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Environmental Radioactivity in Denmark in 1987

Aarkrog, Asker; Bøtter-Jensen, L.; Chen, Q.J.; Dahlgaard, H.; Hansen, H.; Holm, E.; Lauridsen, B.; Nielsen, Sven Poul; Søgaard-Hansen, J.

Publication date:
1989

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

Link back to DTU Orbit

Citation (APA):
Aarkrog, A., Bøtter-Jensen, L., Chen, Q. J., Dahlgaard, H., Hansen, H., Holm, E., ... Søgaard-Hansen, J. (1989). Environmental Radioactivity in Denmark in 1987. (Denmark. Forskningscenter Risoe. Risoe-R; No. 563).

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Risø-R-563

Environmental Radioactivity in Denmark in 1987

A. Aarkrog, L. Bøtter Jensen, Chen Qing Jiang, H. Dahlgaard, Heinz Hansen, Elis Holm+, Bente Lauridsen, S.P. Nielsen and J. Søgaard-Hansen

+International Laboratory for Marine Radioactivity, Monaco

Risø National Laboratory, DK-4000 Roskilde, Denmark
May 1989

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Risø-R-563

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Abstract. Strontium-90, radiocesium, and other radionuclides were determined in samples from all over the country of air, precipitation, stream water, lake water, ground water, drinking water, sea water, soil, sediments, dried milk, fresh milk, meat, fish, cheese, eggs, grain, bread, potatoes, vegetables, fruit, grass, moss, lichen, sea plants, total diet, and humans. Estimates are given of the mean contents of radiostrontium and radiocesium in the human diet in Denmark during 1987. Tritium was determined in precipitation, ground water, other fresh waters, and sea water. 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).

The expanded programme initiated after the Cernobyl accident in 1986 was carried on in 1987 with minor reductions.

ISBN 87-550-1532-8
ISSN 0106-2840
ISSN 0106-407X

Grafisk Service 1989

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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} (= 2.7 pCi)

cal: calorie = 4.186 J
rad: 0.01 Gy
rem: 0.01 Sv
Ci: curie: 3.7×10^{10} Bq (= 2.22×10^{12} dpm)

E: exa: 10^{18}
P: peta: 10^{15}
T: tera: 10^{12}
G: giga: 10^{9}
M: mega: 10^{6}
k: kilo: 10^{3}
m: milli: 10^{-3}
μ: micro: 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.

yr^{-1}: per year (a^{-1})
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 (~0.96 dpm = 0.016 Bq; 1 g K = 30.65 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 of the variance in question to 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 devition >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 thirty-first 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 the report of last year. 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, various vegetation and human tissues. Chapter seven is devoted to a general discussion of environmental tritium studies. External radiation is treated in chapter eight. The names of the authors of each chapter appear at its head.

Although the programmes were expanded substantially after the Chernobyl accident in Ukraine in April 1986, we have not found it necessary to change the organization of the material.

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 1987 and July-December 1987, which are available from Risø Library.

1.4.

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

1.5.

In 1987 the personnel of the Environmental Control Section of the Health Physics Department consisted of three chemists (incl. one guest scientist), one biologist, one physicist, ten laboratory technicians, three sample collectors, and two laboratory assistants. The group for Electronics Development and Maintenance gave assistance with the maintenance of counting equipment.

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 samples are measured as follows:

Alpha (^{239}Pu, ^{241}Am): 22 solid-state surface barrier detectors connected to multichannel analyzers (512 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 used.

Gamma (natural and fallout isotopes): A total of 10 germanium detectors in 10 cm lead shields are used for gamma spectrometric measurements. 5 detectors are connected to hard-wired multichannel analyzers and 5 to MCA-cards in a personal computer. The efficiencies of the detectors are in the range 12-40% relative to a 3" × 3" NaI(Tl) detector. An 8" × 4" NaI(Tl) detector and a detector unit with three 4" × 4" × 16" NaI(Tl) crystals are used in an underground shielded room for gamma-spectrometric whole-body measurements.

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 95 000 sets of results have been registered covering the period from 1957.

3. Environmental Monitoring at Risø, Barsebäck, and Ringhals

by H. Dahlgaard

3.1. Environmental Monitoring at Risø

From the two semiannual reports: Radioactivity in the Risø district January-June 1987 and July-December 1987 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.

