Table 4.6.1. As for ^{137}Cs we may relate the concentrations to the distance from Sellafield as shown in Fig. 4.6. As compared with ^{137}Cs, the ^{99}Tc concentration decreased less rapidly with distance. The exponent for ^{137}Cs was -0.94 while it was -0.62 for ^{99}Tc. This may be due to some sedimentation of ^{137}Cs. However, the discharge pattern[13] of ^{99}Tc is different from that of ^{137}Cs and this may also influence the distance relations (cf. also 4.7).

In Table 4.6.2 we have summarized the ^{99}Tc data for Fucus vesiculosus collected in the North Atlantic region since 1980. The distribution of activity is very similar to that seen for radiocesium[6].

From Table 4.6.1 we may calculate the ^{99}Tc activity ratios between various species and Fucus vesiculosus. We found the following ratios: Fucus serratus/Fu.ve. = 0.60±0.05 (n = 6, ± 1 S.D.): Ascophyllum nodusum/Fu.ve. = 2.4±1.0 (n = 3, ± 1 S.D.) and Pelvetia canaliculata/Fu.ve. = 1.2±0.4 (n = 2, ± 1 S.D.

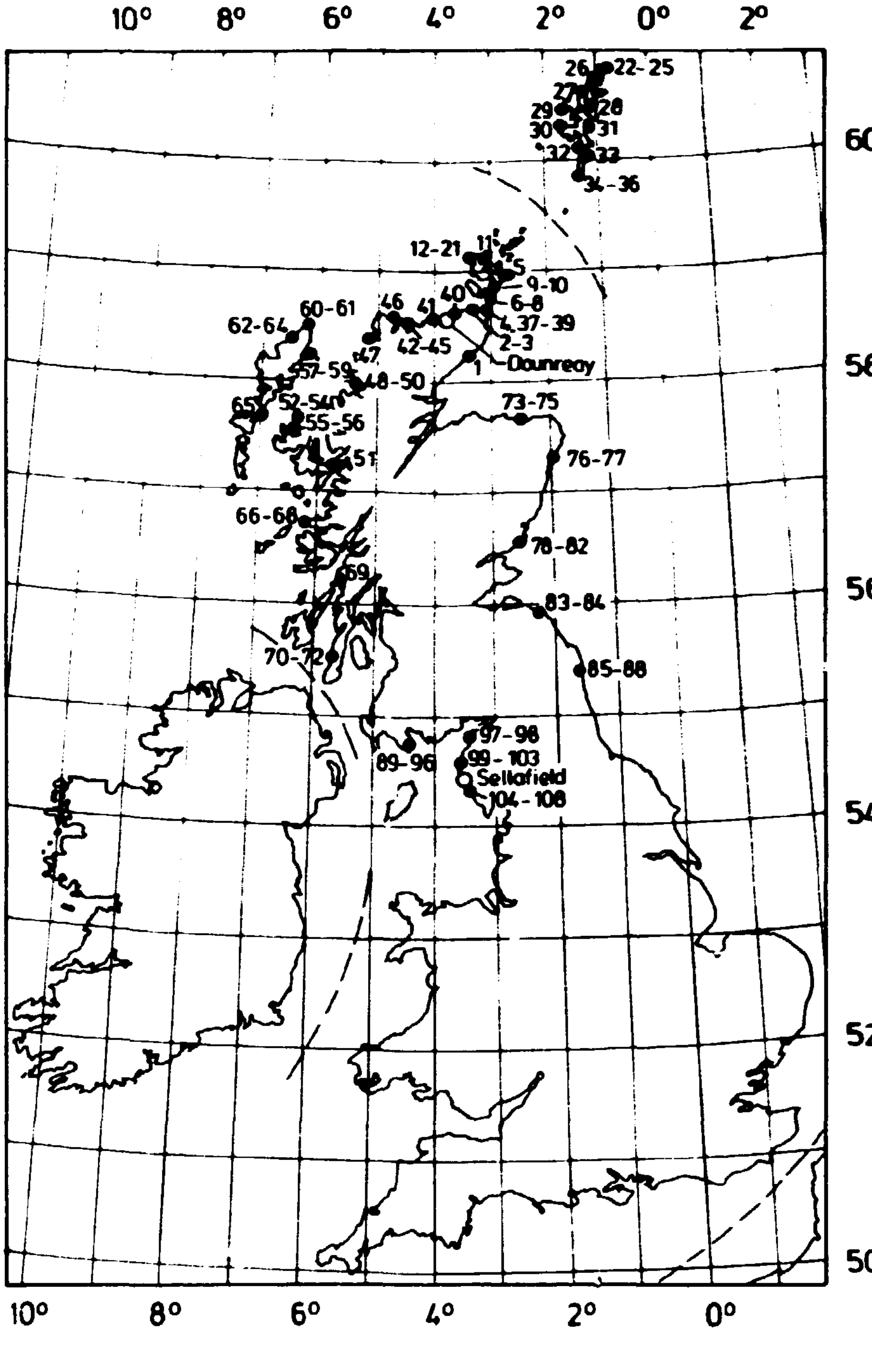


Fig. 4.6.1. Sampling location (station No.) June 1982.

Table 4.6.1. Technetium-99 in sea weed collected in the Northern U.K. in June 1983

