Environmental radioactivity in Denmark in 1983

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

ERRATA to RISØ-R-509

Environmental Radioactivity in Denmark in 1983.

p 16 Table 3.2.1.1.

Cesium-137, 13 December, station 25:
87 Bq kg^{-1}: read 8.7 Bq kg^{-1}

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The tritium results for precipitation are shown in Tables 4.2.7., and 4.2.8. Tritium in ground water is shown in Table 4.3.1. Tables 4.4.3., and 4.4.5. show the tritium content in sea water.

Risø-R-509

ENVIRONMENTAL RADIOACTIVITY IN DENMARK IN 1983

A. Aarkrog, S. Boelskifte, L. Bøtter-Jensen,
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Abstract. Strontium-90 was determined in samples from all over the country of precipitation, ground water, stream and lake water, sea water, dried milk, grain, bread, potatoes, vegetables, fruit, total diet, and human bone. Furthermore, ^{90}Sr was determined in local samples of air, rain water, grass, sea plants, fish and meat. Cesium-137 was determined in air, precipitation, sea water, sediments, milk, grain products, potatoes, vegetables,

(continued)

INIS-Descriptors: AIR; AMERICIUM ISOTOPES; AQUATIC ECOSYSTEMS; ATMOSPHERIC PRECIPITATIONS; BACKGROUND RADIATION; BARSEBAECK-1 REACTOR; BARSEBAECK-2 REACTOR; BONE TISSUES; CESIUM 137; COBALT 58; COBALT 60; DENMARK; DIET; DRINKING WATER; ENVIRONMENT; FALLOUT DEPOSITS; FISHES; FOOD; FOOD CHAINS; GLOBAL FALLOUT; GROUND WATER; LOCAL FALLOUT; MAN; MANGANESE 54; MILK; PLANTS; PLUTONIUM ISOTOPES; RADIOACTIVITY; RINGHALS-1 REACTOR; RINGHALS-2 REACTOR; RINGHALS-3 REACTOR; RISOE NATIONAL LABORATORY; SEAWATER; SEAWEEDS; SEDIMENTS; STRONTIUM 90; TRITIUM; ZINC 65.

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fruit, total diet, sea plants, fish, and meat. Estimates of the mean contents of radiostrontium and radiocesium in the human diet in Denmark during 1983 are given. Tritium was determined in precipitation, ground water and sea water. Plutonium and Americium were measured in marine samples. The γ-background was measured regularly by TLD, ionization chamber and on site γ-spectroscopy at locations around Risø, at ten of the State experimental farms, along the coasts of the Great Belt and around Gylling Næs. The marine environments at Barsebäck and Ringhals were monitored for ^{137}Cs and corrosion products (^{58}Co, ^{60}Co, ^{65}Zn, ^{54}Mn).

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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)

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)
P: peta: 10^{15}
T: tera: 10^{12}
G: giga: 10^{9}
M: mega: 10^{6}
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.

cpm: counts per minute
dpm: disintegrations per minute
OR: observed ratio
CF: concentration factor
FP: fission products
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

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

A: relative standard deviation 20-33%

B: relative standard deviation >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. INTRODUCTION

1.1.

The present report is the twenty-seventh of a series of periodic reports (cf. ref. 1) dealing with measurements of radioactivity in Denmark. The organization of the material in the present report corresponds to that of last years report. After the introduction and a chapter on organization and facilities there follows a chapter on environmental monitoring around nuclear facilities (Risø, Barsebäck and Ringhals). Chapter four deals with fallout nuclides in the abiotic environment, i.e. air, water and soil. Chapters five and six comprise fallout nuclides in the human diet and human tissues, respectively. Chapter seven is devoted to a general discussion of our environmental tritium studies. External radiation is treated in chapter eight. The names of the authors of each chapter appear at its head.

The Becquerel has replaced the Curie, however, in tables (mean values) and figures the Curie is shown for comparison. In the figures we have used the right-hand ordinate for Curie.

1.2.

The methods of radiochemical analysis[2-4] and the statistical treatment of the results[5,12] are still based on the principles established in previous reports[1].

1.3.

The detailed tables of the environmental monitoring programme for Risø National Laboratory appear in the two semiannual reports: Radioactivity in the Risø district January-June 1983 and July-December 1983.

1.4.

The report contains no information on sample collection and analysis except in cases where these procedures have been altered.

1.5.

In 1983 the personnel of the Environmental Control Section of the Health Physics Department consisted of two chemists, one biologist, one statistician, eight laboratory technicians, two sample collectors, and two laboratory assistants. The group for Electronics Development continued to give assistance with the maintenance of counting equipment, with the interpretation of γ-spectra and with data treatment. The programme (cf. 2) used in the calculations of ^{90}Sr and the γ-analysis, as well as the programme for data treatment, were developed by this group.

1.6.

The composition of the average Danish diet used in this report is identical with that proposed in 1962 by the late Professor E. Hoff-Jørgensen, Ph.D.

2. FACILITIES[1,6,7,8]

By S.P. Nielsen

2.1. Detectors

The activity of the samples is measured as follows:

Alpha (^{239}Pu, ^{241}Am): 20 solid-state surface barrier detectors connected to four multichannel analyzers (64 channels per detector) and another two for total alpha counting.

Beta (^{90}Y mainly): Six "multidetector"-systems each containing 5 sample counters and a common anticoincidence shield are now put into regular use. This type of detector has replaced the mechanical sample changers previously used.

Gamma (natural and fallout isotopes): 4 Ge(Li) detectors in 10 cm lead shields and connected to a 8192-channel analyzer with four-input facility. One further Ge(Li) detector mounted on a tripod and a 4096-channel analyzer are used for field measurements, and a 8" × 4" NaI(Tl) in an underground shielded room is used for whole-body counting. The Ge(Li) detectors have an efficiency of ~ 20% (relative to 3" × 3" NaI(Tl)).

2.2. Data treatment

Measured spectra are transferred to a Burroughs B7800 computer for evaluation.

A program system STATDATA[16] is developed for registration and treatment of environmental measurements including multichannel analyzer spectra. To date, approximately 65 000 sets of results have been registered covering the period from 1957.

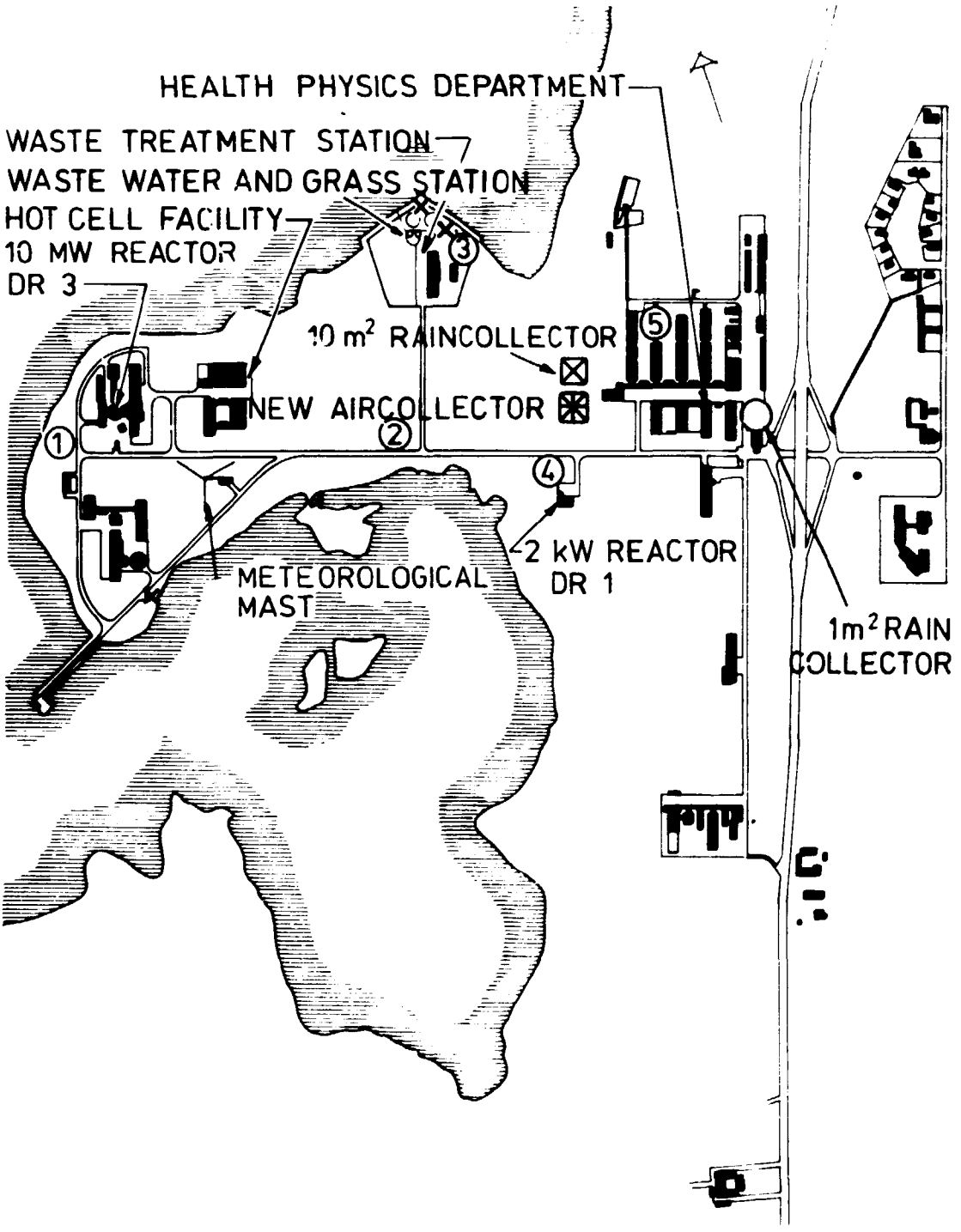

Fig. 3.1.1. Sampling locations at Risø National Laboratory. 1-5: locations for rain bottles (0.03 m^2 each), ion-exchange columns (0.06 m^2 each) and grass samples.

3. ENVIRONMENTAL MONITORING AT RISØ, BARSEBÄCK AND RINGHALS IN 1983

by H. Dahlgaard

3.1 Environmental monitoring at Risø

From the two semiannual reports: Radioactivity in the Risø district January-June 1983 and July-December 1983 the results of the environmental monitoring at Risø are presented. The reports are available from the Risø Library.

The various anthropogenic radionuclides measured outside the Risø area came from non-Risø sources, preferentially from global fallout.

3.2. Marine environmental monitoring at Barsebäck and Ringhals

The radiological monitoring of the marine environment around the two nuclear power plants at Barsebäck and Ringhals in Sweden[1] was continued in 1983.

Figures 3.2.1.1 and 3.2.1.2 show the sampling locations.

3.2.1. γ-emitting radionuclides in brown algae

Tables 3.2.1.1, 3.2.1.2, and 3.2.1.3 show the radionuclide concentrations found by γ-spectrometric analysis in brown algae sampled near Barsebäck and Ringhals in 1983. Monthly data on radionuclides in time-integrated water samples and sea weed from locations 99 and 98 are reported in chapter 3.2.5. Note that the data are expressed on the basis of dry weight. For comparison with other data, the mean values of the ratios fresh weight/dry weight obtained 1977-1982 can be used. For Fucus vesiculosus and Fucus serratus from Ringhals these are 4.43±0.10 (S.E., n = 43) and 3.94±0.06 (S.E., n = 23), re-

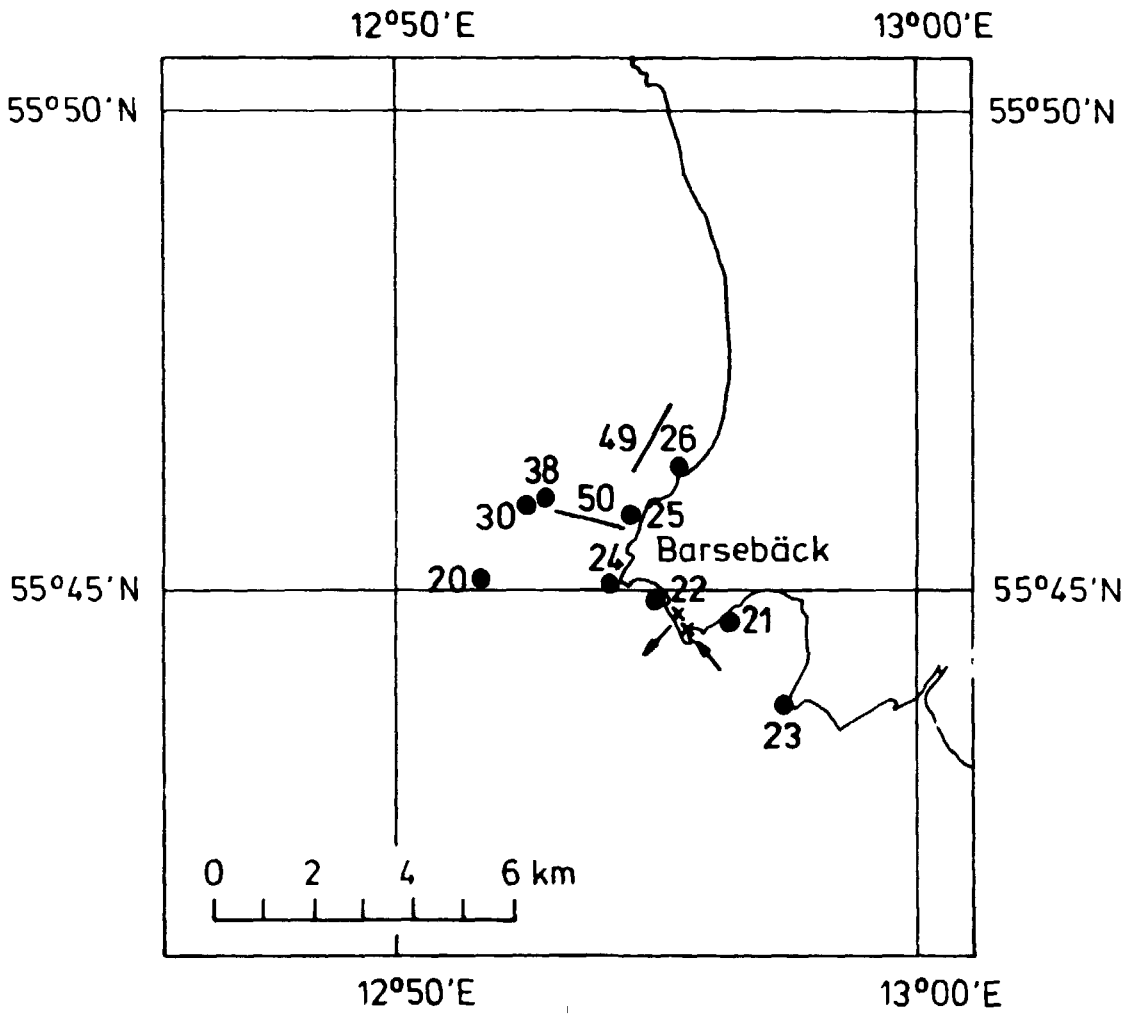

Fig. 3.2.1.1. Sampling locations at Barsebäck. 49 and 50 indicate fishing tracks. Arrows indicate cooling water intake and outlet.

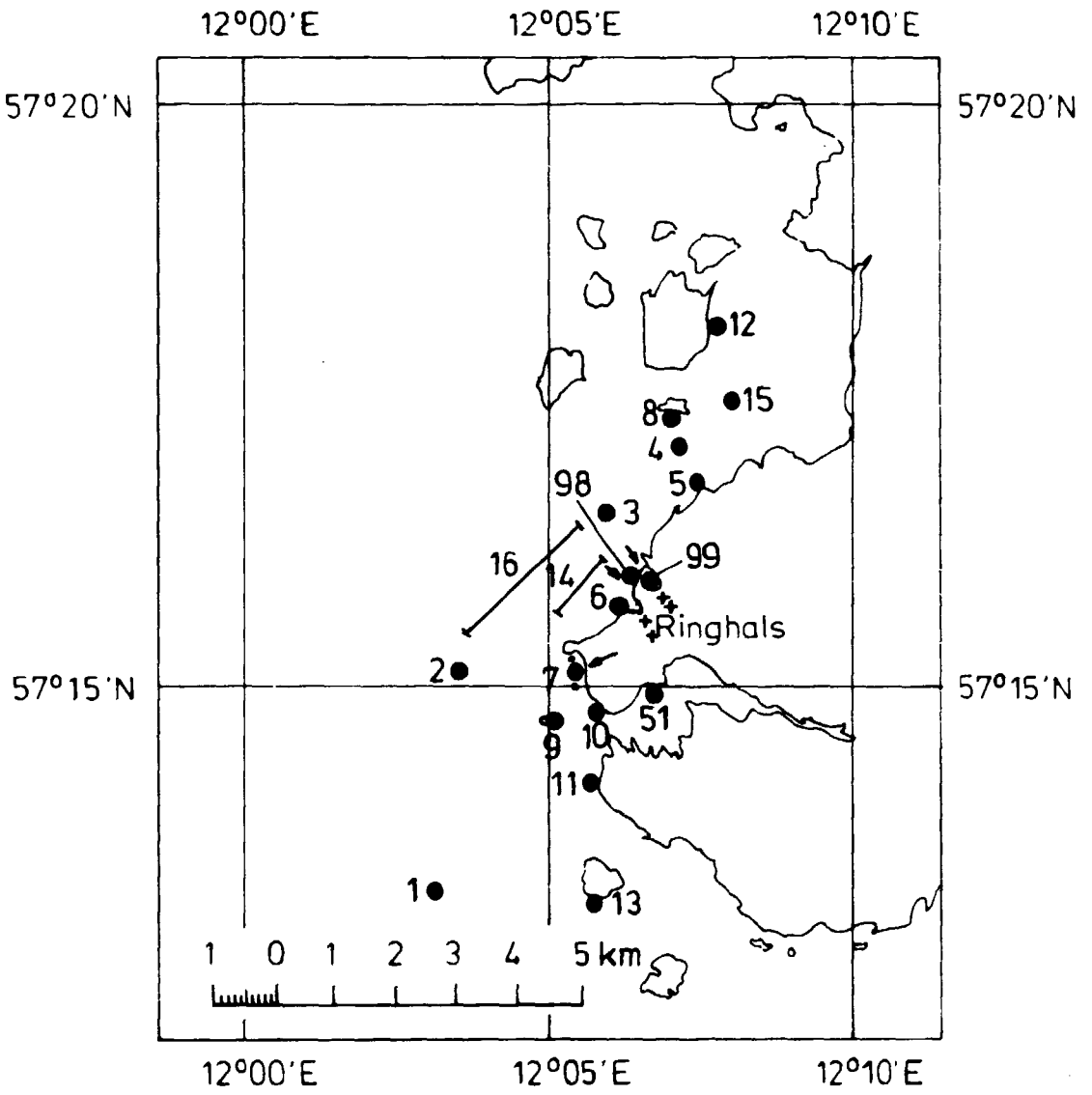

Fig. 3.2.1.2. Sampling locations at Ringhals. 14 and 16 indicate fishing tracks. Arrows indicate cooling water intake and outlet.

Table 3.2.1.1. Gamma-emitting radionuclides in Fucus vesiculosus (Fu.ve.), Fucus serratus (Fu.se.), and Zostera marina (Zo.ma.) collected at Barsebäck in 1983 (Unit: Bq kg^{-1} dry weight)

Date of sampling	9 February			2 May				30 September		13 December	
Station No.**	24	25	25	24$^{\Delta}$	25	25	26$^{\Delta\Delta}$	25	26	24	25
% dry matter	19.8	22.1	20.4	17.7±5.0	21.2	23.4	19.0±1.0	23.0	23.4	20.2	19.6
Species	Fu.ve.	Fu.ve.	Zo.ma.	Fu.ve.	Fu.ve.	Fu.se.	Fu.ve.	Fu.ve.	Zo.ma.	Fu.ve.	Fu.ve.
Distance from outlet in km	1.4	2.9	2.9	1.4	2.9	2.9	4.0	2.9	4.0	1.4	2.9
^{54}Mn	71	18.6	30	81 ± 3	31	24	14.1±0.6	15.4	7.6	47	25
^{58}Co	43	12.6	15.4	33 ± 3	14.3	7.9	8.0±1.1	4.3	3.3		7.8
^{60}Co	1860	340	340	760 ±87	470	380	191 ±34	145	87	1350	680
^{65}Zn	142	41	41	70 ± 6	38	34	19.4±4.4	6.9	8.4	112	42
^{95}Zr				20 A							
^{95}Nb				12 ± 6							
^{110m}Ag			28 A	7.1 A							
^{124}Sb					6 B						
^{125}Sb				4.2 A							
^{131}I	27 A	8 B									
^{137}Cs	10 A	8.3	9.1	13.8±1.6	15.7	10.9	11.8±0.3	9.4	6.6		87

* Locations south of the outlet; the other locations were situated north of the outlet.

**Cf. Fig. 3.2.1.1.

$^{\Delta}$ The error term is 1 S.E. of the mean of 3 samples.

$^{\Delta\Delta}$The error term is 1 S.E. of the mean of 2 samples.

Table 3.2.1.2. Gamma-emitting radionuclides in Fucus vesiculosus (Fu.ve.), Fucus serratus (Fu.se.) and Ascophyllum nodosum (As.no.) collected at Ringhals April 14, 1983. (Unit: Bq kg^{-1} dry weight)

Station No.**	7	7	6	6	5	5	8	8	8	9*	9*	13*
% dry matter	20.8	22.6	22.6	23.0	22.7	22.6	20.7	21.7	24.6	21.8	22.1	19.1
Species	Fu.ve.	As.no.	Fu.ve.	Fu.se.	Fu.ve.	Fu.se.	Fu.ve.	Fu.se.	As.no.	Fu.ve.	Fu.se.	Fu.ve.
Distance from outlet in km	0.2	0.2	1.9	1.9	4.1	4.1	4.8	4.8	4.8	1.1	1.1	4.1
^{54}Mn	4.6	1.4A	1.5A	1.7A	1.3	1.71	0.8A	0.8A		1.66	1.77	
^{58}Co	31	11.0	5.1	6.4	3.2	4.3	2.5	3.1	0.8A	8.5	10.3	1.2A
^{60}Co	110	98	29	36	21	24	11.2	14.0	8.4	34	48	4.8
^{65}Zn	142	210	44	52	31	31	16.8	18.9	13.2	42	73	6.4
^{110m}Ag	5.9	7.8	2.8	0.98	1.57	0.78				1.78	2.5	
^{124}Sb					0.6B							
^{137}Cs	7.6	6.3	8.4	8.4	9.4	8.4	7.8	8.7	5.6	8.0	9.0	6.8

* Locations south of the outlet; the other locations were situated north of the outlet.

**Cf. Fig. 3.2.1.2.

Table 3.2.1.3. Gamma-emitting radionuclides in Fucus vesiculosus (Fu.ve.) and Fucus serratus (Fu.se.) collected at Ringhals August 9, 1983. (Unit: Bq kg^{-1} dry weight)

Station No.**	7	7	6	6	5	5	8	8	8	9*	9*	13*
% dry matter	27.5	31.5	26.0±0.4	26.4	26.1	27.9	25.7	26.4	26.5	25.4±0.9	25.4	22.1
Species	Fu.ve.	Fu.se.	Fu.ve.	Fu.se.	Fu.ve.	Fu.se.	Fu.ve.	Fu.se.	Fu.ve.	Fu.ve.	Fu.se.	Fu.ve.
Distance from outlet in km	0.2	0.2	1.9	1.9	4.1	4.1	4.8	4.8	4.8	1.1	1.1	4.1
^{54}Mn	1.4	1.6	1.2±0.5	0.6	1.6	0.9	1.2	1.2	2A	1.2±0.4	1.2	0.6
^{58}Co	47	53	43 ±3	47	52	42	45	39	2A	22±1.4	25	3A
^{60}Co	140	151	119 ±6	132	66	75	53	48	12A	62±1.4	67	7A
^{65}Zn	140	150	93 ±2	101	63	68	47	46	22A	19±1.1	24	4A
^{110m}Ag	1.4	2A	0.6±0.1	2.1	2.6	1.27	2.1	1.2 A	1.4A	3.2±0.4	3.1 A	2.1
^{124}Sb										4.2		
^{137}Cs	9.3	9.9	7.9±0.9	6.7	7.9	8.6	6.9	9.9	1.9	11.2±1.1	11.4	3.4
^{141}Ce						3.2 A						

* Locations south of the outlet; the other locations were situated north of the outlet.

**Cf. Fig. 3.2.1.2.

± The error term is ± S.E. of the mean of 2 samples.

spectively, and for Fucus vesiculosus from Barsebäck the ratio is 5.02±0.14 (S.E., n = 36).

The activity concentration of reactor produced nuclides in Fucus can be expressed by a power function:

$$A = k\ X^{-\beta}$$

where X is the distance in km from the point of discharge. Northward from Barsebäck, out to ~ 125 km, a β-value of 1.4±0.1 has been found for ^{60}Co (chapter 5.11.3 and refs. 1, 10 and 32).

After normalizing all reactor-related data from Ringhals, the northward distribution showed β-values of 0.631 and 1.02 for the April and August samplings, respectively. Southward, a β-value of 1.02 was recorded at both samplings. Pooled results back to 1977 (n = 11 northward, 10 southward), gives mean values of 0.82±0.14 (S.D) northward and 0.95±0.08 (S.D.) towards the south. The Ringhals-values are calculated only from data within 5 km from the discharge point.

Table 3.2.1.5 shows a comparison of the 3 fucoids Fucus vesiculosus, Fucus serratus and Ascophyllum nodosum. The levels of significance of differences from unity are indicated.

Tables 3.2.1.6-3.2.1.7 report transfer factors calculated as

$$TF = \frac{A_i}{\frac{1}{m}\sum^{m} D_j}\ ,\ \left(\frac{\text{Bq kg}^{-1}}{\text{GBq month}^{-1}}\right)$$

where A_i is the activity of the sample collected in month i (Bq kg^{-1} dry weight), D_j is the discharge during month j (Bq $month^{-1}$) and m is the number of months in the calculation. Here m is chosen as 12, i.e. the transfer factors are based on the mean discharge rate during the 12 months preceding the sampling. Monthly discharges are from reference 36.

Table 3.2.1.5. Ratios of activity concentrations on dry weight basis in Fucus vesiculosus (Fu.ve.), Fucus serratus (Fu.se.) and Ascophyllum nodosum (As.no.) collected at Ringhals 1978-1983

Isotope	Fu.ve./Fu.se.	Fu.ve./As.no.
^{60}Co	0.83**±0.058 (n=17)	1.3 ±0.24 (n=7)
^{58}Co	0.86**±0.043 (n=16)	3.0**±0.36 (n=7)
^{54}Mn	1.09 ±0.070 (n=15)	3.8* ±0.39 (n=4)
^{65}Zn	0.88 ±0.076 (n=17)	1.5 ±0.32 (n=7)
^{110m}Ag	1.57* ±0.212 (n=13)	1.1 ±0.21 (n=5)
^{137}Cs	1.05 ±0.041 (n=16)	1.4**±0.05 (n=5)
^{131}I	0.94 (n=1)	1.4 (n=1)
^{95}Zr	0.89 (n=1)	

The error term was 1 S.E.

In Tables 3.2.1.6 and 3.2.1.7 transfer factors, TF, from Barsebäck and Ringhals from 1983, and mean values from 1977-1983 are reported. As the monthly discharges are very different the TF-values would vary even if the plants accumulated the same fraction of the discharged nuclides throughout the year. Differences in growth and in temperature also contribute to the variation. The fairly good reproducibility of the TF-value for most nuclides from both Barsebäck and Ringhals is therefore remarkable.

As discussed earlier[1,32], the TF-values are higher at Barsebäck than at Ringhals. As furthermore ratios between radionuclides differs, a hydrodynamical explanation will not be sufficient. An experimental programme aiming at elucidating these differences and at estimating concentration factors for the relevant nuclides was initiated in 1983 (cf. chapter 3.2.5).

Table 3.2.1.6. Transfer factor, TF, without decay-correction. Fucus vesiculosus collected at Barsebäck, location 24, 1.4 km north of the outlet

Isotope	Sampling date	Discharge the preceding 12 months±		TF Bq kg^{-1} dry weight	
		GBq month^{-1}	rel. S.D.%	GBq month^{-1}	
^{60}Co	9/2	4.1	83	460	
	2/5	4.1	64	186	
	13/12	4.1	94	330	
^{60}Co mean:	1983			320±78	(n = 3)
	1977-1983			600±79	(n = 19)
^{58}Co	9/2	0.30	133	143	
	2/5	0.31	129	106	
^{58}Co mean:	1983			124±19	(n = 2)
	1977-1983			260±49	(n = 18)
^{54}Mn	9/2	0.24	92	300	
	2/5	0.29	79	280	
	13/12	0.23	74	210	
^{54}Mn mean:	1983			260±30	(n = 3)
	1977-1983			400±42	(n = 19)
^{65}Zn	9/2	0.34	131	410	
	2/5	0.23	62	300	
	13/12	0.22	88	510	
^{65}Zn mean:	1983			410±60	(n = 3)
	1977-1983			550±83	(n = 19)
^{110m}Ag	2/5	0.012	139	580	
^{110m}Ag mean:	1983			580	(n = 1)
	1977-1983			132±47	(n = 11)
^{51}Cr mean:	1977-1981			49±17.5	(n = 4)

The error term was ±1 S.E.

Table 3.2.1.7. Transfer factor, TF, without decay-correction. Fucus vesiculosus (from Tables 3.2.1.2 and 3.2.1.3) collected at Ringhals, location 6, 1.9 km north of the outlet and location 9, 1.1 km south of the outlet

Isotope	Sampling date	Discharge the preceding 12 months		TF = Bq kg^{-1} dry weight / GBq month^{-1}	
		GBq month^{-1}	rel. S.D.%	Location 6	Location 9
^{60}Co	14/4	3.35	65	8.6	10.1
"	9/8	5.19	95	22.7	80.4
^{60}Co mean:	1983			15.6±7.0 (n=2)	45.3±35.2 (n=2)
	1977-1983			11.1±2.0 (n=12)	18.5± 9.0 (n=8)
^{58}Co	14/4	2.20	124	2.3	3.9
"	9/8	4.74	118	16.9	46.8
^{58}Co mean:	1983			9.6±7.3 (n=2)	25.3±21.4 (n=2)
	1977-1983			6.4±1.2 (n=12)	13.2± 5.0 (n=8)
^{54}Mn	14/4	0.32	142	4.7	5.2
"	9/8	0.62	108	17.6	50.1
^{54}Mn mean:	1983			11.2±6.4 (n=2)	27.7±22.5 (n=2)
	1977-1983			13.4±2.2 (n=12)	15.7± 5.2 (n=8)
^{65}Zn	14/4	1.45	107	30.3	29.3
"	9/8	1.56	92	59.6	124.2
^{65}Zn mean:	1983			45.0±14.6 (n=2)	76.7±47.5 (n=2)
	1977-1983			40.5±10.2 (n=12)	91.3±21.9 (n=8)
^{110m}Ag	14/4	0.038	100	73.3	46.6
"	9/8	0.032	100	135.6	92.6
^{110m}Ag mean:	1983			104.4±31.1 (n=2)	69.6±23.0 (n=2)
	1977-1983			76.3±23.2 (n=11)	99.3±30.3 (n=8)
^{51}Cr mean:	1978			1.13 (n=1)	

The error term was ±1 S.E.

3.2.2. γ-emitting radionuclides in benthic invertebrates

Tables 3.2.2.1 and 3.2.2.2 show results of the γ-countings on benthic animals from Barsebäck and Ringhals in 1983, and in Tables 3.2.2.3 and 3.2.2.4 these results have been compared with identical Fucus samples, when available. As for the seaweeds (cf. Chapter 3.2.1), the results for benthic animals are now reported on the basis of dry weights. Averaging data back to 1980 give a mean dry matter content of 9.55% and 13.7% for Mytilus soft parts from Barsebäck and Ringhals, respectively. The dose commitment to a hypothetical critical individual consuming 20 kg Mytilus edulis soft parts (fresh weight) yearly would be approximately 3 μSv y^{-1} based on mussels from location 24 in Table 3.2.2.1. This is < 0.2% of the background radiation dose.

Table 3.2.2.1. Gamma-emitting radionuclides in benthic animals collected at Barsebäck in 1983. (Unit: Bq kg^{-1} dry weight)

Species	Mytilus edulis (soft part)	Mytilus edulis (soft part)	Mytilus edulis (soft part)	Mytilus edulis (soft part)	Asterias rubens
Date	9/2	30/9	30/9	30/9	3/5
Station No.*	24	24 west	24 east	26	30
% dry matter	8.0	9.4	10.3	8.5	22.4
Distance from outlet in km	1.4	1.4	1.4	4.0	3.7
Depth in m	0-1	0-1	0-1	0-1	14
^{51}Cr	37 B				
^{54}Mn	9.6 A				
^{58}Co	17.1				
^{60}Co	250	240	220	40	2.6
^{65}Zn	39	79 A	70		
^{137}Cs	7.7 A			6.3 A	3.1

*Cf. Fig. 3.2.1.1.

Table 3.2.2.2. Gamma-emitting radionuclides in benthic animals collected at Ringhals in 1983. (Unit: Bq kg^{-1} dry weight)

Species	Eupagurus bernhardus (total)	Buccinum undatum (soft part)	Sea urchin (total)	Mytilus edulis (soft part)	Mytilus edulis (soft part)	Mytilus edulis (soft part)	Mytilus edulis (soft part)	Mytilus edulis (soft part)	Mytilus edulis (soft part)	Mytilus edulis (soft part)	Mytilus edulis (soft part)	Mytilus edulis (soft part)
Date	15/4	15/4	14/4	14/4	14/4	14/4	14/4	9/8	9/8	9/8	9/8	9/8
Station No.*	14	14	16	7	5	8	13[Δ]	6	5	8	10[Δ]	13[Δ]
% dry matter	28	18.1	28	17.1	16.4	15.8	12.2	11.9	12.9	10.6	11.6	12.8
Distance from outlet in km	~ 2	~ 2	~ 2	0.2	4.1	4.8	4.1	1.9	4.1	4.8	0.9	4.1
Depth in m				0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1	0-1
^{54}Mn							0.6 B				8.7	
^{58}Co				3.0 A		0.8 B		30 A		17 A	88	15.5 A
^{60}Co		2.8 A	9.0	17.0	4.9	2.2	2.4	48	38	22	112	28
^{65}Zn	9.0	12.3	4 B	99	13.6	9.1	3.4	141	94	84	440	91
^{110m}Ag											10.2	
^{137}Cs	1.7 A	3.3 A	9.9	3.3	4.7	3.2	2.6					2.7

*Cf. Fig. 3.2.1.2.

[Δ]Locations south of the outlet; the other locations were situated north of the outlet.

Table 3.2.2.3. Activity ratios on dry weight basis, Mytilus edulis soft part to Fucus vesiculosus collected at Barsebäck in 1983

Location	Date	^{60}Co	^{58}Co	^{65}Zn	^{137}Cs	^{110m}Ag	^{54}Mn	^{95}Zr	^{144}Ce
24	9/2	0.134	0.40	0.28	0.77		0.135		
Mean 1980-1983		0.165	0.335	0.77	0.456	3.38	0.093	0.297	0.82
S.E.		0.037	0.120	0.29	0.113		0.021		
n		4	4	4	4	1	3	1	1

Table 3.2.2.4. Activity ratios on dry weight basis, Mytilus edulis soft part (from Table 3.2.2.2) to Fucus vesiculosus and Fucus serratus (from Tables 3.2.1.2 and 3.2.1.3) collected at Ringhals in 1983

Brown algae	Location	Date	^{60}Co	^{58}Co	^{65}Zn	^{137}Cs	^{110m}Ag	^{54}Mn	^{95}Zr	^{144}Ce	^{134}Cs
Fucus vesiculosus	7	14/4	0.144	0.097	0.70	0.43					
	5	"	0.23		0.44	0.50					
	8	"	0.196	0.32	0.54	0.33					
	13	"	0.50		0.53	0.38					
	6	9/8	0.41	0.38	1.52						
	5	"	0.58		2.19						
	8	"	0.44	0.42	2.05						
	10	"	0.35	0.34	2.00		0.73	0.36			
	13	"	0.39	0.41	1.99	0.32					
Mean 1983			0.36	0.33	1.32	0.39	0.73	0.36			
S.E.			0.048	0.049	0.25	0.033					
n			9	6	9	5	1	1			
Mean 1977-1983			0.36	0.27	1.16	0.36	0.72	0.160	0.22	0.60	0.58
S.E.			0.052	0.028	0.161	0.038	0.177	0.068	0.05	0.05	
n			20	16	19	13	7	4	3	4	1
Fucus serratus	5	14/4	0.20		0.44	0.55					
	8	"	0.157	0.26	0.48	0.30					
	6	9/8	0.36	0.34	1.41						
	5	"	0.51		1.96						
	8	"	0.46	0.45	1.83						
Mean 1983			0.34	0.35	1.22	0.43					
S.E.			0.069	0.055	0.32	0.130					
n			5	3	5	2					
Mean 1977-1983			0.30	0.23	0.95	0.36	0.36	0.078	0.17		
S.E.			0.063	0.053	0.192	0.063	0.29				
n			12	7	11	6	2	1	1		

3.2.3. γ-emitting radionuclides in fish

Tables 3.2.3.1 and 3.2.3.2 show results from 1983. As the power plants do not contribute to the only significant nuclide measured (^{137}Cs), no dose calculations are reported here.

Table 3.2.3.1. Gamma-emitting radionuclides in fish meat collected at Barsebäck, location 30 (55°45'93N 12°52'72E), 1983. (Unit: Bq kg^{-1} fresh)

Species	Date	^{134}Cs	^{137}Cs
Dab	3/5	0.084 A	3.5
Cod	3/5	0.180	6.7

Table 3.2.3.2. Gamma-emitting radionuclides in fish meat collected at Ringhals, location 14, April 13, 1983. (Unit: Bq kg^{-1} fresh)

Species	^{65}Zn	^{137}Cs
Dab	0.29 A	2.6
Flounder		1.85

3.2.4. γ-emitting radionuclides in sea sediments

As previously, sediments sampled by the HAPS bottom corer were sliced in 3 cm thick sections and analysed by γ-spectrometry (cf. Tables 3.2.4.1-3.2.4.2). ^{60}Co originating from the power plants was detectable at both sites.

3.2.5. Field experiments at Ringhals

Aiming mainly at the determination of concentration factors between Fucus and water, a special programme was initiated in April 1983 at Ringhals. In 1984 Barsebäck and Forsmark will be included too.

Table 3.2.4.1. Gamma-emitting radionuclides in sediment samples collected at Barsebäck, location 38, in 1983.

Date	Depth in m	^{60}Co		^{125}Sb		^{137}Cs	
		Bq kg^{-1} d.w.	Bq m^{-2}	Bq kg^{-1} d.w.	Bq m^{-2}	Bq kg^{-1} d.w.	Bq m^{-2}
9/5	0-3	14.9	98	4.2 A	25 A	86	510
	3-6	5.3	50			50	470
	6-9					38	300
	9-15					7.6	191
	0-15		Σ 138		Σ 25		Σ 1470
14/11	0-3	150	1160	19.9	151	79	600
	3-6	1.88	23			43	520
	6-9					10.5	132
	9-12					3.6	50
	12-15					1.6 A	24 A
	0-15		Σ 1180		Σ 151		Σ 1330

Table 3.2.4.2. Gamma-emitting radionuclides in sediment samples collected at Ringhals, location 2, in 1983. (Area: 0.0145 m^2)

Date	Depth in m	^{54}Mn		^{60}Co		^{125}Sb		^{137}Cs	
		Bq kg^{-1} d.w.	Bq m^{-2}	Bq kg^{-1} d.w.	Bq m^{-2}	Bq kg^{-1} d.w.	Bq m^{-2}	Bq kg^{-1} d.w.	Bq m^{-2}
14/4	0-3			9.4	133			17.8	250
"	3-6	0.3 B	9 B	6.4	220	1.1 A	40 A	12.5	430
"	6-9			0.8 A	32 A			4.7	186
"	9-12			0.6 A	29 A			2.8	123
	0-12		Σ 9		Σ 410		Σ 40		Σ 990
10/3	0-3			10.3	230	3.1 A	70 A	19.1	420
"	3-6			8.8	330	4.6	170	8.4	310
"	6-9							1.93	96
"	9-12							0.9 A	37 A
	0-12				Σ 560		Σ 240		Σ 860

The idea is to measure monthly time-integrated mean values of the ^{60}Co-concentration in seawater and to compare them with seaweed samples. The integration period for the water samples is chosen as one calender month, and the corresponding sea

weed samples are taken as closely as possible to the first day in the next month. This allows a comparison to be made with monthly discharge values[36]. The time-integrated water sample is pumped into a 420 l container by a continously running "Masterflex" peristaltic pump, which is set to ~ 400 l per month. The water is enriched in stable cobalt by adding 50 g $Co(NO_3)_2 \cdot 6H_2O$ and it is spiked with a known amount of ^{57}Co. At the end of the month cobalt is precipitated as CoS by adding 330 g Na_2S dissolved in water. After 1-2 days precipitation the overlying water is siphoned off, and the precipitate is taken to the laboratory for further concentration, drying, and γ-spectrometry. During the precipitation the water from the peristaltic pump is accumulated in another container. The chemical yield is usually 90-100%. In initial tests zinc (as ^{65}Zn) showed similar yields.