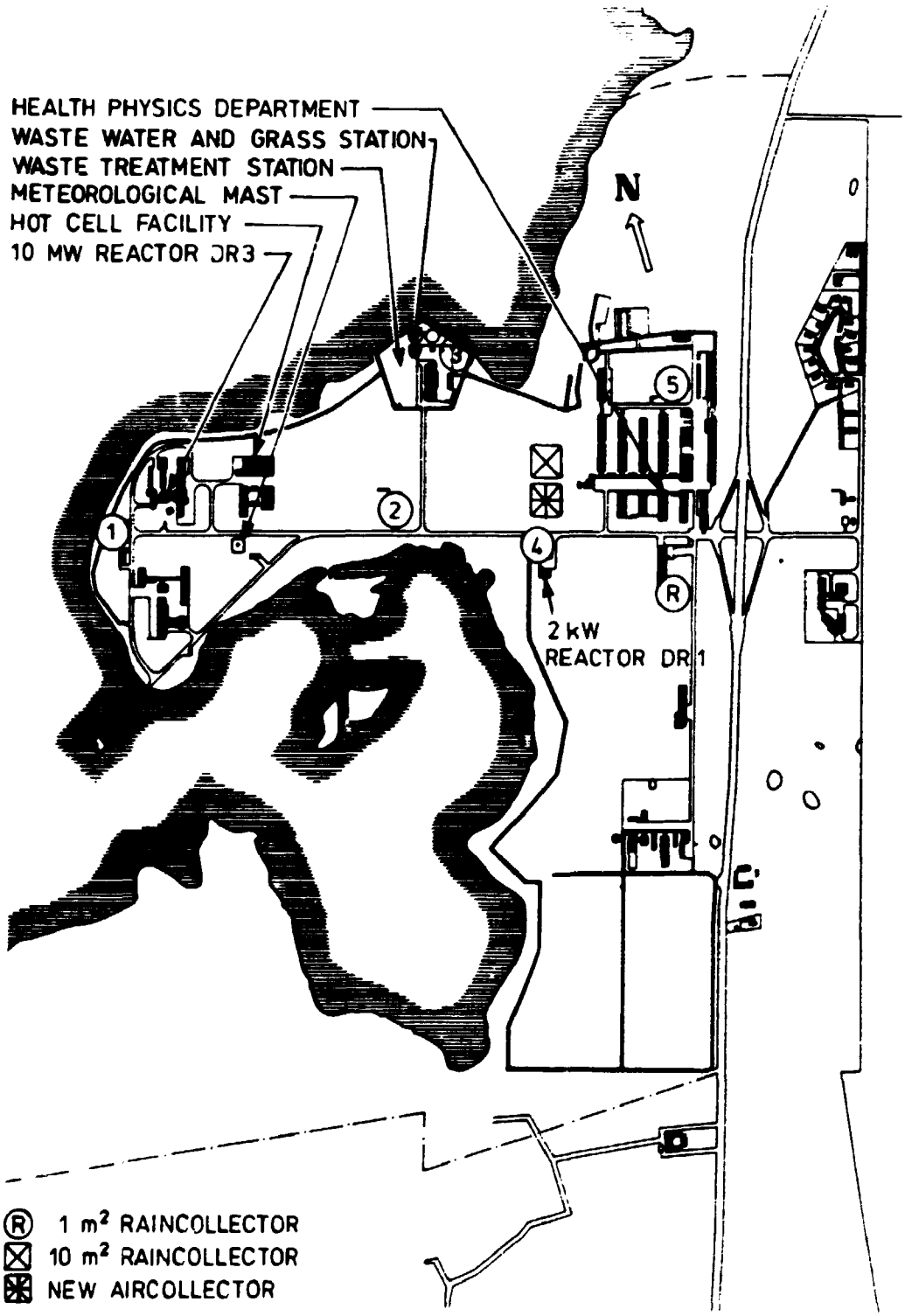


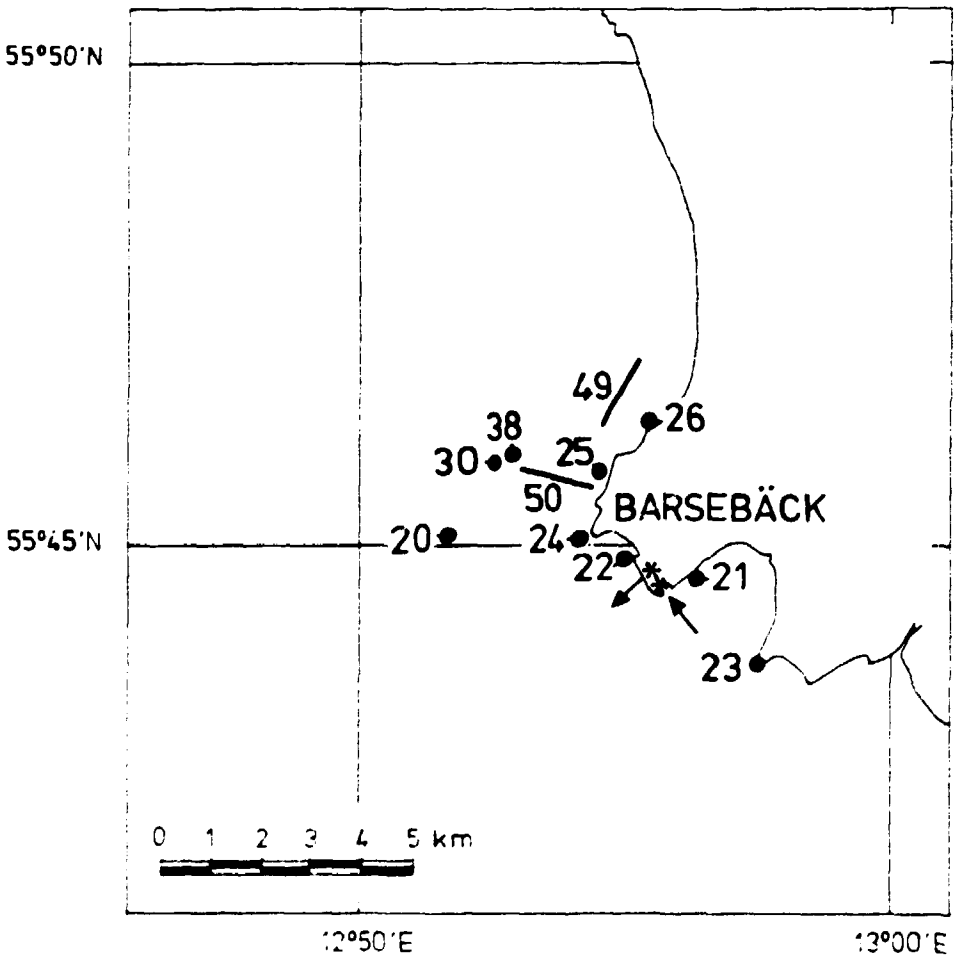
Fig. 3.1.1. Sampling locations at Risø National Laboratory. 1-5: locations for rain bottles (0.03 m² each), ion-exchange columns (0.06 m² each), and grass samples.