Station No.	Lattitude N	Longitude W	Species	Bq ^{99}Tc kg^{-1} dry w.	Distance in km from Sellafield	Name of location
1[Δ]	58°03'	03°30'	Fu.sp.	420	790	Berriedale
2[Δ]	58°31'	03°21'	Fu.se.	50	710	Dunnet Head
4[Δ] & 37[Δ]	58°30'	03°05'	Fu.ve.	675±85*	730	John o'Groats
5[Δ]	58°57'	02°44'	Fu.sp.	240	760	Skaill, Orkneys
6[Δ]	58°44'	03°00'	Fu.ve.	470	730	Burwick, Orkneys
9[Δ]	58°51'	02°56'	Fu.ve.	330	740	S. of Burray, Orkneys
11[Δ]	59°07'	03°07'	Fu.se.	320	740	Evie, Orkneys
14[Δ]	59°07'	03°21'	Fu.se.	430	730	Brough of Birsay, Orkneys
15[Δ]	- " -	- " -	As.no.	1010	730	- " -
16[Δ]	- " -	- " -	Fu.sp.	400	730	- " -
17[Δ]	- " -	- " -	Fu.ve.	710	730	- " -
18[Δ]	- " -	- " -	Pe.ca.	670	730	- " -
20[Δ]	- " -	- " -	La.di.	134	730	- " -
21[Δ]	- " -	- " -	Ha.si.	520	730	- " -
22[Δ]	60°48'	00°46'	Fu.ve.	64	970	Lamba Ness, Shetland Isl.
26[Δ]	60°44'	00°57'	Fu.ve.	69	950	Westing, - " -
27[Δ]	60°35'	01°11'	Fu.ve.	174	930	West Sand Wiek, - " -
28[Δ]	60°30'	01°03'	Fu.ve.	72	940	Burra Voe, - " -
29[Δ]	60°29'	01°37'	Fu.ve.	126	890	Stenness, - " -
30[Δ]	60°18'	01°40'	Fu.ve.	122	880	Melby, - " -
31[Δ]	60°15'	01°09'	Fu.ve.	61	910	Gletness - " -
32[Δ]	60°06'	01°20'	Fu.se.	49	880	Hamna Voe, - " -
33[Δ]	60°03'	01°12'	Fu.ve.	99	890	Aith Wiek - " -
34[Δ]	59°52'	01°18'	Fu.se.	69	860	Sumburgh - " -
40	58°28'	03°42'	Fu.ve.	1400	690	Crosskirk Bay
41	58°26'	03°59'	Fu.sp.	740	680	Balicill
42	58°25'	04°27'	Fu.ve.	1150	650	Talmine
43	58°25'	04°27'	Fu.se.	630	650	Talmine
46	58°27'	04° 43'	Fu.ve.	1470	630	Sangobeg
47	58°17'	05°12'	Fu.ve	1260±20*	590	Tarbet
48	57°55'	05°26'	Fu.ve.	1170	560	Achiltibuie pier
51	57°12'	05°53'	Fu.ve.	1300±28**	440	Kyleakin
54	57°32'	06°30'	Fu.ve.	1660	480	Score Bay
55	57°32'	06°32'	Fu.ve.	1170	480	Uig
59	58°11'	06°15'	Fu.ve.	960±70*	550	Tiumpan Head
60	58°26'	06°16'	Fu.ve.	980	580	Port of Ness
62	58°17'	06°41'	Fu.ve.	1080±20*	570	Arno
65	57°42'	07°07'	Fu.ve.	930	480	Rodel, Harris
68	56°37'	06°28'	Fu.ve.	1430±80*	370	Point of Ardnamurchan
69	56°09'	05°23'	Fu.ve.	1890±140*	290	Asknis Bay
72	55°27'	05°35'	Fu.ve.	1830±20*	210	Bellochantuy Bay

Table 4.6.1. (continued)

Station No.	Lattitude N	Longitude W	Species	Bq ^{99}Tc kg^{-1} dry w.	Distance in km from Sellafield	Name of location
73^Δ	57°32'	02°33'	Fu.ve.	500	840	Banff
76^Δ	57°17'	01°50'	Fu.ve.	520	890	Port Erroll
77^Δ	57°17'	01°50'	Fu.se.	360	890	- " -
78^Δ	56°26'	02°32'	Fu.ve.	300	990	Arbroath
79^Δ	- " -	- " -	Fu.se.	180	990	- " -
83^Δ	55°48'	02°20'	Fu.se.	240	1050	Reed Pt. Cove
84^Δ	- " -	- " -	Fu.ve.	380	1050	- " -
85^Δ	55°16'	01°37'	Fu.ve.	400	1110	Alnmouth
89	54°37'	04°19'	Fu.ve.	2400	66	N of Isle Whithorn
90	- " -	- " -	Fu.ve.	3100	66	- " -
91	- " -	- " -	Fu.ve.	3500	66	- " -
92	- " -	- " -	Fu.ve.	3600	66	- " -
93	- " -	- " -	Fu.se.	1790	66	- " -
94	- " -	- " -	As.no.	11200	66	- " -
95	- " -	- " -	Pe.ca.	4800	66	- " -
97	54°43'	03°23'	Fu.ve.	3300	55	Beckfoot
99	54°17'	03°35'	Fu.ve.	6100	23	Whitehaven
100	- " -	- " -	Fu.sp.	3000	23	- " -
101	- " -	- " -	As.no.	13900	23	- " -
104	54°17'	03°30'	Fu.ve.	19700	3	Seascale
105	- " -	- " -	As.no.	48000	3	- " -

Fe.ve.: Fucus vesiculosus; Fu.se.: Fucus serratus; Fu.sp.: Fucus spiralis;

As.no.: Ascophyllum nodosum; Pe.ca.: Pelvetia canaliculata; Ha.si.: Halidius siliquosa;

La.di.: Laminaria digitata.

^ΔSamples analysed by University of Lund.

*The error term is ± 1 S.E. of the mean of double determinations. **Four determinations.

Table 4.6.2. Technetium-99 in Fucus collected in the North Atlantic region 1980-1983

Location	Position	Bq kg^{-1} dry weight ± 1 S.D.	Number of samples in mean
Sellafield	54°17'N, 03°30'W	19700	1
English west coast	54°30'N-55°00'N	3800±1350	5
Scottish west coast	55°00'N-58°30'N	1220±390	11
Scottish north coast	05°00'W-03°00'W	870±410	10
Irish east coast	53°00'N-54°30'N	570±70	4
The Orkney Islands	58°44'N-59°07'N	410±180	5
Scottish east coast	56°00'N-58°30'N	440±123	3
East England	55°00'N-56°00'N	390±12	2
The Shetland Islands	59°52'N-60°48'N	91±39	10
Irish northwest coast	54°00'N-55°00'N	7.2±0.1	2
The Faroe Islands	62°N, 07°W	1.9±0.3	2
SW-Norway	58°N-60°N	120±40	3
NW-Norway	65°N-71°N	73±23	3
Svalbard	76°N-80°N	15±8	3
East Greenland	65°N-75°N	7±1.3	4
West Greenland	61°N-71°N	3.7±0.1	3
Iceland	63°30'N-66°30'N	1.0±0.4	7