The water-sampling equipment has been placed in a shed by the northern cooling water intake channel ~ 2.5 km north of the discharge point. On the open coast outside the channel, Fucus vesiculosus and Fucus serratus was sampled monthly (Table 3.2.5.1), and Fucus vesiculosus was sampled in the channel (Table 3.2.5.2) close to the water-sampling station. It is not known why the radio-cobalt concentration in sea weed in the channel (location 99) somewhat is higher than at the open coast outside (location 98). Radiocobalt and ^{65}Zn measured in the water samples are reported in Table 3.2.5.3, and by comparison with discharge data (Table 3.2.5.4), transfer factors from monthly discharge to water in the cooling water intake channel have been calculated (Table 3.2.5.5). The mean value of these numbers might be used to estimate the water concentration for months lacking water samples.

In Table 3.2.5.6 the accumulation of nuclides in Fucus vesiculosus transplanted from a low-activity area 20 km south of the power plant to the cooling water intake channel is shown. By comparison with results in Table 3.2.5.2, it is seen that after 2 months ~ 90% of the level of ^{60}Co, ^{65}Zn and ^{54}Mn is reached. Cobalt-58 obtains the same level as the natural population already after the first month because of its short half

Table 3.2.5.1. Gamma-emitting radionuclides in Fucus vesiculosus (Fu.ve.) and Fucus serratus (Fu.se.) outside the northern cooling-water intake at Pinghals (location 98, 2.3 km north of the outlet) in 1983. (Unit: Bq kg^{-1} dry weight)

Date		28/3	2/5	2/6*	30/6	2/8	1/9	3/10	2/12	Mean	S.E.	n
% dry matter	Fu.ve.		15.0	20.6±0.88	16.6	28.0	26.1	19.6	20.6			
	Fu.se.	16.7		20.4±1.89		25.8		23.7	19.6			
^{54}Mn	Fu.ve.		1.88	2.9±0.09	5.8	7.2	6.1	5.2	4.8			
	Fu.se.			3.0±0.33		8.0		4.8	4.4			
	Fu.ve./Fu.se.			0.97		0.90		1.10	1.11	1.02	0.049	4
^{58}Co	Fu.ve.		8.5	11.0±0.82	57	61	39	27	18.6			
	Fu.se.	5.7		11.5±0.52		100		34	27			
	Fu.ve./Fu.se.			0.95		0.61		0.80	0.70	0.76	0.072	4
^{60}Co	Fu.ve.		23	33 ±2.7	63	87	68	72	79			
	Fu.se.	17.9		39 ±1.8		137		85	106			
	Fu.ve./Fu.se.			0.85		0.63		0.84	0.74	0.77	0.051	4
^{65}Zn	Fu.ve.		24	35 ±2.4	35	53	61	82	67			
	Fu.se.	38		42 ±1.8		98		71	77			
	Fu.ve./Fu.se.			0.83		0.54		1.14	0.87	0.85	0.124	4
^{95}Nb	Fu.ve.		2.1									
^{110m}Ag	Fu.ve.				1.3 A	1.9 A	3.5	3.5	4.0			
	Fu.se.					5.1		2.7	3.3			
	Fu.ve./Fu.se.					0.37		1.27	1.20	0.95	0.29	3
^{131}I	Fu.ve.		26									
^{137}Cs	Fu.ve.		9.5	10.1±0.13	10.6	9.4	7.6	6.2	7.8			
	Fu.se.	10.0		10.0±0.74		9.3		6.0	7.6			
	Fu.ve./Fu.se.			1.01		1.00		1.05	1.03	1.02	0.010	4

*The error term is 1 S.E. of the mean of 3 samples.

Table 3.2.5.2. Gamma-emitting radionuclides in Fucus vesiculosus collected from the northern cooling-water intake channel at Ringhals in 1983 (location 99, 2.5 km north of the outlet) for comparison with water samples (cf. Table 3.2.5.3). (Unit: Bq kg^{-1} dry weight)

Date	28/3	2/5	2/6	30/6	2/8	1/9	3/10	1/11	2/12
% dry matter	19.1	17.5	22.1	22.4	26.5	26.1	18.5	17.5	19.5
^{51}Cr		9.8 A							
^{54}Mn	2.3	9.7	11.6	10.4	8.5	8.5	11.9	6.0	6.0
^{58}Co	8.7	46	51	82	79	54	40	20.0	18.5
^{60}Co	38	53	68	94	114	106	128	76	92
^{65}Zn	34	27	47	48	61	65	83	61	51
^{95}Zr		5.6	3.9						
^{95}Nb		9.3	6.4	2.5 B		3.0 A	4.4 A		
^{110m}Ag	0.8 B			3 B	3.1	1.9 A	3.2 A		2.5 A
^{124}Sb			1.3 B		5.2 A				
^{131}I		45							
^{134}Cs	1.40								
^{137}Cs	12.7	11.1	11.5	14.0	11.4	11.0	12.0	13.5	13.7

Table 3.2.5.3. Radiocobalt and Zinc-65 in monthly time-integrated water samples collected from the northern cooling-water intake channel at Ringhals (location 99, 2.5 km north of the outlet) in 1983. (Unit: Bq m^{-3})

	1/4-29/4	2/5-30/5	30/5-29/6	29/6-1/8	1/8-24/8	1/9-30/9	3/10-31/10	1/11-30/11	30/11-19/12
^{58}Co	1.30	1.88	4.38	2.33	0.92	0.70		0.63 A	
^{60}Co	1.68	2.20	2.74	2.55	0.98	1.66	0.72	0.62	0.68
^{65}Zn		1.47		1.3 A		1.0 A			

Table 3.2.5.4. Reported monthly liquid discharges from Ringhals in 1983 from reference 36. (Unit: Bq $month^{-1}$)

Isotope	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
^{51}Cr	5.7×10^{8}	1.67×10^{8}	7.4×10^{8}	1.56×10^{9}	1.07×10^{9}	6.0×10^{9}	2.2×10^{9}	5.8×10^{8}	7.3×10^{8}	2.9×10^{7}	1.59×10^{7}	2.3×10^{8}
^{54}Mn	1.14×10^{8}	9.8×10^{7}	2.4×10^{8}	1.73×10^{9}	9.2×10^{8}	1.04×10^{9}	2.1×10^{9}	4.7×10^{8}	5.1×10^{8}	1.29×10^{8}	2.6×10^{8}	2.0×10^{8}
^{57}Co	0	1.20×10^{5}	1.20×10^{6}	1.60×10^{6}	3.4×10^{6}	1.5×10^{7}	2.2×10^{7}	1.00×10^{5}	1.40×10^{6}	6.2×10^{5}	1.60×10^{6}	2.0×10^{6}
^{58}Co	1.10×10^{9}	1.03×10^{9}	1.18×10^{9}	1.05×10^{10}	5.4×10^{9}	1.75×10^{10}	1.20×10^{10}	4.2×10^{9}	2.3×10^{9}	9.7×10^{8}	2.0×10^{9}	5.4×10^{8}
^{59}Fe	8.0×10^{6}	2.9×10^{6}	5.4×10^{7}	2.1×10^{8}	3.5×10^{7}	1.17×10^{8}	7.5×10^{7}	5.0×10^{7}	5.8×10^{7}	1.63×10^{7}	9.5×10^{6}	1.10×10^{7}
^{60}Co	1.75×10^{9}	2.1×10^{9}	4.2×10^{9}	9.0×10^{9}	5.0×10^{9}	9.6×10^{9}	1.80×10^{10}	5.2×10^{9}	1.00×10^{10}	3.1×10^{9}	4.7×10^{9}	5.3×10^{9}
^{65}Zn	6.3×10^{8}	3.3×10^{8}	8.1×10^{8}	7.1×10^{8}	3.1×10^{9}	1.00×10^{9}	5.4×10^{9}	1.91×10^{9}	3.5×10^{9}	8.6×10^{8}	8.1×10^{8}	6.0×10^{8}
^{110m}Ag	0	2.8×10^{7}	1.98×10^{7}	3.4×10^{7}	0	7.7×10^{7}	1.1×10^{8}	5.6×10^{7}	8.8×10^{7}	4.3×10^{7}	3.4×10^{7}	3.1×10^{7}
^{131}I	8.0×10^{7}	0	2.6×10^{6}	3.2×10^{9}	6.2×10^{7}	4.6×10^{7}	3.8×10^{6}	0	0	0	4.3×10^{6}	8.1×10^{6}
^{134}Cs	3.1×10^{8}	6.0×10^{8}	9.5×10^{8}	1.1×10^{9}	9.7×10^{8}	7.5×10^{8}	9.7×10^{8}	1.32×10^{9}	8.8×10^{8}	3.8×10^{8}	4.9×10^{8}	6.4×10^{7}
^{137}Cs	5.4×10^{8}	9.6×10^{8}	1.93×10^{9}	1.42×10^{9}	1.47×10^{9}	1.32×10^{9}	1.73×10^{9}	2.4×10^{9}	1.66×10^{9}	7.6×10^{8}	9.6×10^{8}	1.76×10^{8}

Table 3.2.5.5. Transfer-factor from reported monthly discharge (GBq) to monthly time-integrated mean water concentration (Bq m^{-3}) in the cooling-water intake (location 99, 2.5 km north of the outlet) at Ringhals in 1983. (Bq m^{-3}/GBq $month^{-1}$ or 10^{-9} × month m^{-3})

	April	May	June	July	Aug	Sept	Oct	Nov	Dec	$\bar{x}$	S.E.	n
^{60}Co	0.19	0.44	0.29	0.14	0.19	0.17	0.23	0.13	0.13	0.211	0.033	9
^{65}Zn		0.47		0.24		0.28						

Table 3.2.5.6. Gamma-emitting radionuclides in Fucus vesiculosus transplanted from Stora Nässs, Varberg (57°07'N 12°11'E) to the northern cooling-water intake channel at Ringhals (location 97) June 2, 1983. (Unit: Bq kg^{-1} dry weight)

Date	2/6-83	30/6-83	2/8-83	1/9-83	3/10-83	1/11-83	2/12-83	1/2-84	1/3-84	2/4-84
% dry matter	19.1	22.9	27.7	26.0	21.6	22.1	21.5	21.1	24.5	23.8
^{54}Mn	0.6 B	5.9	7.2	10.1	10.5	6.1	7.1	4.8	4.8 A	5.0
^{58}Co		92	90	58	46	28	21	13	11.4	7.6
^{60}Co	1.99	65	100	106	122	93	105	85	118	112
^{65}Zn		16.3	57	67	81	63	50	32	30	20
^{110m}Ag		3.4 A					2.6 A			
^{137}Cs	12.0	12.5	8.4	7.9	11.9	10.6	16.3	16.3	15.5	12.7

life. These results shows that in June-August 1983 the sea weed equilibrated with water levels in 2-3 months. Due to the effects of temperature and growth, this equilibration time is expected to be a minimum.

Table 3.2.5.7 shows preliminary numbers for concentration factors between water and Fucus vesiculosus based on the mean transfer factor for ^{60}Co from discharge to water (Table 3.2.5.5) and transfer factors for several nuclides to sea weed sampled 1977-83. Taking an average of ratios between monthly Fucus vesiculosus samples (Table 3.2.5.2) and water samples the preceeding month (Table 3.2.5.3) gives a ^{60}Co-value of 80 000, i.e. a factor 2 higher than the above estimate. This might be because a decreasing concentration in the water gives an exaggerated number for the concentration factor due to ^{60}Co from earlier months in the plants - especially during the winter when growth rates are low. Another explanation might be an inadequate correction for differences between the two locations

- in that case all the reported concentration factors should be raised. The concentration factors for Mytilus are estimated on the basis of ratios between Mytilus soft parts and Fucus (Table 3.2.2.4).

It is noted that these factors apply to the Ringhals environment (18-20 o/oo salinity) and Ringhals-discharges alone. Ratios between the different nuclides are different at Barsebäck[1,32].

Table 3.2.5.7. Concentration factors for Fucus vesiculosus and Mytilus edulis soft parts from Ringhals calculated on the basis of mean transfer factors from discharge to sea weed at location 6, 1977-83 (Table 3.2.1.7), to water at location 99 (Table 3.2.5.5), and on measured ratios between Fucus and Mytilus 1977-83 (Table 3.2.2.4). The distance-related differences between the two locations are corrected by a factor 0.8. The values are preliminary and will be further assessed in the next report. (Units: Bq kg^{-1}/Bq l^{-1}.)

	^{60}Co	^{58}Co	^{54}Mn	^{65}Zn	^{110m}Ag	^{51}Cr
Fucus vesiculosus						
dry weight:	40.000	25.000	50.000	150.000	[illegible]0.000	4.300
fresh weight:	9.500	5.500	11.500	35.000	65.000	1.000
Mytilus edulis, soft parts						
dry weight	15.000	6.500	8.000	180.000	200.000	-
fresh weight	2.000	900	1.100	25.000	30.000	-

4. FALLOUT NUCLIDES IN THE ABIOTIC ENVIRONMENT

by A. Aarkrog and Heinz Hansen

4.1. Air

4.1.1. Strontium-90

The mean air activity for 1983 was 1.8 μBq ^{90}Sr m^{-3}. This is the lowest annual mean found since our measurements began in 1956.

Our paper filters have a background of 4.2 μBq ^{90}Sr m^{-3}. In 1983 we subtracted this background from our results. If we do the same for the 1982 data, they then become been 2.9 μBq ^{90}Sr

Table 4.1.1. Strontium-90 in air collected at Risø in 1983. (Unit: μBq m^{-3})

Month	Daily air filters	Weekly air filters	
	Paper	Glass Shunt	Glass Cut out
January	0.03		
February	2.6	3.3	1.8 A
March	2.2		
April	0.65	6.6 A	
May	1.68	4.5	2.2
June	1.47	4.6 A	
July	2.4		
August	1.00	2.1	1.4
September	0.10		
October	0.17		
November	1.22	0.8 B	0.6
December	B.D.L.		
1983	1.13	2.8	1.5

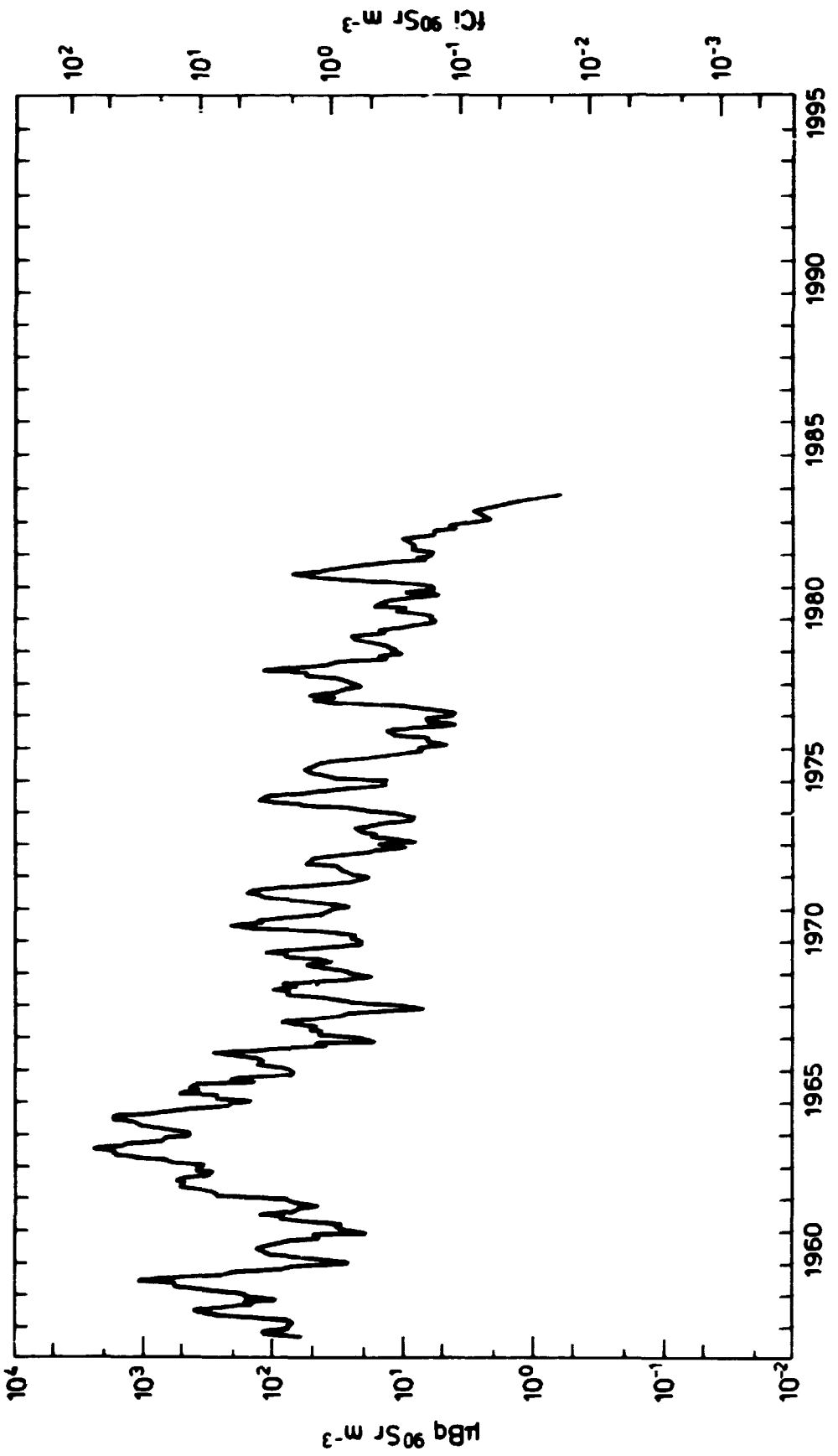

Fig. 4.1.1. Strontium-90 in ground level air at Risø, 1957-1983.

m^{-3}, i.e. from 1982 to 1983 the ^{90}Sr air concentrations decreased by a factor of 2.6.

The results for "shunt" and "cut out" of weekly glass-fibre filters (those used for γ-spectroscopy in Table 4.1.2.1) suggest that there may be an error in our air volume calculations. However, the ^{90}Sr concentrations were too low for a reliable calculation of a possible correction factor.

Figure 4.1.1 shows the quarterly levels of ^{90}Sr in air since 1957.

4.1.2. Cesium-137

Air samples were collected weekly by means of a "new" air sampler installed in 1979 at Risø. The sampler collects the air dust on

Table 4.1.2.1. Cesium-137 in glass-fibre air filters collected once a week at Risø in Denmark in 1983. (Unit: μBq m^{-3})

Month	μBq m^{-3}	n
January	1.40±0.15	4
February	1.83±0.31	4
March	2.0 ±0.34	4
April	2.3 ±0.22	5
May	2.6 ±0.42	4
June	4.1 ±0.64	4
July	3.3 ±0.64	5
August	2.3 ±0.28	4
September	1.44±0.26	5
October	0.80±0.04	4
November	0.79±0.16	4
December	0.81±0.07	5
1983	1.97	

The error term is 1 S.E. of the mean.

6 glass-fibre filters each 56 × 48 cm^2. The filters collect approximately 275,000 m^3 in one week.

Table 4.1.2.1 shows the monthly ^{137}Cs concentrations in air from Risø. The concentrations have decreased by a factor of 2.7 since 1982.

Table 4.1.2.2 shows the annual ^{137}Cs concentrations in air collected at Risø since 1958.

The mean $^{137}Cs/^{90}Sr$ ratio in Risø air was 1.1 in 1983 which is lower than expected. Risø rain showed thus a ratio of 1.71.

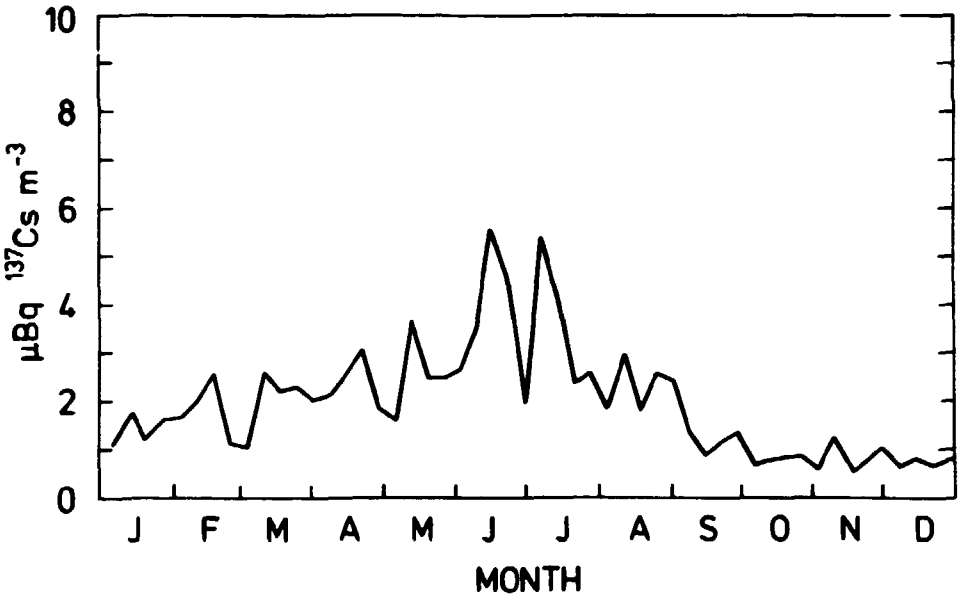

Fig. 4.1.2. Cesium-137 in ground level air at Risø in 1983.

Table 4.1.2.2. Cesium-137 in air collected at Risø 1958-1983

Year	fCi m^{-3}	μBq m^{-3}
1958	4.2	155
1959	13.1	480
1960	1.98	73
1961	2.3	84
1962	23	850
1963	66	2400
1964	31	1150
1965	10.6	390
1966	5.7	210
1967	2.1	79
1968	2.4	88
1969	2.4	91
1970	3.4	127
1971	2.7	98
1972	1.37	51
1973	0.47	17.3
1974	1.96	73
1975	1.30	48
1976	0.42	15.5
1977	1.62	60
1978	1.70	63
1979	0.62	23
1980	0.24	8.7
1981	0.81	30
1982	0.146	5.4
1983	0.053	1.97

4.2. Strontium-90 and various γ-emitters in precipitation

Samples of rain water were collected in 1983 from the State experimental farms (cf. fig. 4.2) in accordance with the principles laid down in Risø Report No. 63, p. 51[1)].

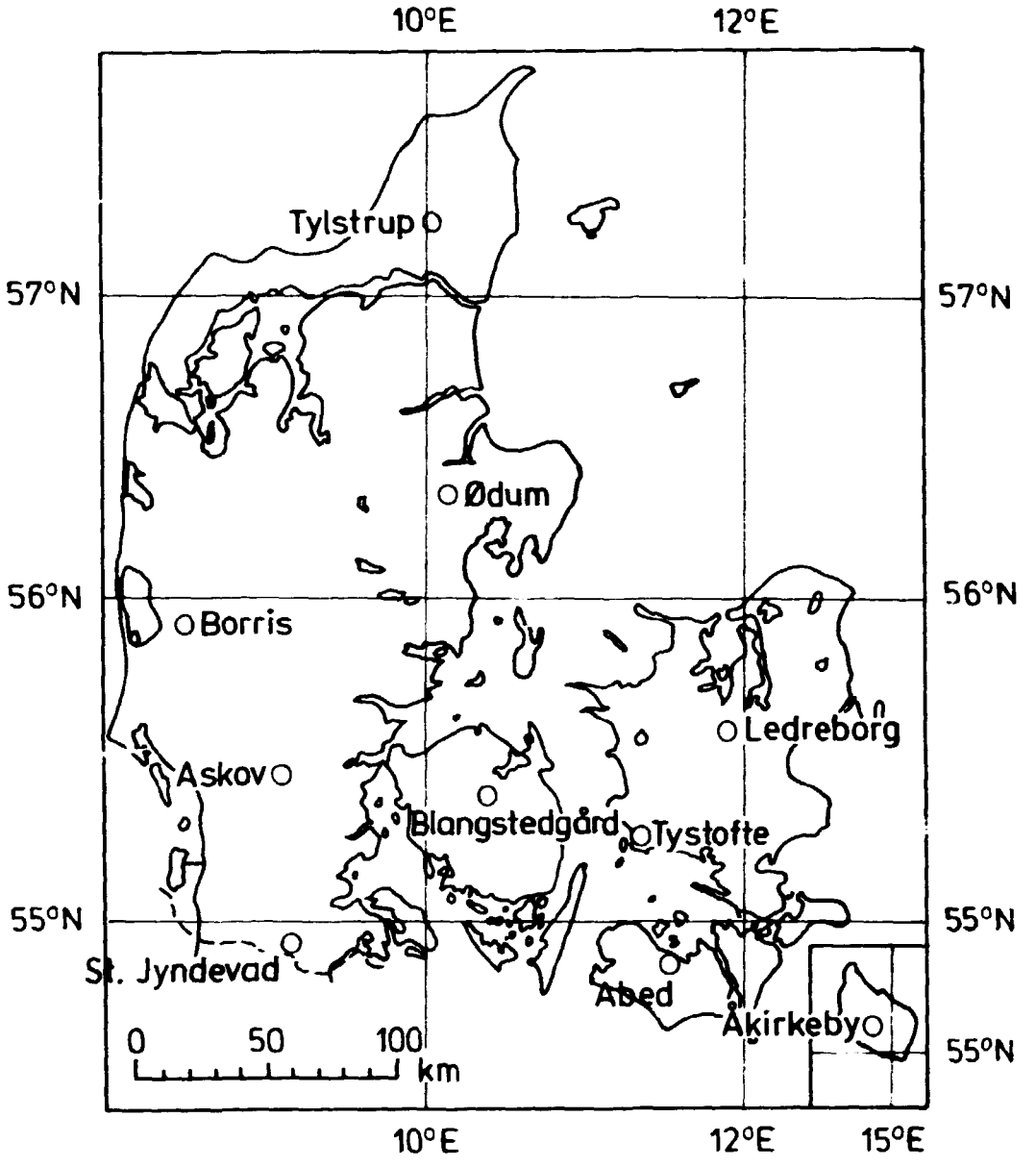

Fig. 4.2. State experimental farms in Denmark.

Table 4.2.1 shows the results of the ^{90}Sr determinations and Tables 4.2.2 and 4.2.3 the analysis of variance of the results.

The maximum concentration in precipitation occurred in July-August when the mean content in precipitation was 14 Bq ^{90}Sr m^{-3}, and the maximum fallout rate also occurred in March-April, 0.45 Bq ^{90}Sr m^{-2}. The mean levels for ten State experimental farms were 1.65 Bq ^{90}Sr m^{-2} and 2.4 Bq ^{90}Sr m^{-3}. The fallout

Table 4.2.1. Strontium-90 fall-out in Denmark in 1983 (sampling area at each location: 0.147 m^2)

Period	Unit	Tylstrup	Borris	Ødum	Askov	St. Jyndevad	Blangstedgård	Tystofte	Abed	Åkirkeby	Ledreborg	Mean
Jan-Feb	Bq m^{-3}	1.43	1.93	1.43	2.8	2.1	1.44	7.7	2.3	6.1	1.90	2.51
	Bq m^{-2}	0.133	0.199	0.108	0.27	0.181	0.102	0.34	0.113	0.23	0.107	0.177
March-April	Bq m^{-3}	1.81	3.4	4.2	1.71	1.99	1.50	5.6	2.1	5.2	2.2	2.9
	Bq m^{-2}	0.29	0.51	0.60	0.35	0.37	0.24	0.82	0.28	0.69	0.32	0.45
May-June	Bq m^{-3}	3.2	2.9	2.5	2.7	1.61 A	2.5	2.6	2.1	5.8	1.99	2.7
	Bq m^{-2}	0.54	0.55	0.31	0.37	0.27 A	0.28	0.30	0.37	0.51	0.23	0.37
July-Aug	Bq m^{-3}	16.5	7.9	6.6 B	(9.3)	4.5	19.6 A	33	9.8	23 A	45	14.2
	Bq m^{-2}	0.81	0.170	0.101B	(0.056)	0.095	0.075A	0.117	0.110	0.51 A	0.171	0.22
Sept-Oct	Bq m^{-3}	1.73	0.89	0.67	0.58	0.91	1.19	4.1	2.2 A	5.1	2.6	1.61
	Bq m^{-2}	0.43	0.30	0.120	0.155	0.21	0.142	0.35	0.188A	0.78	0.24	0.29
Nov-Dec	Bc m^{-3}	1.65	1.11 A	1.06	0.51	0.63	0.90	0.98	1.38	2.4	1.23	1.14
	Bq m^{-2}	0.164	0.170A	0.097	0.081	0.101	0.103	0.096	0.141	0.29	0.124	0.137
1983	Bq m^{-3} $\bar{x}$	2.9	1.99	2.1	1.47	1.44	1.63	4.1	2.2	5.4	2.3	2.4
	Bq m^{-2} Σ	2.4	1.90	1.34	1.28	1.23	0.94	2.0	1.20	3.0	1.19	1.65
m precipitation Σ		0.812	0.961	0.629	0.868	0.851	0.582	0.492	0.551	0.553	0.514	0.681

Figures in brackets were calculated from VAR3[12].

Table 4.2.2. Analysis of variance of ln Bq ^{90}Sr m^{-3} precipitation in 1983 (from Table 4.2.1)

Variation	SSD	f	s^2	v^2	P
Between months	34.872	5	6.974	35.928	> 99.95%
Between locations	9.751	9	1.083	5.582	> 99.95%
Remainder	8.541	44	0.194		

Table 4.2.3. Analysis of variance of ln Bq ^{90}Sr m^{-2} precipitation in 1983 (from Table 4.2.1)

Variation	SSD	f	s^2	v^2	P
Between months	11.370	5	2.274	14.538	> 99.95%
Between locations	6.764	9	0.752	4.805	> 99.95%
Remainder	6.882	44	0.156		

rate in 1983 was 0.8 times that observed in 1982. The ^{90}Sr deposition in 1983 was nearly the same in Jutland and in the Islands. As in 1982 Bornholm (Åkirkeby) shows the highest ^{90}Sr fallout levels.

A comparison between the yearly amounts of precipitation found in the rain gauges used by the Danish Meteorological Institute[9] and the amounts collected in our rain bottles at the same ten locations in 1983 showed a mean ratio of 1.09±0.14 (1 S.D.) between the two sampling systems.

In order to determine the annual ^{137}Cs fallout in Denmark, 10% of all rain samples from the ten state experimental farms were pooled into a single sample for 1983.

The concentration in this sample was 2.8 Bq ^{137}Cs m^{-3} and the deposit was 1.88 Bq ^{137}Cs m^{-2}. Hence the observed $^{137}Cs/^{90}Sr$ in fallout became 1.88/1.65 = 1.14 in 1983.

Table 4.2.4. Strontium-90 in rain water collected in a 10 m^2 ion-exchange column collector at Risø in 1983

Month	m	Bq m^{-3}	Bq m^{-2}
January	0.035	1.47	0.051
February	0.020	1.13	0.022
March	0.076	1.05	0.080
April	0.075	1.13	0.085
May	0.098	2.2	0.21
June	0.052	1.31	0.068
July	0.006	4.3	0.027
August	0.006	3.4	0.022
September	0.072	0.82	0.060
October	0.033	0.86	0.028
November	0.042	0.48	0.020
December	0.045	0.26	0.012
1983	Σ 0.560	$\bar{x}$ 1.22	Σ 0.685

The ratio: $^{137}Cs/^{90}Sr$ measured in monthly rain at Risø was 1.71, i.e. higher than the ratio found at the experimental farms; in air we found the ratio as 1.1.

The washout ratios calculated for Risø was 1.22/1.8 = 0.7 for ^{90}Sr and 2.1/1.97 = 0.78 for ^{137}Cs, these values were in reasonable agreement with the usually observed washout ratio of 1.0[21].

Tables 4.2.4 and 4.2.5 show the ^{90}Sr and ^{137}Cs levels in rain water collected at the 10 m^2 rain collector at Risø. As compared with the State experimental farms in Zealand (Tystofte and Ledreborg in Table 4.2.1) the ^{90}Sr fallout (Bq m^{-2}) measured at Risø was only 43% and the concentration (Bq m^{-3}) was 38%. The amount of precipitation at Risø was 0.560 m which was 111% of the mean of Tystofte and Ledreborg. Our big ion exchange column at Risø may thus have been inefficient for the collection of ^{90}Sr from precipitation. A similar conclusion is reached if we look at Table 4.2.6.

Table 4.2.5. Cesium-137 in rain water collected in a 10 m^2 ion-exchange column collector at Risø in 1983

Month	m	Bq m^{-3}	Bq m^{-2}
January	0.035	3.3	0.116
February	0.020	2.6	0.051
March	0.076	1.41	0.107
April	0.075	1.42	0.107
May	0.098	3.3	0.33
June	0.052	2.4	0.125
July	0.006	9.8	0.061
August	0.006	3.7	0.024
September	0.072	1.25	0.090
October	0.033	1.66	0.055
November	0.042	1.65	0.069
December	0.045	0.74	0.034
1983	Σ 0.560	$\bar{x}$ 2.1	Σ 1.17

Table 4.2.6. Strontium-90 in rain water collected in ion-exchange column collectors at Risø in 1983. (Sampling area 0.325 m^2)

Month	m	Bq ^{90}Sr m^{-3}	Bq ^{90}Sr m^{-2}
January-March	0.092	3.3 A	0.30 A
April-June	0.126	3.1	0.39
July-Sept	0.053	1.84	0.098
Oct-Dec	0.105	0.82	0.086
1983	Σ 0.376	$\bar{x}$ 2.3	Σ 0.87

Table 4.2.7. Tritium in precipitation collected at Risø in 1983

Month	m	1 m^2 rain collector		10 m^2 rain collector	
		kBq m^{-3}	kBq m^{-2}	kBq m^{-3}	kBq m^{-2}
Jan	0.035	2.7±0.6	0.094	16.2±1.1	0.57
Feb	0.020	4.0±0.4	0.080	4.4±1.1	0.088
March	0.076	6.1±0.6*	0.46	8.4±1.1	0.64
April	0.075	15.6±1.3	1.17	3.4±0.6	0.26
May	0.098	3.6±0.4	0.35	3.4±0.2	0.33
June	0.052	4.4±0.4	0.23	3.1±0.2	0.161
July	0.006	5.3±0.2	0.032	5.5±0.0	0.033
Aug	0.006	5.1±0.0	0.031	14.0±1.8	0.084
Sept	0.072	2.8±0.5*	0.20	10.5±0.2	0.76
Oct	0.033	1.6±0.2	0.053	4.0±0.0	0.132
Nov	0.042	4.0±0.7	0.168	5.3±1.3	0.22
Dec	0.045	2.1±0.7	0.094	2.7±0.2	0.122
1983	Σ 0.560	$\bar{x}$ 5.3	Σ 3.0	$\bar{x}$ 6.0	Σ 3.4

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

*Triple determinations.

The surface of the 10 m^2 rain collector is washed every month with diluted HNO_3 and after evaporation the washwater is added to the ion exchange resin before the analysis.

The tritium content of rain-water in 1983 (cf. Table 4.2.7.) was a little higher than in 1982. This is contrary to the decrease observed for ^{90}Sr and ^{137}Cs, because tritium in rain depends also upon the accumulated deposition from previous years (cf. 7). However, the tritium background at Risø is the most important reason for the nearly unchanged levels in 1983.

Table 4.2.8 shows the tritium concentrations in rain-water from three other locations in Denmark. Compared with Risø the average concentration for these three stations was approx. half of that from Risø. The concentrations from Bornholm were higher than those at the stations in Jutland. As earlier mentioned (Risø-R-487[1]) this may reflect the high tritium concentrations in the Baltic Sea as compared with those in the North Sea.

Table 4.2.8. Tritium in precipitation collected in Denmark in 1983. (Unit: kBq m^{-3})

Date	Tylstrup	Jyndevad	Bornholm
Jan-March	2.4±0.6	3.4±1.0	3.3±0.4
April-June	3.0±0.2	3.2±0.1	3.5±0.4
July-Sept	2.7±0.3	3.9±0.0	2.7±0.9
Oct-Dec	1.0±0.0	B.D.L.	2.4±0.2
Precipitation weighted mean	2.3	2.6	2.9

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

4.3. Fresh water

4.3.1. Radionuclides in ground water

As in previous years[1)], ground water was collected in March from the nine locations selected by the Geological Survey of Denmark. Figure 4.3.1.1 shows the sample locations and Table 4.3.1 the results of the ^{90}Sr, tritium and a ^{226}Ra analysis.

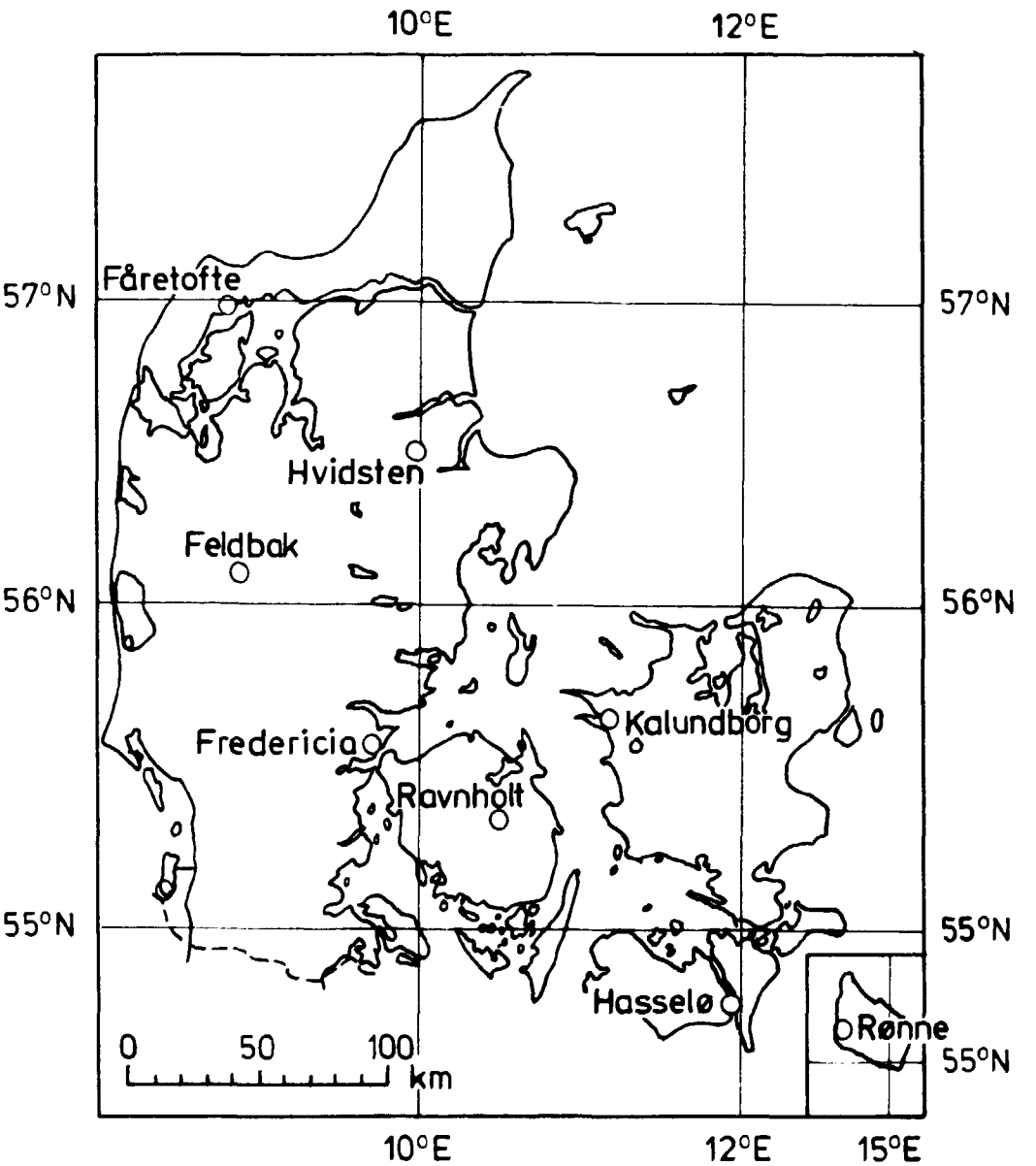

Fig. 4.3.1.1. Ground water sampling locations in Denmark.