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 1987.

Figures 3.2.1.1 and 3.2.1.2 show the sampling locations.

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



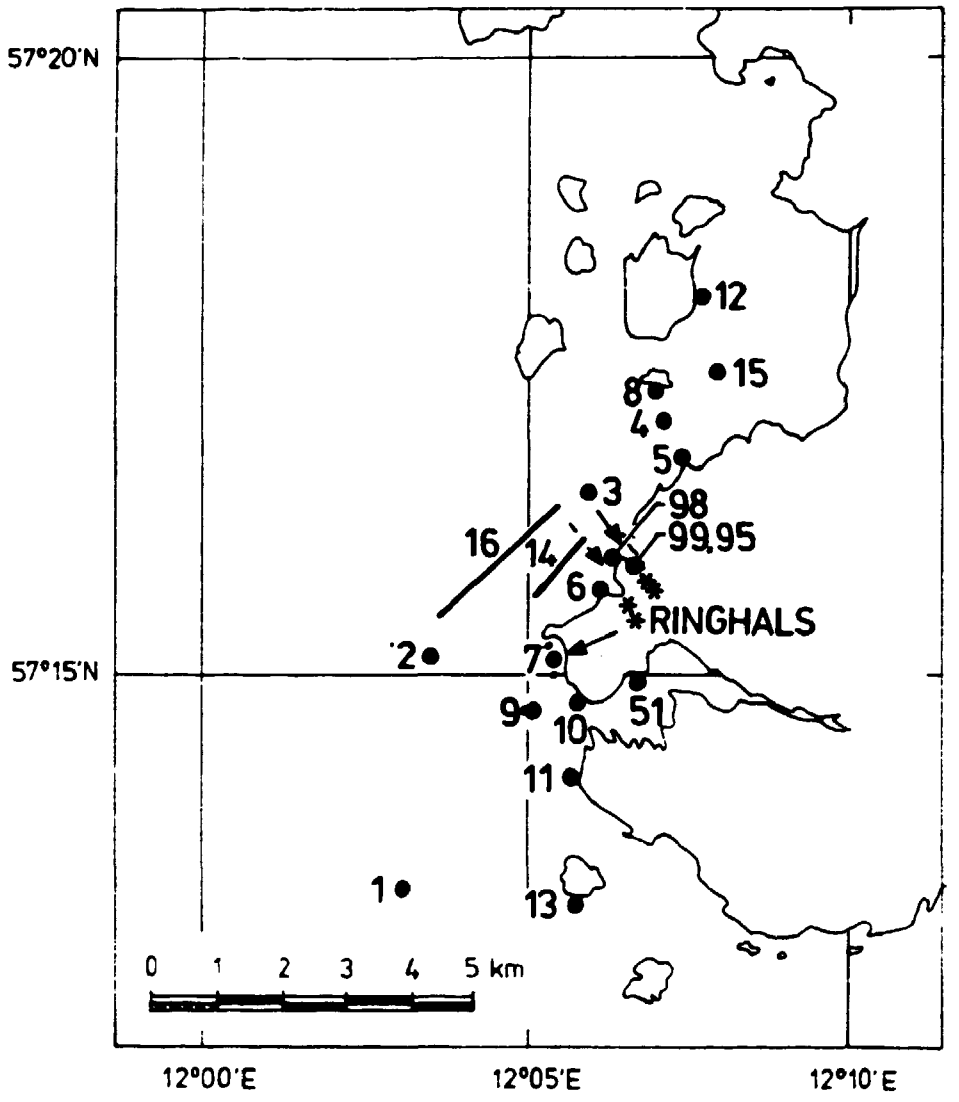


Fig. 3.2.1.2. Sampling locations at Ringhals. 14 and 16 indicate fishing tracks. Arrows indicate cooling water intake and outlet.

3.2.1. γ-Emitting Radionuclides in Brown Algae

Tables 3.2.1.1 and 3.2.1.2 show the radionuclide concentrations found by γ-spectrometric analysis in brown algae sampled near Ringhals in 1987. Monthly data on radionuclides in seaweed from Barsebäck and Ringhald are reported from the experimental programme in Chapter 3.2.5. The data are expressed on the basis of dry weight. Dry matter contents are given.

Table 3.2.1.3 shows a comparison of the 3 fucoids Fucus vesiculosus, Fucus serratus, and Ascophyllum nodosum. The levels of significance of differences from unity are indicated.

Table 3.2.1.1. Radionuclides in Fucus vesiculosus (Fu.ve.) and Fucus serratus (Fu.se.) collected at Ringhals 12-13 May 1987. (Unit: Bq kg^{-1} dry matter)

Station No.**	7	5	9*
% drv matter	20.7	22.6	22.2
Species	Fu.ve.	Fu.se.	Fu.se.
Distance from outlet in km	0.2	4.1	1.1
^{54}Mn	11.2		5.6
^{57}Co	0.4 B		
^{58}Co	36		28
^{60}Co	183	61	138
^{106}Ru	16 A		
^{110m}Ag	14.3		6.0 A
^{134}Cs	4.1	4.3	5.5
^{137}Cs	14.9	17.3	19.5

* Locations south of the outlet; the other locations were situated north of the outlet.
**Cf. Fig. 3.2.1.2.