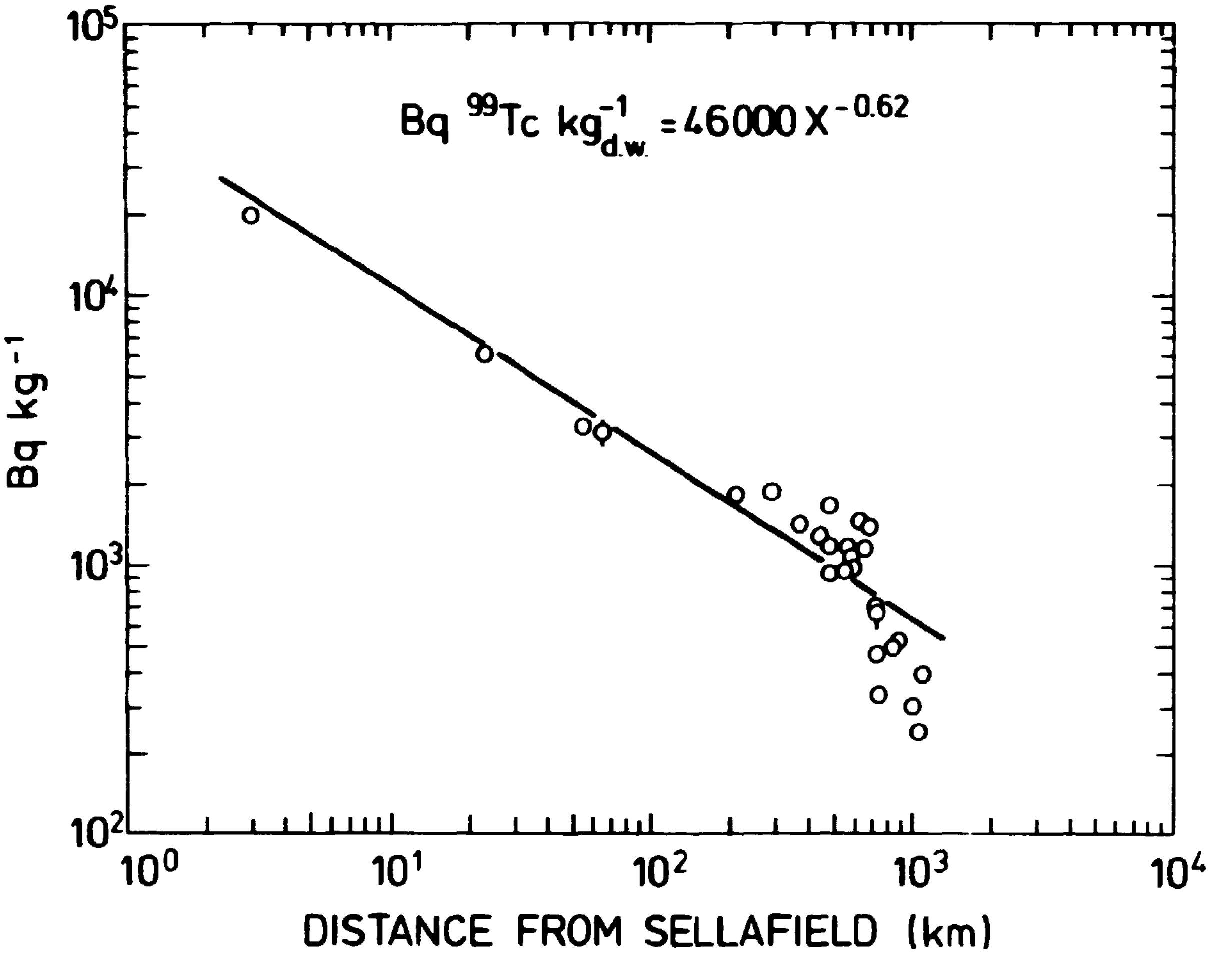


Fig. 4.6.2. Technetium-99 in Fucus vesiculosus collected in the Northern U.K. in June 1982 related to distance from Sellafield.

4.7. Radionuclides in seaweed collected in Ireland and Ulster in 1983

Risø National Laboratory and the University of Lund collected a number of seaweed samples along the Irish west and north coasts in April 1983 (cf. Fig. 4.7). The samples were analysed for radiocesium, transuranic elements and ^{99}Tc (cf. Table 4.7).

The mean ratio of ^{238}Pu to ^{239,240}Pu of those samples, which contained more than 0.5 Bq ^{239,240}Pu kg^{-1} was 0.22±0.01 (n = 9, ± 1 S.D.) and the ^{134}Cs/^{137}Cs mean ratio of the same samples was 0.037±0.003 (n = 6, ± 1 S.D.). This suggests that Sellafield contributed with transuranics as well as radiocesium to these samples. In biota collected along the U.K. west coast out to a distance of 66 km from Sellafield we found in 1982 (Risø-R-