Table 4.3.1. Radionuclides in ground water collected in March 1983

Location	Bq ^{90}Sr m^{-3}	kg Ca m^{-3}	kBq ^{3}H m^{-3} ±1 S.E.	Bq ^{226}Ra m^{-3}
Hvidsten	0.025 B	0.032	B.D.L.	4.5
Feldbak	86	0.027	4.2±0.2	94 ±10
Rømø	0.102 A	0.030	B.D.L.	7.9
Rønne new	0.021 B	0.023	B.D.L.	1.62
Rønne old	0.117	0.0106	B.D.L.	12.1
Hasselø	0.081 B	0.143	1.7±0.8	7.1
Fåretofte	0.086 A	0.147	4.1±1.2$^{\Delta}$	6.8
Kalundborg	0.56	0.0181	4.6±0.0	6.0
Ravnholt	0.062 B	0.107	5.9±1.4	3.4 ±0.6
Fredericia	0.49	0.084	4.0±1.4	8.9 ±0.8
Geometric mean	0.097*	0.062**	2.4±2.3** (1 S.D.)	5.7*
Median	0.094	0.031	2.8	7.0

A sample of ground water from Maglekilde in Roskilde contained 1.36 Bq ^{90}Sr m^{-3}, 6.8±0.9 kBq ^{3}H m^{-3}, 14.2 Bq ^{226}Ra m^{-3} and 0.088 kg Ca m^{-3}.

* Feldbak was not included in the geometric mean.

**Arithmetic mean.

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

$^{\Delta}$Triple determinations.

The median level of ^{90}Sr in 1982 was compatible with the values found since 1967 (cf. Fig. 4.3.1.2) but there seems to be a decreasing tendency with time.

The tritium concentrations in 1983 were similar to the 1982 levels. The tritium content of ground water has been decreasing since 1977 (cf. Fig. 4.3.1.4). The locations may be grouped as "high", "medium" and "low" level stations. Feldbak and Fåretofte were not included in this grouping because they showed a

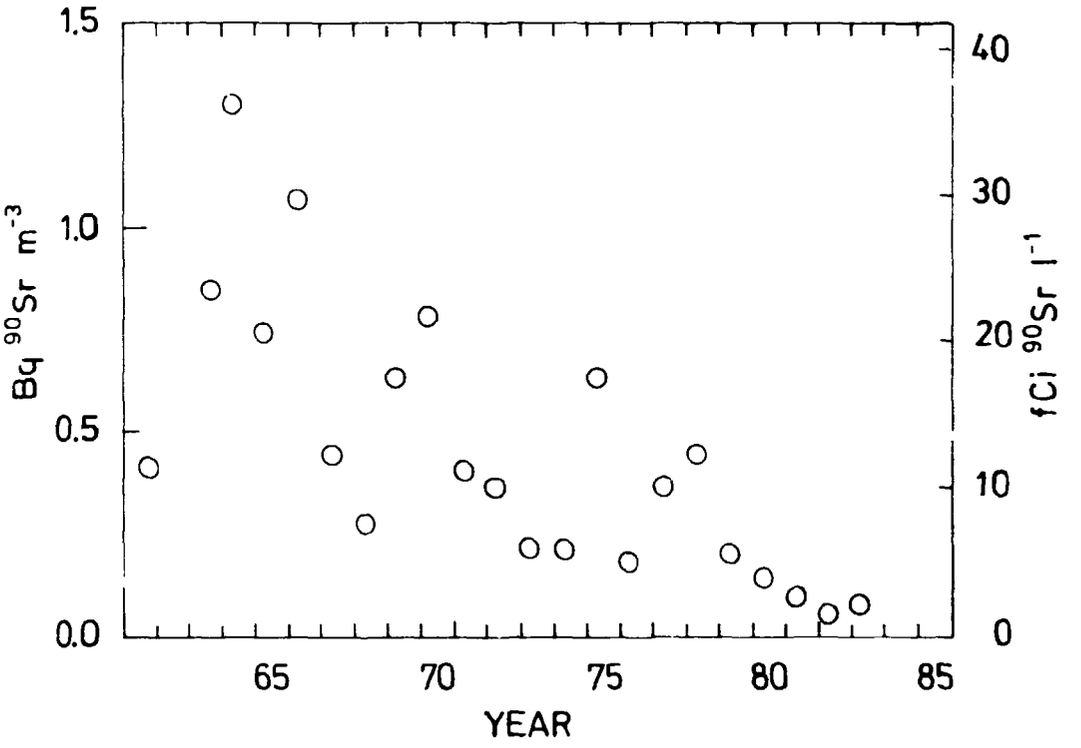

Fig. 4.3.1.2. Median ^{90}Sr levels in Danish ground water, 1961-1983.

time variation different from that of the other stations; in other words, there was an interaction between locations and years if these two stations were included.

The radium content in Danish ground water was determined in 1983. The concentrations varied from 1.6 to 94 Bq m^{-3}. The median was 7 Bq ^{226}Ra m^{-3}. The highest concentration was found in the water from Feldbak.

As appears from fig. 4.3.1.3, the ^{90}Sr levels in ground water from Feldbak have been in the order of 50-100 Bq m^{-3} in later years. The arithmetic mean of ^{90}Sr in Danish ground water in 1983 (excluding Feldbak and including Maglekilde) was 0.29 Bq m^{-3}.

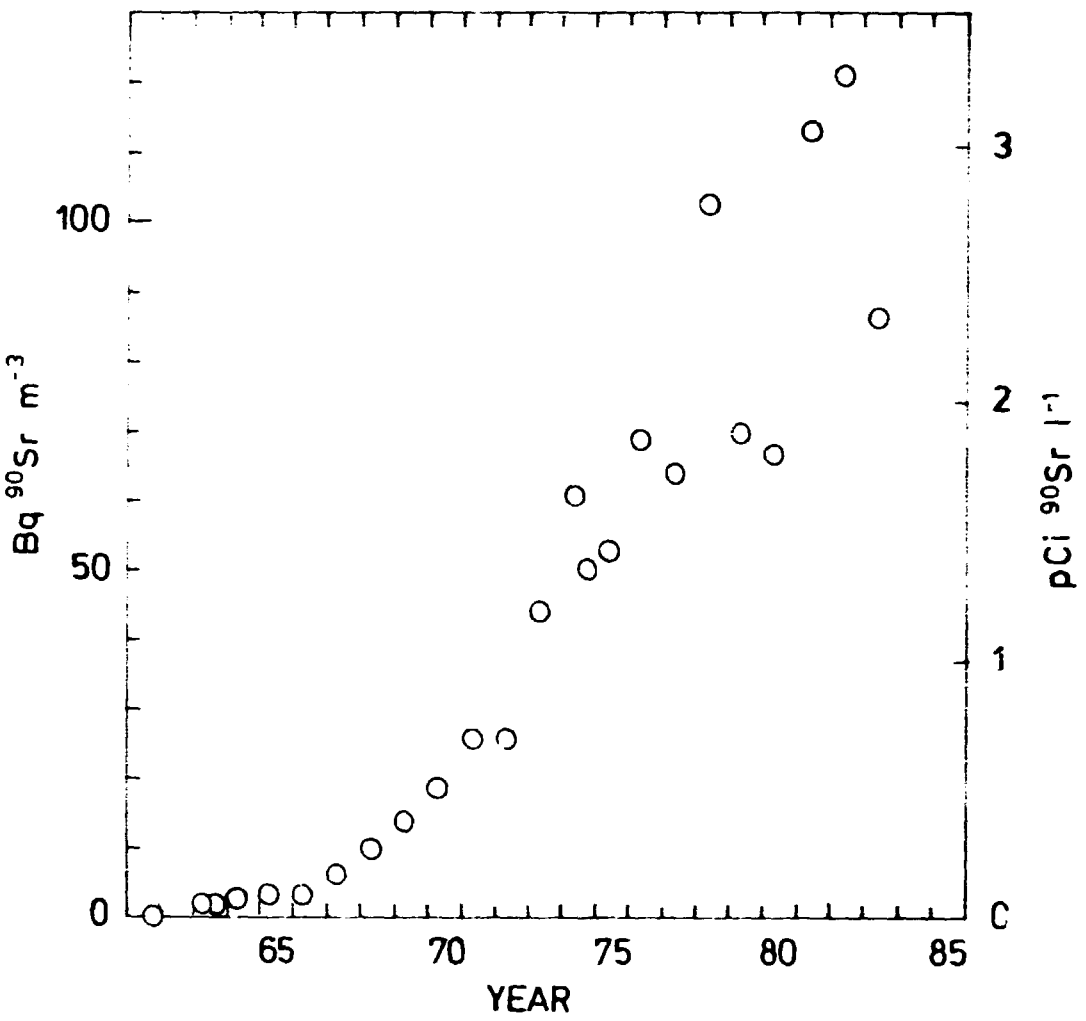

Fig. 4.3.1.3. Strontium-90 in ground water at Feldbak 1961-1983.

4.3.2. Strontium-90 in fresh water from Danish lakes and streams

The ^{90}Sr content of stream water was higher in 1983 than in 1981. We have no explanation for this increase, and it is not expected by our prediction model (cf. Appendix C1). The streams from the western part of the country especially showed enhanced concentrations.

The lake water contained a little less ^{90}Sr than in 1981.

4.3.3 Strontium-90 in Danish drinking water

No samples in 1983.

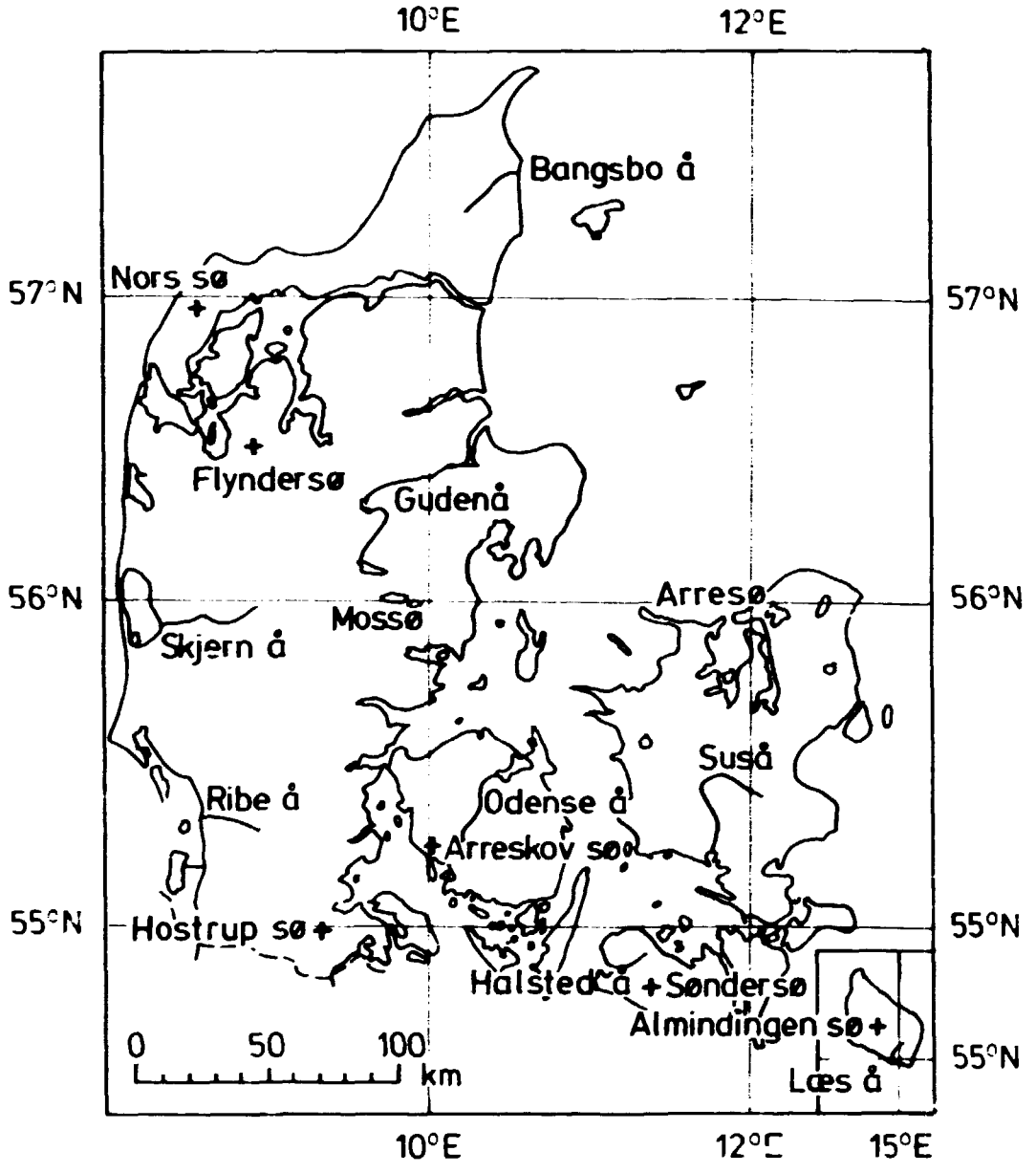

Fig. 4.3.2.1. Sample locations for fresh water from Danish streams (å) and lakes (sø).

Table 4.3.2. Strontium-90 in Danish streams and lakes in March 1983

Zone		Streams		Lakes	
			Bq ^{90}Sr m^{-3}		Bq ^{90}Sr m^{-3}
I:	North Jutland	Bangsbo å	19	Norssø	43
II:	East Jutland	Randers å	17	Mossø	13.2
III:	West Jutland	Skjern å	19	Flyndersø	12.7
IV:	South Jutland	Ribe å	12.6	Hostrup sø	21
V:	Funen	Odense å	12.7	Arreskov sø	13.6
VI:	Zealand	Suså	8.2	Arresø	34
VII:	Lolland-Falster	Halsted å	8.6	Søndersø	27
VIII:	Bornholm	Læs å	17	Almindingen sø	18.3
Mean			14.3		23
±1 S.E.			1.6		3.9

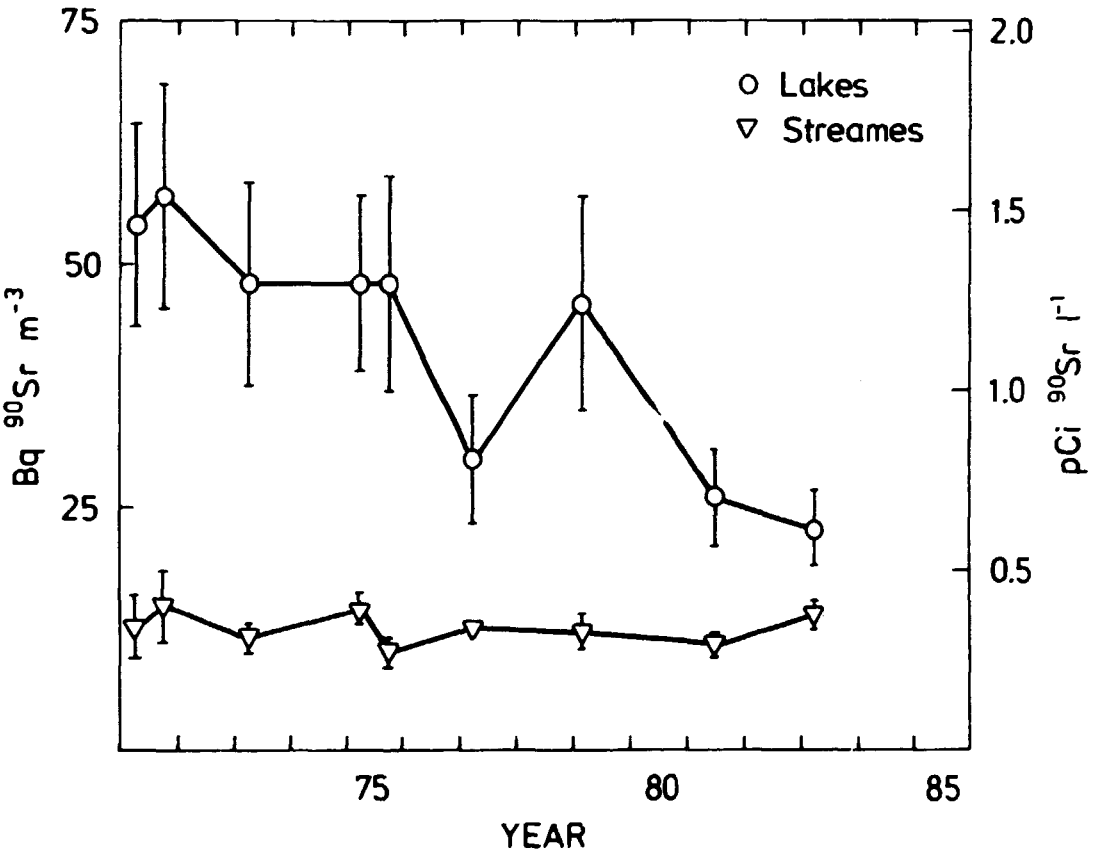

Fig. 4.3.2.2. Strontium-90 concentrations (±1 S.E.) in 8 Danish streams and 8 Danish lakes collected every second year since 1971.

4.4. Radionuclides in sea water in 1983

As in previous years, sea water samples were collected by M/S Fyrholm from inner Danish waters (cf. Table 4.4.1 and figs. 4.4.1, 4.4.2 and 4.4.3). Furthermore, sea water samples were collected at Barsebäck in the Sound, and at Ringhals in the Kattegat (Table 4.4.3). Samples were obtained from the research vessel DANA, which in 1983 have collected samples from the Danish straits as well as from the North and the Baltic Seas (Table 4.4.3). Furthermore, samples were obtained from F/S Gauss and from F/S Polarstern (Tables 4.4.3 and 4.4.4).

Figure 4.4.2 shows that the maximum ^{137}Cs concentration in bottom water occurred in 1979, since then the levels have decreased. Also the surface water shows decreasing ^{137}Cs concentrations in 1983.

As earlier (Risø Reports Nos. 421, 447, 469 and 487)[1] we found in 1983 that the transport time of radiocesium from Sellafield (Windscale) to the Danish straits was approximately 4 years and that somewhat less than 1% of the ^{137}Cs released from Sellafield enters the Baltic Sea. From the regression given in Fig. 4.4.6 the ^{137}Cs concentration in 35 o/oo sea water was estimated at 69 Bq m^{-3} and we found 75 Bq m^{-3} according to the equation for ^{137}Cs related to salinity in 1983.

Table 4.4.1. Strontium-90, Cesium-137 and Cesium-134 in sea water collected around Zealand in May 1983

	Position N	Position E	Depth in m	^{90}Sr Bq m^{-3}	^{137}Cs Bq m^{-3}	^{134}Cs Bq m^{-3}	Salinity o/oo
Kullen	56°15'	12°25'	0		24	B.D.L.	11.8
"			17	23	74	2.7	33.3
Hesselø*	56°10'	11°47'	0	26	45	B.D.L.	20.1
"			23		60	2.4 A	31.2
Kattegat SW	56°07'	11°10'	0		31	B.D.L.	14.7
"			27	18.9	66	2.4	33.4
Asnæs rev	55°38'	10°47'	0	26	24	B.D.L.	12.4
" "			32		67	2.2	32.9
Halskov rev	55°23'	11°02'	0		24	B.D.L.	11.8
" "			19	27	70	2.1	32.2
Langeland bælt	54°52'	10°50'	0	26	18.8	B.D.L.	9.6
" "			29		67	1.79	31.0
Fømern bælt	54°36'	11°05'	0		19.8	B.D.L.	9.6
" "			21	25	59	2.3 A	28.9
Gedser odde	54°28'	11°59'	0	26	18.9	B.D.L.	9.2
" "			17		45	1.28	20.0
Møen	54°57'	12°41'	0		16.5	B.D.L.	8.3
"			22	25	21	B.D.L.	10.0
The Sound - South	55°25'	12°37'	0	30	16.7	B.D.L.	7.8
" " "			10		16.4	B.D.L.	8.0
The Sound - North A	55°48'	12°43'	0		16.6	B.D.L.	8.7
" " "			14	25	42	B.D.L.	18.9
The Sound - North B	55°59'	12°42'	0	25	19.5	B.D.L.	9.7
" " "			25		76	2.3	31.6
Mean			Surface	26	23		11.1
S.D.				1.76	8.15		3.45
S.E.				0.72	2.35		1.00
Mean			Bottom	24	55		26.0
S.D.				2.79	19.98		9.30
S.E.				1.14	5.77		2.69

*Collected in August.

Table 4.4.2. Strontium-90, Cesium-137 and Cesium-134 in sea water collected around Zealand in November 1983

	Position N	Position E	Depth in m	^{90}Sr Bq m^{-3}	^{137}Cs Bq m^{-3}	^{134}Cs Bq m^{-3}	Salinity o/oo
Kullen	56°15'	12°25'	0		23	B.D.L.	11.3
"			22		59	1.8 A	27.3
Hesselø	56°10'	11°47'	0		51	1.8 A	25.0
"			23	26	60	B.D.L.	26.8
Kattegat SW	56°07'	11°10'	0				
"			35				
Asnæs rev	55°38'	10°47'	0		32	B.D.L.	16.8
" "			23	28	44	B.D.L.	23.1
Halskov rev	55°23'	11°03'	0		31	B.D.L.	15.8
" "			18		41	B.D.L.	21.2
Langeland bælt	54°52'	10°50'	0		30	B.D.L.	14.8
" "			29		44	B.D.L.	21.6
Femern bælt	54°36'	11°05'	0	24	29	B.D.L.	15.1
" "			22		39	B.D.L.	19.2
Gedser odde	54°28'	11°59'	0		21	B.D.L.	11.3
" "			15	28	26	B.D.L.	13.5
Møen	54°57'	12°41'	0	29	18.0	B.D.L.	9.9
"			20		21	B.D.L.	10.4
The Sound - South	55°25'	12°37'	0		18.9	B.D.L.	10.2
" " "			11		19.4	B.D.L.	10.7
The Sound - North A	55°48'	12°44'	0	25	18.6	B.D.L.	10.5
" " "			14		22	B.D.L.	11.1
The Sound - North B	55°59'	12°42'	0		21	B.D.L.	10.8
" " "			25		56	B.D.L.	27.3
Mean			Surface	26	27		13.8
S.D.				2.65	9.66		4.49
S.E.				1.53	2.91		1.35
Mean			Bottom	27	39		19.3
S.D.				1.15	15.33		6.79
S.E.				0.67	4.62		2.05

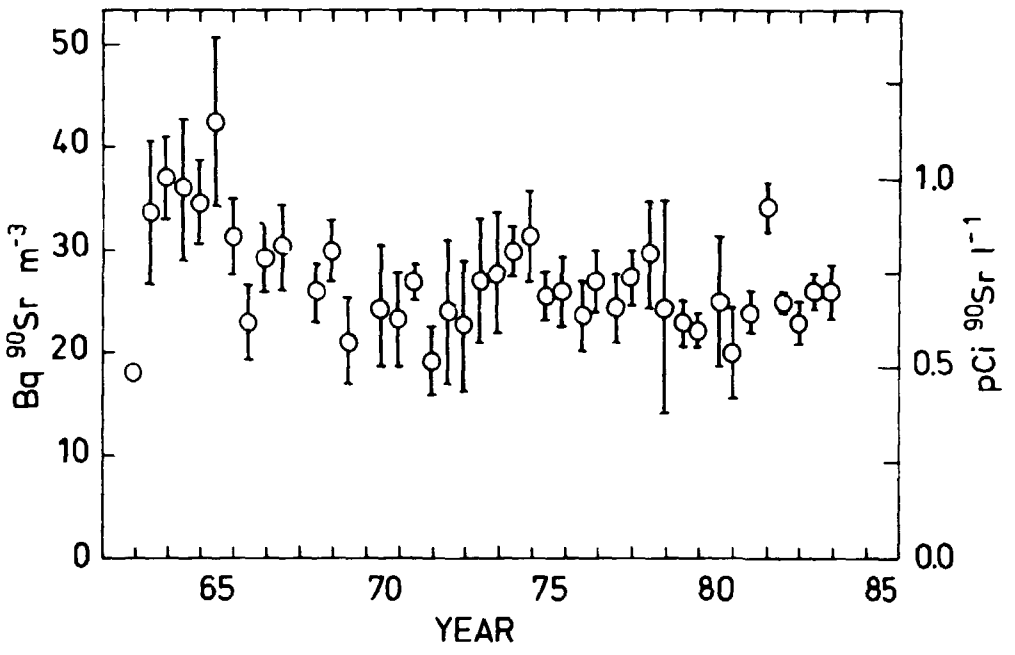

Fig. 4.4.1. Strontium-90 in surface sea water from inner Danish waters, 1962-1983. (1 S.D. indicated) (from Table 4.4.1).

As was done earlier we calculated the regression equations between salinity and ^{90}Sr and ^{137}Cs activity in the sea water:

Bq ^{90}Sr m^{-3} = 34.8-0.67 o/oo (1967-1971)
Bq ^{90}Sr m^{-3} = 35.9-0.74 o/oo (1972)
Bq ^{90}Sr m^{-3} = 35.2-0.52 o/oo (1973)
Bq ^{90}Sr m^{-3} = 34.4-0.37 o/oo (1974)
Bq ^{90}Sr m^{-3} = 29.2-0.22 o/oo (1975)
Bq ^{90}Sr m^{-3} = 26.3-0.074 o/oo (1976)
Bq ^{90}Sr m^{-3} = 26.3-0.056 o/oo (1977)
Bq ^{90}Sr m^{-3} = 27.8-0.107 o/oo (1978)
Bq ^{90}Sr m^{-3} = 27.8-0.31 o/oo (1979)
Bq ^{90}Sr m^{-3} = 20.8+0.159 o/oo (1980)
Bq ^{90}Sr m^{-3} = 25.9+0.098 o/oo (1981)
Bq ^{90}Sr m^{-3} = 26.8-0.197 o/oo (1982)
Bq ^{90}Sr m^{-3} = 27.6-0.056 o/oo (1983)

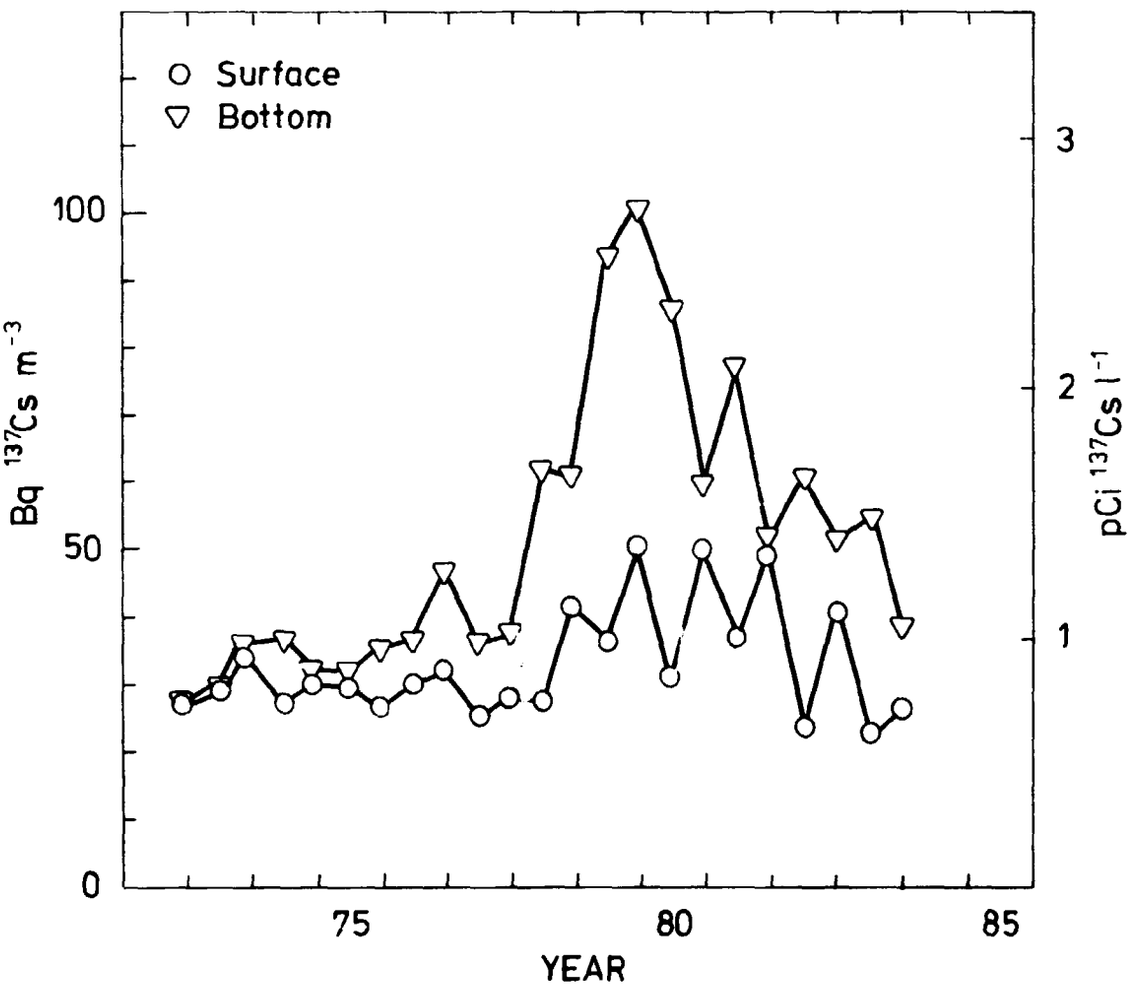

Fig. 4.4.2. Cesium-137 in surface and bottom water collected in inner Danish waters 1972-1983.

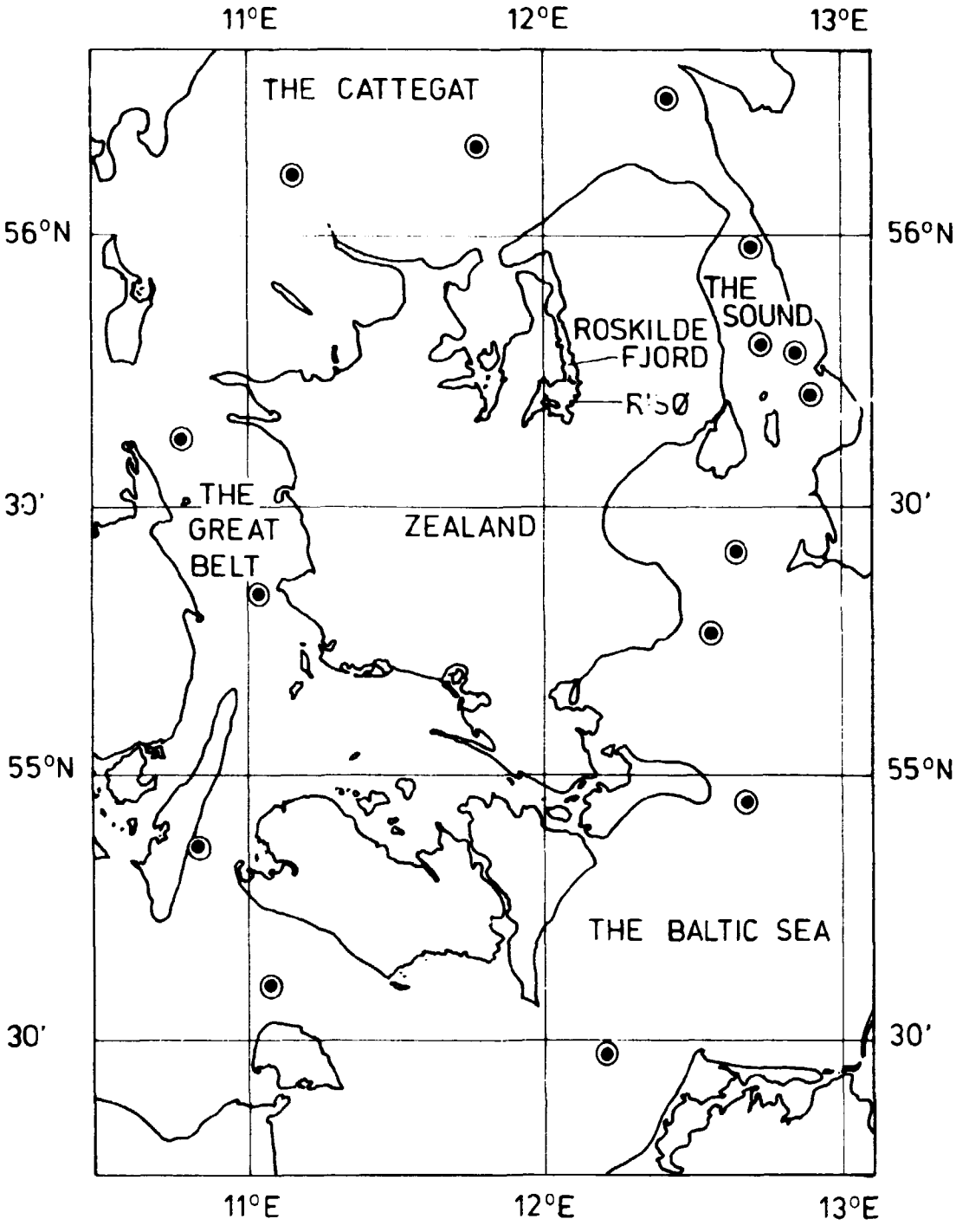

Fig. 4.4.3. Sea water locations around Zealand.

The regression analysis showed only significant regression in 1967-1971, 1972 and in 1974.

Bq $^{137}Cs\ m^{-3}$ = 29.6 -0.16 o/oo (1972)
Bq $^{137}Cs\ m^{-3}$ = 22.2 +0.44 o/oo (1973)
Bq $^{137}Cs\ m^{-3}$ = 20.0 +0.67 o/oo (1974)
Bq $^{137}Cs\ m^{-3}$ = 23.7 +0.37 o/oo (1975)
Bq $^{137}Cs\ m^{-3}$ = 19.6 +0.70 o/oo (1976)
Bq $^{137}Cs\ m^{-3}$ = 15.2 +1.00 o/oo (1977)
Bq $^{137}Cs\ m^{-3}$ = -10.4 +2.85 o/oo (1978)
Bq $^{137}Cs\ m^{-3}$ = -33.3 +4.44 o/oo (1979)
Bq $^{137}Cs\ m^{-3}$ = - 9.1 +3.26 o/oo (1980)
Bq $^{137}Cs\ m^{-3}$ = - 5.0 +3.04 o/oo (1981)
Bq $^{137}Cs\ m^{-3}$ = - 4.11+2.56 o/oo (1982)
Bq $^{137}Cs\ m^{-3}$ = - 2.34+2.19 o/oo (1983)

The regression analysis showed significant or probably significant regression in all years except in 1972.

In a recent report[17] from a cooperative programme under IAEA on the study of radioactive materials in the Baltic Sea, we have calculated the transfer factors of radiocesium and ^{90}Sr from Sellafield to the Danish Straits.