Table 3.2.1.2. Radionuclides in Fucus vesiculosus (Fu.ve.) and Fucus serratus (Fu.se.) collected at Ringhals 15-16 December 1987 (Unit: Bq kg^{-1} dry matter)

Station No.**	7	7	6	6	5	8	9*	13*
% dry matter	24.6	21.9	18.5	18.8	20.2	20.8	32.0	18.2
Species	Fu.ve.	Fu.se.	Fu.ve.	Fu.se.	Fu.se.	Fu.ve.	Fu.se.	Fu.ve.
Distance from outlet in km	0.2	0.2	1.9	1.9	4.1	4.8	1.1	4.1
^{54}Mn	53	37	2.8	3.8	3.4	2.3	16.1	4.6
^{57}Co	2.7	3.0					1.18	0.60 A
^{58}Co	330	330	48	50	30	21	162	58
^{60}Co	800	750	95	94	52	34	230	50
^{65}Zn	130	131	16.7	14.5	5.7	4.0 A	34	6.6
^{110m}Ag	12.6	16.1	3.7 A	3.5 B	2.7	2.8 A	21	4.9
^{134}Cs	3.8 A	3.8 A	2.5	3.2	2.6	3.1	2.9	1.3 B
^{137}Cs	12.1	22	12.2	14.6	13.9	13.4	12.2	12.3

* 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. 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 1978-1987

Isotope	Fu.ve/Fu.se.			Fu.ve/As.no.		
^{60}Co	0.82***	±0.045	(n=32)	1.3*	±0.13	(n=17)
^{58}Co	0.83***	±0.038	(n=31)	2.4***	±0.27	(n=15)
^{54}Mn	0.99	±0.066	(n=27)	3.5***	±0.33	(n=8)
^{65}Zn	0.82***	±0.056	(n=27)	1.2	±0.17	(n=16)
^{110m}Ag	1.46**	±0.149	(n=20)	1.2	±0.18	(n=11)
^{137}Cs	1.02	±0.035	(n=31)	1.4***	±0.05	(n=15)
^{131}I	0.94		(n=1)	1.2		(n=1)
^{95}Zr	0.89		(n=1)			
^{124}Sb	0.70		(n=1)	1.3		(n=1)
^{57}Co	0.90		(n=1)	0.8		(n=1)
^{134}Cs	0.99	±0.054	(n=7)	1.5	±0.04	(n=2)
^{103}Ru	1.29	±0.249	(n=5)	2.5	±1.17	(n=2)
^{106}Ru	1.25	±0.261	(n=5)	2.3	±0.38	(n=2)
^{144}Ce	0.47		(n=1)			

The error term was 1 S.E.

3.2.2. γ-Emitting Radionuclides in Benthic Invertebrates and Fish

Table 3.2.2.1 shows results of the γ-countings on benthic animals and fish from Ringhals and Barsebäck in 1987. The dose commitment to a hypothetical critical individual consuming 20 kg Mytilus edulis soft parts (fresh weight) yearly would be approximately 18 μSv yr^{-1} based on mussels from Barsebäck, Table 3.2.2.1. This is < 1% of the background radiation dose (≈ 2 mSv yr^{-1}). The Barsebäck mussels are not normally consumed.

Consumption of 100 kg dab meat would give approximately 5 μSv from radiocesium based on data in Table 3.2.2.1. The cesium isotopes do not originate from the two power plants.

Table 3.2.2.1. Gamma-emitting radionuclides in benthic animals and fish collected at Ringhals and Barsebäck in 1987. (Unit: Bq kg^{-1} fresh)

Species	Dab	Dab	Dab	Mytilus edulis soft part	Mytilus edulis soft part
Date	266	1612	135	410	311
Location	Barsebäck	Ringhals	Ringhals	Barsebäck	Barsebäck
Station No.*	30	8	14	25	25
% dry matter	-	-	-	9.2	8.2
Depth in m	12-20	13	32	0.1	0.1
^{54}Mn				5.6	2.6 A
^{60}Co				111	95
^{65}Zn				9.4 A	9.1 A
^{134}Cs	0.83	0.79	0.56		2.7 A
^{137}Cs	3.37	3.41	2.93	7.2	9.0

*Cf. Figs. 3.2.1.1 and 3.2.1.2.

3.2.4. γ-Emitting Radionuclides in Sea Sediments

Results from sediment samples collected at Ringhals with the HAPS bottom corer are shown in Table 3.2.4.2. The sediment sampling at Barsebäck failed in 1987.