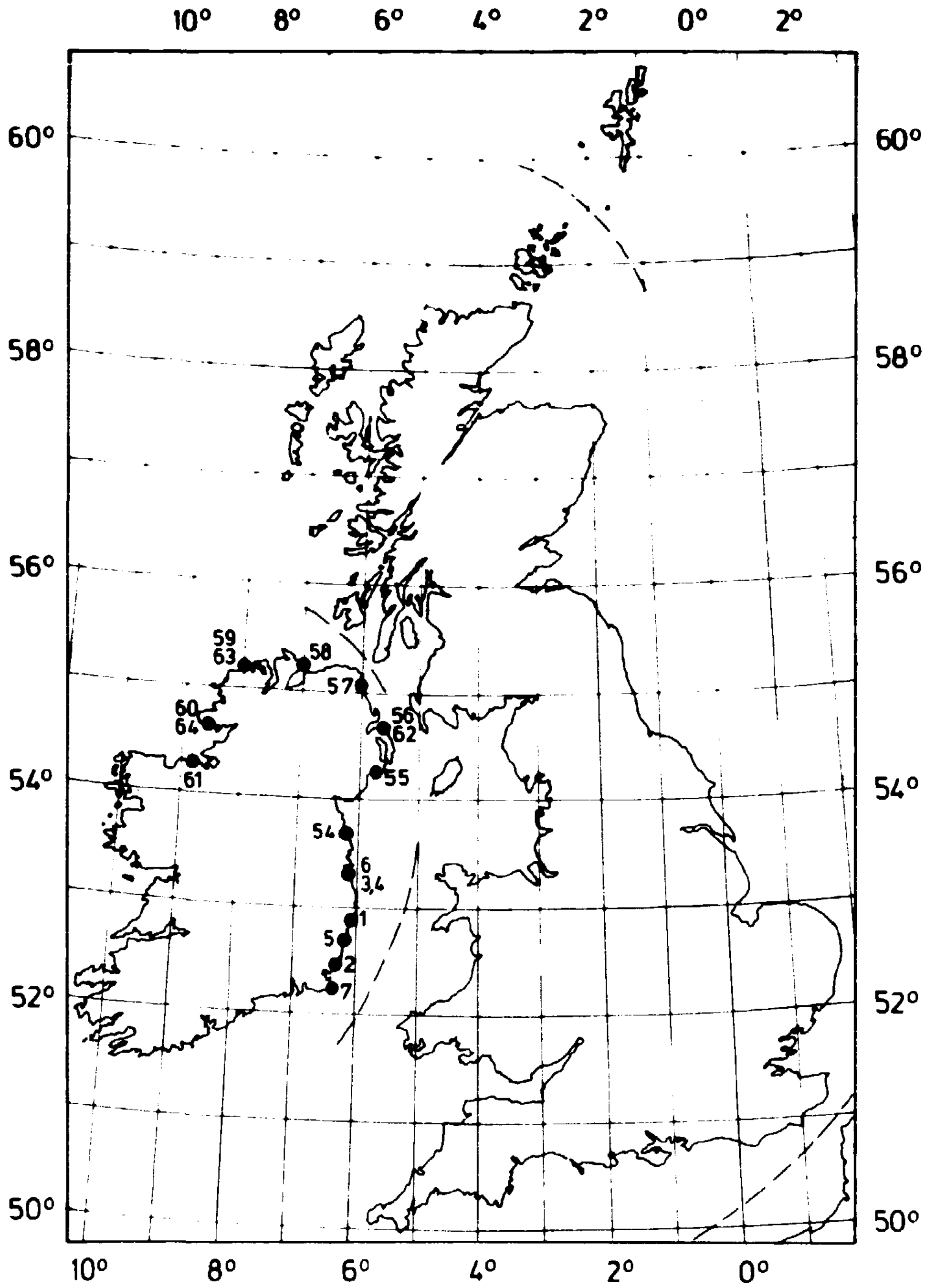


Fig. 4.7. Sampling stations for sea weed in Ireland in April 1983.

488)[1] a $^{238}Pu/^{239,240}Pu$ mean ratio of 0.23±0.08 (n = 20, ± 1 S.D.) and a $^{134}Cs/^{137}Cs$ ratio of: 0.036±0.003 (n = 20, ± 1 S.D.) decay corrected to 1983.

We may relate the ^{99}Tc and ^{137}Cs levels in seaweed to the distance from the sampling point with the highest activity, i.e. No. 56 (cf. Fig. 4.7). If we transfer all samples to Fucus vesiculosus by multiplying the ^{99}Tc levels with the following fac-

Table 4.7. Radionuclides in sea weed collected in Ireland in April 1983. (Unit: Bq kg^{-1} dry weight)

Station No. (cf.Fig.4.7)	Name of location	Lattitude N	Longitude W	Species	^{99}Tc	^{134}Cs	^{137}Cs	^{238}Pu	$^{239,240}Pu$	^{241}Am
1	Mizen Head	52°50'	6°08'	Fu.ve.	172	1.6	34.9	0.086	0.467	0.068
2	Wexford	52°20'	6°28'	Fu.ve.	41	0.5	11.6	0.017	0.155	0.035
3 + 4	Dun Laoghaire	53°18'	6°10'	As.no.	1270	2.8	77	0.23	1.09	0.132
5	Courtown	52°38'	6°14'	Fu.sp.	250	1.0	26.5	0.12	0.56	0.089
6	Dun Laoghaire	53°18'	6°10'	Fu.sp.	280	2.5	63.5	0.19	0.84	0.071
7	Rosslare	52°14'	6°21'	Fu.sp.	52	0.2	7.0	0.010	0.067	0.010
54*	Balbriggan			Fu.ve.	500	3.4	86	0.72	3.26	0.181
55*	Minerstown			Fu.sp.	350	3.6	94	0.74	3.45	0.061
56*	Donaghadee			Fu.se.	690	4.9	153	5.1	22.4	2.3
57*	Waterfoot			Fu.se.	450		77	1.98	9.2	1.67
58*	Inishowen Head			Fu.se.	140		10	0.43	1.85	0.193
59*	Dunfanaghy			Fu.ve.	15		1.7	-	0.13	0.08
60*	Laghy			Fu.ve.	7.2			-	0.087	B.D.L.
61*	Easky			Fu.ve.	7.3		1.2	-	0.114	0.024
62*	Donaghadee			La.di.			147	0.52	2.27	0.43
63*	Dunfanaghy			Fu.se.			1.4	-	0.16	0.015
64*	Laghy			Pe.ca.			0.7	-	0.060	0.003

Fu.ve.: Fucus vesiculosus; Fu.se.: Fucus serratus; Fu.sp.: Fucus spiralis; As.no.: Ascophyllum nodosum; Pe.ca.: Pelvetia canaliculata; La.di.: Laminaria digitata

*Samples collected and analysed by the University of Lund.

tors given by Holm et al.[10]: Fucus serratus: 1.77, Fucus spiralis: 1.85, Ascophyllum nodosum: 0.48 and Laminaria: 3.85, we get the following two equations: clockwise (southward) from station 56: Bq ^{99}Tc kg^{-1} = 1780 $A^{-0.36}$, and anticlockwise (northward) from station 56: Bq ^{99}Tc kg^{-1} = 2900 $A^{-0.84}$ for ^{137}Cs, we found: Bq ^{137}Cs kg^{-1} = 230 $A^{-0.33}$ (clockwise) and Bq ^{137}Cs kg^{-1} = 300 $A^{-0.86}$ (anticlockwise), where A is the distance in km from station A. In case of ^{137}Cs we did not transfer the levels to Fucus vesiculosus, because the various species do not differ significantly with respect to ^{137}Cs concentration factor. We notice that ^{99}Tc and ^{137}Cs show the same pattern. The levels are generaly lower south of location 56 than northward, but the activity decreases more rapidly northward.

As compared with the ^{137}Cs concentrations found on the English side of the Irish Sea the Irish levels were for the same lattitude band (54°N-55°N) lower by one order of magnitude and the ^{99}Tc levels were approximately 7 times lower on the Irish side.