For surface water (mean salinity 15 o/oo) we found:

16 Bq $^{90}Sr\ m^{-3}$ per PBq ^{90}Sr discharged per year from Sellafield
13 Bq $^{134}Cs\ m^{-3}$ (PBq $^{134}Cs\ a^{-1}$)$^{-1}$
7 Bq $^{137}Cs\ m^{-3}$ (PBq $^{137}Cs\ a^{-1}$)$^{-1}$

and for bottom water (mean salinity 33-34 o/oo):

58 Bq $^{90}Sr\ m^{-3}$ (PBq $^{90}Sr\ a^{-1}$)$^{-1}$
29 Bq $^{134}Cs\ m^{-3}$ (PBq $^{134}Cs\ a^{-1}$)$^{-1}$
26 Bq $^{137}Cs\ m^{-3}$ (PBq $^{137}Cs\ a^{-1}$)$^{-1}$

In these calculations discharges as well as water concentrations were all decay corrected to the same year (1983), i.e. we have

Table 4.4.3. Radionuclides in sea water collected in the Danish straits, the North and the Baltic Seas in 1983

	Position N	E el. W	Date	Depth in m	Salinity o/oo	^{90}Sr Bq m^{-3}	^{137}Cs Bq m^{-3}	^{134}Cs Bq m^{-3}	^{3}H kBq m^{-3}	$^{239,240}Pu$ mBq m^{-3}	^{241}Am mBq m^{-3}
Barsebäck	55°45'29	12°52'77E	9/5	0	8.0		16.8	B.D.L.			
"	"	"	"	18	33.0		74	2.0 A			
"	55°46'01	12°52'68E	14/4	2	10.4		19.1	B.D.L.			
"	"	"	"	11	10.6		21	B.D.L.			
Ringhals	57°15'15	12°03'60E	14/4	0	18.2		37	B.D.L.			
"	"	"	"	24	33.7		65	2.3 A			
"	57°15'17	12°03'55E	10/8	0	20.5		44	B.D.L.			
"	"	"	"	18	28.3		55	B.D.L.			
Dana Togt 1	54°45'	0°30' E	15/2	0	34.9		171	5.6			
" "	55°15'	0°30' E	21/2	0	35.0	31	157	5.1			
" "	56°15'	0°30' E	15/2	0	34.5		189	6.7			
" "	57°45'	0°30' E	15/2	0	35.5	10.6	48	2.1			
" "	59°45'	0°30' E	13/2	0	35.1		34	B.D.L.			
" "	60°45'	0°30' E	14/2	0	35.4		3.8	B.D.L.			
" "	59°15'	1°30' E	13/2	0	35.3	6.9	28	B.D.L.			
" "	60°15'	1°30' E	14/2	0	35.7	3.7	8.3	B.D.L.			
" "	61°15'	1°30' E	14/2	0	35.5	2.8	3.5	B.D.L.			
" "	58°45'	2°30' E	13/2	0	34.5		69	2.2 A			
" "	55°15'	3°30' E	22/2	0	35.0		136	4.1			
" "	58°15'	3°30' E	12/2	0	35.3	7.2	28	B.D.L.			
" "	58°15'	4°30' E	12/2	0	34.2		85	2.4			
" "	53°45'	5°30' E	25/2	0	33.8	31	98	4.1			
" "	55°15'	5°30' E	22/2	0	35.1	18.8	113	4.1			
" "	57°15'	5°30' E	11/2	0	35.4		39	B.D.L.			
" "	57°45'	5°30' E	11/2	0	34.8	11.1	47	B.D.L.			
" "	57°15'	6°30' E	10/2	0	35.0		106	3.6			
" "	55°15'	7°30' E	22/2	0	33.9		34	2.9			
" "	57°15'	7°30' E	10/2	0	34.9	15.3	64	2.3			
Dana Togt 7	57°18'3	8°20'5 E	10/5	0	33.2		71	2.4 A			
" "	57°57'5	7°51'0 E	9/5	0	23.6		46	B.D.L.			
" "	58°15'8	9°17'2 E	15/5	2	29.7		60	2.8			
" "	58°00'	9°26' E	16/5	0	32.6		87	3.1			
Dana Togt 8	55°	7°50' E	27/5	0	29.6		20	2.9			
" "	54°16'	7°38' E	"	0	30.5	24	18.1	2.0			
" "	55°40'	7°47' E	28/5	0	29.6	25	24	2.4 A			
" "	56°09'	7°52' E	"	0	29.5		23	2.2			
" "	55°53'	7°59' E	29/5	0	30.6	27	30	2.4			

Table 4.4.3. (continued)

	Position N	E el. W	Date	Depth in m	Salinity o/oo	^{90}Sr Bq m^{-3}	^{137}Cs Bq m^{-3}	^{134}Cs Bq m^{-3}	^{3}H kBq m^{-3}	$^{239,240}Pu$ mBq m^{-3}	^{241}Am mBq m^{-3}
Dana Togt 9	57°10'60	7°36'42E	6/6	0	31.6		73	2.9			
" "	57°09'96	6°17'29E	7/6	0	32.2	20	71	3.1			
" "	57°10'79	5°27'41E	7/6	0	34.9		89	3.2			
" "	57°09'87	4°28'34E	7/6	0	34.9	16.3	87	3.4			
" "	57°09'10	3°28'07E	7/6	0	35.0		92	3.4			
" "	57°10'60	2°30'20E	8/6	0	34.8	26	139	5.2			
" "	57°09'94	1°26'33E	8/6	0	34.7		136	3.9			
" "	57°08'30	0°29'86E	8/6	0	34.9	19.0	95	3.1			
Dana Hanstholm	57°10'10	8°26'8 E	10/5	0	30.6	31	36	B.D.L.			
" Mandal 2	57°49'6	7°57'6 E	9/5	0	32.0	22	68	2.8 A			
" Arendal 1	58°21'4	8°58'9 E	15/5	0	19.7	23	43	1.4 A			
" Arendal 3	58°08'5	9°36'4 E	15/5	0	30.0	27	60	3.0			
" Skagen	57°48'1	10°52'5 E	16/5	0	28.3	30	61	3.1			
Hals Limfj.	56°59'51	10°18'20E	2/8	0	26.0	31	37	B.D.L.	2.3±0.2		
Gjøl "	57°03'74	9°42'05E	2/8	0	24.6	29	27	B.D.L.	2.1±0.7		
Aatoft "	57°00'32	8°56'70E	3/8	0	26.2	27	25	B.D.L.			
Sillerslev Lim.	56°40'83	8°44'05E	3/8	0	29.1	29	31	B.D.L.			
Thyborøn	56°42'78	8°13'76E	3/8	0	32.0	32	77	2.6 A			
Hanstholm	57°07'29	8°36'20E	4/8	0	32.0		74	3.8			
Hirtshals	57°35'b0	9°57'83E	4/8	0	31.3		71	2.9			
Skagen	57°43'85	10°35'52E	4/8	0	31.6	26	76	2.6			
Læsø East	57°19'	11°08' E	10/8	0	22.4	25	45	B.D.L.			
" West	57°18'	10°56' E	10/8	0	21.5		44	B.D.L.			
Anholt	56°43'	11°31' E	10/8	0	20.1	31	40	1.8 A			
Hesselø	56°11'70	11°42'55E	11/8	0	19.7		41	B.D.L.			
GAUSS 8	55°00'08	10°06'11E	26/5	0	11.9	25	26	B.D.L.		6.7*	0.67 A*
" "	"	"	"	34	25.7	35	56	B.D.L.			
GAUSS 22	54°46'2	12°45'8 E	27/5	0	8.3	26	17.7**	0.108**		3.4*	0.21 B*
" "	"	"	"	17	8.5	31	19.1	B.D.L.			
" 24	55°49'89	10°48'29E	28/5	0	13.5					3.2*	0.60 A*
" 27 Δ	56°30'03	11°29'97E	29/5	0	15					3.2*	0.28 A*
" 30	57°30'02	11°29'99E	"	0	16					3.0 A*	0.24 B*
" 33 Δ	56°15'	12°22' E	30/5	0	14.5					2.8*	0.26 B*
" "	55°10'06	16°00'04E	1/6	4	8	26.1	16.2	Spiked		3.1 A	0.58 B
Polarstern 2+3	57°54'	4°07' E	30/6	5	32.6	18.8	62	2.8 A	1.2±0.4	17.1*	1.75*
" 4	60°33'	4°00' E	30/6	10	30.2	19.7	53	2.0 A	1.8±0.4		

Table 6.6.3. (continued)

	Position N	Position E el. W	Date	Depth in m	Salinity o/oo	^{90}Sr Bq m^{-3}	^{137}Cs Bq m^{-3}	^{134}Cs Bq m^{-3}	^{3}H kBq m^{-3}	$^{239,240}Pu$ mBq m^{-3}	^{241}Am mBq m^{-3}
Dana Toqt 16	60°15'	2°10' W	16/9	0	34.6	10.7	45	B.D.L.			
" "	60°04'	2°01' W	"	0	35.2		33	B.D.L.			
" "	59°55'	2°18' W	"	0	35.2		37	1.9 A			
" "	59°45'	2°09' W	"	0	34.7	8.5	31	B.D.L.			
" "	59°35'	2°14' W	17/9	0	35.1		88	2.9 A			
" "	58°35'	2°50' W	29/9	0	34.9		147	5.6			
" "	58°34'	2°58' W	"	0	34.9		157	5.7			
" "	58°46'	2°49' W	"	0	35.0		148	5.0			
" "	58°56'	2°29' W	"	0	35.0		134	5.6			
" "	59°05'	2°25' W	"	0	34.8		164	6.9			
" "	59°15'	2°10' W	"	0	34.2		159	6.6			
Dana Toqt 16	54°46'	13°31' E	20/10	0	11.1		23	B.D.L.			
" "	55°38'	15°15' E	21/10	0	9.4		20	B.D.L.		2.6**	
" "	"	"	"	60	9.6		18.6	B.D.L.		2.8**	
" "	56°48'	15°34' E	27/10	0	8.3		17.6	B.D.L.			
" "	"	"	"	60	8.4		17.3	B.D.L.			
" "	55°03'	16°29' E	22/10	0	8.2		14.4	B.D.L.			
" "	56°07'	17°05' E	24/10	0	7.8		16.5	B.D.L.			
" "	"	"	"	30	7.9		16.2	B.D.L.			
" "	55°21'	18°37' E	25/10	0	7.7		14.9	B.D.L.			
" "	56°20'	20°15' E	"	0	7.7		16.4	B.D.L.			
" "	"	"	"	45	7.7		14.4	B.D.L.			
" "	55°30'	20°25' E	24/10	0	7.8	27	15.7	B.D.L.			
The Gulf of Finland	60°15'14	25°48'95E	23/10	0	5.8		11.5	B.D.L.			
Riso			15/5	0	10.9		19.3	B.D.L.			
"			16/5	0	"		18.3	B.D.L.			
"			18/5	0	"		18.3	B.D.L.			
Bolund at Riso			6/6	0	10.3		20	B.D.L.			
Rona	55°05'	8°34' E	10/1	0	25.9		20	1.91			
Esbjerg	55°29'	8°25' E	10/1	0	27.9		18.2	1.44 A			

* 0.2 m^3

** ~ 1.7 m^3

A These samples were analysed for ^{60}Co (1600 l). Both samples contained 0.12 Bq ^{60}Co m^{-3}.
All other samples were ~ 0.35 m^3.

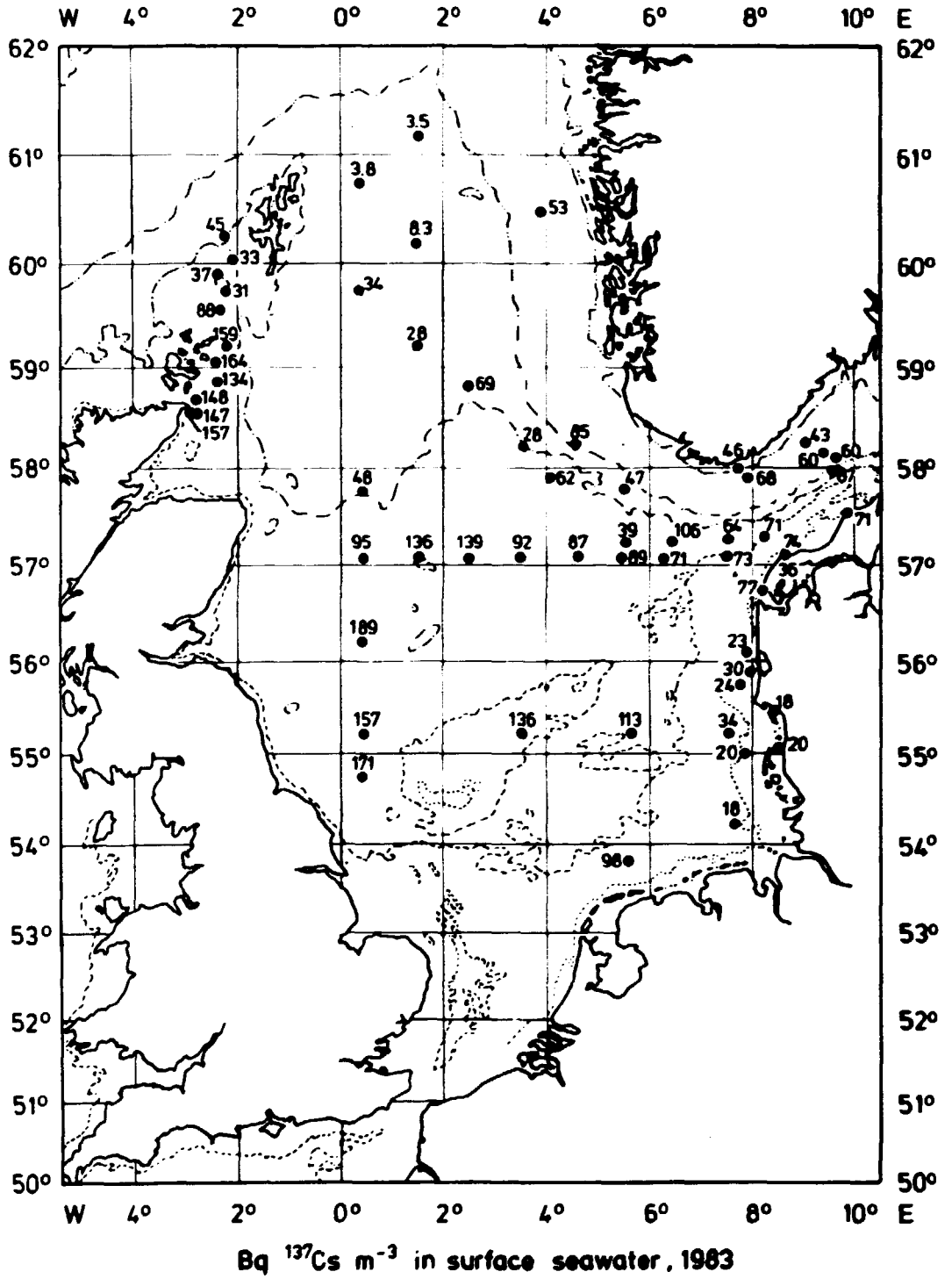

Fig. 4.4.4. Cesium-137 in the North Sea in 1983. (Unit: Bq m^{-3}) (cf. Table 4.4.3).

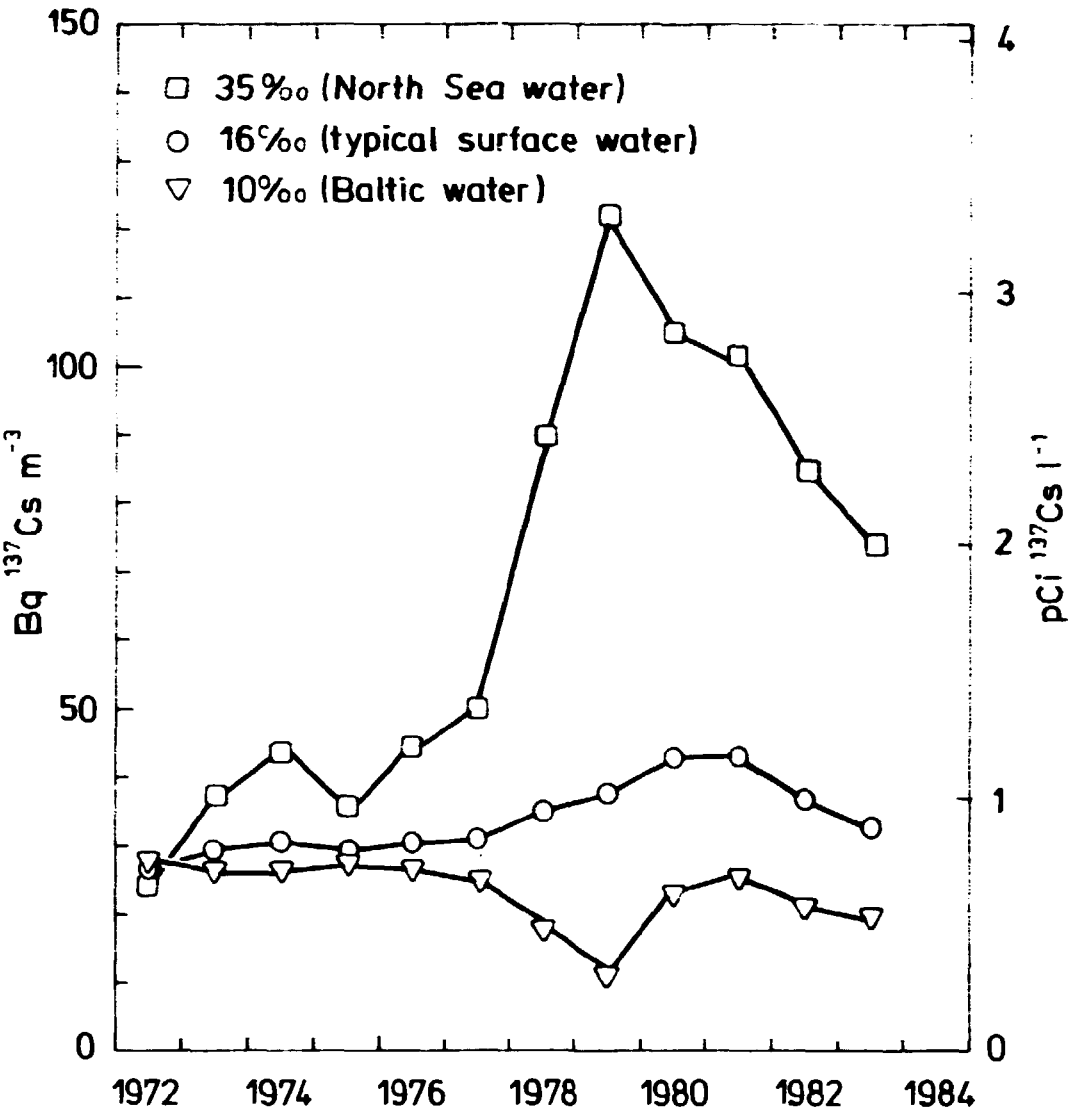

Fig. 4.4.5. Cesium-137 in inner Danish waters of 3 different salinities (1972-1983). The values were calculated from the regression equations in 4.4.

assumed no radioactive decay of the radionuclides during their transfer from Sellafield to the Danish Straits. Hence the two radiocesium isotopes should show the same transfer factor. This is the case only for bottom water. The discrepancy found for surface water, however, is hardly significant considering the many uncertainties in such calculations as these. The lower transfer factors for radiocesium than for ^{90}Sr are due to sedimentation of ^{137}Cs and ^{134}Cs.

In 1983 a number of samples were obtained from the Jutland Current. The samples, in particular those along the south-western part of Jutland (cf. fig. 4.4.4), contained relatively low ^{137}Cs concentrations. The $^{134}Cs/^{137}Cs$ ratios (~ 0.1) were, however, higher than those seen in samples contaminated from Sellafield only. We assume that the samples were contaminated by effluents from Cap de La Hague in France. In these samples the $^{90}Sr/^{137}Cs$ ratios were also higher than is usually observed in the North Sea.

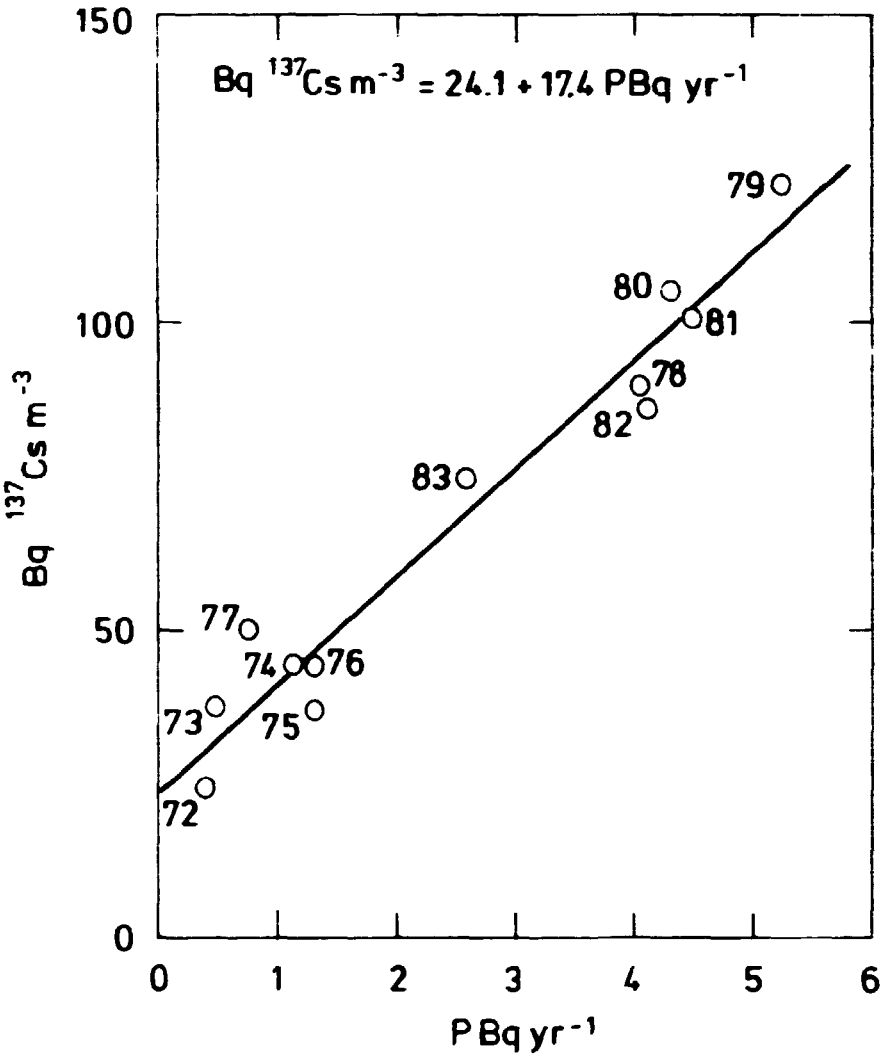

Fig. 4.4.6. Cesium-137 concentrations in "North Sea water" (35 o/oo salinity) in the Danish Straits related to discharges from Sellafield 4 years earlier.

Table 4.4.4. Particulate Plutonium and Americium collected on filters at the Gauss cruise 26-30 May 1983 in the Danish straits

Position N	Position E	mBq $^{239,240}Pu$ m^{-3} (±1 S.D. %)	$^{238}Pu/^{239,240}Pu$ (±1 S.D. %)	mBq ^{241}Am m^{-3} (±1 S.D. %)	Sample size m^3	Filter
55°00'	10°06'	1.09 (10)	0.09 (34)	0.16 (32)	1.234	Millipore
54°46'	12°46'	0.15 (26)	-	0.16 (45)	1.082	Millipore
55°50'	10°48'	0.56 (21)	-	0.06 (58)	1.486	Millipore
- " -		0.61 (24)	-	-	0.995	Gelmann
56°30'	11°30'	0.23 (32)	-	0.11 (35)	1.168	Millipore
57°30'	11°30'	-	-	0.10 (26)	2.800	Millipore
- " -		0.41 (18)	-	0.15 (33)	1.183	Gelmann
56°15'	12°22'	0.53 (16)	-	0.07 (30)	2.547	Millipore

The mean ratio: $\frac{\text{Pu-particulate}}{\text{total Pu (cf. Table 4.4.3)}}$ = 0.15±0.07 (±1 S.D., N = 7)

Table 4.4.5. Tritium in sea water collected in Roskilde Fjord, I (cf. Fig. 4.6.1), 1983

Month	kBq ^{3}H m^{-3}
January	4.0±0.7
February	5.1±0.4
March	5.5±1.1
April	4.0±0.0
May	6.4±1.3
June	4.7±0.7
July	4.5±0.6
August	4.4±0.4
September	4.9±0.6
October	2.9±1.1
November	9.4±0.2
December	7.3±0.7

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

4.5. Strontium-90 in soil

No samples in 1983.

4.6. Sediments

We collected sediments from Roskilde Fjord (Table 4.6.1), Limfjorden (Table 4.6.2) and the Danish Straits (Table 4.6.3). The latter samples were collected from F/S Gauss during the joint German-Scandinavian Baltic Cruise in May-June 1983. The results show that the sedimentation of ^{137}Cs in the Danish Straits varies by a factor of nearly 50. The geometric mean was 810 Bq ^{137}Cs m^{-2}. The total area of the Danish Straits is 43,900 km^2, i.e. 36 TBq ^{137}Cs are in the sediments; this is nearly the same as in the water.

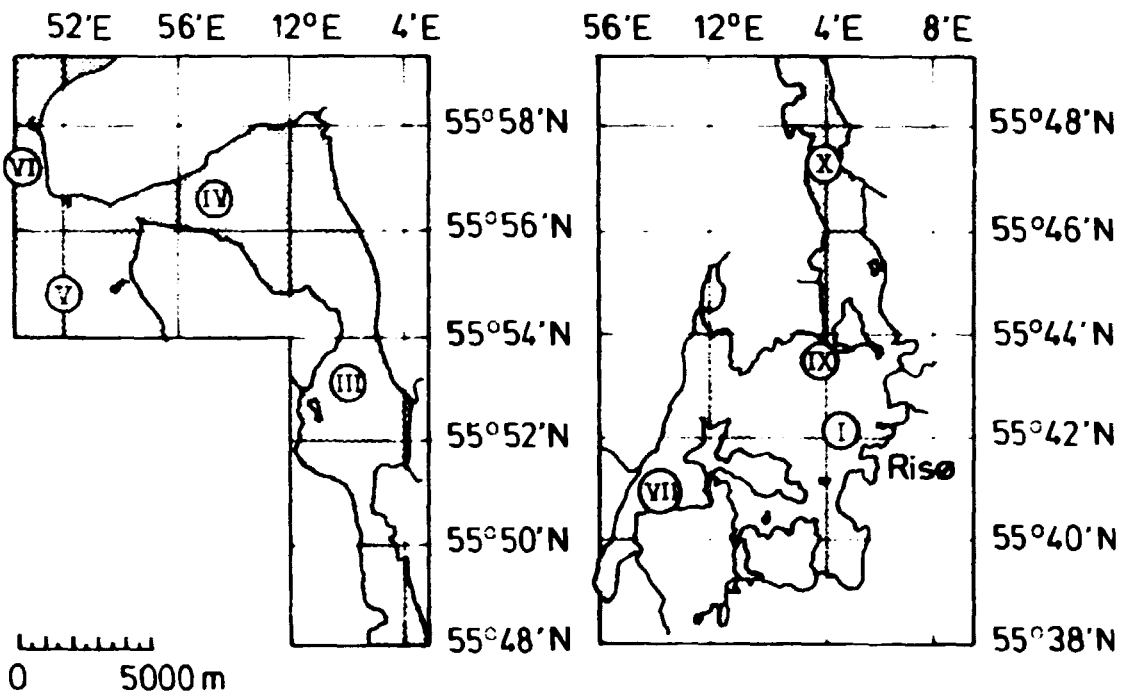

Fig. 4.6.1. Roskilde fjord.

Table 4.6.1. Cesium-137 in sediment samples collected in Roskilde fjord, 1982. (HAPS) (Area 0.0145 m^2)

Location	Depth in cm	Date	Bq kg^{-1} dry	Bq m^{-2}
At Bolund	0-7	6/6	7.3	520
55°40'N 12°05'E		25/7	16.6	2400

Table 4.6.2. Cesium-137 and Cesium-134 in sediments collected in Limfjorden in 1983 (HAPS) (Area: 0.0145 m^2)

Location			Depth	Date	Depth in cm	Bq ^{137}Cs kg^{-1} dry	Bq ^{137}Cs m^{-2}	Bq ^{134}Cs kg^{-1} dry	Bq ^{134}Cs m^{-2}
56°59'N	10°18'E	Hals	7 m	2/8	0-3	2.4	130		
"	"	"	"	"	3-6	1.64	92		
					0-6		Σ 220		
56°60'N	8°57'E	Amtoft	6 m	3/8	0-3	5.6	191		
"	"	"	"	"	3-6	4.2	178		
					0-6		Σ 370		
56°38'N	8°17'E	Nissum Bredning	5.5 m	3/8	0-3	12.1	270	0.8 A	18 A
"	"	"	"	"	3-6	15.2	360		
"	"	"	"	"	6-9	16.9	370		
"	"	"	"	"	9-12	15.3	500		
					0-12		Σ 1500		Σ 18

Table 6.6.3. Cesium-137 in sediments collected in inner Danish waters in May 1983 by GAUSS. (MAPS) (Area: 0.0145 m^2)

Location		Station no.	Date	Depth in cm	Bq kg^{-1} dry	Bq m^{-2}
54°46'N	12°46'E	22	27	0-3	1.0 A	46
"	"	"	"	3-6	1.2	53
				0-6		Σ 99
54°39.68'N	10°45.41'E	23 A	28	0-3	16.7	420
"	"	"	"	3-6	9.1	350
				0-6		Σ 770
"	"	23 B	28	0-3	19.4	440
"	"	"	"	3-6	8.6	280
"	"	"	"	6-9	2.8	100
				0-9		Σ 820
"	"	23 C	28	0-3	15.6	530
"	"	"	"	3-6	6.7	250
"	"	"	"	6-9	2.7	110
				0-9		Σ 890
55°50'N	10°48'E	24	28	0-3	20	430
"	"	"	"	3-6	8.3	260
"	"	"	"	6-9	5.1	180
"	"	"	"	9-12	1.96	70
				0-12		Σ 940
56°30'N	11°30'E	27	29	0-3	6.1	230
"	"	"	"	3-6	7.6	270
				0-6		Σ 500
56°15'N	12°22'E	33	30	0-3	18.1	540
"	"	"	"	3-6	14.9	510
"	"	"	"	6-9	6.1	250
"	"	"	"	9-12	1.54	50
				0-12		Σ 1350
57°30'N	11°30'E	30	29	0-3	62	780
"	"	"	"	3-6	65	970
"	"	"	"	6-9	64	1080
"	"	"	"	9-12	55	990
"	"	"	"	12-15	40	770
"	"	"	"	15-18	12	620
				0-18		Σ 5200

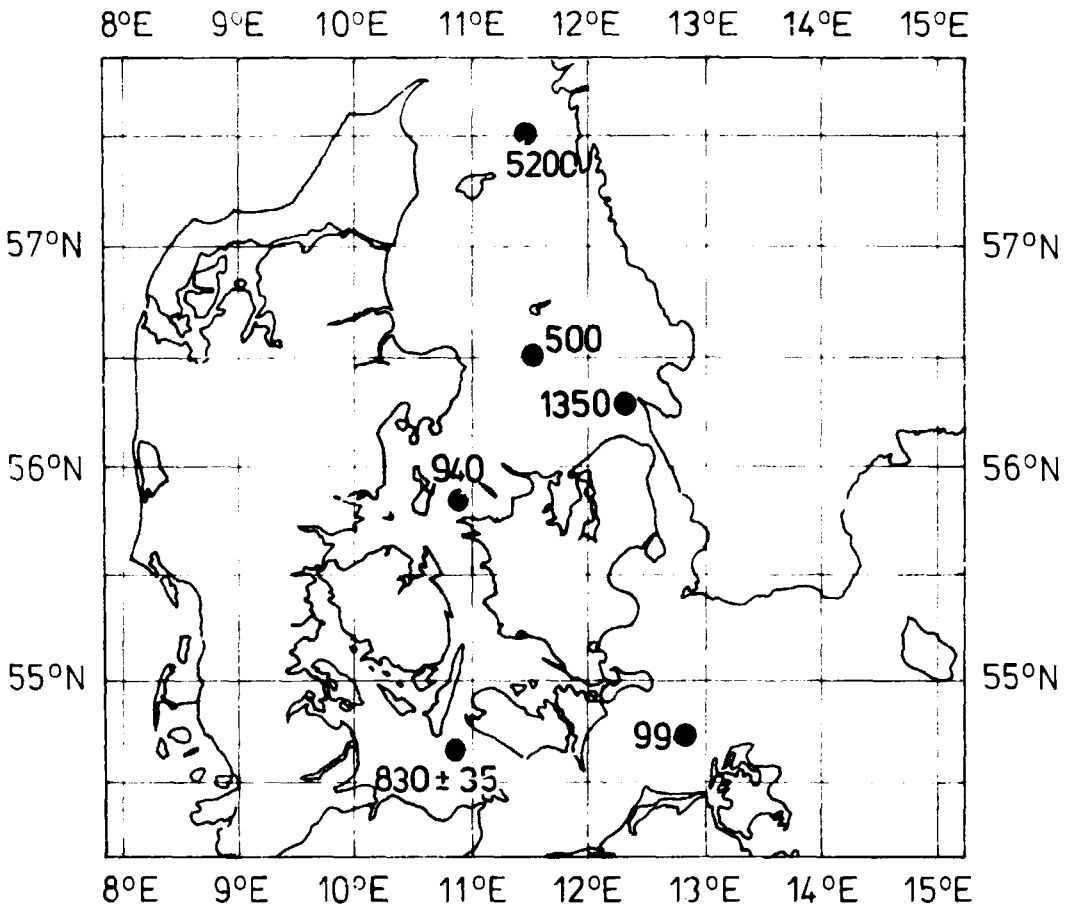

Fig. 4.6.2. Cesium-137 in sediments (cf. Table 4.6.3) collected in the Danish Straits in 1983. Unit: Bq m^{-2}.

5. DANISH FOOD AND VARIOUS VEGETATION

by A. Aarkrog and S. Boelskifte

5.1. Strontium-90 and Cesium-137 in dried milk from the entire country

As in previous years, monthly samples of dried milk were collected from seven locations in Denmark (cf. fig. 5.1.1). Table 5.1.1 shows the results of the ^{90}Sr determinations and Table 5.1.2 the analysis of variance of the results. As in recent years, the local variation was significant for Bq ^{90}Sr (kg Ca)$^{-1}$. Milk from eastern Denmark showed as usual lower levels than the milk from Jutland. The Bq ^{90}Sr (kg Ca)$^{-1}$ mean level in 1983 was 80 Bq ^{90}Sr (kg Ca)$^{-1}$, i.e. 80% of the 1979-1982 means.

Table 5.1.3 shows the results of the ^{137}Cs determinations and Table 5.1.4 the analysis of variance of the results. The ^{137}Cs mean level in 1983 was 46 Bq ^{137}Cs (kg K)$^{-1}$, or 73% of the 1982 level.

Table 5.1.1. Strontium-90 in dried milk in 1983. (Unit: Bq (kg Ca)$^{-1}$)

Month	Hjørring	Randers	Videbæk	Åbenrå	Nyborg	Ringsted	Nakskov	Mean
Jan	106	96	135	103	85	64	64	93
March	123	110	118	107	48	66	70	92
May	103	98	107	94	50	66	60	83
July	116	95	96	96	53	66	56	83
Sept	86	(74)	76	72	36	50	56	64
Nov	62	80	73	70	64	47	58	65
Mean	99	92	101	90	56	60	61	80

As 1 cubic meter of milk contains 1.2 kg Ca, the mean ^{90}Sr content in Danish milk produced in 1983 was 96 Bq m^{-3}.

Figures in brackets were calculated from VAR3[12].

Table 5.1.2. Analysis of variance of ln Bq ^{90}Sr (kg Ca)$^{-1}$ in Danish dried milk in 1983 (from Table 5.1.1)

Variation	SSD	f	s^2	v^2	P
Between months	0.827	5	0.165	7.982	> 99.95%
Between locations	2.485	6	0.414	19.989	> 99.95%
Remainder	0.601	29	0.021		

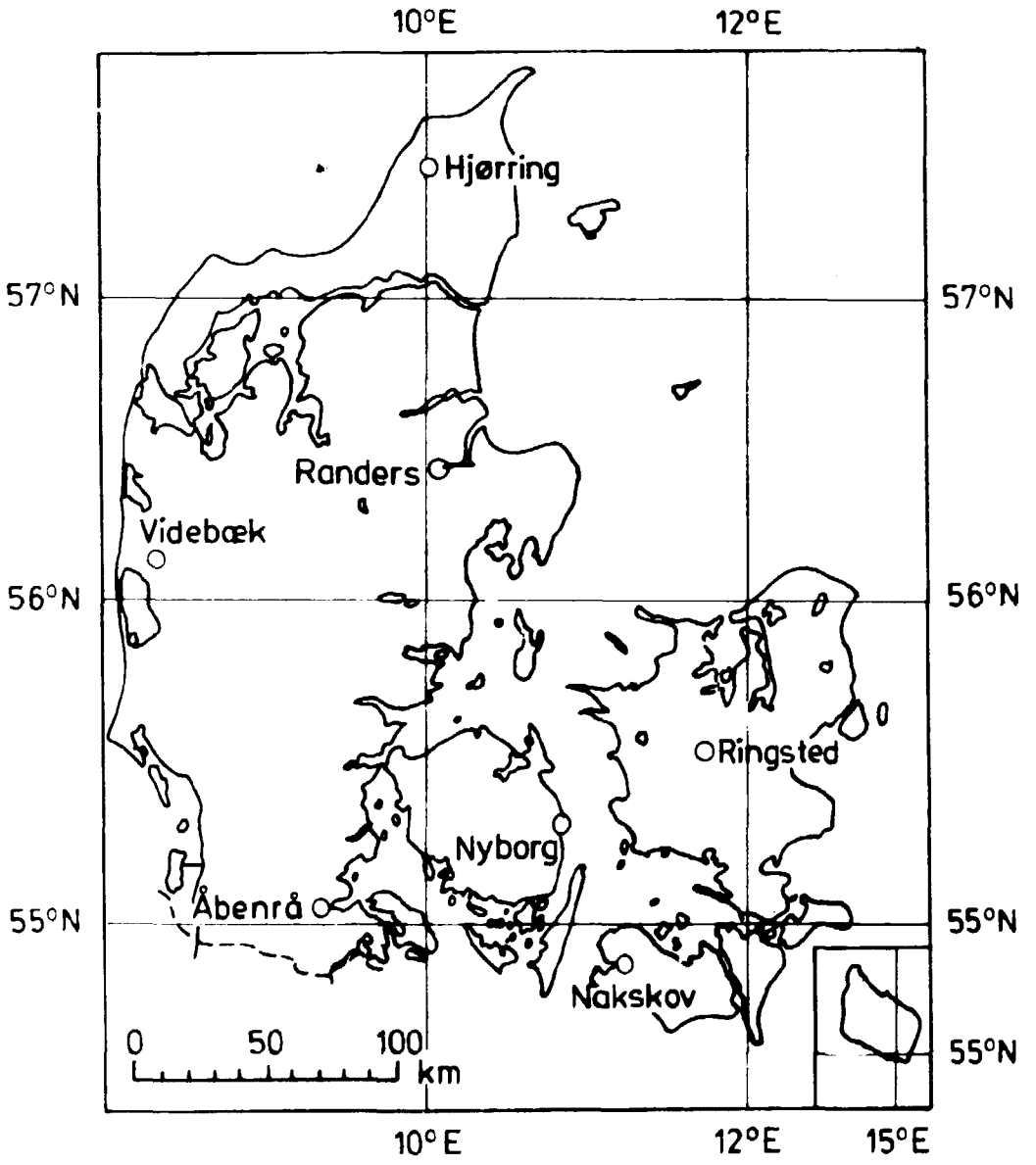

Fig. 5.1.1. Dried milk factories in Denmark.

Table 5.1.3. Cesium-137 in Danish dried milk in 1983. (Unit: Bq $(kg\ K)^{-1}$)

Month	Jutland	The Islands	Mean
January	61	46	54
February	54	22	38
March	60	23	41
April	54	15.8	35
May	58	23	41
June	59	26	42
July	77	18.4	48
August	107	24	65
September	80	30	55
October	68	18.1 A	43
November	54	28	41
December	69	21	45
Mean	67	25	46
Mean pCi $(g\ K)^{-1}$	1.80	0.66	1.23

As 1 cubic meter of milk contains approx. 1.66 kg K, the mean ^{137}Cs content in Danish milk produced in 1983 was estimated at 76 Bq m^{-3}.

Table 5.1.4. Analysis of variance of ln Bq ^{137}Cs $(kg\ K)^{-1}$ in Danish dried milk in 1983 (from Table 5.1.3)

Variation	SSD	f	s^2	v^2	P
Between months	0.568	11	0.052	0.760	-
Between locations	6.127	1	6.127	90.174	> 99.95%
Remainder	0.747	11	0.068		

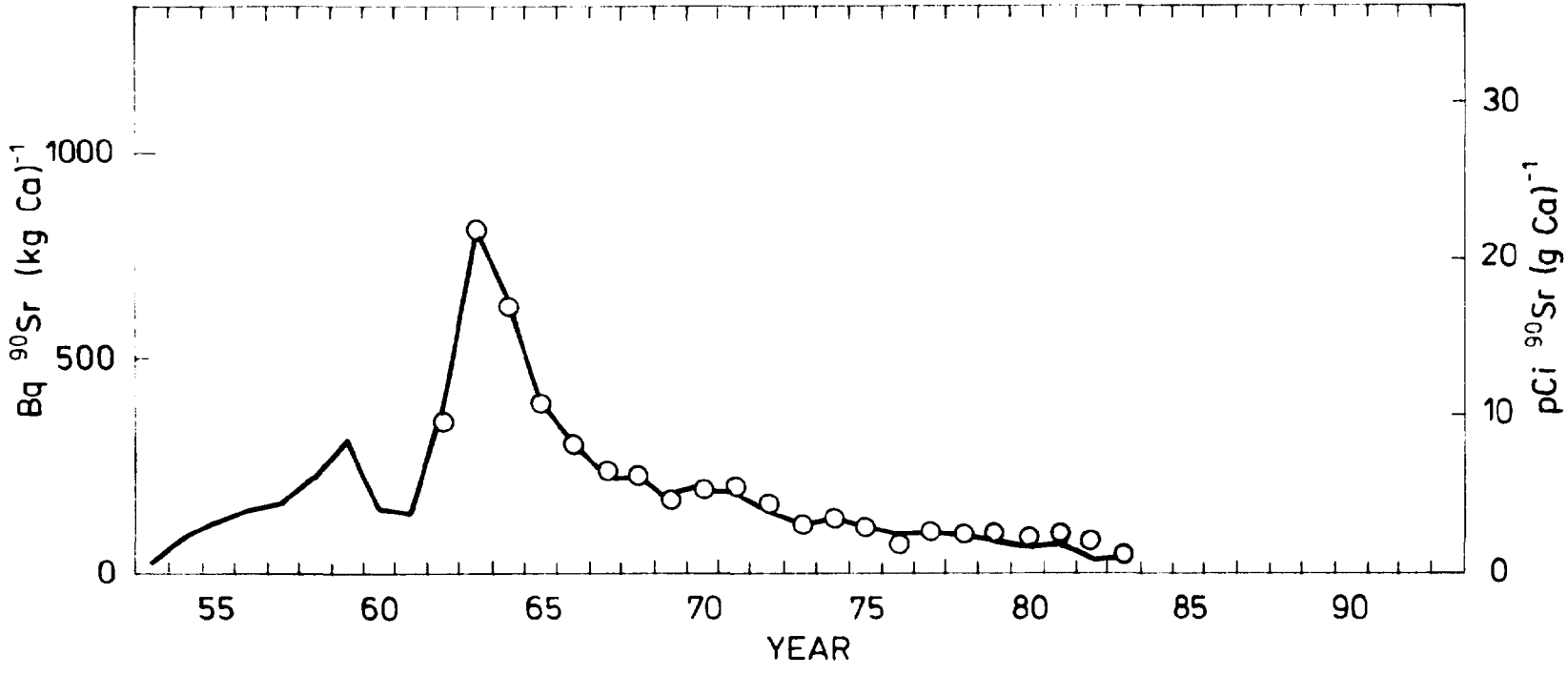

Fig. 5.1.2. Predicted (curve) and observed ^{90}Sr/Ca levels in dried milk from the Islands (May 1962-April 1984).