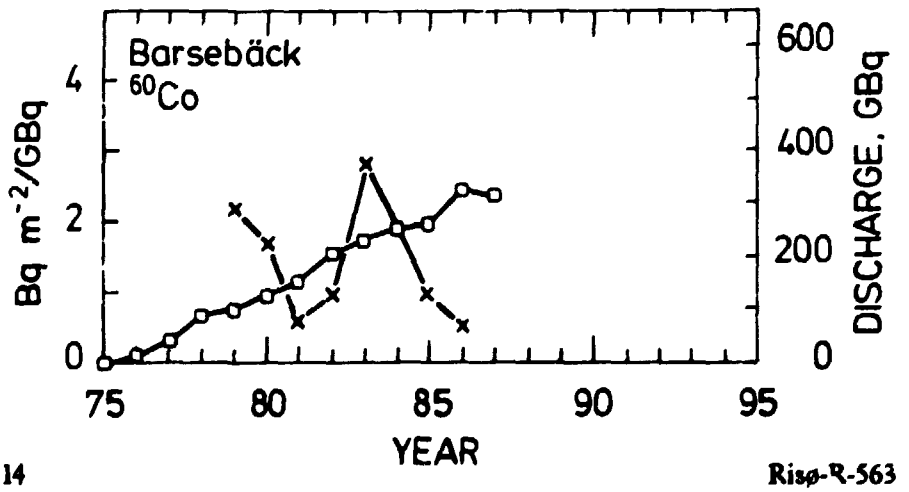
At both power plants the ^{60}Co that has been detectable in the sediments for several years has been compared with the reported annual discharges from Tables 3.2.5.2 and 3.2.5.10. The total amount of ^{60}Co accumulated in the sediments at Ringhals location 2 and Barsebäck location 38 expressed as Bq m^{-2} has been divided for each year with the total amount of ^{60}Co discharged from each power plant (GBq, decay corrected) summed up till the year of sampling. The result is a transfer factor from the total accumulated discharge to one square meter of sediment at the specified location, i.e. Bq m^{-2}/GBq or $m^{-2} \times 10^{-9}$.

These sediment transfer factors are shown in Figs. 3.2.4.1 and 3.2.4.2. A stable transfer factor would indicate that the deposited ^{60}Co remains in the sediment, whereas a significant leaking of sedimented ^{60}Co would be seen as a decreasing transfer factor. It is seen that the variation in the measured ^{60}Co deposition at the two sediment sampling locations is too large to see any tendency in the results. From the present material it cannot be judged whether this is due to inhomogeneity within the sampling locations or reflects actual variations in ^{60}Co loads in the sediments.

Table 3.2.4.2. Gamma-emitting radionuclides in sediment samples collected at Ringhals, 57°15'N 12°04'E, location 2, in 1987. (Area: 0.0145 m^2)

Date	Layer in cm	^{60}Co Bq kg^{-1} dry	^{60}Co Bq m^{-2}	^{106}Ru Bq kg^{-1} dry	^{106}Ru Bq m^{-2}	^{125}Sb Bq kg^{-1} dry	^{125}Sb Bq m^{-2}	^{134}Cs Bq kg^{-1} dry	^{134}Cs Bq m^{-2}	^{137}Cs Bq kg^{-1} dry	^{137}Cs Bq m^{-2}
1/5	0-3	16.3	330	22 A	440 A	-	-	4.0	81	24	490
	3-6	23.0	600	-	-	4.5 A	120 A	1.3 A	34 A	21	560
	6-9	7.9	180	-	-	-	-	-	-	14.5	330
	9-12	2.8	56	-	-	-	-	-	-	9.4	188
	0-12		Σ 1170		Σ 440		Σ 120		Σ 115		Σ 1570

Fig. 3.2.4.1 Total accumulated discharge of ^{60}Co (GBq, decay-corrected) from Barsebäck (□), and transfer factor to one square meter of sediment c: location 38 (×) calculated as Bq m^{-2}/GBq.



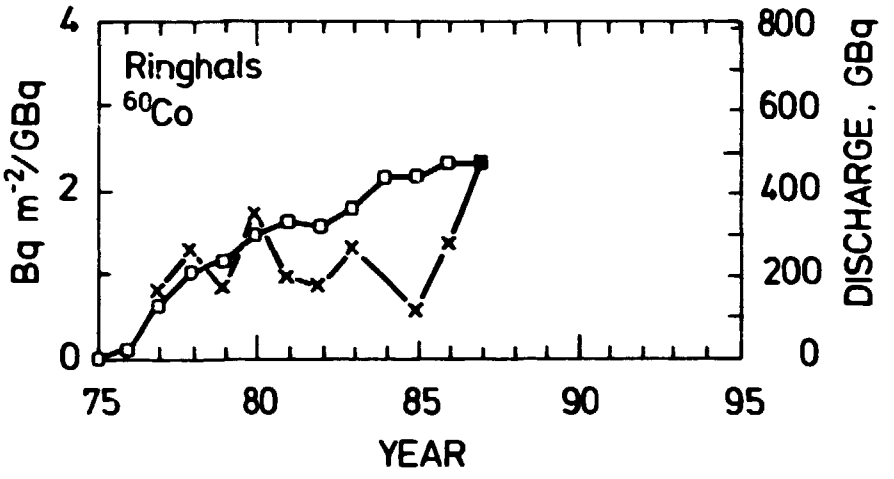


Fig. 3.2.4.2. Total accumulated discharge of ^{60}Co (GBq, decay-corrected) from Ringhals (□) and transfer factor to one square meter of sediment at location 2 (×) calculated as Bq m^{-2}/GBq.

3.2.5. Field Experiments at Ringhals, Barsebäck, and Forsmark

The time-integrated water samplings at Forsmark were stopped May 1987. At Barsebäck and Ringhals, the monthly sampling programme had again 3 parts: 1) Local Fucus vesiculosus plants and at Ringhals also Fucus serratus; 2) uncontaminated Fucus vesiculosus transplanted to the contaminated areas one month prior to sampling; and 3) contaminated plant transplanted to an uncontaminated area, where they should be sampled monthly for 6 months. The transplantations to and from the power plants were brought to an end during 1987, whereas the monthly sampling of the "native" plants is planned to continue. The overall idea of this programme was to gather data to support a model that especially describes seasonal variation in bioindicator response.