4.8. Technetium-99 in seaweed collected along the Norwegian West-coast, at Svalbard and at Jan Mayen in 1980-1984

Institute of Energy Technology in Norway has with financial support from the Nordic Council of Ministers collected seaweed samples along the Norwegian coast since 1980[8,15]. The samples have been analysed for radiocesium, transuranic and technetium-99. Table 4.8.1 show the ^{99}Tc data from four stations ranging from station 3 in the far north to station 10 in south

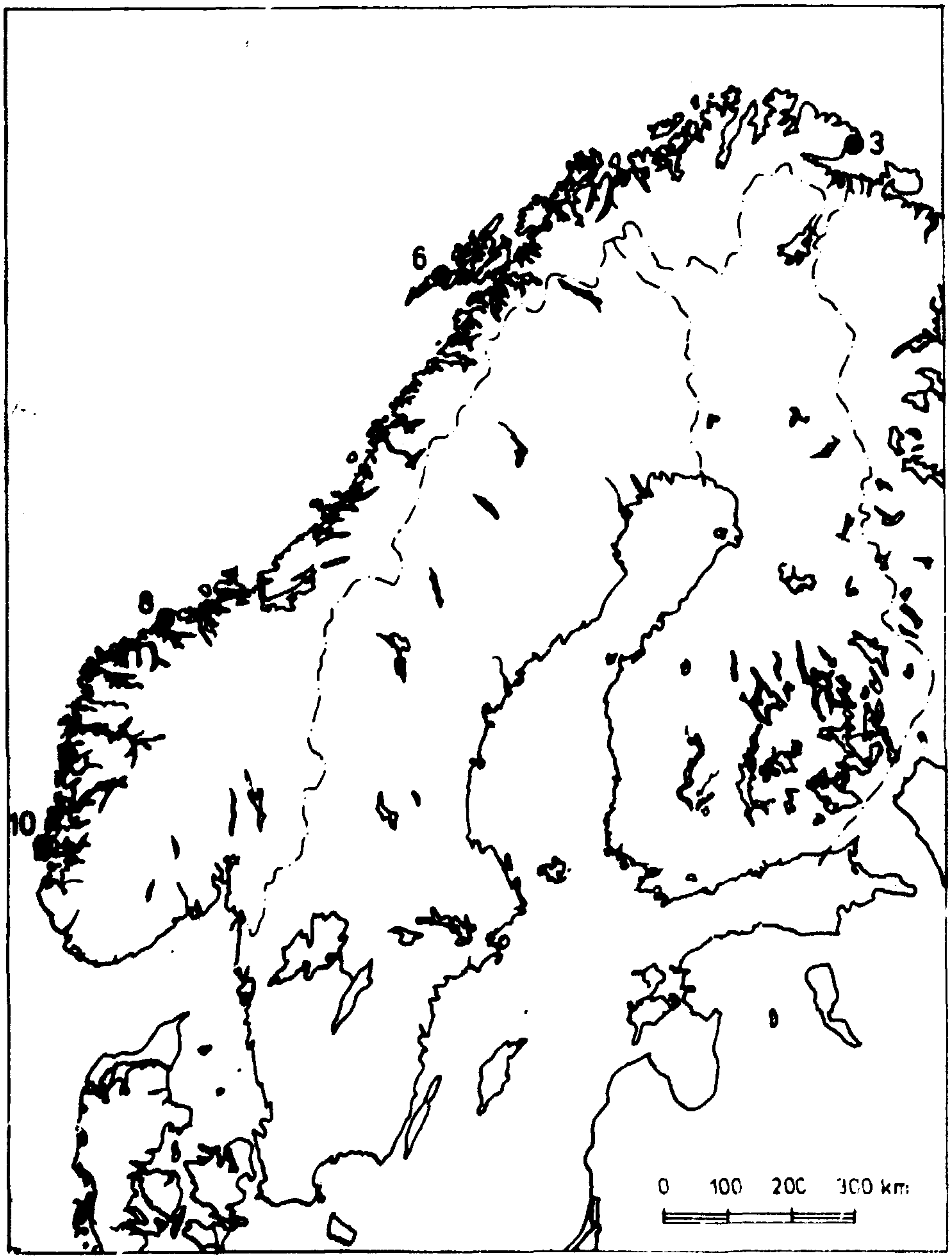


Fig. 4.8.1. Sampling locations for sea weed along the

Table 4.8.1. Technetium-99 in Fucus vesiculosus collected along the Norwegian west coast 1980-1984

Station No. (cf. Fig. 4.8.1)	Location	Bq ^{99}Tc kg^{-1} dry weight 1980	1981	1982	1983	1984	Estimated transit time from Sellafield in years	Approximate distance in km from Sellafield with currents
3	Indre Kiberg 70°17'N 30°56'E	20*	44	54	57		4	4000
6	Vestvågøy 68°10'N 13°50'E	40*	85	94	149		3-4	3000
8	Bud 62°38'N 7°35'E	60*	93	121	143		3(-4)	2300
10	Utsira 59°19'N 4°54'E	97*	200	107	144	178	3	1800

*Analysed by the University of Lund.