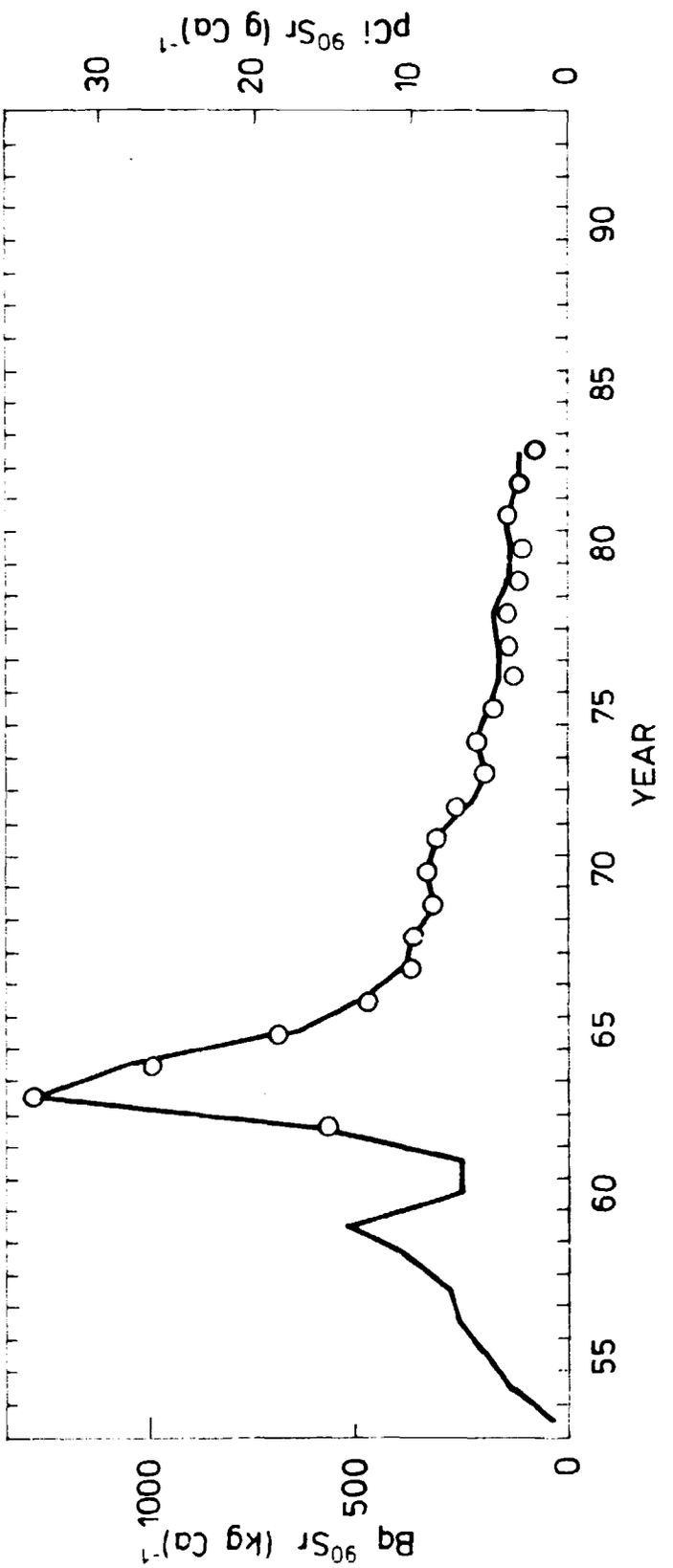

Fig. 5.1.3. Predicted (curve) and observed ^{90}Sr/Ca levels in dried milk from Jutland (May 1962-April 1984).

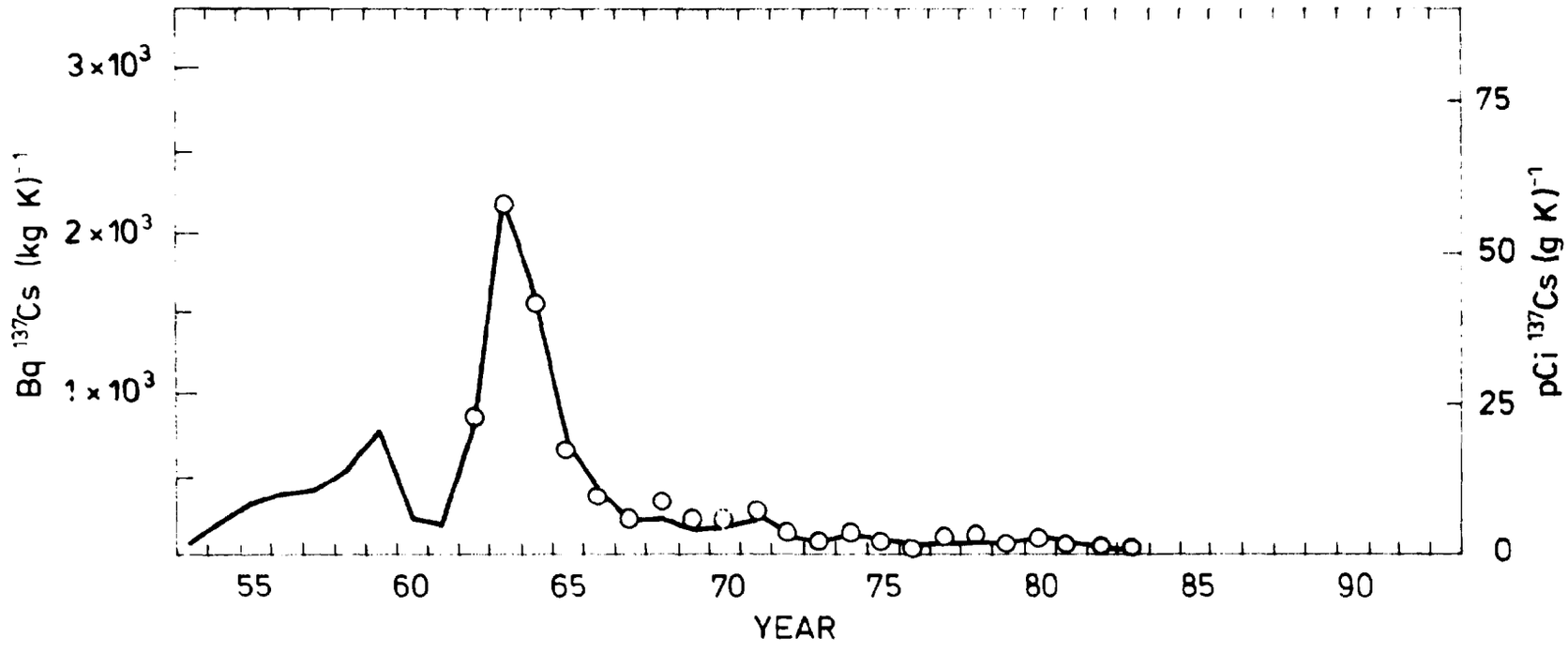

Fig. 5.1.4. Predicted (curve) and observed $^{137}Cs/K$ levels in dried milk from the Islands (May 1962-April 1984).

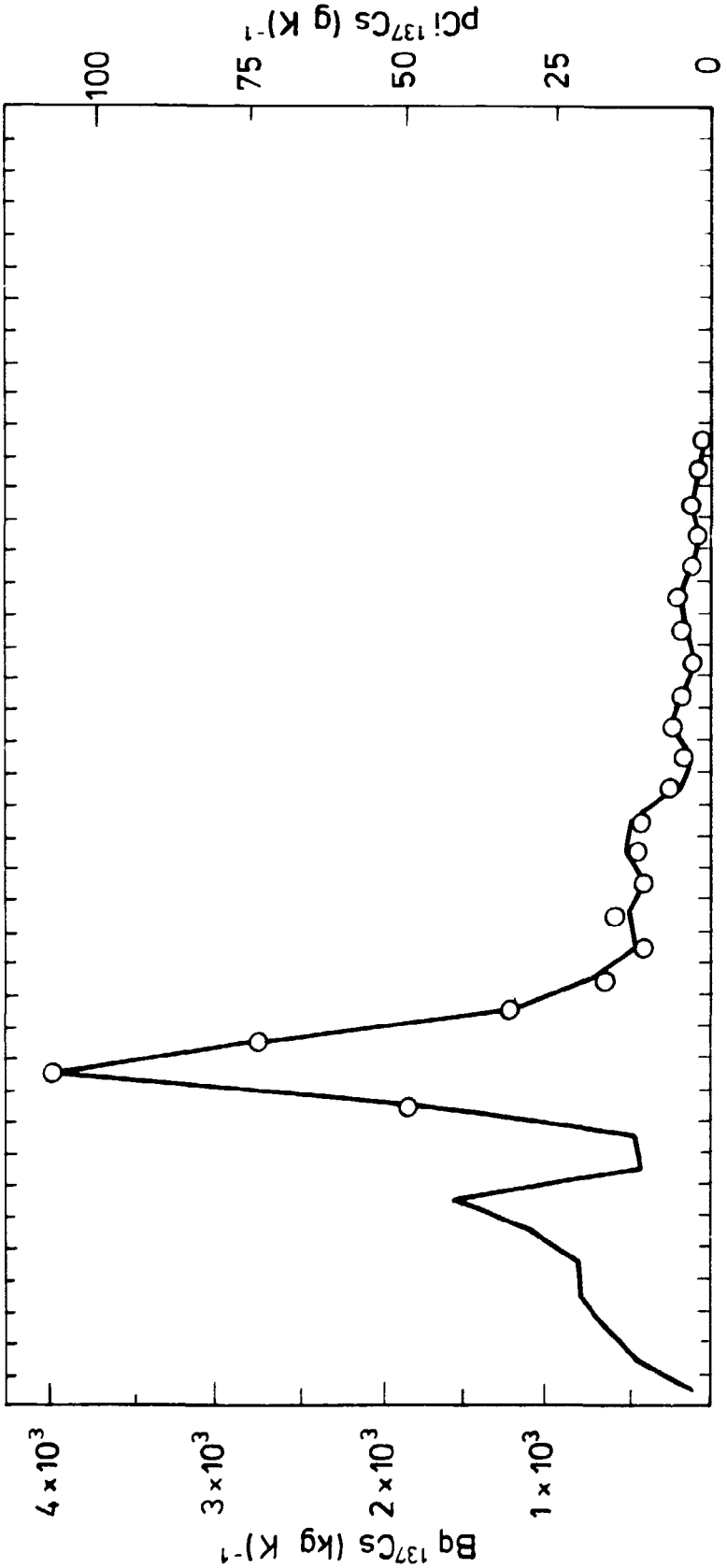

Fig. 5.1.5. Predicted (curve) and observed ^{137}Ca/K levels in dried milk from Jutland (May 1962-April 1984).

We found no significant variation in ^{137}Cs concentrations between months in 1982 (Table 5.1.4); this is unusual.

Figures 5.1.2-5.1.5 show the ^{90}Sr and ^{137}Cs levels in dried milk compared with the predicted values (cf. Appendix C). The observed ^{90}Sr levels in 1983 were 1.02 times the predicted, while the observed ^{137}Cs levels were 1.33 times the predicted ones (means of Jutland and the Islands).

5.2. Fresh milk

No samples in 1983.

5.3. Strontium-90 and Cesium-137 in grain from the entire country

As in previous years, grain samples were obtained from the State experimental farms (cf. Fig. 4.2). Strontium-90 was determined as previously (Risø Report No. 63[1]), and ^{137}Cs was measured on ashed samples by γ-spectrometry on a Ge(Li) detector. Due to the low ^{137}Cs concentrations the samples were combined in two sets of samples: one for Jutland and one from the Islands, each sample represented five farms.

Tables 5.3.1 and 5.3.2 show the measurements of ^{90}Sr in grain in 1983. Table 5.3.4 gives the analysis of variance of the Bq ^{90}Sr (kg Ca)$^{-1}$ figures and Table 5.3.3 that of the Bq ^{90}Sr kg^{-1} grain figures.

Table 5.3.3 shows that the variation in Bq ^{90}Sr kg^{-1} between species was significant. Oats showed the highest Bq ^{90}Sr kg^{-1} levels.

As in previous years, the variation with location was highly significant; the mean Bq ^{90}Sr kg^{-1} level for grain from Jutland was 1.4 times that in eastern Denmark. The observed Bq ^{90}Sr kg^{-1} levels in grain from 1983 were 1.60±1.02 (1 S.D.) times those

Table 5.3.1. Strontium-90 in Danish grain in 1983. (Unit: Bq kg^{-1})

	Rye Winter	Barley		Wheat		Oats Spring
		Spring	Winter	Winter	Spring	
Tylstrup	0.40	1.17	0.52	0.64		1.56
Ødum	0.31	0.37	0.82	0.98	0.168	0.43
Askov	0.49	0.70	0.74	0.51		1.30
Borris	0.53	0.65	0.87	0.64		1.23
St. Jyndevad	0.64	0.94	0.89	0.76		
Funen	0.59	0.90	0.77	0.59		1.10
Tystofte	0.48	0.31	0.72	0.46	0.24	0.95
Ledreborg	0.29	0.53	0.67	0.41		0.35
Abed		0.173	0.42		0.26	0.58
Bornholm	0.48	0.27	0.63			0.38
Mean	Rye: 0.47	Barley: 0.65		Wheat: 0.51		Oats: 0.88

Table 5.3.2. Strontium-90 in Danish grain in 1983. (Unit: Bq (kg Ca)$^{-1}$)

	Rye Winter	Barley		Wheat		Oats Spring
		Spring	Winter	Winter	Spring	
Tylstrup	1610	2700	1250	1850		3300
Ødum	1120	780	1650	2600	450	520
Askov	1380	1440	1240	1600		1360
Borris	1530	1440	1920	3100		1520
St. Jyndevad	2100	1970	1650	2500		
Funen	1650	2200	1350	1910		1130
Tystofte	1020	710	1560	1640	750	1160
Ledreborg	960	980	1020	1560		370
Abed		420	760		720	540
Bornholm	1340	570	1380			400
Mean	Rye: 1410	Barley: 1350		Wheat: 1700		Oats: 1140

Table 5.3.3. Analysis of variance of ln Bq ^{90}Sr kg^{-1} in grain in 1983 (from Table 5.3.1)

Variation	SSD	f	s^2	v^2	P
Between species	2.312	3	0.771	9.623	> 99.95%
Between locations	5.064	9	0.563	7.024	> 99.95%
Spec. × loc.	1.922	24	0.080	0.266	
Remainder	3.618	12	0.301		

Table 5.3.4. Analysis of variance of ln Bq ^{90}Sr (kg Ca)$^{-1}$ in grain in 1983 (from Table 5.3.2)

Variation	SSD	f	s^2	v^2	P
Between species	1.006	3	0.335	3.380	> 95%
Between locations	6.842	9	0.760	7.659	> 99.95%
Spec. × loc.	2.382	24	0.099	0.343	
Remainder	3.477	12	0.290		

predicted (cf. Appendix C). If we look at Denmark as a whole the ratio between observed and predicted Bq ^{90}Sr kg^{-1} in grain became 1.10±0.16.

Tables 5.3.5 and 5.3.6 show the measurements of ^{137}Cs in grain in 1983. The ^{137}Cs mean level in grain from 1983 was 0.9 times the level in 1982. The fallout in May-August 1983 was 0.6 times that of the fallout in May-August 1982.

Table 5.3.5. Cesium-137 in Danish grain in 1983. (Unit: Bq kg^{-1})

	Rye	Barley s	Barley w	Wheat	Oats
Jutland	0.156	0.060		0.101	0.33
The Islands	0.077	0.026 B	0.044	0.034 A	0.071
Mean	0.117	Barley 0.043		0.067	0.20

Table 5.3.6. Cesium-137 in Danish grain in 1983. (Unit: Bq (kg K)$^{-1}$)

	Rye	Barley s	Barley w	Wheat	Oats
Jutland	35	13.1		23	72
The Islands	18.1	6.1 B	9.3	8.7 A	15.7
Mean	27	Barley: 9.5		15.9	44

The ANOVA's (Tables 5.3.7 and 5.3.8) showed probably significant variation between locations (Jutland = 2.84 × The Islands).

The observed pCi ^{137}Cs kg^{-1} levels in grain from 1983 were 1.96± 2.07 (1 S.D.) times those predicted (cf. Appendix C). The concentration of ^{137}Cs in oats from Jutland was considerably higher than expected and this was the main reason for the large devi-

Table 5.3.7. Analysis of variance of ln Bq ^{137}Cs kg^{-1} in grain in 1983 (from Table 5.3.5)

Variation	SSD	f	s^2	v^2	P
Between species	1.995	3	0.665	6.628	-
Between locations	1.919	1	1.919	19.132	> 97.5%
Spec. × loc.	0.301	3	0.100	0.800	-
Remainder	0.125	1	0.125		

Table 5.3.8. Analysis of variance of ln Bq ^{137}Cs (kg K)$^{-1}$ in grain in 1983 (from Table 5.3.6)

Variation	SSD	f	s^2	v^2	P
Between species	1.943	3	0.648	6.418	-
Between locations	1.756	1	1.756	17.400	> 95%
Spec. × loc.	0.303	3	0.101	1.123	-
Remainder	0.090	1	0.090		

ation between observed and predicted values. It is evident that the root uptake of ^{137}Cs now plays an important role especially for the grain grown in Jutland.

5.4. Strontium-90 and Cesium-137 in bread from the entire country

In 1983, samples of white bread (75% extraction) and dark rye bread (100% extraction) were collected all over the country (cf. fig. 5.4) in June, and ^{90}Sr and ^{137}Cs were determined on pooled samples from Jutland and the Islands respectively. Samples from Copenhagen were analysed separately. The ^{137}Cs determinations were carried out on the ash by Ge(Li)γ-spectroscopy.

Table 5.4.1 shows the results. It is assumed that 1 kg flour yields approximately 1.35 kg bread[11] and that wheat flour of 75% extraction contains 20% of the ^{90}Sr and 50% of the ^{137}Cs found in wheat grain[1], while rye flour is 100% extraction. Hence we can compare the 1983 bread levels with the 1982 grain levels (cf. Table 5.4.2). The above assumptions for transfer of ^{137}Cs from grain to bread seem justified, however, the transfer of ^{90}Sr from wheat to white bread may be underestimated. This has in fact been envisaged in Risø-R-437 p. 86[21] where it is predicted that the transfer will increase from 20 to 33%.

The mean ratios between observed and predicted bread values were 1.19 for ^{90}Sr and 0.52 for ^{137}Cs (cf. Appendix C).

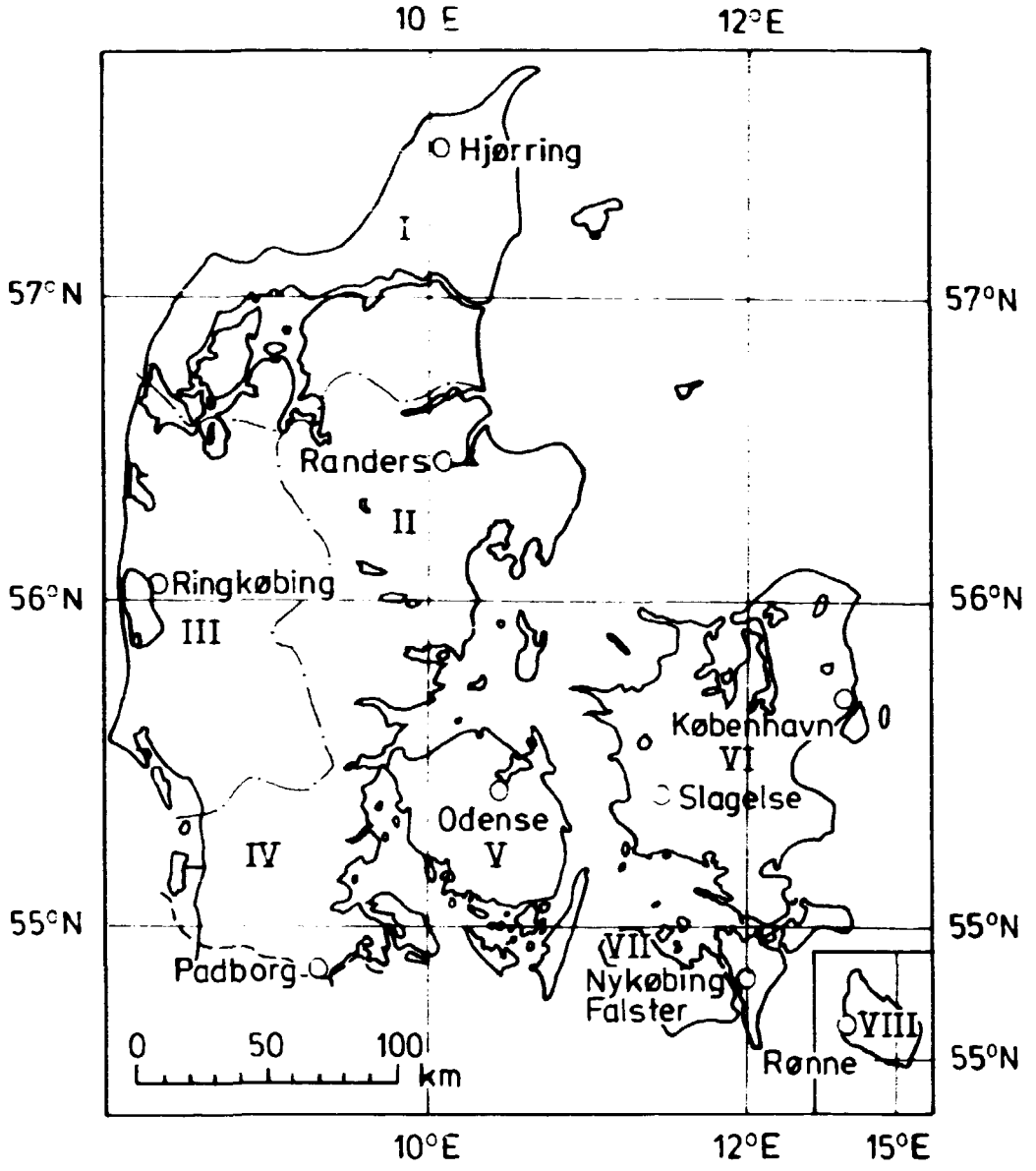

Fig. 5.4. Sample locations for bread and total diet.

Table 5.4.1. Strontium-90 and Cesium-137 in Danish bread collected in June 1983

Zone	Rye bread				White bread			
	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr $(kg\ Ca)^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs $(kg\ K)^{-1}$	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr $(kg\ Ca)^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs $(kg\ K)^{-1}$
Jutland	0.48	172	0.186	70	0.135	65	0.027	22
The Islands	0.29	115	0.087	32	0.185	103	0.032	26
Mean	0.38	144	0.136	51	0.160	84	0.029	24
Copenhagen	0.27	146	0.122	39	0.136	67	0.046 A	28 A
Population-weighted mean	0.37	149	0.141	51	0.150	76	0.03(	25

Table 5.4.2. A comparison between ^{90}Sr and ^{137}Cs levels in bread and grain 1983

Nuclide	Species	Bread activity in June 1983 calculated as grain in Bq kg^{-1} (cf. text)	Activity in grain from harvest 1982[1] Bq kg^{-1}	"Bread"/grain ratio
^{90}Sr	Wheat	1.08	0.52	2.1
	Rye	0.51	0.65	0.8
^{137}Cs	Wheat	0.078	0.10	0.8
	Rye	0.22	0.18	1.2

5.5. Strontium-90 and Cesium-137 in potatoes from the entire country

The samples of potatoes were collected in September from ten of the State experimental farms (cf. fig. 4.2) and analysed for ^{90}Sr and ^{137}Cs (γ-spectroscopy of bulked samples of the ash).

Table 5.5.1 shows the ^{90}Sr and ^{137}Cs contents in potatoes. The mean contents for the country were 0.066 Bq ^{90}Sr kg^{-1}, or 1360

Table 5.5.1. Strontium-90 and Cesium-137 in Danish potatoes in 1983

	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$
Tylstrup	0.043	1660		
Borris	0.094	2080		
Ødum	0.032	990	0.084	18.5
Askov	0.103	2100		
St. Jyndevad	0.037	1520		
Blangstedgård	0.072	1000		
Tystofte	0.061	950		
Ledreborg	0.074	1520	0.0133	2.7
Aved	0.048	770		
Rønne	0.094	980		
Mean	0.066	1360	0.048	10.6

Bq ^{90}Sr (kg Ca)$^{-1}$, and 0.048 Bq ^{137}Cs kg^{-1} or 10.6 Bq ^{137}Cs (kg K)$^{-1}$. The ^{90}Sr levels were equal to those in 1982, and the ^{137}Cs concentrations were 76% of the in 1982 values.

The mean ratio between observed and predicted ^{90}Sr concentrations in potatoes was 0.68 and for ^{137}Cs we found 1.09 (cf. Appendix C).

5.6. Strontium-90 and Cesium-137 in vegetables and fruits from the entire country

In 1983, as in previous years, vegetables and fruit were collected in the autumn from eight larger provincial towns, one in each of the eight zones (cf. fig. 5.4).

Table 5.6.1. Strontium-90 in vegetables and fruits collected in 1983

	Jutland		The Islands		Mean	
	Bq kg^{-1}	Bq (kg Ca)$^{-1}$	Bq kg^{-1}	Bq (kg Ca)$^{-1}$	Bq kg^{-1}	Bq (kg Ca)$^{-1}$
White cabbage	0.57	1320	0.19	430	0.38	875
Carrots	0.49	1780	0.36	1140	0.43	1460
Beans	0.66	1230	0.36	670	0.51	950
Peas	-	-	0.053	800	(0.053)	(800)
Strawberry	-	-	0.10	570	(0.10)	(570)
Apples	0.052	1060	0.028	830	0.04	945

The γ-measurements were performed on bulked ash samples representing the entire country (cf. Table 5.6.2).

Table 5.6.3 shows a calculation of the mean contents of ^{90}Sr and ^{137}Cs in Danish vegetables collected in 1983. The ^{90}Sr levels are equal to the 1982 concentrations.

The ^{137}Cs concentrations in 1983 were approximately two times those in 1982, but this was due to a surprisingly high ^{137}Cs in cabbage from Jutland.

Table 5.6.2. Cesium-137 in vegetables and fruits collected in 1983

	Jutland		The Islands		Mean	
	Bq kg^{-1}	Bq $(kg\ K)^{-1}$	Bq kg^{-1}	Bq $(kg\ K)^{-1}$	Bq kg^{-1}	Bq $(kg\ K)^{-1}$
White cabbage	0.27*	120	<0.01	-	0.14	60
Carrots	0.065	36	0.020	9.6	0.042	23
Beans	0.044	21	0.011	4.1	0.028	12.8
Peas	-	-	0.19	21	(0.19)	(21)
Strawberry	-	-	0.006	3.8	(0.006)	(3.8)
Apples	0.060	48	0.015	15	0.037	32

*The concentrations in white cabbage from the four sampling zones in Jutland were as follows: I: 0.90, II: 0.13, III: 0.083, IV: 0.15 Bq $^{137}Cs\ kg^{-1}$. In other words the unexpected high mean value was due to the sample obtained from Zone I: North Jutland.

Table 5.6.3. Calculated ^{90}Sr and ^{137}Cs mean levels in vegetables in 1983

Daily intake in g	Bq $^{90}Sr\ kg^{-1}$	Bq $^{90}Sr\ (kg\ Ca)^{-1}$	Bq $^{137}Cs\ kg^{-1}$	Bq $^{137}Cs\ (kg\ K)^{-1}$
50 leaf vegetables (cabbage)	0.38	875	0.14	60
30 root vegetables (carrot)	0.43	1460	0.042	23
40 peas and beans	0.28	875	0.11	17
120 g	0.36	1020	0.11	36

The 1982 levels in Danish fruit were calculated from apples (80%) and strawberries (20%). The mean levels in Danish fruit were thus 0.052 Bq $^{90}Sr\ kg^{-1}$ and 0.031 Bq $^{137}Cs\ kg^{-1}$. The observed Bq $^{90}Sr\ kg^{-1}$ levels in vegetables and fruit in 1983 were 1.59±0.87 (1 S.D.) times those predicted (cf. Appendix C). In the case of ^{137}Cs, the observed values were 2.75±1.41 times the predicted ones.

5.7. Strontium-90 and Cesium-137 in total diet from the entire country

In 1983 total-food samples representing an average Danish diet according to E. Hoff-Jørgensen (cf. Appendix B in Risø Report No. 63[1]) were collected from eight towns each representing one of the eight zones (cf. Fig. 5.2.1) and from Copenhagen. The sampling took place as previously in June and December.

Tables 5.7.1 and 5.7.2 show the results. The ^{90}Sr diet levels from Jutland were 7% lower than those from the Islands, and the ^{137}Cs levels were 38% higher. This is an unusual picture as the ^{90}Sr levels from Jutland used to be higher than those from the Islands.

Figure 5.7.1 show the zone mean Bq ^{90}Sr (kg Ca)$^{-1}$ levels (not population-weighted) in total diet compared with the predicted values (cf. Appendix C), the observed value was 0.84 times that predicted.

Table 5.7.1. Strontium-90 and Cesium-137 in Danish total diet collected in June 1983

Zone	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{90}Sr d^{-1}	g Ca d^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	Bq ^{137}Cs d^{-1}
I: N. Jutland	118±4	0.21 ±0.01	1.81±0.01	73	0.29
II: E. Jutland	123±2	0.20 ±0.00	1.62±0.01	64	0.25
III: W. Jutland	150±5	0.22 ±0.01	1.46±0.00	67	0.27
IV: S. Jutland	147±3	0.24 ±0.00	1.65±0.00	57	0.22
V: Funen	135±1	0.21 ±0.00	1.58±0.02	45	0.176
VI: Zealand	107±5	0.178±0.007	1.66±0.00	51	0.196
VII: Lolland-Falster	98±4	0.149±0.006	1.52±0.00	40	0.154
VIII: Bornholm	141±0	0.22 ±0.00	1.54±0.00	44	0.173
Mean	127	0.20	1.60	55	0.22
Copenhagen	139±12	0.23 ±0.02	1.63±0.00	57	0.21
Population-weighted mean	130	0.21	1.63	58	0.23
Relative error due to analysis	6%	6%			

Table 5.7.2. Strontium-90 and Cesium-137 in Danish total diet collected in December 1983

Zone	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{90}Sr d^{-1}	g Ca d^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	Bq ^{137}Cs d^{-1}
I: N. Jutland	105±7	0.174±0.011	1.66±0.00	81	0.32
II: E. Jutland	134±7	0.197±0.010	1.50±0.03	63	0.25
III: W. Jutland	109±4	0.182±0.006	1.66±0.00	67	0.26
IV: S. Jutland	134±5	0.191±0.008	1.43±0.00	58	0.22
V: Funen	139±3	0.22 ±0.006	1.55±0.00	44	0.182
VI: Zealand	95±6	0.163±0.010	1.70±0.02	72	0.28
VII: Lolland-Falster	111±6	0.182±0.009	1.64±0.00	43	0.157
VIII: Bornholm	132±7	0.20 ±0.009	1.51±0.01	49	0.199
Mean	120	0.189	1.58	59	0.23
Copenhagen	120±10	0.188±0.016	1.56±0.00	76	0.28
Population-weighted mean	118	0.187		68	0.26
Relative error due to analysis	8%	7%			

The ^{90}Sr 1983 levels (mean of June and December values) in the total diet were 85% of the 1982 levels, while the ^{137}Cs levels were 58% on y.

From the total-diet sampling it is possible to estimate the mean levels of ^{90}Sr and ^{137}Cs in the Danish diet in 1983. For the period January-March 1983, the ^{90}Sr level in the total diet is assumed to have been equal to that measured in December 1982, Risø Report No. 447[1]. For the period April-September we assume the level to have corresponded to that measured in June 1983. The December 1983 figures are taken to represent the last three months of the year. Hence the mean content in the total diet in 1983 was 128 Bq ^{90}Sr (kg Ca)$^{-1}$, or 0.20 Bq ^{90}Sr (day)$^{-1}$.

Similarly, the ^{137}Cs content in the Danish diet in 1983 was estimated to be 0.25 Bq ^{137}Cs (day)$^{-1}$ or 64 Bq ^{137}Cs (kg K)$^{-1}$. The observed ^{137}Cs fallout level in total diet was 1.43 times that predicted (cf. Appendix C.2) (corrected for ^{137}Cs from Sellafield cf. 5.8.2).

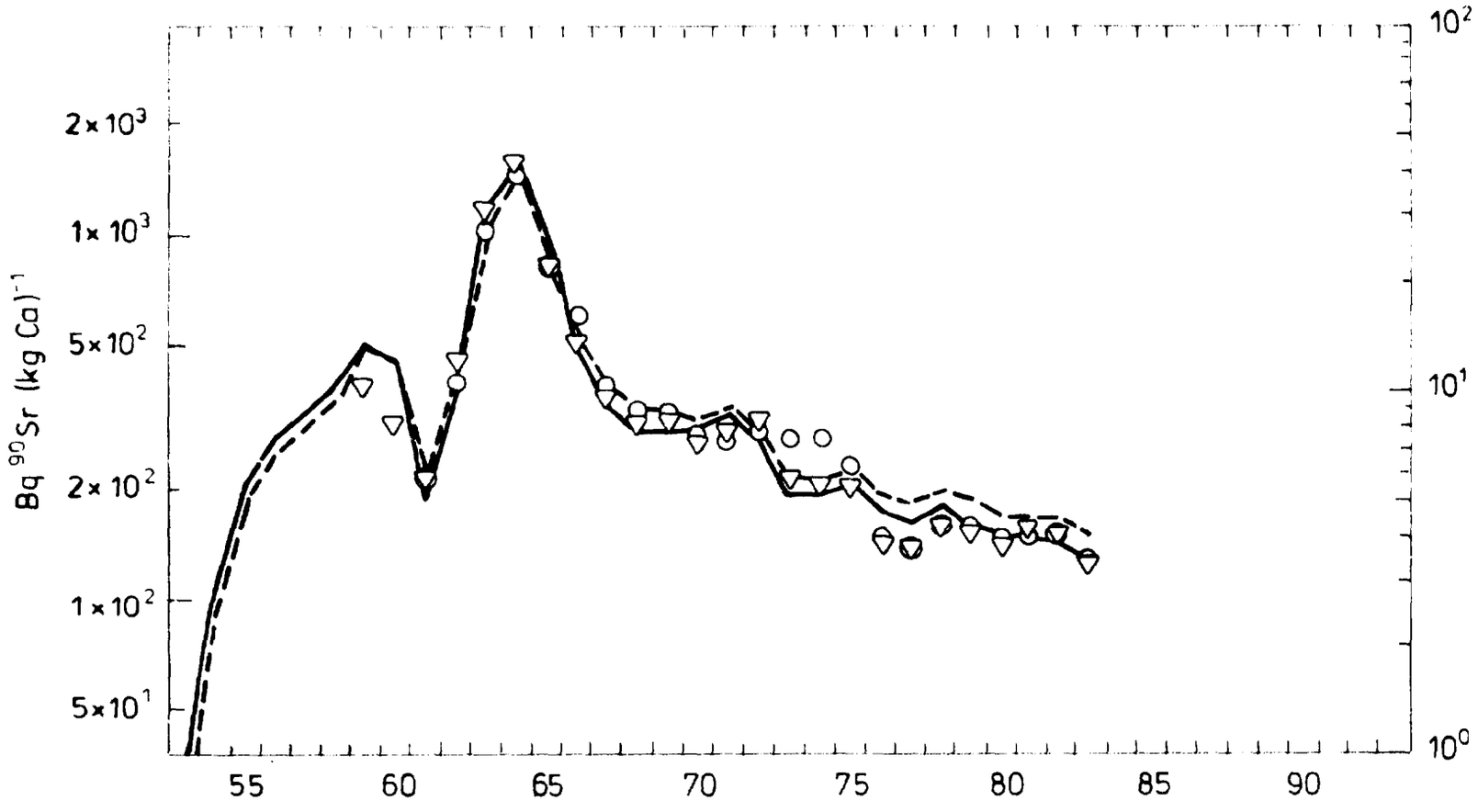

Fig. 5.7.1. Predicted and observed ^{90}Sr levels in the Danish total diet. The dotted curve represents the predicted values for "Diet C" (cf. Tables 5.7.1 and 5.7.2) and the circles are the corresponding observed values. The unbroken curve represents the predicted values for "Diet P" (cf. Table 5.9.3), and the triangles the corresponding observed values.

5.8. Strontium-90 and Cesium-137 in miscellaneous foodstuffs

5.8.1. Strontium-90 and Cesium-137 in meat

Pork and beef samples were collected in Copenhagen in three large shops in September. Table 5.8.1 shows the results. As compared with 1982, the mean levels were a little lower in 1983.

The mean ratio between observed and predicted (cf. Appendix C.2) ^{137}Cs levels in meat was 2.63 and for ^{90}Sr the mean ratio was 0.94.

Table 5.8.1. Strontium-90 and Cesium-137 in Danish meat collected in Copenhagen in 1983

	Pork				Beef			
Month	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$
Sept	0.022	83	0.20	53	0.036	310	0.43	105

5.8.2. Strontium-90, Cesium-137 and Cesium-134 in fish

Fish samples were collected in the North Sea and in inner Danish waters. Tables 5.8.2.1 and 5.8.2.2 show the results. The mean levels of the two samplings were 0.030±0.008 (1 S.E., N = 6) Bq ^{90}Sr kg^{-1} and 4.0±0.7 Bq ^{137}Cs kg^{-1}. The $^{134}Cs/^{137}Cs$ mean ratio was 0.021±0.005.

If we include the data from Roskilde Fjord (Table 5.8.2.3) and Baltic Sea (Table 5.8.2.4) the mean levels become 0.031± 0.006 Bq ^{90}Sr kg^{-1} (±1 S.E., N = 11) and 4.0±0.6 Bq ^{137}Cs kg^{-1} (±1 S.E., N = 12). The twelve samples showed a mean content of 0.072 Bq ^{134}Cs kg^{-1}. As the mean ratio of ^{137}Cs to ^{134}Cs discharged from Sellafield throughout the years was 45.2 in 1983, we may estimate e.g. Sellafield's contribution in Danish fish in 1983 as 45.2 × 0.072 = 3.26 Bq ^{137}Cs kg^{-1} or 82% of the total ^{137}Cs content.

If we had used the data from Tables 5.8.2.1 and 5.8.2.2 only, as earlier, we would have found that $\frac{0.021}{0.022} \times 100 = 95\%$ of the ^{137}Cs was from Sellafield.

Table 5.8.2.1. Strontium-90, Cesium-137 and Cesium-134 in fish from the North Sea purchased in Ringkøbing in September 1983

Species	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	$^{134}Cs/^{137}Cs$
Cod	0.022	30 (16.3)	5.1	1450	0.028
Plaice	0.0152	23 (16.6)	0.91	360	
Herring	0.009 A	29 A(6.0)	4.1	1320	0.032

Bone levels are shown in brackets.

Table 5.8.2.2. Strontium-90, Cesium-137 and Cesium-134 in fish from inner Danish waters purchased in Hundested in September 1983

Species	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	$^{134}Cs/^{137}Cs$
Cod	0.052	64 (47)	4.9	1190	0.014
Flounder	0.056	40 (30)	3.8	840	0.027
Herring	0.026	51 (8.4)	5.2	980	0.024

Bone levels are shown in brackets.

Table 5.8.2.3. Strontium-90, Cesium-137 and Cesium-134 in fish collected in the *Cattegat and Roskilde fjord in 1983*

Species	Location	Date	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	$^{134}Cs/^{137}Cs$
Herring	Roskilde fj.	April	0.028	64 (14.3)	4.6	1060	
Garpike	Kikhavn	3/5			9.3	2300	0.022

Bone levels are shown in brackets.

As previously, based upon the considerations above, we will assume that 90% of the ^{137}Cs in Danish fish in 1983 came from Sellafield.

The dose from Sellafield to the Danish population then becomes $4.0 \times 0.9 \times 5 \times 10^6 \times 10.9 \times 0.05 \times (4 \times 10^6)^{-1} = 2.45$ manSv (5×10^6 population size, 10.9: annual pro capite fish consumption in kg, 0.05 Sievert pr 4×10^6 Bq ^{137}Cs).

Table 5.8.2.4. Strontium-90, Cesium-137 and Cesium-134 in fish meat caught in the Baltic Sea in 1983

Species	Location	Date	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	$^{134}Cs/^{137}Cs$
Flounder	Bornholm	17/11	0.047	78	2.4	580	
Herring*	54°52'N 13°27'E	20/10	0.010 A	24 A	1.82	530	
Herring*	55°00'N 13°58'E	27/10	0.015 A	42 A	3.4	910	0.027
Cod*	55°44'N 20°10'E	24/10	0.057	72	2.5	690	

*Caught from the R/V DANA.