Ringhals Results

Tables 3.2.5.1-3.2.5.8 give the Ringhals data. The concentrations of anthropogenic gamma emitters in Fucus outside the northern cooling water intake channel was as found earlier lower than in Fucus sampled in the channel even if the last site is 200 m further away from the power plant. Table 3.2.5.5 gives annual average values for the ratio.

The ratios seem to group in two: ^{40}K and ^{65}Zn, which do not show different values, and the rest showing higher levels in the channel. Also the radionuclides that do not originate from Ringhals show highest concentrations in the channel. These are the Chernobyl radionuclides and the short-lived cosmic nuclide ^{7}Be. Furthermore, radiocesium has higher values in the channel both before and after Chernobyl even if its physiological analog ^{40}K gives equal values.

These observations makes the explanation less plausible that the difference could be caused by intake of another water mass with a higher concentration of power plant discharges in the cooling water channel.

Thus, the reason for the higher concentration inside the channel compared with that outside can only be speculated upon. One suggestion could be that the constant high water flow through the channel exposes the surface of the Fucus plants to a higher total amount of radionuclides, even if the concentration in the water is not higher. If this were the case, it implies that the uptake of radionuclides under normal "calm" circumstances is limited by the exchange of water through the seaweed "blanket"; i.e. the average concentration in the microlayer in close contact with the seaweed surface will be depleted for metals and radionuclides. If this were the case, local differences in water exchange and seaweed population densities should be considered as parameters causing variation in bioindicator response. This speculative suggestion could be followed up by laboratory experiments. It is hard to understand, however, why ^{65}Zn did not react like the other nuclides. Another explanation could be that the growth conditions in the channel may be less favorable, thus showing less growth dilution of earlier accumulated material.

Table 3.2.5.1. Reported monthly liquid discharges from Ringhals in 1987, reference 36. (Unit: Bq month^{-1})

Isotop	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
^{51}Cr	1.1×10^{8}	8.4×10^{5}	2.8×10^{8}	3.5×10^{9}	4.5×10^{8}	6.6×10^{8}	2.1×10^{8}	9.6×10^{8}	1.1×10^{9}	6.6×10^{8}	1.7×10^{9}	3.0×10^{9}
^{54}Mn	3.1×10^{8}	6.1×10^{7}	3.1×10^{8}	4.8×10^{8}	2.4×10^{8}	6.9×10^{8}	2.0×10^{8}	8.1×10^{8}	5.2×10^{8}	2.7×10^{8}	1.9×10^{8}	1.4×10^{8}
^{57}Co	1.8×10^{7}	2.2×10^{6}	2.2×10^{7}	3.1×10^{7}	8.2×10^{6}	6.3×10^{7}	1.7×10^{7}	5.2×10^{7}	2.9×10^{8}	1.7×10^{7}	3.2×10^{7}	6.7×10^{6}
^{58}Co	1.2×10^{9}	2.6×10^{8}	1.8×10^{9}	6.7×10^{9}	4.1×10^{9}	2.4×10^{10}	4.3×10^{8}	1.8×10^{10}	8.0×10^{9}	2.4×10^{9}	4.4×10^{9}	1.2×10^{9}
^{59}Fe	0	0	1.6×10^{7}	1.9×10^{8}	4.3×10^{7}	6.6×10^{7}	1.0×10^{8}	5.5×10^{8}	7.0×10^{7}	8.6×10^{8}	2.9×10^{8}	4.8×10^{7}
^{60}Co	3.7×10^{8}	1.3×10^{8}	3.3×10^{9}	1.6×10^{10}	2.5×10^{9}	1.1×10^{10}	2.3×10^{8}	4.9×10^{9}	8.1×10^{9}	4.6×10^{9}	4.9×10^{9}	2.6×10^{9}
^{65}Zn	6.4×10^{7}	4.2×10^{7}	1.4×10^{8}	1.5×10^{8}	9.8×10^{7}	2.4×10^{9}	5.1×10^{7}	1.5×10^{9}	6.4×10^{8}	1.0×10^{8}	1.7×10^{8}	1.4×10^{8}
^{110m}Ag	1.1×10^{7}	2.0×10^{6}	3.9×10^{7}	1.1×10^{7}	1.5×10^{7}	1.3×10^{7}	4.1×10^{6}	6.4×10^{6}	6.4×10^{6}	2.7×10^{8}	1.2×10^{8}	7.8×10^{7}
^{131}I	1.1×10^{8}	3.2×10^{7}	1.4×10^{8}	5.4×10^{8}	5.9×10^{7}	3.9×10^{7}	2.1×10^{7}	4.0×10^{5}	7.0×10^{8}	1.6×10^{7}	3.4×10^{6}	8.3×10^{6}
^{134}Cs	1.6×10^{8}	4.9×10^{7}	1.8×10^{9}	6.4×10^{8}	3.2×10^{8}	9.8×10^{8}	1.6×10^{8}	9.2×10^{8}	7.5×10^{8}	1.2×10^{8}	1.6×10^{8}	9.3×10^{7}
^{137}Cs	3.2×10^{8}	1.3×10^{8}	3.2×10^{8}	9.1×10^{8}	5.9×10^{8}	1.6×10^{9}	2.8×10^{8}	8.4×10^{8}	1.4×10^{9}	8.4×10^{8}	3.8×10^{8}	9.8×10^{7}