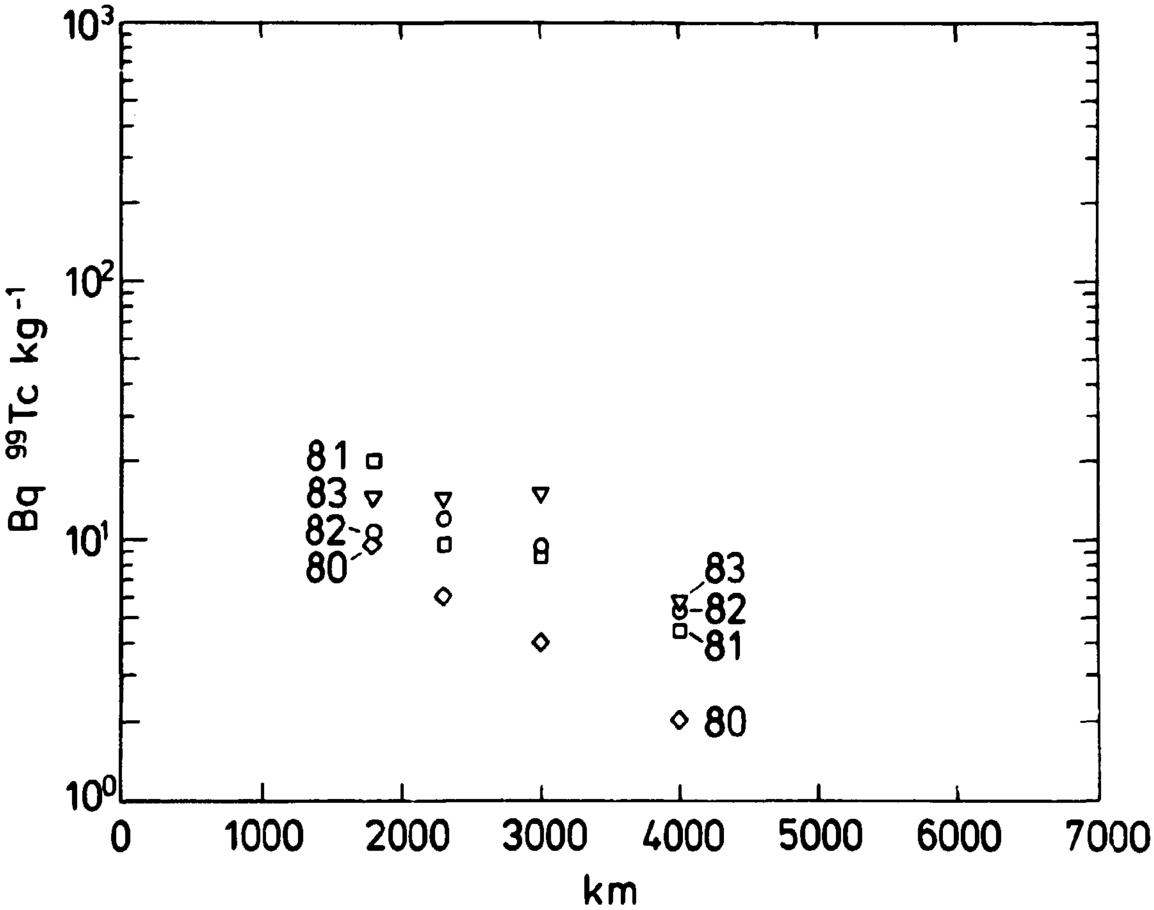


Fig. 4.8.2. Four-year observations of ^{99}Tc in Fucus vesiculosus collected along the Norwegian west coast in 1980-1983.

Table 4.8.2. Technetium-99 in sea weed collected at Svalbard and Jan Mayen in 1983

Station No.	Location (cf. Fig. 4.8.3)	Species	Date of sampling	Bq ^{99}Tc kg^{-1} dry weight
20-1	Jan Mayen 71°00'N 8°00'W	Al.es.	29 Aug	1.5
20-2	Jan Mayen 71°00'N 8°00'W	La.di.	29 Aug	0.62
20-3	Jan Mayen 71°00'N 8°00'W	La.sa.	29 Aug	0.74
23-5	Hinlopen 79°50'N 18°20'E	Al.es.	29 July	1.93
23-6	Dickson Fjord 78°46'N 15°00'E	Fu.sp.	5 Aug	8.0
23-7	Gråhuken 79°50'N 14°30'E	Al.es.	13 Aug	8.9
23-8	Calypsobyen 77°45'N 14°20'E	Al.es.	16 Aug	2.4
23-9	Mosselbakta 79°50'N 16°00'E	Fu.sp.	30 Aug	9.9
23-10	Kapp Martin 77°45'N 13°45'E	Al.es.	14 Sep	3.2
23-11	Dickson Fjord 78°46'N 15°00'E	Al.es.	5 Aug	6.7

Al.es.: Alaria esculenta; La.di.: Laminaria digitata;

La.sa.: Laminaria saccharina; Fu.sp.: Fucus spiralis.

west Norway (cf. Fig. 4.8.1). From 1980 to 1983 the levels at the northern stations increased by a factor of 3 while the southern increased by a factor of 1.5 to 2 (cf. Fig. 4.8.2). The transit time from Sellafield to station 10 is approximately 3 years, while we assume that it takes approximately 4 years for the effluents to reach station 3 in the north[7]. If we use the Sellafield discharges given in Table 4.4.2 and calculated in 4.5, we can estimate the following transfer factors to Fucus vesiculosus collected along the Norwegian coastline. Station 3: 0.7±0.2 Bq ^{99}Tc kg^{-1} per TBq ^{99}Tc a^{-1}; station 6: 1.3±0.5; station 8: 1.5±0.5 and station 10: 1.9±0.4: (n = 4, ± 1 S.E.). As mentioned earlier (4.5) we may in the later years also see a contribution of ^{99}Tc from Cap de la Hague. This may explain why the transfer factors are increasing in 1982, and in particular in 1983.

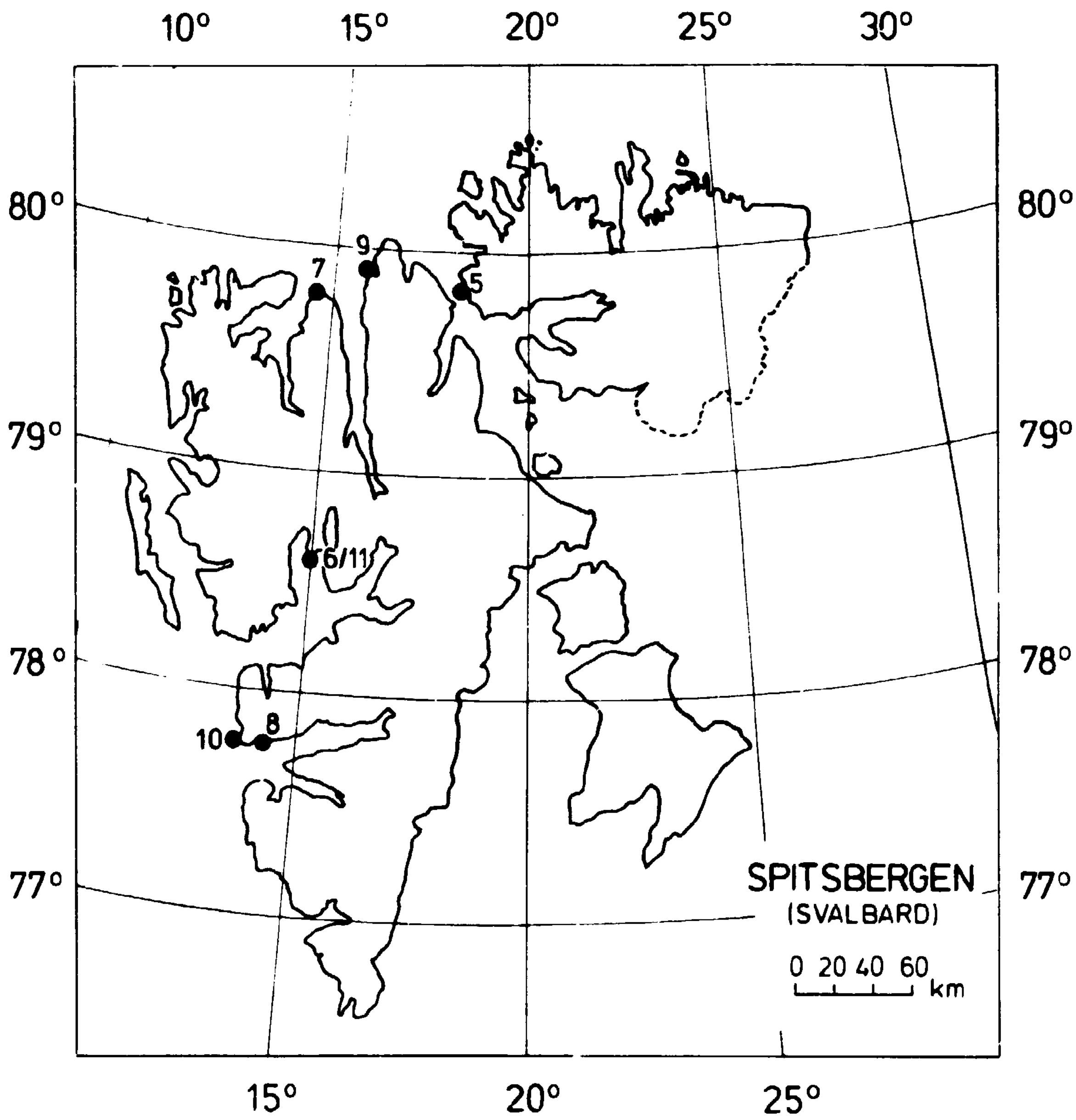


Fig. 4.8.3. Sampling locations for sea weed at Svalbard (cf. Table 4.8.2).