Table 5.8.2.5 shows radionuclide concentrations in Mytilus edulis from Danish waters. The ^{137}Cs mean content in flesh was 0.45±0.18 Bq kg^{-1} fresh weight (±1 S.D., N = 11). This is 1.4 times the level observed in 1982. Cobalt-60 was also detectable in mussels. A sample of Patella flesh collected at Østerby, Læsø in April 1983 contained 7.4 Bq ^{137}Cs kg^{-1} dry weight or 1.2 Bq kg^{-1} fresh weight.

Table 5.8.2.5. Cesium-137 and Cobalt-60 in Mytilus edulis flesh collected in inner Danish waters in 1983. (Unit: Bq kg^{-1} dry weight)

Location	Date	% dry matter	Depth in m	^{137}Cs	^{106}Ru	^{60}Co	^{40}K*
57°00'N 10°18'E Hals	1/8	13.3		2.7 A			8.9
57°03'N 9°42'E Gjøl	2/8	12.2	0.5	3.6 A			8.8
57°00'N 8°57'E Amtoft	3/8	12.1	0.5	2.0			7.9
56°41'N 8°44'E Sillerslev	3/8	15.6	0.5	1.72			7.8
57°07'N 8°36'E Hanstholm	4/8	17.4	0.5	3.2		< 0.7	6.6
57°36'N 9°58'E Hirtshals	15/3	16.0	0.5	4.5	20	0.8	17.6
57°44'N 10°36'E Skagen	4/8	15.8	0.5	2.4		1.1 A	6.0
57°18'N 10°56'E Læsø W	15/4	16.1	0.5	4.2		< 1.1	11.0
57°19'N 11°08'E Læsø E	15/4	15.8	0.5	3.9		0.66 A	10.9
57°18'N 10°56'E Læsø W	10/8	10.8	0.5	1.6 A			4.1
55°58'N 12°01'E Frederiksværk	24/3	10.6		5.1			11.7

5.8.3. Strontium-90 and Cesium-137 in eggs

Eggs were collected in Copenhagen in 1983. They contained 0.034 Bq ^{90}Sr kg^{-1} (54 Bq ^{90}Sr (kg Ca)$^{-1}$) and 0.033 Bq ^{137}Cs kg^{-1} (27 Bq ^{137}Cs (kg K)$^{-1}$). The predicted values for eggs (cf. Appendix C) were 0.013 Bq ^{90}Sr kg^{-1} and 0.023 Bq ^{137}Cs kg^{-1}.

5.8.4 Strontium-90 and cesium-137 in various vegetable foods

No samples in 1983.

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

5.9.1. The annual quantities

The annual quantities are calculated by multiplication of the daily quantities by 365 (as stated by E. Hoff-Jørgensen, cf. Risø Report No. 63, Table B[1]).

5.9.2. Milk and cream

The ^{90}Sr and ^{137}Cs contents per kg milk were calculated from the annual mean values for dried milk (cf. Tables 5.1.1 and 5.1.3). 1 kg ~ 1 l milk, containing approximately 1.2 g Ca and 1.66 g K. Hence the mean contents in milk were 0.096 Bq ^{90}Sr kg^{-1} and 0.076 Bq ^{137}Cs kg^{-1}.

5.9.3. Cheese

One kg of cheese contains approximately 8.5 g Ca and 1.2 g K. The ^{90}Sr and ^{137}Cs contents in cheese were calculated from these figures and from the ^{90}Sr/Ca and ^{137}Cs/K ratios in dried milk (cf. Tables 5.1.1 and 5.1.3). One kg of cheese appeared to contain 0.68 Bq ^{90}Sr and 0.055 Bq ^{137}Cs.

5.9.4. Grain products

Tables 5.9.1 and 5.9.2 show the estimates of ^{90}Sr and ^{137}Cs, respectively, in grain products consumed in 1983. From these

Table 5.9.1. Estimate of the ^{90}Sr content in grain products consumed per caput in 1983

Type	Fraction from harvest 1982			Fraction from harvest 1983			Total Bq
	kg flour	Bq kg^{-1}	Bq	kg flour	Bq kg^{-1}	Bq	
Rye flour 100% extraction	21.9	0.65	14.24	7.3	0.47	3.43	17.67
Wheat flour 75% extraction	32.9	0.10	3.29	10.9	0.10	1.09	4.38
Grits	5.5	0.20	1.10	1.8	0.29	0.52	1.62
Total	60.3	0.31	18.63	20.0	0.25	5.04	23.67

Table 5.9.2. Estimate of the ^{137}Cs content in grain products consumed per caput in 1983

Type	Fraction from harvest 1982			Fraction from harvest 1983			Total Bq
	kg flour	Bq kg^{-1}	Bq	kg flour	Bq kg^{-1}	Bq	
Rye flour 100% extraction	21.9	0.18	3.94	7.3	0.117	0.85	4.80
Wheat flour 75% extraction	32.9	0.05	1.65	10.9	0.034	0.37	2.02
Grits	5.5	0.05	0.28	1.8	0.10	0.18	0.46
Total	60.3	0.10	5.87	20.0	0.07	1.40	7.28

tables, the activity levels in grain products were estimated at 0.29 Bq ^{90}Sr kg^{-1} and 0.091 Bq ^{137}Cs kg^{-1}.

5.9.5. Potatoes

The figures in Table 5.5.1 were used, i.e. 0.066 Bq ^{90}Sr kg^{-1} and 0.048 Bq ^{137}Cs kg^{-1}.

5.9.6. Vegetables

Table 5.6.3 shows the calculation of ^{90}Sr and ^{137}Cs in Danish vegetables consumed in 1983. The mean contents were 0.36 Bq ^{90}Sr kg^{-1} and 0.11 Bq ^{137}Cs kg^{-1}.

5.9.7. Fruit

The levels in imported fruit in 1983 are assumed to be equal to the mean levels found in oranges and bananas collected in Copenhagen in 1982, i.e. 0.132 Bq ^{90}Sr kg^{-1} and 0.024 Bq ^{137}Cs kg^{-1}. The mean levels in Danish fruit (cf. 5.6) in 1983 were 0.052 Bq ^{90}Sr kg^{-1} and 0.031 Bq ^{137}Cs kg^{-1}. The daily mean consumption of fruit consisted of 100 g of Danish and 40 g of foreign origin. Hence the mean contents in fruit were 0.075 Bq ^{90}Sr kg^{-1} and 0.029 Bq ^{137}Cs kg^{-1}.

5.9.8. Meat

The annual mean values of ^{90}Sr and ^{137}Cs in meat were calculated from Table 5.8.1: 0.027 Bq ^{90}Sr kg^{-1} and 0.28 Bq ^{137}Cs kg^{-1}. (In a Danish diet meat comprises 2/3 pork and 1/3 beef).

5.9.9. Fish

The ^{90}Sr and ^{137}Cs contents in fish are estimated from 5.8.2 at 0.031 Bq ^{90}Sr kg^{-1} and 4.0 Bq ^{137}Cs kg^{-1}.

5.9.10. Eggs

The contents of activity in eggs were estimated from 5.8.3. The levels were 0.034 Bq ^{90}Sr kg^{-1} and 0.033 Bq ^{137}Cs kg^{-1}.

5.9.11. Coffee and tea

One third of the total consumption consists of tea and two thirds of coffee. We use the mean contents from 1982: 0.87 Bq ^{90}Sr kg^{-1} and 2.53 Bq ^{137}Cs kg^{-1}.1)

5.9.12. Drinking water

The ^{90}Sr level (population-weighted mean) found in drinking water collected in April 1982 (4.3.3) was used as the mean level for drinking water, i.e. 0.0005 Bq ^{90}Sr kg^{-1}. The ^{137}Cs content in drinking water is assumed to be negligible.

5.9.13. Discussion

Tables 5.9.3 and 5.9.4 show the estimates of ^{90}Sr and ^{137}Cs in the Danish diet in 1983. The figures should be compared with the levels calculated from the total-diet samples (cf. 5.7). The ^{90}Sr estimates obtained by the two methods (cf. also fig. 5.7.1) were 125 Bq (kg Ca)$^{-1}$ and 128 Bq (kg Ca)$^{-1}$, respectively, and the ^{137}Cs estimates were 0.28 Bq ^{137}Cs (day)$^{-1}$ and 0.25 Bq ^{137}Cs (day)$^{-1}$.

Table 5.9.3. Estimate of the mean content of ^{90}Sr in the human diet 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	164.0	0.096	15.74	20.4
Cheese	9.1	0.68	6.19	8.0
Grain products	80.3	0.29	23.67	30.6
Potatoes	73.0	0.066	4.82	6.2
Vegetables	43.8	0.36	15.77	20.4
Fruit	51.1	0.075	3.83	5.0
Meat	54.7	0.027	1.48	1.9
Eggs	10.9	0.034	0.37	0.5
Fish	10.9	0.031	0.34	0.4
Coffee and tea	5.5	0.87	4.78	6.2
Drinkirg water	548	0.0005	0.27	0.4
Total			77.26	

The mean Ca intake was estimated at 0.62 kg y^{-1} (approx. 0.2-0.25 kg creta praeparata). Hence the $^{90}Sr/Ca$ ratio in total diet was 125 Bq ^{90}Sr (kg Ca)$^{-1}$ (3.4 S.U.) in 1983.

Table 5.9.4. Estimate of the mean content of ^{137}Cs in the human diet 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	164.0	0.076	12.46	12.1 (19.5)
Cheese	9.1	0.055	0.50	0.5 (0.8)
Grain products	80.3	0.091	7.28	7.1 (11.4)
Potatoes	73.0	0.048	3.50	3.4 (5.5)
Vegetables	43.8	0.11	4.82	4.7 (7.5)
Fruit	51.1	0.029	1.48	1.4 (2.3)
Meat	54.7	0.28	15.32	14.8 (23.9)
Eggs	10.9	0.033	0.36	0.3 (0.6)
Fish	10.9	4.0	43.60(4.36)	42.2 (6.8)
Coffee and tea	5.5	2.53	13.92	13.5 (21.7)
Drinking water	548	0	0	0 (0)
Total			103.24 (64.00)	

In brackets are shown the values if the contribution of Sellafield ^{137}Cs in fish is excluded. This contribution is approx. 90% of the ^{137}Cs content in Danish fish. Sellafield thus contributed with approximately 38% of the total ^{137}Cs content in Danish diet in 1983.

As the approximate intake of potassium was 1.365 kg y^{-1} the $^{137}Cs/K$ ratios were 75.6 (46.9) Bq ^{137}Cs (kg $K)^{-1}$ or 2.0 (1.27) M.U. in 1983.

The ratio between observed and predicted (cf. Appendix C) diet levels was 1.01 for ^{90}Sr and 1.02 for ^{137}Cs (corrected for Sellafield ^{137}Cs).

The relative contribution of ^{90}Sr from milk products (~ 28%) was similar to those in 1978-1982. The contribution from potatoes, other vegetables, and fruit was ~ 32%, and that from cereals was 31%. The relative contribution of ^{137}Cs in the total diet changed from 1982 to 1983 as follows: milk products (12 to 13%), grain products decreased from 30 to 11%, and meat

increased (14 to 15%). Fish contributed 42% to the total ^{137}Cs intake in 1983, and is thus together with meat the most important source of ^{137}Cs. This is, however, due to the ^{137}Cs contribution from Sellafield. If this was excluded, milk products would contribute with 20%, grain: 11%, meat: 24% and fish: 7%.

5.10. Grass samples

5.10.1. Grass collected around Risø

Table 5.10.1.1 shows the ^{90}Sr content in grass ash from Zealand in 1983. The mean ^{90}Sr activity was 37 Bq ^{90}Sr (kg ash)$^{-1}$, or 610 Bq ^{90}Sr (kg Ca)$^{-1}$, i.e. the 1983 level was 90% of the 1982 level. Figure 5.10 shows the ^{90}Sr concentration in grass since 1957. The ratio between observed and predicted (cf. Appendix C.1) ^{90}Sr level in grass in 1983 was 1.27.

Table 5.10.1.1. Strontium-90 in grass from Zealand, 1983

	Bq ^{90}Sr (kg ash)$^{-1}$	Bq ^{90}Sr (kg Ca)$^{-1}$
Jan-March	28	640
April-June	18.6	520
July-Sept	46	730
Oct-Dec	32	560
Mean	31	610

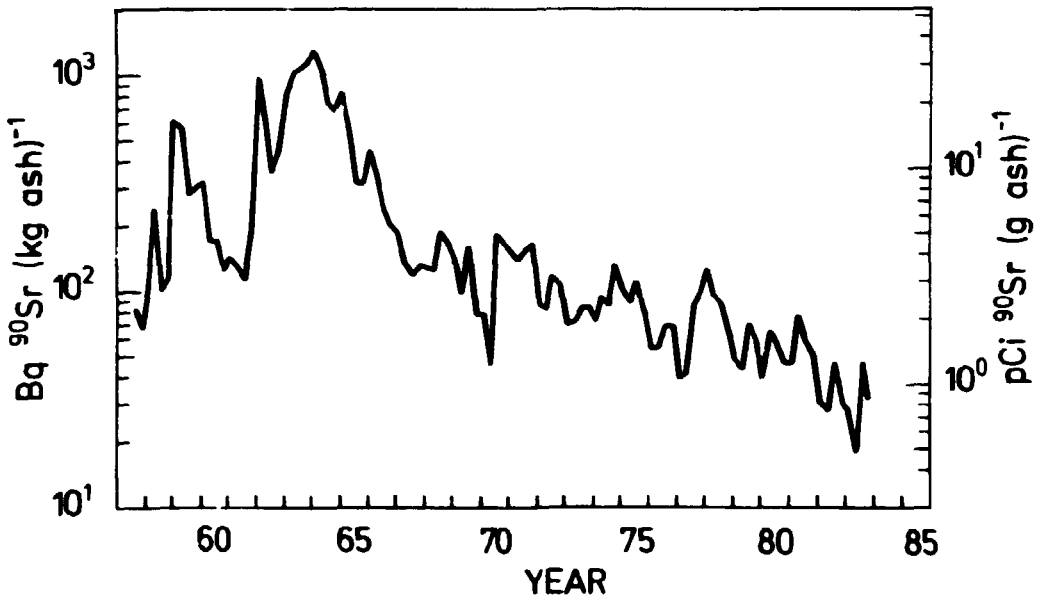

Fig. 5.10. Quarterly ^{90}Sr levels in grass, 1957-1983.

Table 5.10.1.2. Kalium-40 in grass from Risø, 1983

Month	n	g ^{40}K kg^{-1} fresh
January	5	3.4±0.4
February		(snow)
March	4	2.3±0.5
April	4	3.7±0.6
May	5	4.6±0.3
June	4	5.1±0.1
July	4	5.6±0.5
August	5	6.1±0.6
September	4	4.4±0.4
October	5	5.9±0.2
November	4	3.7±0.5
December	2	3.6±0.2

The error term is 1 S.E. of the mean.

5.11. Sea plants

5.11.1. Sea plants collected in Roskilde Fjord

Figure 5.11.1 shows the Bq ^{90}Sr (kg Ca)$^{-1}$ levels in sea plants since 1959 and Table 5.11.1 the results for 1983. The mean level in Fucus vesiculosus was 295 Bq ^{90}Sr (kg Ca)$^{-1}$ (6.2 Bq kg^{-1} dry weight). We got no samples of Zostera marina in 1983. The mean ratio between observed and predicted ^{90}Sr levels in fucus was 0.64.

Fucus contained 8.4 Bq ^{137}Cs kg^{-1} dry weight.

Table 5.11.1. Strontium-90 and Cesium-137 in Fucus vesiculosus from Roskilde Fjord in 1983

Location	Date	% dry matter	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{90}Sr kg^{-1} dry weight	Bq ^{137}Cs (kg K)$^{-1}$	Bq ^{137}Cs kg^{-1} dry weight
At Bolund	25/1	24.3			250	7.4
- " -	21/3	18.4	191	5.6	230	6.9
- " -	11/8	19.6			340	11.6
- " -	20/12	16.9	410	5.8	206	7.2
IX	12/12	18.0	189	7.2	220	8.0
X	12/12	16.2	390	6.1	230	9.5

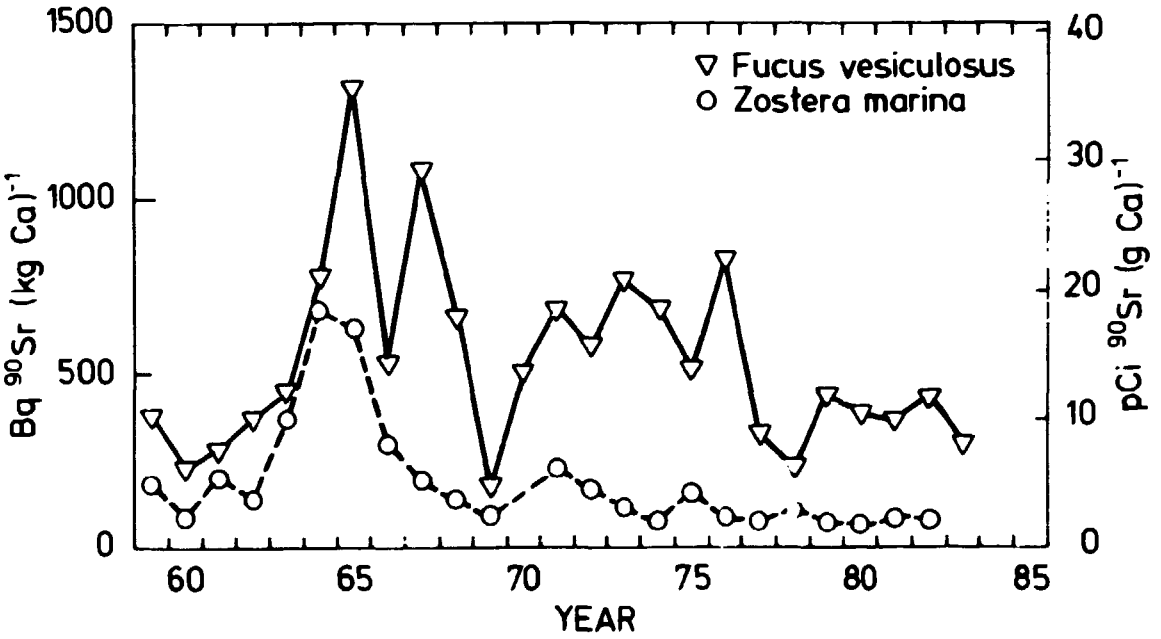

Fig. 5.11.1. Strontium-90 in sea plants from Roskilde fjord, 1959-1983.

5.11.2. Sea plants collected at Klint (55°58'N, 11°35'E)

The two Fucus species most often found in Denmark, Fucus vesiculosus and Fucus serratus, had been collected to test the difference between the two species and to get data of the important seasonal variation. All samples have been analysed for γ-emitting radionuclides and some of them also for ^{90}Sr, ^{99}Tc, Pu and Am. In one month five samples of each species were taken.

For most of the radionuclides there is a significant difference between the two species, but for ^{60}Co and ^{137}Cs this difference is not constant during the year. The seasonal variation has to be taken into account when using Fucus as a bioindicator, and to get a better estimate of this variation the sampling programme will continue in the future.

Table 5.11.2. Radionuclides in the brown algae Fucus vesiculosus (Fu.ve.) and Fucus serratus (Fu.se.) collected at Klint (55°58'N 11°35'E) in 1983 (Unit: Bq kg^{-1} dry weight)

Species	Date	% dry matter	Salinity o/oo	^{40}K*	^{54}Mn	^{60}Co	^{90}Sr	^{99}Tc	^{125}Sb	^{134}Cs	^{137}Cs	$^{239,240}Pu$	^{241}Am
Fu.ve.	14/2	24.9		21	0.4 A	1.32					7.5		
Fu.se.	"	24.6		30	0.69	2.6			1.47		9.5		
Fu.ve.	24/3	19.3		24	0.4 B	1.32	5.0	50		0.4 A	8.1	0.29	0.057
Fu.ve.	"	18.0		24	0.4 A	1.26	6.0	151			7.9	0.29	0.035
Fu.ve.	"	19.0		23		1.06	5.0	180			7.6	0.23	0.023
Fu.ve.	"	19.2		25		1.45	5.7	137			8.3	0.32	0.042
Fu.ve.	"	17.4		26	0.4 A	1.28	5.1	187			8.7	0.24	0.030
Fu.se.	"	19.7		27	0.64	1.96	9.0	81	1.28		9.7	0.54	0.057
Fu.se.	"	18.6		29	0.95	2.1	10.3	87	1.22		9.0	0.62	0.046
Fu.se.	"	19.2		32	0.7 A	2.3	8.8	93	1.3 A		11.4	0.50	0.039
Fu.se.	"	20.0		29	0.86	2.1	11.1	86	1.45	0.4 A	9.9	0.35	0.110
Fu.se.	"	18.6		31	0.84	2.1	9.8	79	1.0 A		9.7	0.61	0.073
Fu.ve.	25/7	18.3	19.0	27		2.3					9.8		
Fu.se.	"	22.7	19.0	26	0.5 B	2.3					9.9		
Fu.ve.	18/8	18.9	20.3	32		2.8					8.1		
Fu.se.	"	22.1	20.3	26		3.0					7.6		
Fu.ve.	16/9	20.5	22.4	39	0.4 B	2.7					11.0		
Fu.se.	"	24.0	22.4	19	0.5 A	2.6					6.9		
Fu.ve.	21/10	18.6	26.4	30		3.0					7.7		
Fu.se.	"	24.4	26.4	27		3.0					6.6		
Fu.ve.	24/11	19.7	24.9	31		2.8					7.2		
Fu.se.	"	20.6	24.9	34		3.7					8.6		
Fu.ve.	21/12	21.4		29		1.92					7.7		

*Unit: g K kg^{-1} dry weight.

5.11.3. Sea plants collected in Danish waters

Apart from the Klint collection, 83 other samples were taken in 1983. They consist of 3 samples of Zostera marina, 1 of Laminaria, 3 of Fucus spiralis, 12 of Fucus serratus, and 64 of Fucus vesiculosus. The samples have been analysed for γ-emitters, especially radiocesium and ^{60}Co.

The mean ^{137}Cs content in Fucus vesiculosus collected in the inner Danish waters was 9.35±1.75 Bq kg^{-1} dry weight (1 S.D., n = 54).

^{60}Co was measurable in nearly all samples. The data suggest that Barsebäck and Ringhals are the important sources in inner Danish waters. For ^{60}Co in the Sound and Kattegat a relation can be found between the levels found in Fucus vesiculosus and the distance X (in km) from Barsebäck:

Concentration in Fucus (Bq ^{60}Co kg^{-1} dry)=1200(±400)$X^{-1.4(\pm 0.1)}$
This correlation is in good agreement with earlier results (Risø-R-469)[1], thereby indicating a steady-state situation for ^{60}Co in that area. The samples from the North Sea are probably contaminated with ^{60}Co from sources in the UK and France. (A further discussion can be found in Boelskifte, (1984)[10]).

^{54}Mn was measurable in several samples. There was no correlation with the ^{60}Co concentrations (r = 0.18). This shows that ^{54}Mn resulted from fall-out rather than from nuclear power plants. The mean concentration for ^{54}Mn in Fucus vesiculosus in the Danish Straits was 0.57±0.25(N = 22) Bq ^{54}Mn kg^{-1} dry weight; in the North Sea ^{54}Mn was found in only two samples (0.36 and 0.32 Bq kg^{-1} dry).

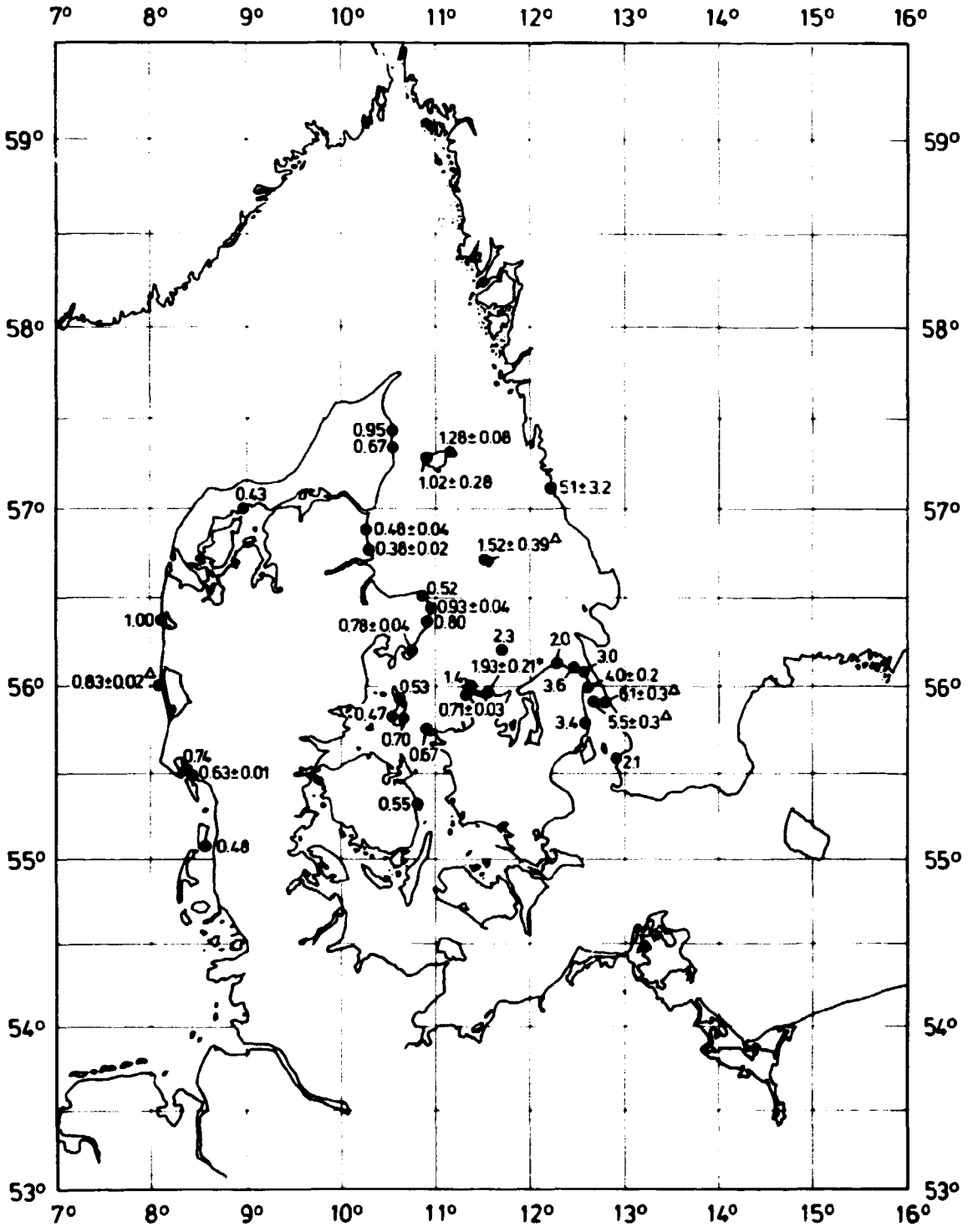

Fig. 5.11.3. Cobalt-60 in Fucus vesiculosus collected in the Danish Straits 1983. (Unit: Bq kg^{-1} dry weight). The error term is 1 S.E. of the mean of double determinations. ΔTriple determinations. *Twelve determinations.

Table 5.11.3.1. Radionuclides in brown algae collected in inner Danish waters in 1983 (Unit: Bq kg^{-1} dry)

Species	Position N	Position E	Date	% dry matter	Salinity o/oo	^{40}K	^{54}Mn	^{58}Co	^{60}Co	^{65}Zn
Fu.sp.	57°44'	10°36'	4/8	21.8		35			1.05	
La.sp.	57°36'	09°58'	4/8	20.0		38	0.41 B		0.42 A	
Fu.ve.	57°27'	10°33'	2/8	25.1		30			0.95	
Fu.ve.	57°20'	10°32'	2/8	22.9		32			0.67 A	
Fu.se.	57°19'	11°08'	10/8	27.6		24			1.98	
Fu.ve.	57°19'	11°08'	10/8	21.2		33			1.37	
Fu.ve.	57°19'	11°08'	15/4	21.4		25			1.20	
Fu.se.	57°18'	10°56'	10/8	24.8		32			2.1	
Fu.ve.	57°18'	10°56'	10/8	23.7		29	0.32 A		1.30	
Fu.se.	57°18'	10°56'	15/4	21.6		26	0.28 A		0.83	
Fu.ve.	57°18'	10°56'	15/4	20.1		27	0.33 A		0.74	
Fu.ve.	57°09'	10°26'	2/8	19.5		33				
Fu.ve.	57°07'	12°11'	1/12	17.5		37		1.04	8.3	3.1
Fu.ve.	57°07'	12°11'	2/6	19.1		28	0.6 B		1.99	
Fu.sp.	57°07'	08°36'	4/8	26.1		28			1.37	
Fu.sp.	57°04'	10°22'	2/8	20.5		29				
Zo.ma.	57°04'	09°42'	2/8	19.1		27				
Fu.ve.	57°00'	10°18'	1/8	29.2		22				
Zo.ma.	57°00'	10°18'	1/8	24.8		19				
Fu.se.	57°00'	08°57'	3/8	26.9		25	0.41 A		0.50	
Fu.ve.	57°00'	08°57'	3/8	28.7		29			0.43 A	
Fu.ve.	56°54'	10°16'	2/8	22.3		31	1.06 A		0.44 A	
Fu.ve.	56°54'	10°16'	2/8	23.5	25.4	32			0.51 B	
Fu.ve.	56°45'	10°18'	2/8	21.0		24				
Fu.ve.	56°45'	10°18'	2/8	22.9		28			0.36 A	
Fu.ve.	56°45'	10°18'	2/8	22.6	24.8	28			0.40 B	
Fu.se.	56°43'	11°31'	10/8	22.6		28			1.65	
Fu.ve.	56°43'	11°31'	10/8	19.5		32	0.46 A		2.3	
Fu.ve.	56°43'	11°31'	23/5	13.2		35			1.15 A	
Fu.ve.	56°43'	11°31'	17/1	22.2		39	0.25 A		1.11	
Zo.ma.	56°41'	08°44'	3/8	20.7		25			1.13	
Fu.ve.	56°36'	10°19'	2/8	19.8		30				
Fu.ve.	56°31'	10°27'	2/8	23.4	22.8	25	0.59 B		0.52 A	
Fu.ve.	56°27'	10°58'	2/8	23.3		29			0.89	
Fu.ve.	56°27'	10°58'	2/8	23.3		30			0.96	
Fu.ve.	56°23'	10°56'	2/8	22.1		28			0.80 A	
Fu.ve.	56°22'	08°07'	3/8	19.0	22.5	35			1.00	
Fu.se.	56°12'	11°43'	11/8	24.6		22		0.65 A	2.8	
Fu.ve.	56°12'	11°43'	11/8	21.2		31			2.3	
Fu.ve.	56°12'	10°40'	2/8	23.2		40			0.82	
Fu.ve.	56°12'	10°40'	19/1	24.0		32			0.74	
Fu.ve.	56°07'	12°19'	29/7	24.4	16.3	28			2.0	

Table 5.11.3.1. (continued)

Species	Position N	Position E	Date	% dry matter	Salinity o/oo	^{40}K*	^{54}Mn	^{58}Co	^{60}Co	^{65}Zn
Fu.ve.	56°06'	12°28'	29/7	23.6	17.8	21		0.56 B	3.6	
Fu.ve.	56°04'	12°33'	29/7	20.4	17.5	32	0.59 A		3.0	
Fu.se.	56°03'	12°36'	29/7	22.3	16.3	24	0.45 B		6.1	
Fu.se.	56°03'	12°36'	17/2	21.6		30	0.76		4.6	
Fu.ve.	56°00'	12°36'	29/7	23.0	14.9	25	0.56 A		4.2	
Fu.ve.	56°00'	12°35'	17/2	20.4		27	0.44 A		3.8	
Fu.ve.	56°00'	08°08'	3/8	18.1	23.8	32			0.82	
Fu.ve.	56°00'	08°08'	3/8	17.4	23.8	29			0.81	
Fu.ve.	56°00'	08°08'	8/3	19.6		32	0.32 A		0.86	
Fu.ve.	55°59'	11°21'	14/2	19.8		32			1.40	
Fu.ve.	55°58'	11°17'	25/7	24.4		24	0.51 A		0.68	
Fu.ve.	55°58'	11°17'	14/2	22.8	22.8	25	0.50		0.73	
Fu.ve.	55°56'	10°04'	27/7	26.0		27				
Fu.ve.	55°56'	10°03'	6/6	19.1		24	0.3 B			
Fu.ve.	55°55'	12°40'	13/9	19 2	20.7	32	0.57 A	0.46 B	6.1	
Fu.ve.	55°55'	12°40'	13/9	19.1	20.7	31	0.41 B		5.2	
Fu.ve.	55°55'	12°40'	13/9	24.2	20.7	30	0.43 A	0.38 B	5.1	
Fu.se.	55°55'	10°39'	27/7	23.9		29				
Fu.ve.	55°55'	10°39'	27/7	23.5	21.0	29	0.34 B		0.53 A	
Fu.ve.	55°53'	12°43'	13/9	18.6	20.9	32	0.55		5.6	
Fu.ve.	55°53'	12°43'	13/9	18.6	20.9	32	0.63 A		6.5	
Fu.ve.	55°53'	12°43'	13/9	19.9	20.9	31	0.68 A		6.3	
Fu.se.	55°52'	10°03'	27/7	26.2		28				
Fu.ve.	55°52'	10°03'	27/7	24.3		26				
Fu.ve.	55°49'	10°39'	27/7	23.0		28			0.70 A	
Fu.ve.	55°48'	10°32'	27/7	25.2	20.8	24			0.47	
Fu.ve.	55°46'	12°36'	28/7	22.7	14.1	22	0.4 B		3.4	
Fu.ve.	55°45'	10°57'	27/7	25.1	20.8	33			0.67	
Fu.ve.	55°41'	11°05'	27/7	23.1		28				
Fu.ve.	55°35'	12°55'	1/12	16.3		26	0.6 B		2.1	
Fu.ve.	55°31'	09°46'	4/8	19.8		29				
Fu.ve.	55°27'	08°28'	3/8	24.6	29.7	32			0.64	
Fu.ve.	55°27'	08°28'	3/8	22.9	29.7	40			0.61 A	
Fu.ve.	55°27'	08°25'	3/8	20.7	29.1	28	0.36 B		0.74	
Fu.ve.	55°21'	11°07'	4/8	22.9		25				
Fu.ve.	55°18'	10°51'	4/8	22.2	22.2	36			0.55 A	
Fu.se.	55°05'	15°09'	17/11	18.6		28	0.91		0.33 A	
Fu.ve.	55°05'	15°09'	25/5	20.0		23	0.66			
Fu.ve.	55°05'	08°34'	3/8	26.6		29			0.48 A	
Fu.ve.	54°40'	11°44'	29/12	22.1		3?	1.37			
Fu.ve.**	53°33'	08°35'	28/6	lost		28				

Table 5.11.3.2. Radionuclides in brown algae collected in inner Danish waters in 1983 (Unit: Bq kg^{-1} dry)

Species	Position N	Position E	Date	% dry matter	Salinity o/oo	^{95}Nb	^{106}Ru	^{125}Sb	^{131}J	^{134}Cs	^{137}Cs
Fu.sp.	57°44'	10°36'	4/8	21.8						0.37 A	9.9
La.sp.	57°36'	09°58'	4/8	20.0			6.8	0.85 A		0.51 A	8.1
Fu.ve.	57°27'	10°33'	2/8	25.1							9.1
Fu.ve.	57°20'	10°32'	2/8	22.9							9.3
Fu.se.	57°19'	11°08'	10/8	27.6							8.8
Fu.ve.	57°19'	11°08'	10/8	21.2							9.3
Fu.ve.	57°19'	11°08'	15/4	21.4							6.7
Fu.se.	57°18'	10°56'	10/8	24.8							11.6
Fu.ve.	57°18'	10°56'	10/8	23.7							9.0
Fu.se.	57°18'	10°56'	15/4	21.6		0.5 A	3 B			0.27 A	8.5
Fu.ve.	57°18'	10°56'	15/4	20.1						0.32 A	8.0
Fu.ve.	57°09'	10°26'	2/8	19.5							10.1
Fu.ve.	57°07'	12°11'	1/12	17.5							10.3
Fu.ve.	57°07'	12°11'	2/6	19.1							12.0
Fu.sp.	57°07'	08°36'	4/8	26.1			4.7 A			0.36 A	7.7
Fu.sp.	57°04'	10°22'	2/8	20.5							9.6
Zo.ma.	57°04'	09°42'	2/8	19.1				5.9			1.4 A
Fu.ve.	57°00'	10°18'	1/8	29.2							4.6
Zo.ma.	57°00'	10°18'	1/8	24.8							7.2
Fu.se.	57°00'	08°57'	3/8	26.9				0.61 A			6.3
Fu.ve.	57°00'	08°57'	3/8	28.7							4.9
Fu.ve.	56°54'	10°16'	2/8	22.3							12.7
Fu.ve.	56°54'	10°16'	2/8	23.5	25.4						13.2
Fu.ve.	56°45'	10°18'	2/8	21.0							10.1
Fu.ve.	56°45'	10°18'	2/8	22.9							14.2
Fu.ve.	56°45'	10°18'	2/8	22.6	24.8						11.0
Fu.se.	56°43'	11°31'	10/8	22.6							10.4
Fu.ve.	56°43'	11°31'	10/8	19.5							7.3
Fu.ve.	56°43'	11°31'	23/5	13.2							11.3
Fu.ve.	56°43'	11°31'	17/1	22.2			2.2 B			0.16 B	9.3
Zo.ma.	56°41'	08°44'	3/8	20.7				5.7			2.5
Fu.ve.	56°36'	10°19'	2/8	19.8				1.9 A			11.1
Fu.ve.	56°31'	10°27'	2/8	23.4	22.8						8.5
Fu.ve.	56°27'	10°58'	2/8	23.3							10.7
Fu.ve.	56°27'	10°58'	2/8	23.3							9.5
Fu.ve.	56°23'	10°56'	2/8	22.1							9.1
Fu.ve.	56°22'	08°07'	3/8	19.0	22.5		4.3 B				8.2
Fu.se.	56°12'	11°43'	11/8	24.6							10.0
Fu.ve.	56°12'	11°43'	11/8	21.2							9.8
Fu.ve.	56°12'	10°40'	2/8	23.2							5.1
Fu.ve.	56°12'	10°40'	19/1	24.0						0.18 B	8.3
Fu.ve.	56°07'	12°19'	29/7	24.4	16.3						7.4

Table 5.11.3.2. (continued)

Species	Position N	Position E	Date	% dry matter	Salinity o/oo	^{95}Nb	^{106}Ru	^{125}Sb	^{131}J	^{134}Cs	^{137}Cs
Fu.ve.	56°06'	12°28'	29/7	23.6	17.8			1.39 A			8.9
Fu.ve.	56°04'	12°33'	29/7	20.4	17.5						9.8
Fu.se.	56°03'	12°36'	29/7	22.3	16.3						8.5
Fu.se.	56°03'	12°36'	17/2	21.6					2.2 A		7.9
Fu.ve.	56°00'	12°36'	29/7	23.0	14.9						8.6
Fu.ve.	56°00'	12°35'	17/2	20.4		0.42 B			2.1 A		8.1
Fu.ve.	56°00'	08°08'	3/8	18.1	23.8		5.1 A	1.45 A			7.7
Fu.ve.	56°00'	08°08'	3/8	17.4	23.8	1.5 A		1.1 A			7.1
Fu.ve.	56°00'	08°08'	8/3	19.6			2.8 A	0.76			3.1
Fu.ve.	55°59'	11°21'	14/2	19.8				0.83 A			8.8
Fu.ve.	55°58'	11°17'	25/7	24.4							9.5
Fu.ve.	55°58'	11°17'	14/2	22.8						0.22 A	8.1
Fu.ve.	55°56'	10°04'	27/7	26.0							9.3
Fu.ve.	55°56'	10°03'	6/6	19.1							9.6
Fu.ve.	55°55'	12°40'	13/9	19.2	20.7			3.3	3.2 A		9.8
Fu.ve.	55°55'	12°40'	13/9	19.1	20.7			1.4	3.4		9.2
Fu.ve.	55°55'	12°40'	13/9	24.	20.7			3.6	3.0 B		8.7
Fu.se.	55°55'	10°39'	27/7	23.9							13.7
Fu.ve.	55°55'	10°39'	27/7	23.5	21.0					0.44 A	10.8
Fu.ve.	55°53'	12°43'	13/9	18.6	20.9			0.96 A	4.2 A		8.9
Fu.ve.	55°53'	12°43'	13/9	18.6	20.9			0.97 A	3.7 A		8.3
Fu.ve.	55°53'	12°43'	13/9	19.9	20.9			1.0 A	4.5 A		9.1
Fu.se.	55°52'	10°03'	27/7	26.2							11.8
Fu.ve.	55°52'	10°03'	27/7	24.3							9.1
Fu.ve.	55°49'	10°39'	27/7	23.0							8.9
Fu.ve.	55°48'	10°32'	27/7	25.2	20.8					0.23 B	8.5
Fu.ve.	55°46'	12°36'	28/7	22.7	14.1				10 B		8.8
Fu.ve.	55°45'	10°57'	27/7	25.1	20.8					0.34 A	12.4
Fu.ve.	55°41'	11°05'	27/7	23.1							10.1
Fu.ve.	55°35'	12°55'	1/12	16.3					1.5 A		8.2
Fu.ve.	55°31'	09°46'	4/8	19.8							11.0
Fu.ve.	55°27'	08°28'	3/8	24.6	29.7		4.5 A				5.4
Fu.ve.	55°27'	08°28'	3/8	22.9	29.7			1.28 A			4.8
Fu.ve.	55°27'	08°25'	1/8	20.7	29.1					0.25 A	10.4
Fu.ve.	55°21'	11°07'	4/8	22.9							8.6
Fu.ve.	55°18'	10°51'	4/8	22.2	22.2						10.8
Fu.se.	55°05'	15°09'	17/11	18.6							7.5
Fu.ve.	55°05'	15°09'	25/5	20.0							6.4
Fu.ve.	55°05'	08°34'	3/8	26.6				0.79 A			4.5
Fu.ve.	54°40'	11°44'	29/12	22.1							8.2
Fu.ve.**	53°33'	08°35'	28/6	lost							3.5

Fu.ve. Fucus vesiculosus

Fu.se. Fucus serratus

Fu.sp. Fucus spiralis

Zo.ma. Zostera marina

La.sp. Laminaria species

* Unit: g * kg^{-1} dry weight.