Table 3.2.5.2. Reported annual liquid discharges from Ringhals 1975-1987, reference 36. (Unit: Bq year^{-1})

Isotope	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
^{51}Cr		2.3×10^{9}	1.3×10^{11}	3.9×10^{10}	7.5×10^{9}	6.0×10^{9}	1.6×10^{10}	5.5×10^{9}	1.4×10^{10}	8.1×10^{9}	1.9×10^{10}	1.0×10^{10}	1.3×10^{10}
^{54}Mn		3.4×10^{9}	3.3×10^{10}	1.1×10^{10}	5.2×10^{9}	5.4×10^{9}	4.0×10^{9}	2.2×10^{9}	7.8×10^{9}	8.1×10^{9}	5.1×10^{9}	5.5×10^{9}	4.2×10^{9}
^{57}Co						1.6×10^{8}	1.1×10^{8}	2.2×10^{7}	4.9×10^{7}	1.1×10^{8}	2.6×10^{8}	3.1×10^{8}	5.6×10^{8}
^{58}Co	0	1.5×10^{10}	3.1×10^{11}	5.1×10^{10}	2.7×10^{10}	1.8×10^{10}	2.6×10^{10}	1.8×10^{10}	5.9×10^{10}	1.2×10^{11}	6.7×10^{10}	9.1×10^{10}	7.3×10^{10}
^{59}Fe		0	1.1×10^{9}	1.1×10^{10}	1.3×10^{9}	9.9×10^{8}	1.1×10^{9}	1.1×10^{8}	6.5×10^{8}	6.6×10^{8}	2.7×10^{9}	8.0×10^{8}	2.2×10^{9}
^{60}Co	4.4×10^{5}	2.2×10^{10}	1.1×10^{11}	9.8×10^{10}	5.2×10^{10}	9.3×10^{10}	6.5×10^{10}	3.3×10^{10}	7.8×10^{10}	1.2×10^{11}	5.7×10^{10}	8.6×10^{10}	6.5×10^{10}
^{65}Zn		8.1×10^{9}	3.8×10^{10}	4.0×10^{10}	8.5×10^{10}	4.2×10^{10}	8.8×10^{10}	2.2×10^{10}	2.0×10^{10}	9.7×10^{9}	3.6×10^{9}	4.6×10^{9}	4.1×10^{9}
^{110m}Ag		3.0×10^{9}	9.3×10^{9}	4.6×10^{9}	1.1×10^{9}	1.1×10^{9}	9.8×10^{8}	6.0×10^{8}	5.2×10^{8}	5.1×10^{8}	3.1×10^{8}	6.0×10^{8}	5.8×10^{8}
^{131}I		2.4×10^{9}	0	3.6×10^{7}	0	2.4×10^{9}	1.8×10^{9}	3.0×10^{9}	3.4×10^{9}	4.8×10^{9}	951	6.1×10^{8}	1.7×10^{9}
^{134}Cs			6.2×10^{9}	1.2×10^{10}	4.9×10^{10}	1.5×10^{10}	1.5×10^{10}	2.5×10^{10}	8.8×10^{9}	2.8×10^{9}	1.8×10^{9}	7.9×10^{9}	4.5×10^{9}
^{137}Cs			8.4×10^{9}	2.6×10^{10}	6.6×10^{10}	2.1×10^{10}	2.0×10^{10}	3.3×10^{10}	1.5×10^{10}	6.2×10^{9}	3.8×10^{9}	1.5×10^{10}	7.7×10^{9}

Table 3.2.5.3. Gamma-emitting radionuclides in Fucus vesiculosus (Fu.ve.) and Fucus serratus (Fu.se.) outside the northern cooling-water intake at Ringhals (location 98, 2.3 km north of the outlet) in 1987. (Unit: Bq kg^{-1} dry weight)

Date		2/2	1/5	1/6	1/7	1/8	1/9	1/10	2/11	1/12	30/12	Mean	S.E.	N	Mean	S.E.	N
% dry	Fu.ve.	-	19.5	16.7	16.2	18.5	18.3	17.6	21.8	22.3	-	1987			1983-		
matter	Fu.se.	20.6	20.0	19.1	19.2	22.0	19.9	21.1	20.6	22.7	20.8				1987		
^{54}Mn	Fu.ve.	-	-	2.9A	3.9	-	5.3	-	6.8	4.0	-						
	Fu.se.	3.6	3.4	-	4.1	3.1	-	5.7	-	4.3	3.0						
Fu.ve/Fu.se.		-	-	-	0.95	-	-	-	-	0.93	-	0.94	0.010	2	0.99	0.044	31
^{58}Co	Fu.ve.	-	9.0	28	56	31	49	81	71	54	-						
	Fu.se.	20	10.3	31	70	54	64	85	59	46	41						
Fu.ve/Fu.se.		-	0.87	0.90	0.80	0.57	0.77	0.95	1.20	1.18	-	0.91	0.074	8	0.80	0.040	40
^{60}Co	Fu.ve.	-	50	34	28	20	25	75	80	81	-						
	Fu.se.	78	96	79	40	43	41	76	72	74	79						
Fu.ve/Fu.se.		-	0.53	0.43	0.65	0.47	0.61	0.99	1.11	1.09	-	0.73	0.100	8	0.80	0.035	40
^{65}Zn	Fu.ve.	-	-	-	-	-	-	-	10.1	9.6	-						
	Fu.se.	9.4	-	-	7.0	4.4A	3.9	11.6	8.7	8.5	-						
Fu.ve/Fu.se.		-	-	-	-	-	-	-	1.16	1.13	-	1.15	0.016	2	0.84	0.040	28
^{106}Ru	Fu.se.	36	35	-	-	-	-	-	-	-	-	-	-	-	-	-	-
^{110m}Ag	Fu.ve.	-	6.8	3.8	-	-	3.8	-	2.8A	2.2	-						
	Fu.se.	13.5	7.7	6.A	2.6	3.7	-	-	-	2.8	4.1						
Fu.ve/Fu.se.		-	0.88	0.5	-	-	-	-	-	0.79	-	0.72	0.115	3	1.08	0.080	16
^{134}Cs	Fu.ve.	-	-	5.8	4.1	-	5.0	3.8	3.8	3.6	-						
	Fu.se.	3.2	3.6	6.8	3.9	2.6	4.4	3.1	2.8	3.3	2.8						
Fu.ve/Fu.se.		-	-	0.85	1.05	-	1.14	1.23	1.36	1.09	-	1.12	0.069	6	1.12	0.070	9
^{137}Cs	Fu.ve.	-	16.7	21	15.5	7.7	18.9	13.3	13.8	15.3	-						
	Fu.se.	9.9	16.2	24	14.8	9.1	17.8	12.9	13.3	12.6	8.0						
Fu.ve/Fu.se.		-	1.03	0.88	1.05	0.85	1.06	1.03	1.04	1.21	-	1.02	0.041	8	0.98	0.029	40