Table 4.8.2 shows some results from Jan Mayen and Svalbard (cf. Fig. 4.8.3) from samples collected in 1983. Compared with the ^{99}Tc levels found in 1981 by Holm et al.[15] at Svalbard there have only been minor changes in 1983. Unfortunately, none of the samples consist of Fucus vesiculosus. However, if we use the correction factors given by Holm et al.[10] (cf. 4.7) we may estimate that the hypothetical Fucus vesiculosus level has been 2-3 Bq ^{99}Tc kg^{-1} at Jan Mayen and 16-17 Bq ^{99}Tc kg^{-1} at Svalbard. If the transit time to Jan Mayen is 6-7 years[16], and if the fallout background in Fucus is 1-2 Bq ^{99}Tc kg^{-1} (cf. 4.3) the transfer factor becomes approximately 20 Bq ^{99}Tc kg^{-1} per PBq ^{99}Tc a^{-1}. At Svalbard, to where the transit time is 5-6 years[7], the transfer factor becomes approximately 120 Bq ^{99}Tc kg^{-1} per PBq ^{99}Tc a^{-1}.

These hypothetical transfer factors to Fucus from Jan Mayen and Svalbard are lower by nearly an order of magnitude than we would expect from our seawater measurements[6]. As the transfer factors calculated from the Greenland fucus samples (cf. 4.3), on the other hand, are an order af magnitude higher than expected from the seawater measurements, we need more information on Fucus (and other algae) and seawater ^{99}Tc concentrations in the Arctic. As mentioned above (4.3) the concentration factor for ^{99}Tc in Fucus may show local variations.

4.9. Intercomparison studies of transuranics in North Atlantic deep sea sediments from the NEA dumpsite

Two cores (Nos. 4 and 11) taken on the Tyro 82 cruise to the NEA dumpsite (45°50'N to 46°10'N and between 16°W and 17°30'W) in August-September 1982[16] were obtained from Dr. V. Noshkin, Lawrence Livermore National Laboratory. The cores had been sectioned into 1 cm depth increments and the surface area of each section is 28.2 cm^2. The two cores were subcores from two different 0.25 m^2 Mark III box cores, from each of which Dr. Noshkin had analysed another duplicate subcore.

Ten (or twenty for the weakest samples) grammes aliquots of dried sediments were analysed for Pu and Am by the methods of Talvitie[17] and Holm[18].

Table 4.9.1. Plutonium and americium in core T 8204 B collected at the NEA dump site in 1982

No.		Segment in cm	$^{239,240}Pu$ Bq kg^{-1}	$^{239,240}Pu$ Bq m^{-2}	^{239}Pu Bq kg^{-1}	^{241}Am Bq kg^{-1}
PMSG	Ø88	0-1	0.36 (7)	2.43	0.023 (23)	0.093 (10)
-	89	1-2	0.164 (10)	1.17	0.0156(30)	0.018 (32)
-	90	2-3	0.100 (10)	0.71	0.0084(27)	-
-	91	3-4	0.067 (13)	0.50	0.0047(33)	-
-	92	4-5	0.049 (16)	0.34	-	-
-	93	5-6	lost	-	-	-
-	94	6-7	0.0148(18)	0.11	-	-
-	95	7-8	0.040 (17)	0.30	-	-
-	96	8-9	0.0182(21)	0.14	-	-
-	97	9-10	0.0092(27)	0.07	-	-
-	98	10-11	0.0067(33)	0.06	-	-

The relative S.D. (in %) due to counting statistics are shown in brackets.

Core 4 (Table 4.9.1) shows an exponentially decreasing $^{239,240}Pu$ concentration with a half depth of 2 cm. Core 11 (Table 4.9.2) shows a subsurface maximum at 2-4 cm depth. The $^{239,240}Pu$ inventories of the two cores down to 11 cm were 5.83 Bq m^{-2} (0.16 mCi km^{-2}) and 7.01 Bq m^{-2} (0.19 mCi km^{-2}), respectively. Noshkin[16)] found 0.16 and 0.22 mCi $^{239,240}Pu$ km^{-2}, respectively, in his corresponding subcores. The mean ratio of the concentrations in the various layers found by Risø and Livermore was 1.08±0.70 (n = 18; ± 1 S.D.). This shows that the horizontal activity distribution of the box cores are inhomogeneous. However, the inventories of the 0-11 cm layers within a core are the same. The results, furthermore, show that there is no systematic bias between the Pu-analysis performed by Livermore and Risø.

Table 4.9.2. Plutonium and americium in core T 8211 B collected at the NEA dump site in 1982

No.	Segment in cm	$^{239,240}Pu$ Bq kg^{-1}	$^{239,240}Pu$ Bq m^{-2}	^{239}Pu Bq kg^{-1}	^{241}Am Bq kg^{-1}
PMSG 198	0-1	0.23 (9)	1.41	0.0172(32)	0.098 (12)
- 199	1-2	0.093 (11)	0.66	-	-
- 200	2-3	0.172 (6)	1.22	0.0187(30)	0.054 (14)
- 201	3-4	0.207 (7)	1.63	-	0.038 (18)
- 202	4-5	0.054 (17)	0.40	-	-
- 203	5-6	0.074 (10)	0.55	0.0040(33)	-
- 204	6-7	0.027 (16)	0.21	-	-
- 205	7-8	0.030 (17)	0.22	-	-
- 206	8-9	0.035 (17)	0.28	-	-
- 207	9-10	0.045 (14)	0.33	-	-
- 208	10-11	0.0135(27)	0.10	-	-

The relative S.D. (in %) due to counting statistics are shown in brackets.