**Collected at Bremerhaven.

6. STRONTIUM-90 AND CESIUM-137 IN MAN IN 1983

by A. Aarkrog

6.1. Stronium-90 in human bone

The collection of human vertebrae from the institutes of forensic medicine in Copenhagen and Århus was continued in 1983. As in the total-diet survey (cf. 5.7), the country was divided into eight zones. The samples were divided into five age groups: new-born (< 1 month) (no samples in 1983), infants (1 month-4 years), children and teenagers (5-19 years), adults (≤ 29 years), and adults (> 29 years).

Tables 6.1.1-6.1.5 show the results for the five groups. The ^{90}Sr concentrations in human bone collected in 1983 were nearly unchanged from those observed in 1979-1982

The observed mean concentration in adults (≥ 30 years) was 76% of that predicted (cf. Appendix C).

Table 6.1.1. Strontium-90 in bone from new-born children (< 1 month old) in 1983

No samples.

Table 6.1.2. Strontium-90 in bone from infants (≤ 4 years) in 1983

Zone	Age in years and month	Month of death	Sex	Bq (kg Ca)$^{-1}$
III	3 m	10	M	42 A
"	6 m	10	M	22

Table 6.1.3. Strontium-90 in bone from children and teenagers (≤ 19 years) in 1983

Zone	Age in years	Month of death	Sex	Bq (kg Ca)$^{-1}$
I	6	6	F	20
II	9	6	M	24
"	18	9	M	36
"	18	8	M	32

Table 6.1.4. Strontium-90 in vertebrae from adults (≤ 29 years) in 1983

Zone	Age in years	Month of death	Sex	Bq (kg Ca)$^{-1}$
I	26	9	M	23
II	26	11	M	38
"	28	9	M	27
III	22	6	M	22
"	28	6	M	35
VI	21	6	F	22
"	26	11	M	28
"	27	10	M	27

Table 6.1.5. Strontium-90 in vertebrae from adults (> 29 years) in 1983

Zone	Age in years	Month of death	Sex	Bq (kg Ca)$^{-1}$
I	32	10	F	30
"	48		M	19.5
"	67	9	M	52
"	80	6	M	28
"	83	11	F	44
II	37	12	F	22
"	41	11	F	17.6
"	44	9	M	20
"	46	11	F	49
"	46	10	M	28
"	48	11	M	26
"	50	11	F	35
"	58	8	F	32
"	58	12	M	18.1 A
"	59	6	M	27
"	62	9	M	13.5
"	66	6	M	26
"	66	9	M	41
"	68	11	F	36
III	55	11	F	35
"	60		M	27
"	68	6	M	66
IV	50	9	M	26
VI	31	10	M	22
"	43	11	F	33
"	43	11	F	37
"	45	10	M	26
"	55	6	F	30
"	57	6	F	31
"	65	10	M	26
"	73	6	M	30
"	76	11	F	48

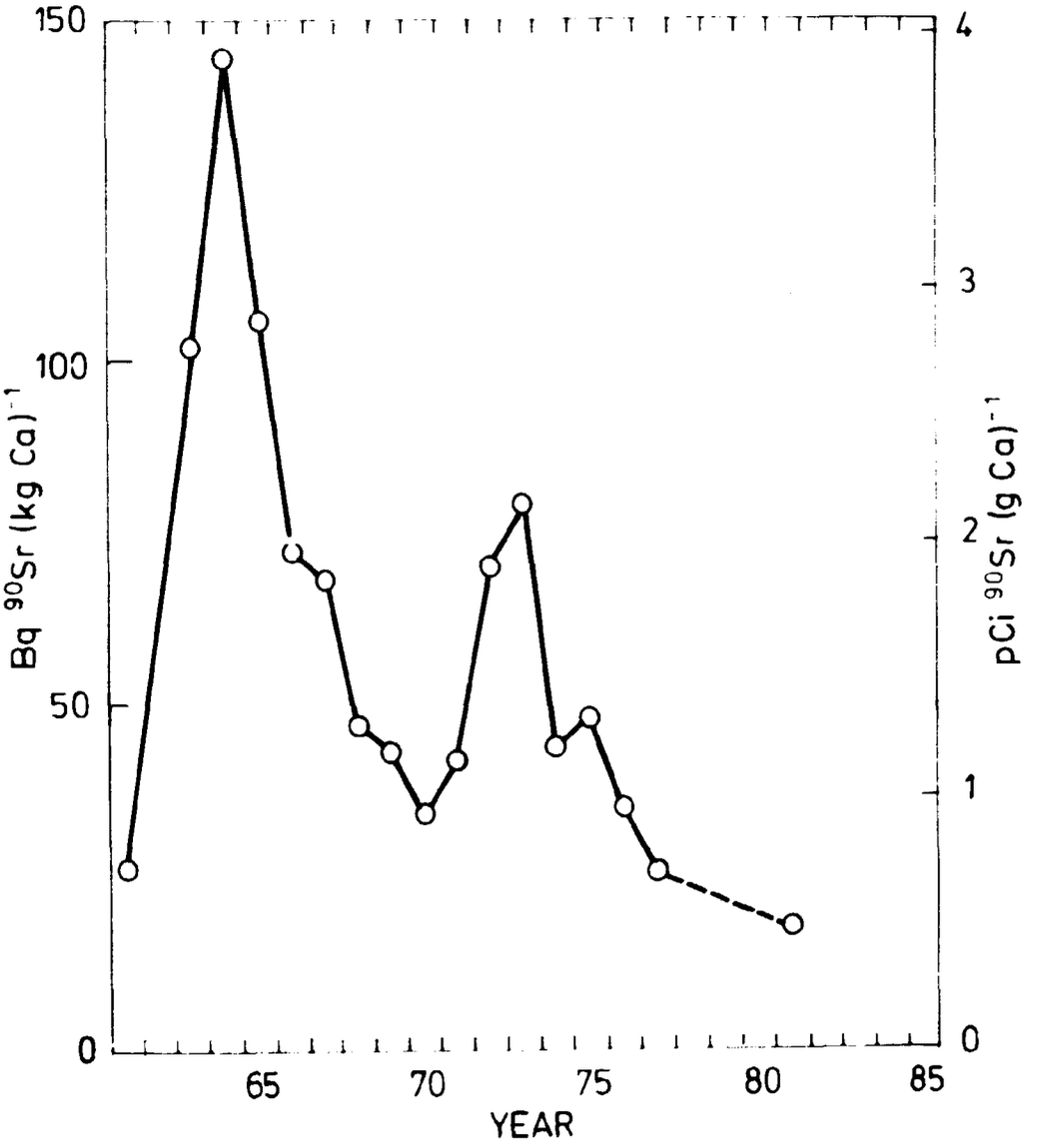

Fig. 6.1.1. Strontium-90 levels (sample number weighted mean) in bone from newborn (< 1 month) 1961-1983.

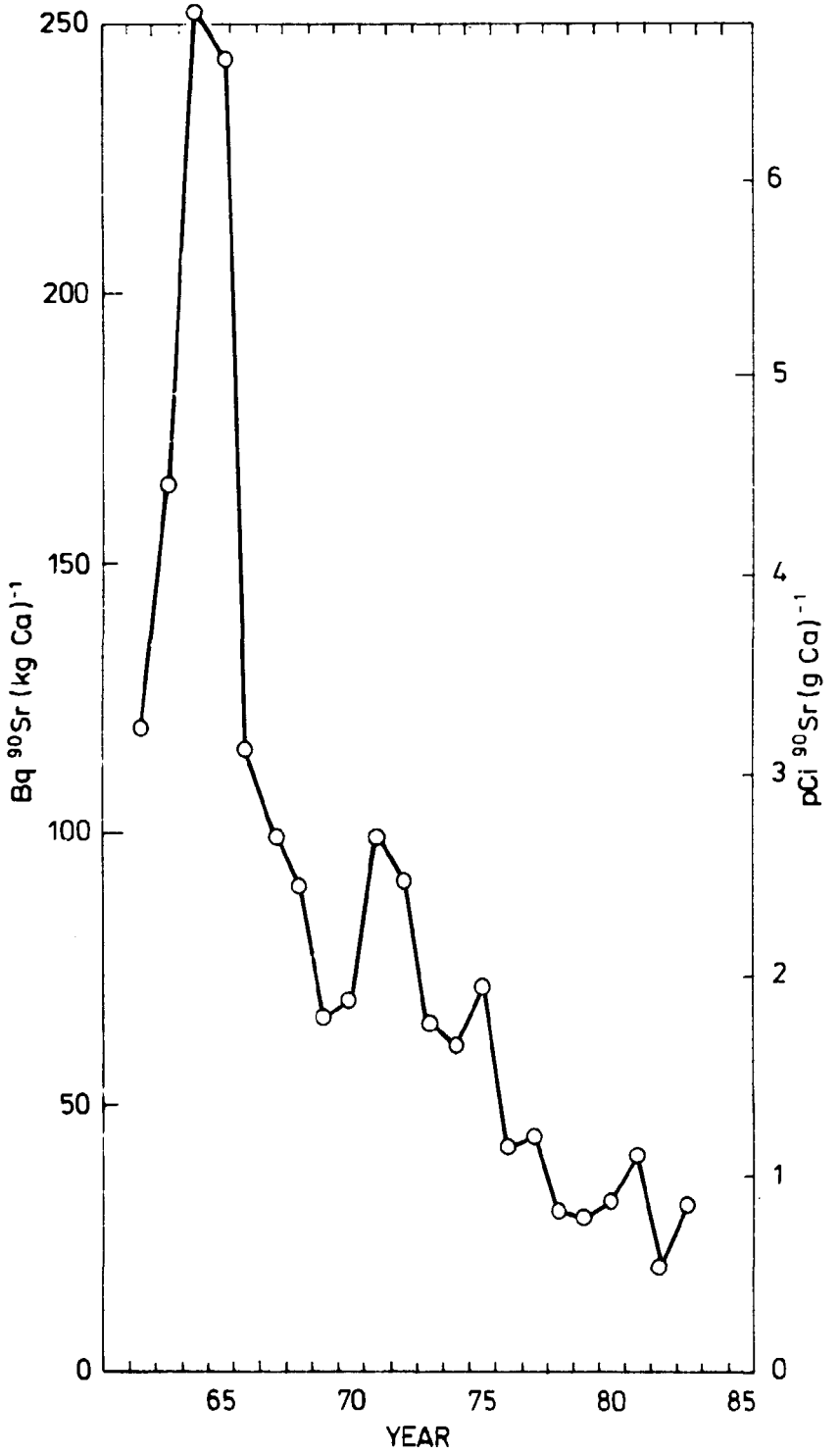

Fig. 6.1.2. Strontium-90 levels (sample number weighted mean) in bone from infants (> 1 month $\leq$ 4 years) 1962-1983.

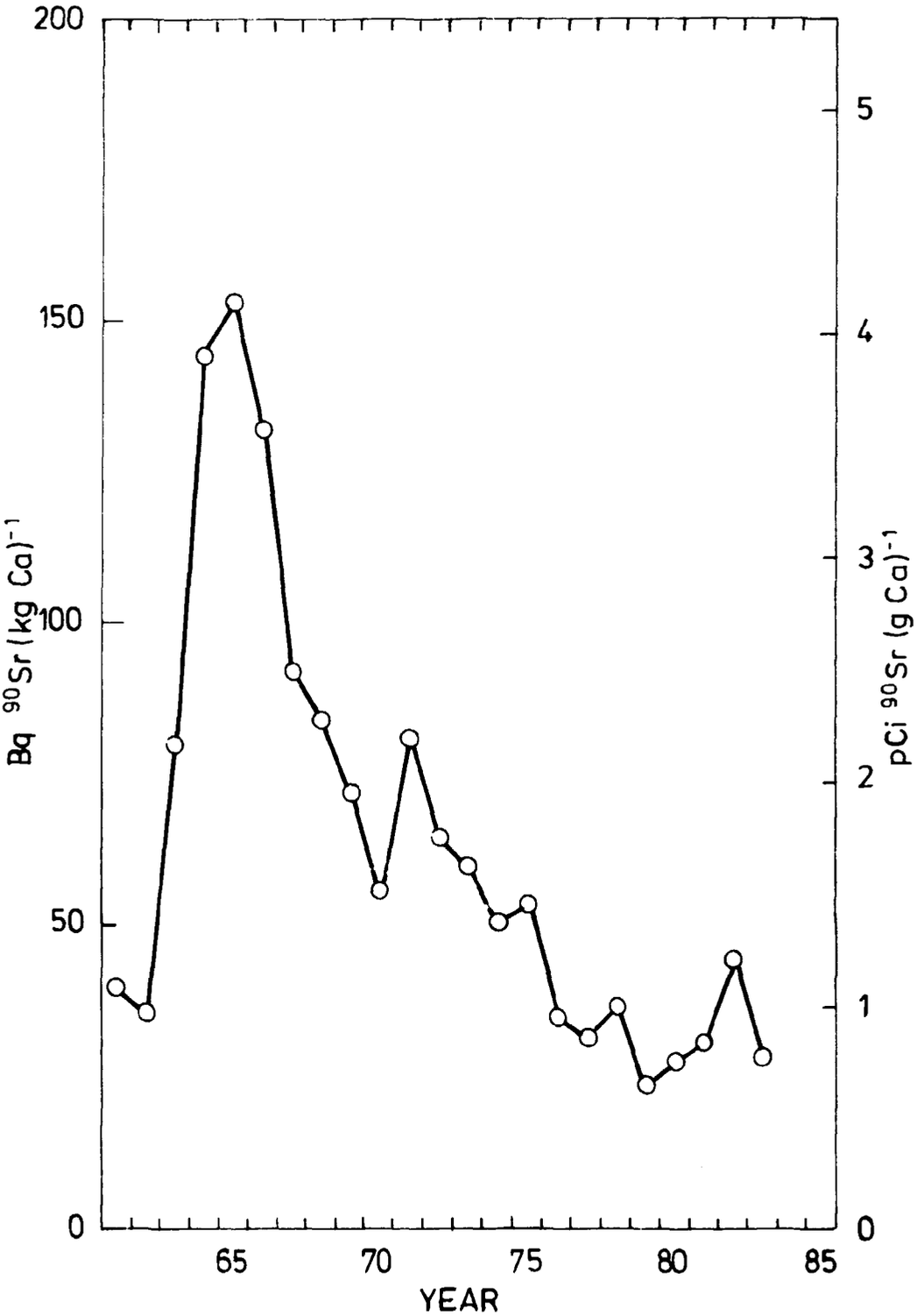

Fig. 6.1.3. *Strontium-90 levels (sample number weighted mean) in* bone from children (> 4 years ≤ 19 years) 1961-1983.

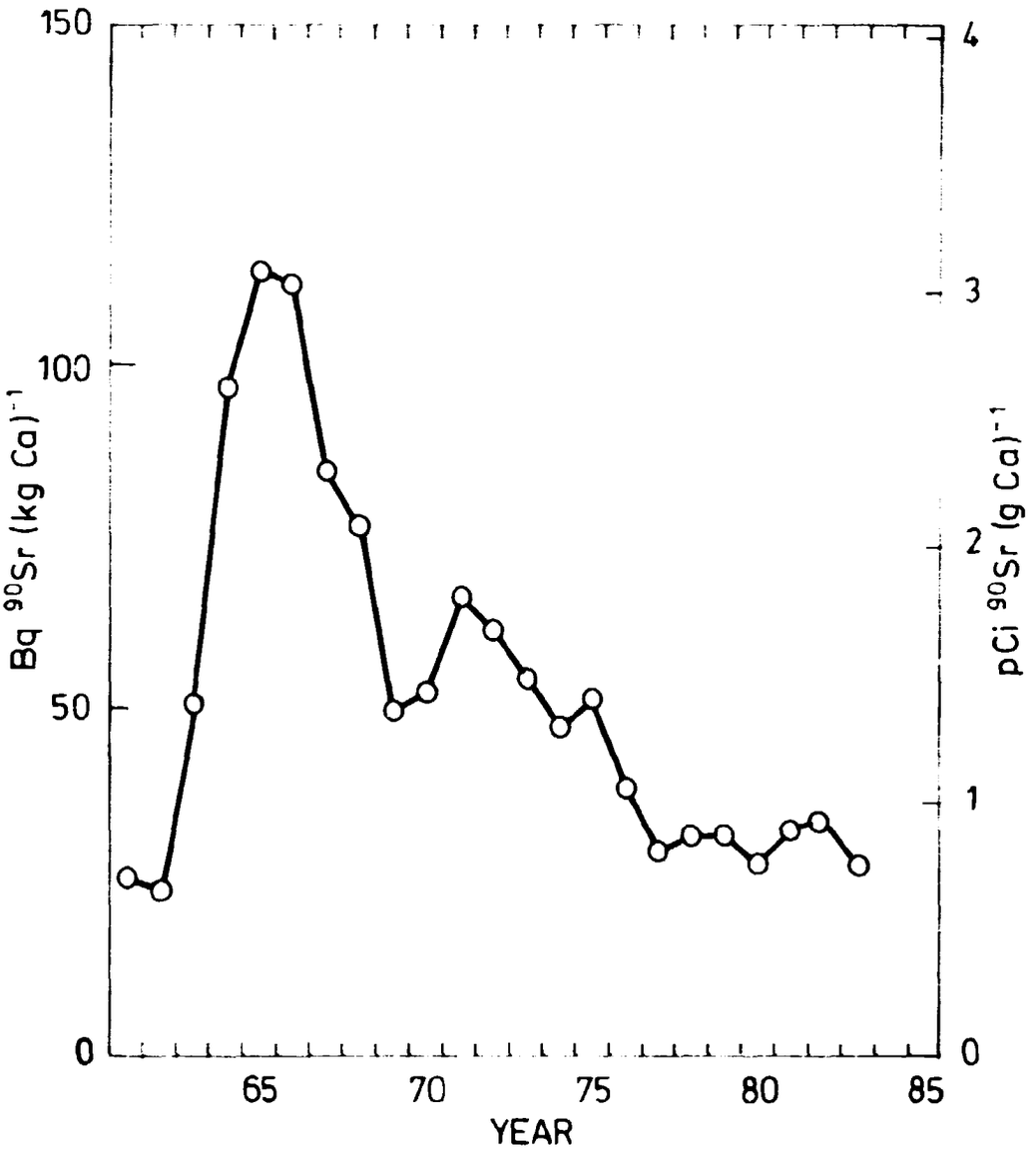

Fig. 6.1.4. Strontium-90 levels (sample number weighted mean) in bone from adults (> 19 years $\leq$ 29 years) 1961-1983.

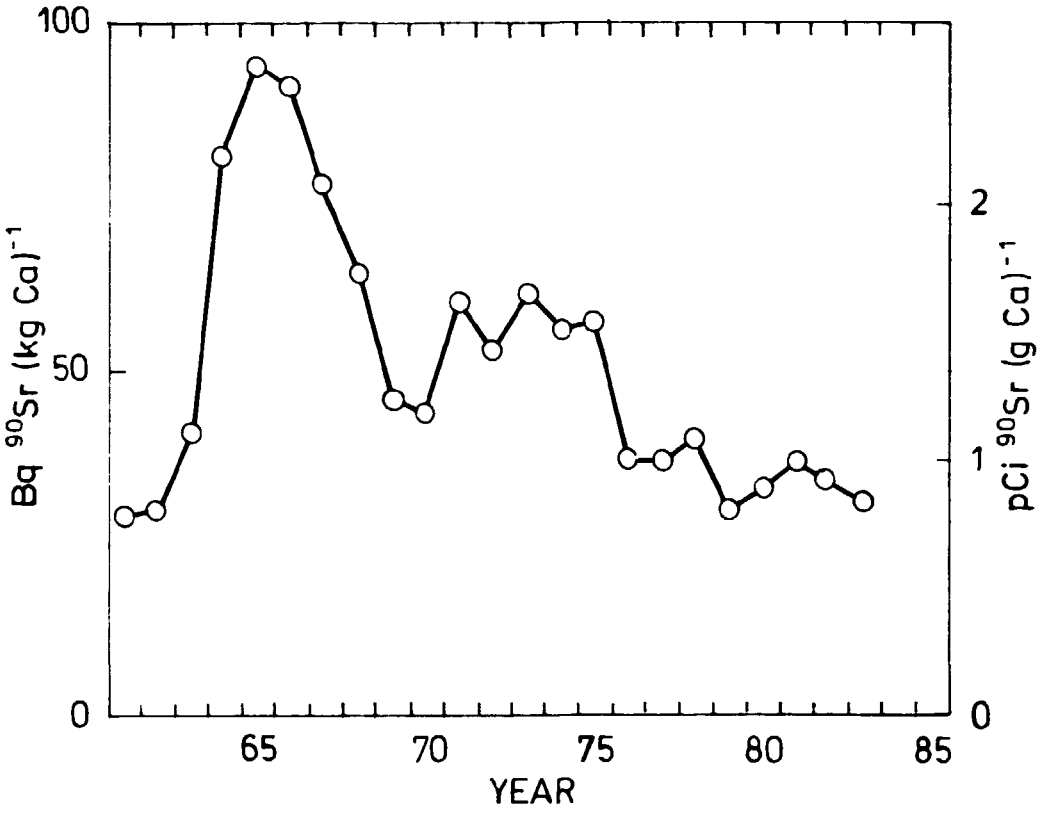

Fig. 6.1.5. Strontium-90 levels (sample number weighted mean) in bone from adults (> 29 years) 1961-1983.

Table 6.1.6. Strontium-90 in human vertebrae collected in Denmark in 1983. (Unit: Bq (kg Ca)$^{-1}$)

Age group	Number of samples	Min.	Max.	Median	Mean
New-born (< 1 month)	0				
Infants (≤ 4 years)	2	22	42	32	32
Children (≤ 19 years)	4	20	36	28	28
Adults (≤ 29 years)	8	22	38	27	28
Adults (> 29 years)	32	13.5	66	29	31

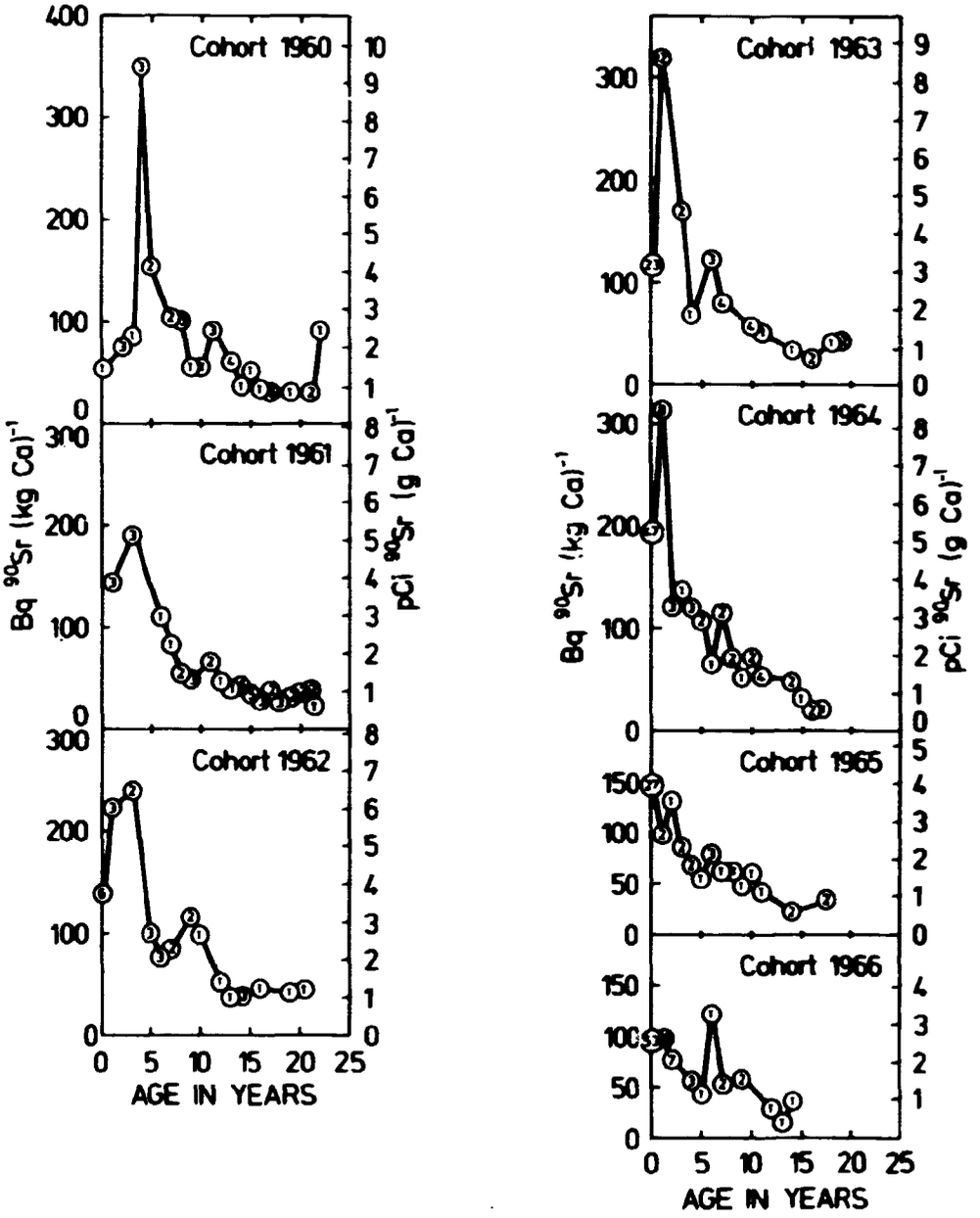

Fig. 6.1.6. Strontium-90 in human bone from Danish cohorts 1960-1966. Abscissa: age in years. Ordinate: bone level in Bq ^{90}Sr (kg Ca)$^{-1}$.

6.2. Cesium-137 in the human body

Whole-body measurements were initiated at Risø in July 1963 (cf. 2.3 in Risø Report No. 85[1]). A control group from the Health Physics Department was selected and has since then been measured as far as possible three times a year.

However, due to the decreasing ^{137}Cs content in the body the contribution from interfering radionuclides to the γ-spectra has made the determination of ^{137}Cs unreliable and since 1978 we have not published whole-body measurements. From the prediction model[21] for whole body ^{137}Cs we have estimated the level in 1983 at 84 Bq ^{137}Cs (kg K)$^{-1}$ (= 2.3 pCi ^{137}Cs (g K)$^{-1}$) and

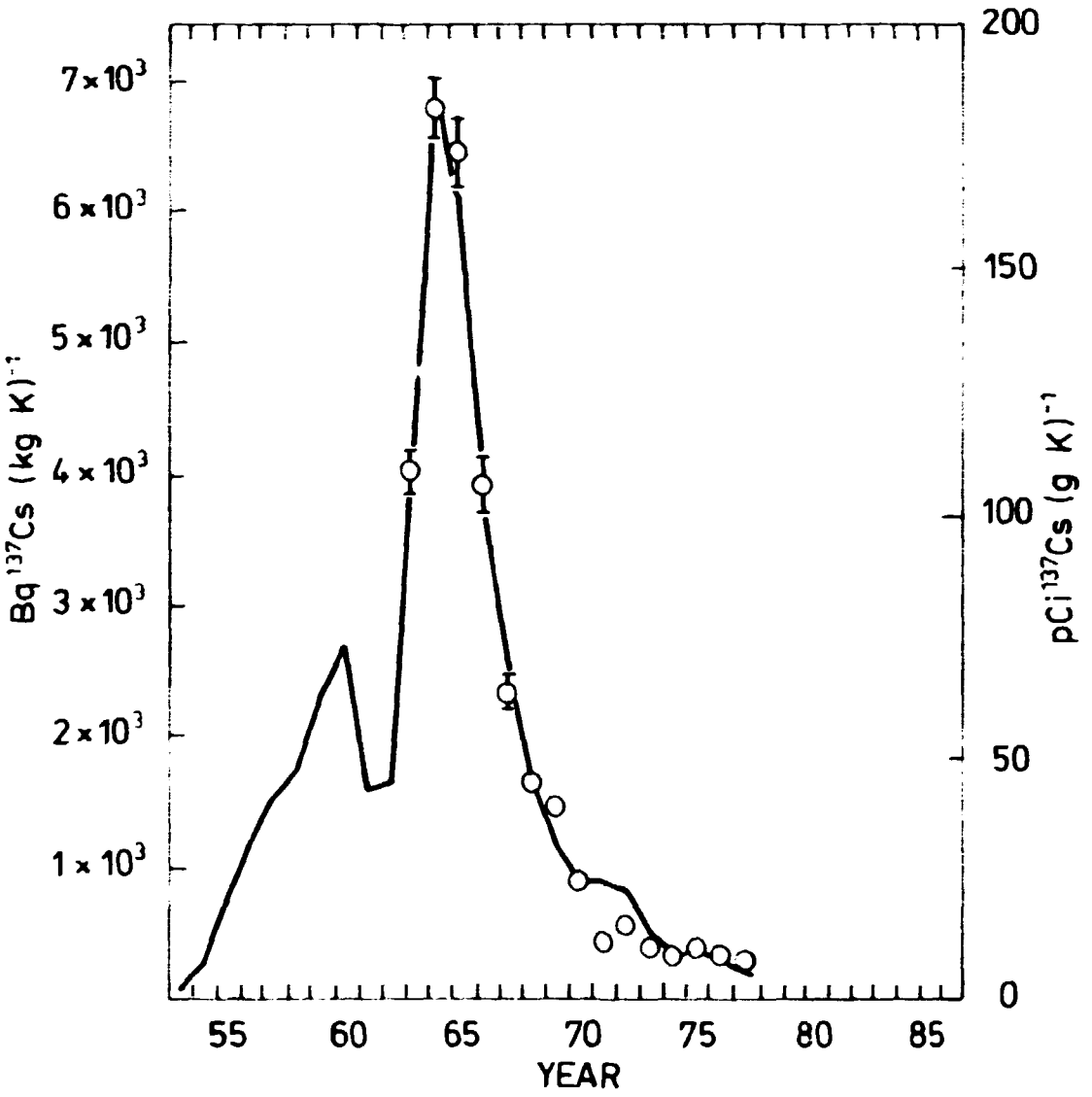

Fig. 6.2. A comparison between observed (±1 S.E.) and calculated[21] Bq ^{137}Cs (kg K)$^{-1}$ levels in whole-body from the Islands.

from the diet measurements for the Islands our estimate becomes: $2.85 \cdot 56 = 160$ Bq ^{137}Cs $(kg\ K)^{-1}$ (= 4.3 pCi ^{137}Cs $(g\ K)^{-1}$, where 2.85 is the observed ratio between $^{137}Cs/K$ in body and diet[21]). The difference between the two estimates is mainly due to the fact that the latter includes the contribution of radiocesium from Sellafield whereas the former estimate is based on fallout ^{137}Cs only.

7. TRITIUM IN THE ENVIRONMENT

by Heinz Hansen

7.1. Introduction

Tritium is produced naturally in the atmosphere by the interaction of cosmic-ray protons and neutrons with nitrogen, oxygen or argon. Surface waters contain about 0.4 kBq m^{-3} from this source[25]. Tritium is also produced and injected into the stratosphere as the result of thermonuclear explosions. At present, this latter source has enhanced the natural inventory by about a factor of ten[25]. Finally, tritium is produced as a by-product of the peaceful uses of atomic energy: it is released both during reactor operation and fuel reprocessing.

Before Denmark builds any nuclear power stations of her own, it is of interest to know the general tritium levels in the environment that could be affected by this new energy source. Also, an assay of the current tritium levels can be used already now to control any tritium which may be released from the Swedish nuclear power stations at Barsebäck and Ringhals, and from the reprocessing plants at Sellafield and La Hague.

7.2. Assay of tritium in low-level amounts

The present assays of tritium levels in water are based on a relative enrichment of ^3H_2O by electrolysis and subsequent liquid scintillation counting as previously described (Risø Reports Nos. 386 etc. [1]).

We have recently found that the tritium background in the air in our laboratory makes it impossible to produce reliable results if the concentrations are below 2 kBq m^{-3} (Personal Communication G. Östlund, 1984). Hence we have discarded such results. We have furthermore applied a background correction by subtraction of 1.2 kBq ^3H m^{-3} from our measured values.

8. MEASUREMENTS OF BACKGROUND RADIATION IN 1983

by L. Bøtter-Jensen and S.P. Nielsen

8.1. Instrumentation

Measurements of the background radiation were made with thermoluminescence dosimeters (TLD's), a mobile Ge(Li) spectrometer system[24], a high-pressure ionization chamber (Reuter-Stokes RSS-111), and a NaI(Tl) detector.

8.2. State experimental farms

The State experimental farms are situated as shown in fig. 4.2. The results of the TLD measurements are shown in Table 8.2.1. The results of the NaI(Tl) detector measurements are shown in Table 8.2.2.

Table 8.2.1. TLD-measurements of the background radiation (integrated over 12 months and normalized to $\mu R\ h^{-1}$) at the State experimental farms in 1982/83

	Sep 1982 - Oct 1983 $\mu R\ h^{-1}$
Tylstrup	7.3
Borris	6.9
Ødum	7.9
Askov	6.9
St. Jyndevad	5.9
Blangstedgård	6.7
Tystofte	8.3
Abed	8.0
Mean	7.2

Table 8.2.2. Terrestrial exposure rates at the State experimental farms measured with the NaI(Tl) detector in 1983 ($\mu R\ h^{-1}$)

Location	Jan	May	Oct	Mean
Tylstrup	3.1	3.1	3.1	3.1
Borris	3.7	3.9	3.3	3.6
Ødum	4.5	4.6	4.7	4.6
Askov	2.9	3.2	3.6	3.2
St. Jyndevad	2.0	1.9	2.0	2.0
Blangstedgaard	4.7	4.7	4.7	4.7
Ledreborg	4.4	4.9	4.6	4.6
Tystofte	5.2	5.1	5.1	5.1
Abed	5.1	4.8	5.2	5.0
Mean	4.0	4.0	4.0	4.0

Table 8.2.3. Ionization chamber measurements of the background radiation at the State experimental farms in September 1983 ($\mu R\ h^{-1}$)

Location	September
Tylstrup	7.4
Borris	7.0
Ødum	8.5
Askov	7.3
St. Jyndevad	5.9
Blangstedgård	8.3
Ledreborg	8.2
Tystofte	8.4
Abed	8.8
Tornbygård	9.5
Mean	7.9

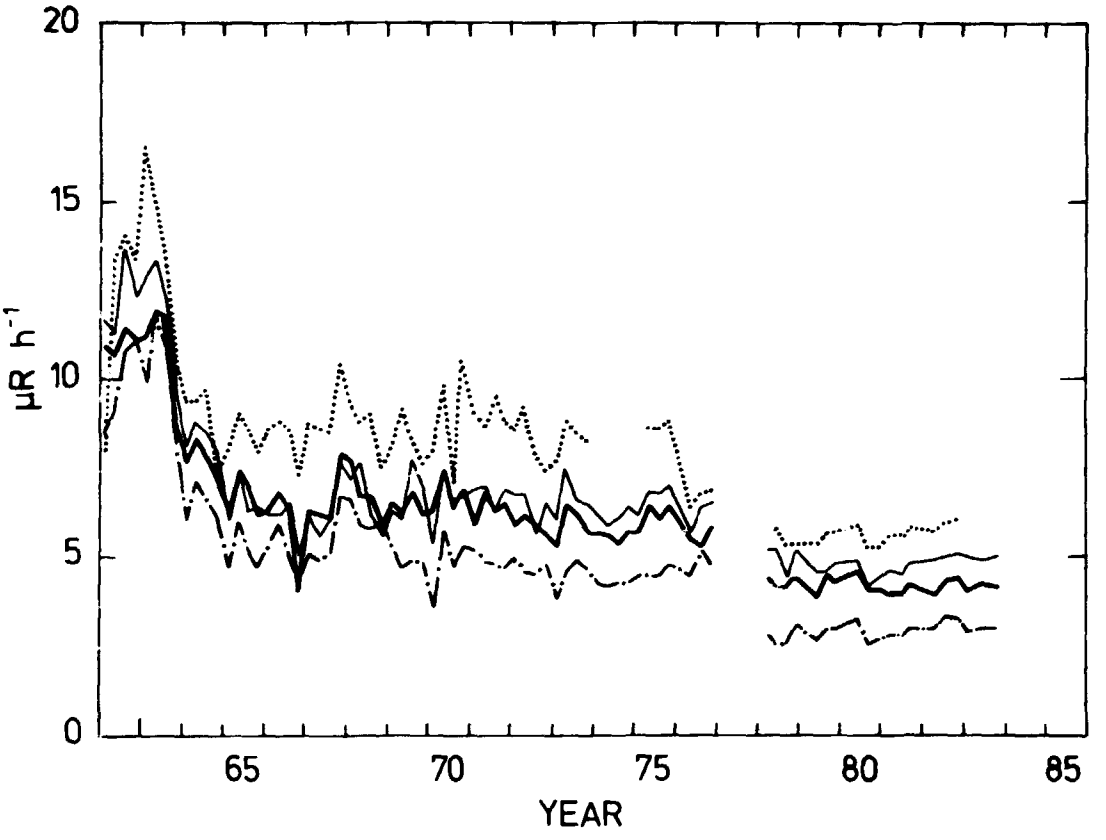

Fig. 8.2.1. Terrestrial exposure rates at the State experimental farms in 1962-1976 and 1978-1983 measured with the NaI(Tl) detector ($\mu R\ h^{-1}$).

..... Åkirkeby/Tornbygård

—— Abed, Blangstedgård, Tystofte

▬▬ Virumgård/Ledreborg, Ødum, Tylstrup

—·— Jyndevad, Askov, Studsgård/Borris

The γ-background measured with the NaI(Tl) detector in four groups of sampling stations is shown in fig. 8.2.1 from 1962 to 1983. The change of levels in 1977 is due to a modification of the instrument and of the calculational procedure[31].

The results of the ionization chamber measurements are shown in Table 8.2.3. The results of Ge(Li) spectrometer measurements are absent due to a detector malfunction.

8.3. Risø environment

The five zones around Risø are located as shown in fig. 8.3.1. The results of the TLD measurements are shown in Table 8.3.1, and the results of the NaI(Tl) detector measurements are shown in Table 8.3.2.

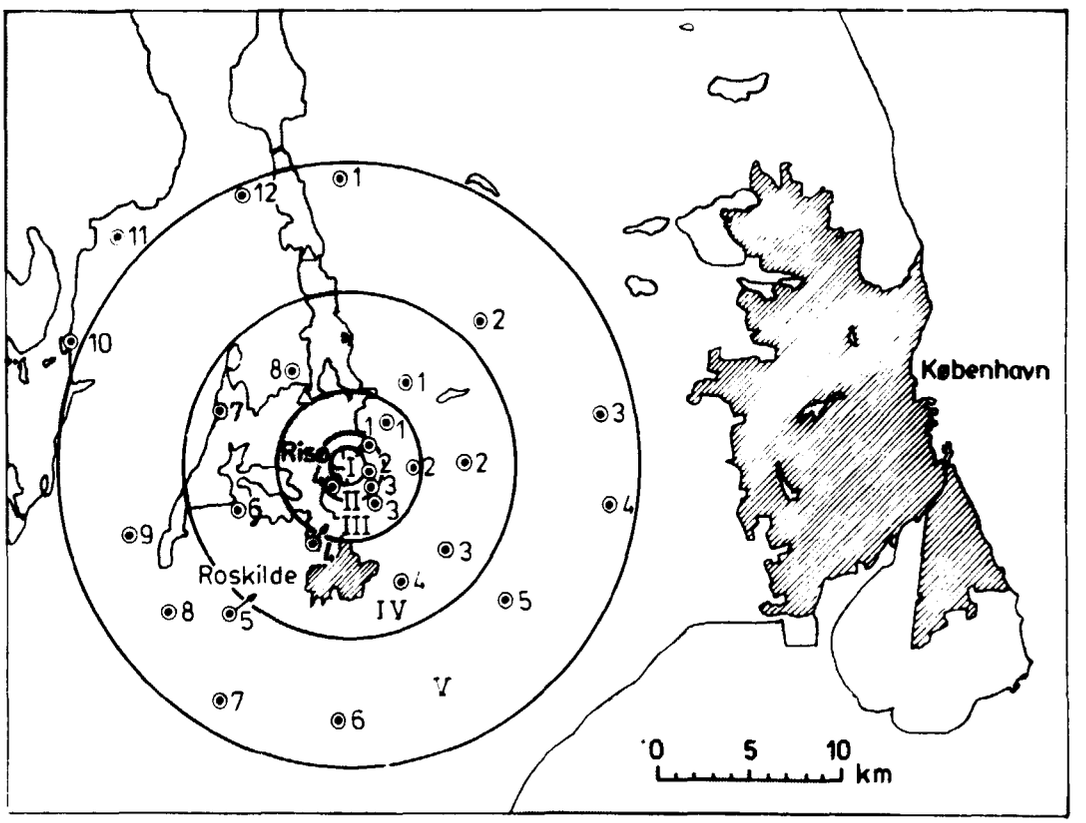

Fig. 8.3.1. The environment of Risø. Locations for measurements of the background radiation.

Table 8.3.1. TLD-measurements of the background radiation (7-month integration period and normalized to $\mu R\ h^{-1}$) in five zones (I-V) around Risø in 1983

Risø zone	Location	Feb-Sep 1983 $\mu R\ h^{-1}$
I	1	8.1
"	2	8.7
"	3	20.6
"	4	8.4
"	5	11.1
Mean		11.4
II	1	7.6
"	2	8.3
"	3	7.6
"	4	7.9
Mean		7.9
III	1	8.8
"	2	8.4
"	3	8.2
Mean		8.5
IV	1	7.3
"	2	8.3
"	3	8.1
"	4	8.6
"	5	6.9
"	6	7.8
"	7	8.9
Mean		8.0
V	1	-
"	2	8.7
"	3	8.8
"	4	7.9
"	5	8.3
"	6	8.1
"	7	8.6
"	8	7.1
"	9	8.5
"	10	7.5
Mean		8.2

Table 8.3.2. Terrestrial exposure rates at the Risø zones in 1983 measured with the NaI(Tl) detector ($\mu R\ h^{-1}$)

Risø zone	Location	January	April	July	October
I	1	5.0	5.6	7.3	5.3
"	2	6.6	6.5	7.0	6.8
"	3	60.2	59.6	65.6	67.9
"	4	5.1	5.1	5.7	5.7
"	5	9.2	9.0	10.0	9.4
Mean		17.2	17.2	19.1	19.0
II	1	4.2	4.3	4.5	4.6
"	2	5.0	4.8	5.2	5.0
"	3	4.7	5.0	4.9	5.0
"	4	4.3	4.4	4.6	4.5
Mean		4.6	4.6	4.8	4.8
III	1		5.0		4.9
"	2		4.3		4.4
"	3		4.1		4.1
Mean			4.5		4.5
IV	1		3.8		4.0
"	2		4.1		4.0
"	3		4.6		4.7
"	4		4.3		4.3
"	5		2.8		2.7
"	6		3.7		3.8
"	7		4.2		4.9
Mean			3.9		4.1
V	1		4.6		4.6
"	2		5.1		5.2
"	3		4.3		4.5
"	4		4.3		4.3
"	5		3.9		3.9
"	6		4.5		4.5
"	7		4.9		4.7
"	8		4.4		4.9
"	9		4.5		4.5
"	10		3.2		3.3
Mean			4.4		4.4

8.4. Gylling Næs environment

The Gylling Næs environment (a potential nuclear power plant site) is routinely monitored with TLD's, and the results from the site are given in Table 8.4.1. The locations are shown in Fig. 8.4.1.

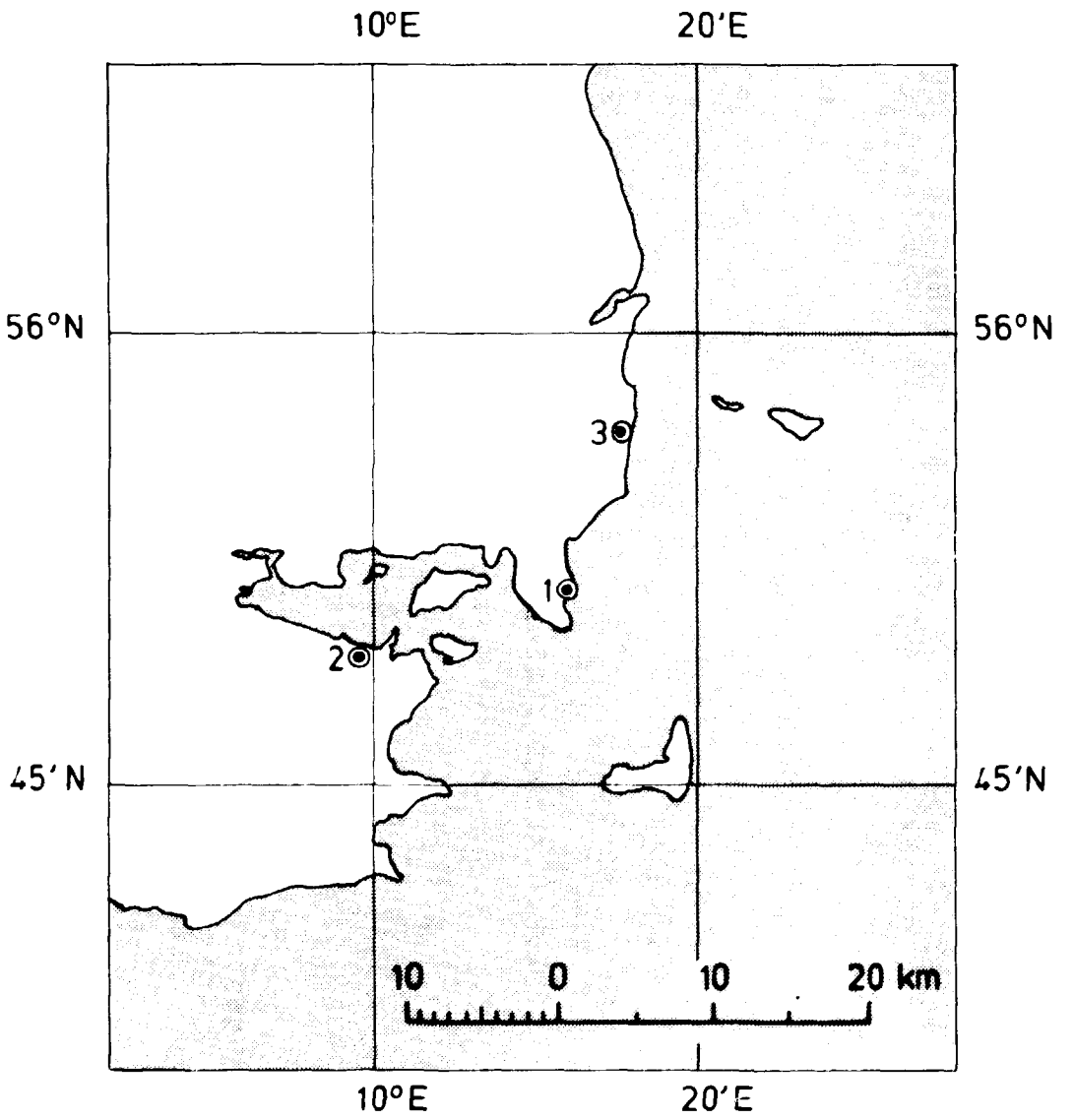

Fig. 8.4.1. The environment of Gylling Næs. Locations for measurements of the background radiation.

Table 8.4.1. TLD-measurements of the background radiation (integrated over 12 months and normalized to μR h^{-1}) around the Gyllingnæs site in 1982/83

Location	Sep 1982 - Oct 1983 μR h^{-1}
1	7.6
2	7.9
3	8.0
Mean	7.8

8.5. Great Belt and Langeland Belt areas

Locations on both shores of the Great Belt and the Langeland Belt (an international shipping route) are likewise routinely monitored with TLD's; the results and locations are shown in Table 8.5.1 and Fig. 8.5.1, respectively.

Table 8.5.1. TLD-measurements of the background radiation (integrated over 12 months and normalized to μR h^{-1}) along the coasts of the Great Belt and Langeland Belt in 1982/83

Location	Sep 1982 - Oct 1983 μR h^{-1}
Røsnæs	7.4
Reersø	8.3
Svendstrup	7.1
Vesternæs	8.5
Frederiksdal	8.4
Kelds Nor	8.8
Tranekær	8.4
Hov	-
Fyns Hoved	7.8
Knuds Hoved	8.1
Mean	8.1

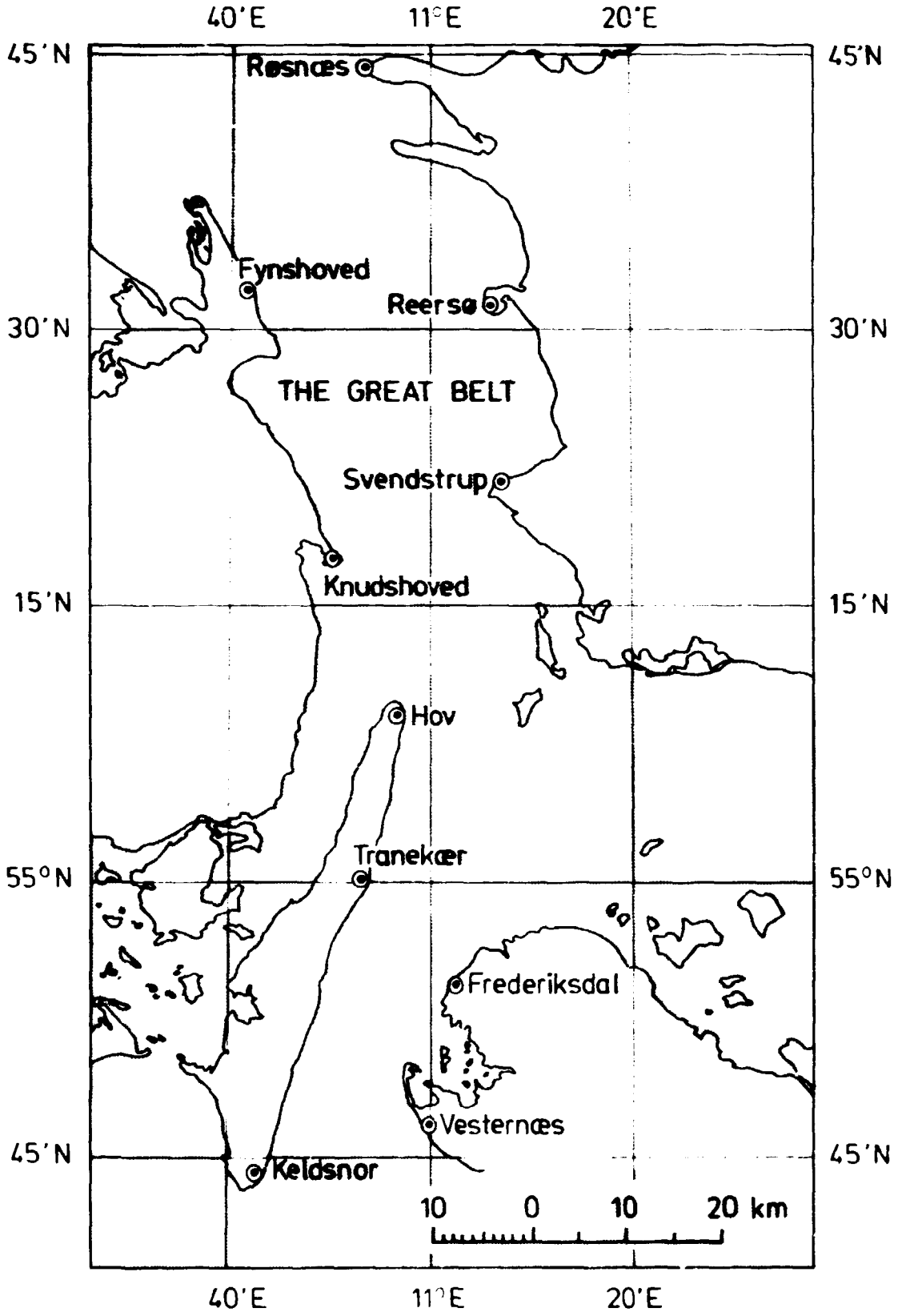

Fig. 8.5.1. The coasts of the Great Belt. Locations for measurements of the background radiation.

8.6. The Baltic island, Bornholm

Locations on the island of Bornholm have been monitored with TLD's in the period June 1982-May 1983. The results and locations are shown in Table 8.6.1 and Fig. 8.6.1, respectively.

Table 8.6.1. TLD-measurements of the background radiation (integrated over 11 months and normalized to $\mu R\ h^{-1}$) on the island Bornholm in 1982/83

Location	June 1982 - May 1983 $\mu R\ h^{-1}$
1	9.3
2	9.2
3	8.6
4	17.1
Mean	11.1

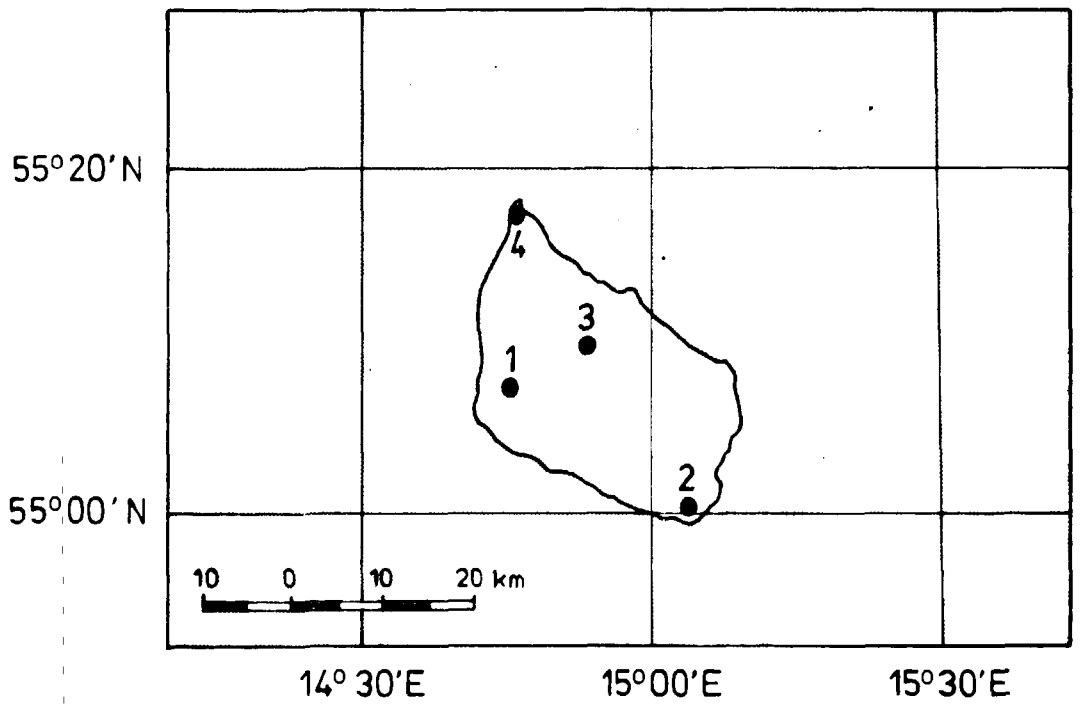

Fig. 8.6.1. Locations for measurements on Bornholm.

8.7. Discussion

The reported results are in reasonable agreement with those obtained in 1982.

9. CONCLUSION

9.1. Environmental monitoring at Risø, Barsebäck and Ringhals

No radioactive contamination of the environment originating from the operation of the National Laboratory was ascertained outside Risø in 1983.

Benthic brown algae, mussels and fish collected at the Swedish nuclear plants at Barsebäck and Ringhals were analysed for radioactive pollution. Transfer factors from releases of various radionuclides to Fucus were calculated. The radioactive contamination of the marine environment due to the operation of the Swedish nuclear power plants resulted into doses of less than 1% of the background radiation to any individual eating 20 kg mussel and 100 kg fish per year.

9.2. Nuclear-weapon debris in the abiotic environment

The mean content of ^{90}Sr in air collected in 1983 was 1.8 µBq m^{-3} (0.05 fCi ^{90}Sr m^{-3}), i.e. approximately 40% of the (corrected) 1982 level. The average fallout at the State experimental farms in 1983 was 1.6 Bq ^{90}Sr m^{-2} (0.045 mCi ^{90}Sr km^{-2}) or 80% of the 1982 figure, and the mean concentration of ^{90}Sr in rain water was 2.4 Bq ^{90}Sr m^{-3} (0.06 pCi ^{90}Sr l^{-1}).

By the end of 1983 the accumulated fallout was approximately 1640 Bq ^{90}Sr m^{-2} (44 mCi ^{90}Sr km^{-2}). The corresponding ^{137}Cs was estimated at 2620 Bq m^{-2}.

The median level of ^{90}Sr in Danish ground water was 0.09 Bq m^{-3} (2.5 fCi ^{90}Sr l^{-1}). Stream and lake water showed mean levels of 14 and 23 Bq ^{90}Sr m^{-3}, respectively.

Inner Danish surface waters (salinity ~ 16 o/oo) contained 26 Bq ^{90}Sr m^{-3} (0.7 pCi ^{90}Sr l^{-1}) and 25 Bq ^{137}Cs m^{-3} (0.7 pCi ^{137}Cs l^{-1}). This shows a decreasing contribution of ^{137}Cs from Sellafield as compared with that observed in the previous years.

9.3. Fallout nuclides in the human diet

The mean level of ^{90}Sr in Danish milk was 80 Bq (kg Ca)$^{-1}$ (2.2 S.U.), and the mean content of ^{137}Cs was approximately 76 Bq m^{-3} (2.1 pCi ^{137}Cs l^{-1}).

The 1983 ^{90}Sr and ^{137}Cs levels were 0.8 and 0.7 times respectively the levels found in milk produced in 1982.

The ^{90}Sr mean content in grain from the 1983 harvest was 0.63 Bq kg^{-1} (17 pCi ^{90}Sr kg^{-1}). The ^{137}Cs mean content in grain was 0.11 Bq kg^{-1} (2.9 pCi ^{137}Cs kg^{-1}). The ^{90}Sr level in grain from the 1983 harvest was 1.1 times the level found in the 1982 harvest, and ^{137}Cs was 0.9 times the 1982 level.

The mean contents of ^{90}Sr and ^{137}Cs in Danish vegetables collected in 1983 were 0.36 Bq ^{90}Sr kg^{-1} (9.7 pCi kg^{-1}) and 0.11 Bq ^{137}Cs kg^{-1} (3.0 pCi kg^{-1}), respectively, and in fruit 0.04 Bq ^{90}Sr kg^{-1} (1.1 pCi kg^{-1}) and 0.037 Bq ^{137}Cs kg^{-1} (1.0 pCi kg^{-1}); potatoes contained 0.066 Bq ^{90}Sr kg^{-1} (1.8 pCi kg^{-1}) and 0.048 Bq ^{137}Cs kg^{-1} (1.3 pCi kg^{-1}).

The mean levels of ^{90}Sr and ^{137}Cs in total-diet samples collected in 1983 were 128 Bq ^{90}Sr (kg Ca)$^{-1}$ (3.5 S.U.) and 64 Bq ^{137}Cs (kg K)$^{-1}$ (1.7 M.U.), respectively. From analyses of the individual diet components, the ^{90}Sr level in the Danish average diet was estimated to be 125 Bq ^{90}Sr (kg Ca)$^{-1}$ (3.4 S.U.) and the ^{137}Cs level to be 76 Bq ^{137}Cs (kg K)$^{-1}$ (2.0 M.U.). The levels of ^{90}Sr and ^{137}Cs in the Danish total diet consumed in 1983 were respectively 0.8 and 0.6 times those observed in 1982.

Grain products contributed 31% and milk products 28% to the total ^{90}Sr intake; 30% of the ^{137}Cs in the diet originated from grain products, 15% from meat, and 12% from milk products. Fish contributed with 42% to the ^{137}Cs diet intake, of this 90% were estimated to be due to radiocesium from Sellafield (Windscale).

Both ^{90}Sr and ^{137}Cs diet levels were on the average higher in Jutland than in eastern Denmark.

9.4. Strontium-90 and Cesium-137 in humans

The ^{90}Sr mean content in human bone (vertebrae) collected in 1983 was about 30 Bq $(kg\ Ca)^{-1}$ (0.8 S.U.).

Whole-body measurements of ^{137}Cs have been suspended due to the low ^{137}Cs concentrations in man. The estimated level in 1983 was 160 Bq ^{137}Cs $(kg\ K)^{-1}$ (4.3 pCi ^{137}Cs $(g\ K)^{-1}$).

9.5. Tritium in environmental samples

The tritium concentration in ground water was approximately 2.4 kBq m^{-3} in 1983. The mean content of precipitation was nearly the same.

9.6. Background radiation

The average total background exposure rate measured with TLD's at the State experimental farms was 7.2 $\mu R\ h^{-1}$. The average terrestrial background exposure rate measured with a NaI(Tl) detector at the State experimental farms was 4.0 $\mu R\ h^{-1}$. These results are a little lower than those observed in 1982.

ACKNOWLEDGEMENTS

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We are specially indebted to the staffs of the ten State experimental farms at Tylstrup, Ødum, Borris, Askov, St. Jyndevad, Blangstedgård, Tystofte, Ledreborg, Abed, and Åkirkeby, who have continued to supply us with a number of the most important samples dealt with in this report.

R/V DANA belonging to the Ministry of Fisheries have collected surface water samples from the North Sea, the Danish Straits and the Baltic Sea in 1983.

F/S Gauss and F/S Polarstern have collected marine samples from the Danish Straits, the Baltic Sea, and the North Atlantic in 1983 and we convey our thanks to these ships from the Federal Republic of Germany for their hospitality and assistance.

Appendix A. Calculated fallout in Denmark in 1983

Zone	mm precipitation in 1983	Bq ^{90}Sr m^{-2} in 1983	Accumulated Bq ^{90}Sr m^{-2} by the end of 1983
I: N. Jutland II: E. Jutland III: W. Jutland IV: S. Jutland	824 (843)	1.6	1827
V: Funen VI: Zealand VII: Lolland-Falster	609 (596)	1.3	1458
VIII: Bornholm	681 (749)	3.0	-
Area-weighted mean	759 (769)	1.5	1717

The amounts of precipitation were obtained from ref. 9. The ^{90}Sr deposition was estimated from 4.2 and appendix D.

The precipitations in brackets were the mean of values measured by the Meteorological Institute at the State experimental farms (or neighbouring locations):
Jutland: Tylstrup, Ødum, Borris, Askov, St. Jyndevad;
The Islands: Blangstedgård, Tystofte, Ledreborg, Abed;
Bornholm: Åkirkeby.

Appendix B. Statistical information

Zone		Area in km^2 15) 1971	Population in thousands 28) 1976	Annual milk production in mega-kg 14) 1971	Annual wheat production in mega-kg 13) 1972	Annual rye production in mega-kg 13) 1972	Annual potato production in mega-kg 13) 1972	Vegetable area in km^2 13) 1972
I:	N. Jutland	6,171	471	911				
II:	E. Jutland	7,561	881	1,258	145	155	609	14
III:	W. Jutland	12,104	687	926				
IV:	S. Jutland	3,929	245	572				
V:	Funen	3,486	446	393				
VI:	Zealand	7,435	2,165*	395				
VII:	Lolland-Falster	1,795	123	68	448	71	100	73
VIII:	Bornholm	588	47	39				
Total		43,069	5,065	4,562	593	226	709	87

*1,270,000 people were living in Greater Copenhagen and 895,000 in the remaining part of Zealand.

APPENDIX C

For the calculation of the ^{137}Cs levels we have assumed the $^{137}Cs/^{90}Sr$ ratio equal to 1.6 because that was the ratio used in reference 21.

Appendix C.1. Comparison between observed and predicted ^{90}Sr levels in environmental samples collected in 1983

Sample	Location	Unit	Observed	Predicted	Obs./pred.	Model in reference (21)
Dried milk*	Jutland	Bq ^{90}Sr (kg Ca)$^{-1}$	89	119	0.75	C.3.2.1 No. 1
" "	Islands	- " -	63	49	1.29	- " - No. 3
Rye	Jutland	Bq ^{90}Sr kg^{-1}	0.47	0.43	1.09	C.2.2.1 No. 1
"	Islands	- " -	0.46	0.117	3.93	- " - No. 3
Barley	Jutland	- " -	0.77	0.62	1.24	- " - No. 4
"	Islands	- " -	0.54	0.26	2.08	- " - No. 6
Wheat	Jutland	- " -	0.62	0.57	1.09	- " - No. 8
"	Islands	- " -	0.39	0.26	1.50	- " - No. 10
Oats	Jutland	- " -	1.13	1.40	0.81	- " - No. 12
"	Islands	- " -	0.67	0.65	1.03	- " - No. 13
Rye bread	Denmark	- " -	0.38	0.35	1.09	C.2.3.1 No. 1
White bread	"	- " -	0.16	0.124	1.29	- " - No. 2
Potatoes	Jutland	- " -	0.062	0.104	0.60	C.2.5.1 No. 8
"	Islands	- " -	0.070	0.094	0.75	- " - No. 10
Cabbage	Jutland	- " -	0.57	0.33	1.73	- " - No. 1
"	Islands	- " -	0.19	0.28	0.68	- " - No. 3
Carrot	Jutland	- " -	0.49	0.56	0.88	- " - No. 5
"	Islands	- " -	0.36	0.20	1.80	- " - No. 6
Apples	Denmark	- " -	0.040	0.014	2.86	C.2.5.1 No. 13
Pork*	"	- " -	0.022	0.025	0.88	C.3.4.1 No. 3
Beef*	"	- " -	0.036	0.036	1.00	- " - No. 1
Eggs	"	- " -	0.034	0.013	2.62	C.3.6.1 No. 6
Total diet C	"	Bq ^{90}Sr (kg Ca)$^{-1}$	128	151	0.84	C.4.2.1 No. 1
" " P	"	- " -	125	125	1.01	- " - No. 7
Human bone > 29 yr	"	- " -	31	41	0.76	C.4.3.1 No. 13
Whole year grass	Islands	- " -	610	480	1.27	C.2.4.1 No. 1
Fucus vesiculosus	"	- " -	295	459	0.64	C.2.7.1 No. 3
Ground water	Denmark	Bq ^{90}Sr m^{-3}	0.29	0.29	1.00	C.1.4.1 No. 1
Stream water	"	- " -	14	7	2.00	- " - No. 3
Lake water	"	- " -	23	37	0.62	- " - No. 6

*May 1983 - April 1984 ("milk year" (21)).

Appendix C.2. Comparison between observed and predicted ^{137}Cs levels in environmental samples collected in 1983

Sample	Location	Unit	Observed	Predicted	Obs./pred.	Model in reference (21)
Dried milk*	Jutland	Bq ^{137}Cs $(kg\ K)^{-1}$	66	42	1.57	C.3.2.2 No. 1
" "	Islands	- " -	29	27	1.08	- " - No. 3
Rye	Jutland	Bq ^{137}Cs kg^{-1}	0.156	0.092	1.70	C.2.2.4 No. 2
"	Islands	- " -	0.077	0.065	1.18	- " - No. 3
Barley	Jutland	- " -	0.060	0.067	0.90	- " - No. 4
"	Islands	- " -	0.035	0.044	0.80	- " - No. 5
Wheat	Jutland	- " -	0.101	0.068	1.49	- " - No. 6
"	Islands	- " -	0.034	0.037	0.92	- " - No. 7
Oats	Jutland	- " -	0.33	0.055	6.00	- " - No. 8
"	Islands	- " -	0.071	0.041	1.73	- " - No. 9
Rye bread	Denmark	- " -	0.136	0.195	0.70	C.2.3.1 No. 4
White bread	"	- " -	0.029	0.088	0.33	- " - No. 5
Potatoes	Jutland	- " -	0.084	0.127	0.66	C.2.5.3 No. 5
"	Islands	- " -	0.013	0.0088	1.51	- " - No. 7
Cabbage	Denmark	- " -	0.14	0.036	3.89	- " - No. 1
Carrot	"	- " -	0.042	0.0104	4.04	- " - No. 3
Apples	"	- " -	0.037	0.024	1.54	C.2.5.3 No. 11
Pork*	"	- " -	0.20	0.12	1.67	C.3.4.2 No. 3
Beef*	"	- " -	0.43	0.12	3.58	- " - No. 1
Eggs	"	- " -	0.033	0.023	1.43	C.3.6.2 No. 6
Total diet C	"	Bq ^{137}Cs $(kg\ K)^{-1}$	40	28	1.43	C.4.2.2 No. 1
" " P	"	- " -	47**	46	1.02	- " - No. 6

* (cf. note to Appendix C.1)

**Exclusive contribution of ^{137}Cs from Sellafield. (38% Sellafield, 62% fallout)

APPENDIX D

d_i:

Annual fallout rate in mCi ^{90}Sr km^{-2} y^{-1}.

Accumulated fallout by the end of the year (i) assuming effective half-lives of ^{90}Sr of 27.7 y. Unit: mCi ^{90}Sr km^{-2}.

$d_{i(May-Aug)}$ and $d_{i(July-Aug)}$:

The fallout rates in the periods: May-Aug and July-Aug, respectively. Unit: mCi ^{90}Sr km^{-2} $period^{-1}$.

The fallout rate (d_i) was based on precipitation data collected for all Denmark in the period 1962-1983 (cf. Table 4.2.1[1]). Before 1962 the levels in the tables were estimated from the HASL data for New York (HASL Appendix 291, 1975)[29] considering that the mean ratio between ^{90}Sr fallout in Denmark and New York was 0.7 in the period 1962-1974.

The $d_{i(May-Aug)}$ and $d_{i(July-Aug)}$ values were also obtained from Table 4.2.1[1] for the period 1962-1983. For the years 1959-1961 the values were calculated from data obtained from ^{90}Sr analysis of air (1959) and precipitation samples (1962 and 1961) collected at Risø. Before 1959, the values were estimated from the corresponding d_i values assuming that the ratios $d_{i(May-Aug)}/d_i$ and $d_{i(July-Aug)}/d_i$ were constant in time and equal to the means found for the period 1962-1974, which were 0.54 (1 S.D.: 0.09) and 0.24 (1 S.D.: 0.06), respectively.

Appendix D. Fallout rates and accumulated fallout (mCi ^{90}Sr km^{-2}) in Denmark 1950-1983

	Denmark		Jutland		Islands	
	di	$Ai_{(27.7)}$	di	$Ai_{(27.7)}$	di	$Ai_{(27.7)}$
1950	0.021	0.020	0.022	0.021	0.020	0.020
1951	0.101	0.118	0.114	0.132	0.088	0.105
1952	0.198	0.309	0.224	0.347	0.172	0.270
1953	0.500	0.789	0.566	0.891	0.436	0.687
1954	1.901	2.623	2.152	2.967	1.650	2.279
1955	2.501	4.997	2.831	5.655	2.171	4.340
1956	3.101	7.898	3.510	8.939	2.692	6.858
1957	3.101	10.728	3.510	12.142	2.692	9.313
1958	4.302	14.658	4.869	16.591	3.734	12.725
1959	6.102	20.247	6.908	22.918	5.297	17.576
1960	1.140	20.859	1.291	23.610	0.990	18.107
1961	1.481	21.787	1.676	24.661	1.285	18.913
1962	7.428	28.493	7.976	31.830	6.880	25.155
1963	16.695	44.071	18.453	49.041	14.937	39.101
1964	10.412	53.136	11.605	59.225	9.139	47.048
1965	3.954	55.679	4.204	61.861	3.704	49.497
1966	2.145	56.395	2.166	62.445	2.124	50.345
1967	1.047	56.023	1.176	62.048	0.918	49.997
1968	1.403	56.006	1.568	62.045	1.237	49.968
1969	1.035	55.632	1.241	61.721	0.829	49.542
1970	1.647	55.863	1.993	62.140	1.301	49.586
1971	1.506	55.951	1.726	62.288	1.286	49.615
1972	0.435	54.993	0.457	61.194	0.413	48.792
1973	0.192	53.821	0.215	59.891	0.168	47.750
1974	0.710	53.183	0.779	59.171	0.643	47.197
1975	0.414	52.272	0.452	58.150	0.376	46.397
1976	0.103	51.082	0.116	56.826	0.090	45.339
1977	0.384	50.204	0.405	55.827	0.362	44.581
1978	0.463	49.426	0.538	54.985	0.388	43.867
1979	0.166	48.379	0.174	53.810	0.156	42.947
1980	0.116	47.307	0.140	52.628	0.095	41.988
1981	0.353	46.482	0.379	51.697	0.330	41.272
1982	0.056	45.380	0.059	50.477	0.053	40.304
1983	0.0445	44.271	0.044	49.272	0.045	39.352

Denmark		Jutland		Islands	
$di_{(May-Aug)}$	$di_{(July-Aug)}$	$di_{(May-Aug)}$	$di_{(July-Aug)}$	$di_{(May-Aug)}$	$di_{(July-Aug)}$
0.01	0.01	0.01	0.01	0.01	0.01
0.05	0.02	0.06	0.03	0.05	0.02
0.11	0.05	0.12	0.05	0.09	0.04
0.27	0.12	0.31	0.14	0.23	0.10
1.03	0.46	1.16	0.52	0.89	0.40
1.35	0.60	1.53	0.68	1.17	0.52
1.67	0.74	1.90	0.84	1.45	0.65
1.67	0.74	1.90	0.84	1.45	0.65
2.32	1.03	2.63	1.17	2.02	0.90
2.50	0.68	2.76	0.75	2.24	0.61
0.47	0.31	0.52	0.34	0.42	0.28
0.66	0.47	0.73	0.52	0.59	0.42
4.223	1.857	4.566	2.052	3.880	1.662
9.965	5.629	10.753	5.932	9.177	5.327
6.235	2.568	7.170	2.910	5.299	2.226
2.029	0.850	2.094	0.852	1.964	0.848
1.049	0.418	0.984	0.496	1.114	0.340
0.367	0.141	0.380	0.134	0.354	0.148
0.848	0.426	0.910	0.460	0.786	0.392
0.614	0.276	0.723	0.319	0.505	0.233
0.908	0.547	1.076	0.632	0.740	0.462
0.992	0.405	1.154	0.516	0.830	0.294
0.253	0.084	0.262	0.084	0.244	0.084
0.075	0.033	0.093	0.039	0.057	0.027
0.421	0.190	0.463	0.219	0.378	0.162
0.159	0.075	0.179	0.091	0.157	0.060
0.032	0.010	0.032	0.011	0.032	0.009
0.178	0.107	0.164	0.085	0.190	0.129
0.232	0.096	0.275	0.098	0.188	0.093
0.086	0.030	0.087	0.031	0.084	0.029
0.063	0.027	0.079	0.031	0.047	0.022
0.214	0.073	0.215	0.071	0.213	0.075
0.027	0.0087	0.029	0.0104	0.025	0.0071
0.016	0.0059	0.018	0.0067	0.014	0.0053

REFERENCES

1) Risø Reports Nos. 1, 3, 9, 14, 23, 41, 63, 85, 107, 130, 154, 180, 201, 220, 245, 265, 291, 305, 323, 345, 361, 386, 403, 421, 447, 469 and 487 (1957-83).
2) R.G. Osmond, M.J. Owers, C. Healy, and A.P. Mead, The Determination of Radioactivity due to Caesium, Strontium, Barium and Cerium in Waters and Filters. AERE-R 2899 (1959).
3) F.J. Bryant, A. Morgan, and G.S. Spicer, The Determination of Radiostrontium in Biological Materials. AERE-R 3030 (1959).
4) John H. Harley, Manual of Standard Procedures. HASL-300 (1972).
5) A. Hald, private communication (1958).
6) J. Lippert, Low Level Counting. Risø Report No. 44 (1963).
7) P. Quittner, Nucl. Instr. and Methods 76, 115-124 (1969).
8) J. Lippert, Some Applications for Semiconductor Detectors in Health Physics. Proc. of the First International Congress of Radiation Protection, 271-277 (Pergamon Press, 1968).
9) Meteorologisk Institut, Ugeberetning om nedbør m.m. 1982.
10) S. Boelskifte, The application of Fucus vesiculosus as a bioindicator of ^{60}Co concentrations in the Danish Straits. Accepted for publication in Journal of Environmental Radioactivity.
11) Folmer Dam and Agnes Elgström, Vore fødemidler (Svegårds Forlag, Sorø, 1968).
12) J. Vestergaard, Analysis of Variance with Unequal Numbers in Group. GIER System Library No. 211 (A/S Regnecentralen, Copenhagen, 1964).
13) Landbrugsstatistik 1975. Danmarks Statistik (Copenhagen, 1977).
14) Fortegnelse over samtlige mejerier og mejeriorganisationer i Danmark (Århus, 1972).
15) Statistisk årbog 1972 (Statistical Yearbook) (Copenhagen, 1972).

16) J. Lippert, Statdata, Risø-M-1780, June 1975.

17) A.Aarkrog, H. Dahlgaard and S. Boelskifte, Transfer of Radiocesium and ^{90}Sr from Sellafield to the Danish Straits. To be published in a TEC-DOC from IAEA under a cooperative programme on the Study of radioactive materials in the Baltic Sea.

21) A. Aarkrog, Environmental Studies on Radioecological Sensitivity and Variability with Special Emphasis on the Fallout Nuclides ^{90}Sr and ^{137}Cs. Risø-R-437 (June 1979).

24) S.P. Nielsen, In situ measurements of environmental gamma radiation using a mobile Ge(Li) spectrometer system. Risø Report No. 367 (1977).

25) UNSCEAR. United Nations Scientific Committee on the Effects of Atomic Radiation. Ionizing Radiation: Sources and biological effects. (New York) 773 pp. (1982).

28) Statistisk årbog 1977 (Statistical yearbook) (Copenhagen 1978).

31) S.P. Nielsen and L. Bøtter-Jensen, Intercomparison of Instruments for Measurements of Background Radiation, Risø-M-2239 (1981).

32) Henning Dahlgaard, Bioindicators for monitoring radioactive pollution of the marine environment. Risø-R-443 (1981).

36) Sydkraft: Månadsrapport, and Vattenfall: Rapport över luft- och vätskeburna utsläpp, ... Ringhals. (Monthly reports to the Swedish authorities on discharges from Barsebäck and Ringhals, respectively) (in Swedish).

37) R.S. Cambray, Annual Discharges of Certain Long-lived Radionuclides to the Sea and to the Atmosphere from the Sellafield Works, Cumbria 1957-1981. AERE-M 3269 (1982).