The $^{238}Pu/^{239,240}Pu$ mean ratio was 0.08±0.02 (n = 7; ∓ 1 S.D.) and the $^{241}Am/^{239,240}Pu$ mean ratio was 0.26±0.12 (n = 5; ± 1 S.D.). These ratios are compatible with those expected from global fallout. We can thus support the conclusion of Noshkin[16)] who stated that no evidence of plutonium contamination in these samples from any other source than global fallout had been found.

Throughout the years Risø National Laboratory has participated in the intercalibration exercises organised by the IAEA Monaco Laboratory.

In the intercomparison of marine sediment SD-N-1/1[19)] we had laboratory code No. 3. The mean of the accepted $^{239,240}Pu$ results was 0.57, we found 0.53 (mBq g^{-1}); our ^{238}Pu and ^{241}Am results were also within the accepted range.

ACKNOWLEDGEMENTS

The authors wish to thank Anna Holm Petersen, Else Marie Sørensen, Jytte Clausen, Anna Madsen, Karen Wie Nielsen, Elise Ebling, Oda Brandstrup, Alice Kjølhede, Helle Porsdal, and Karen Mandrup Jensen for their conscientious performance of the analyses.

Martin Munch Hansen the Greenland Fisheries and Environmental Research Institute kindly provided us with fucus samples from West Greenland in 1982-1983.

Our thanks are furthermore due the Institute of Hygiene in Thorshavn, to the district physicians in Greenland and the telestations, GTO and all other persons and institutions in Greenland, the Faroe Islands and Denmark who have contributed by collecting samples.

The Alfred Wegener Institute for Polar Research, Bremerhaven, is acknowledged for its kind invitation to participate in the 1983 Mizex- and Fram Strait cruise on board the icebreaking R.V. "Polarstern".

The present study was partly sponsored by the C.E.C. Radiation Protection Research Programme and the Nordic Liaison Committee for Atomic Energy (NKA).

We finally thank the Commission for Scientific Research in Greenland for permission to collect samples in Greenland.

REFERENCES

1) Environmental Radioactivity in the Faroes 1962-1982. Risø Reports Nos. 64, 86, 108, 131, 155, 181, 202, 221, 246, 266, 292, 306, 324, 346, 362, 387, 404, 422, 448, 470 and 488 (1963-1983).

2) Environmental Radioactivity in Greenland 1962-1982. Risø Reports Nos. 65, 87, 109, 132, 155, 182, 203, 222, 247, 267, 293, 307, 325, 347, 363, 388, 405, 423, 448, 471 and 489 (1963-1983).

3) A. Aarkrog, S. Boelskifte, L. Bøtter-Jensen, H. Dahlgaard, Heinz Hansen, and S.P. Nielsen, Environmental Radioactivity in Denmark in 1983. Risø Report No. 509 (1984).

5) A. Aarkrog, Environmental Studies on Radioecological Sensitivity and Variability. Risø-R-437 (June 1979).

6) A. Aarkrog, H. Dahlgaard, H. Hansen, E. Holm, L. Hallstadius, J. Rioseco and G. Christensen. Radioactive Tracer Studies in the Surface Waters of the North Atlantic. To be published in RIT FISKIDEILDAR as proceedings from a Nordic Symposium on Chemical Tracers for Studying Water Masses and Physical Processes in the Sea in Reykjavik Aug 28-Sept 1, 1984.

7) H. Dahlgaard, A. Aarkrog, L. Hallstadius, E. Holm and J. Rioseco. Radiocesium Transport from the Irish Sea via the North Sea and the Norwegian Coastal Current to East Greenland. Proceedings from Symposium on Contaminant Fluxes through the Coastal Zone. Nantes, France, 14-16 May 1984.

8) G. C. Christensen. Radioaktivitet i Blæretang (Fu. ve.) langs Norskekysten 1980-1981. 3. Nordic Seminar on Radioecocology in Hyvinkää, Finland 11-13 May 1982.

9) A. Aarkrog, H. Dahlgaard, L. Hallstadius, E. Holm, S. Mattsson & J. Rioseco. Time Trend of ^{99}Tc in Seaweed from Greenland Waters. Proceeding from Scientific Seminar on the Behaviour of Technetium in the Environment. Cadarache, France 23-26 Oct. 1984 (to be published in Journal of Environmental Radioactivity).

10) E. Holm, J. Rioseco, A. Aarkrog, H. Dahlgaard, L. Hallstadius. Technetium-99 in Algae from Temperate and Arctic Waters of the North Atlantic. (Ibid 9).

11) A. Aarkrog, H. Dahlgaard, L. Hallstadius, H. Hansen and E. Holm. Radiocesium from Sellafield Effluents in Greenland Waters. Nature 304, p. 49-51 (1983).

12) D.J. Ellett and N. MacDougall. Some monitoring results from west of Britain. In: Time Series of Ocean Measurement, Vol. 1-1983, UNESCO, p. 21-25.

13) BNFL 1978-1983. Annual Report on Radioactive Discharge and Monitoring of the Environment. British Nuclear Fuels Limited, Risley, Warrington, Cheshire, U.K.

14) A. Aarkrog, H. Dahlgaard and S. Boelskifte. Transfer of Radiocesium and ^{90}Sr from Sellafield to the Danish Straits. Cooperative Programme on the Study of Radioactive Materials in the Baltic Sea. IAEA, Vienna 1984.

15) E. Holm, J. Rioseco and G.C. Christensen. ^{99}Tc in Fucus from Norwegian Waters. In: International Symposium on the Behaviour of Long-lived Radionuclides in the Marine Environment p. 357-367. Report EUR 9214 EN, CEC, Brussel, 1984.

16) V.E. Noshkin, K.M. Wong and R.J. Eagle, "Radionuclides in sediments from the North-East Atlantic Disposal Site". UCID 199 24. Lawrence Livermore Laboratory (1983).

17) N.A. Talvitie, "Radiochemical Determination of Plutonium in Environmental and Biological Samples by Ion Exchange. Anal. Chem. 43, 1827 (1971).

18) E. Holm, S. Ballestra and R. Fukai. A Method for Ion Exchange Separation of Low Levels of Americium in Environmental Samples. Talanta, 26, 791-794 (1979).

19) IAEA, Monaco Laboratory. "Intercomparison of Artificial Radionuclide Measurements on Marine Sediment SD-N-1/1. Report No. 21 (1984).

Sales distributors:
G.E.C. Gad Strøget
Vimmelskaftet 32
DK-1161 Copenhagen K, Denmark

Available on exchange from:
Risø Library, Risø National Laboratory,
P.O.Box 49, DK-4000 Roskilde, Denmark

ISBN 87-550-1036-9
ISSN 0106-2840