Fu.se. 1 October 1987: 0.4 Bq ^{57}Co kg^{-1} dry weight.

Table 3.2.5.4. Gamma-emitting radionuclides in Fucus vesiculosus collected from the northern cooling-water intake channel at Ringhals in 1987 (location 95 (local), 2.5 km north of the outlet). (Unit: Bq kg^{-1} dry weight)

Date	2/2	2/4	1/5	1/6	1/7	1/9	1/10	2/11	1/12
% dry matter	18.2	21.9	17.5	15.0	16.6	17.6	18.9	20.9	16.1
^{51}Cr	-	-	-	-	-	-	99 B	-	-
^{54}Mn	6.6 A	3.5	6.5	10.2	4.3A	10.0	23	12.4	13.7
^{57}Co	-	-	-	-	-	-	0.93A	-	-
^{58}Co	30	11.2	39	84	79	119	179	81	84
^{59}Fe	-	-	-	-	-	-	-	14.4	-
^{60}Co	114	69	66	88	43	69	210	144	260
^{65}Zn	10 B	-	-	-	-	-	14.0	7.2A	6.9A
^{95}Zr	-	-	-	-	-	-	20	-	-
^{106}Ru	79	33	-	-	-	-	-	-	-
^{110m}Ag	11.4	7.5	-	-	-	-	-	7.8	-
^{134}Cs	9.7	8.3	8.4	12.2	5.9	5.8	8.1	6.9	10.7
^{137}Cs	33	25	29	40	22	22	31	29	48

Table 3.2.5.5. Ratios of activity concentrations in Fucus vesiculosus sampled in the northern cooling-water channel at Ringhals (locations 95 and 99) to those just outside the channel (location 98). Mean values and S.E. for 1983 - 1987 are given

	^{7}Be	^{40}K	^{54}Mn	^{58}Co	^{60}Co	^{65}Zn	^{103}Ru	^{106}Ru	^{110m}Ag	^{134}Cs	^{137}Cs
1983	2.50 ± 0.46 (n = 7)	0.93 ± 0.03 (n = 8)	2.40 ± 0.57 (n = 7)	2.36 ± 0.66 (n = 8)	1.70 ± 0.17 (n = 7)	1.06 ± 0.12 (n = 8)			1.45 ± 0.37 (n = 6)		2 (n = 7)
1984	3.20 ± 0.30 (n = 13)	1.01 ± 0.04 (n = 13)	1.92 ± 0.17 (n = 13)	1.77 ± 0.16 (n = 13)	2.07 ± 0.27 (n = 13)	0.97 ± 0.07 (n = 13)			0.88 ± 0.13 (n = 3)		2 ± 0.2 (n = 1
1985	3.42 ± 0.51 (n = 7)	0.91 ± 0.05 (n = 10)	1.99 ± 0.32 (n = 10)	1.82 ± 0.30 (n = 10)	2.01 ± 0.42 (n = 10)	1.05 ± 0.14 (n = 8)			1.12 ± 0.14 (n = 2)		1.69 ± (n =
1986	3.67 ± 1.07 (n = 4)	0.99 ± 0.08 (n = 7)	2.45 ± 0.27 (n = 6)	2.30 ± 0.43 (n = 8)	1.97 ± 0.22 (n = 8)	0.89 ± 0.10 (n = 2)	3.38 ± 0.64 (n = 4)	2.56 ± 0.33 (n = 3)	1.38 ± 0.20 (n = 3)	1.9 (n = 4)	2.71 ± 0.48 (n = 8)
1987		0.84 ± 0.08 (n = 7)	2.36 ± 0.49 (n = 5)	2.30 ± 0.42 (n = 7)	2.32 ± 0.27 (n = 7)	0.72 ± 0.00 (n = 2)			2.77 ± 0.0 (n = 1)	1 ± 0.26 (n = 6)	1.97 ± 0.24 (n = 7)
1983-1987	3.15 ± 0.24 (n = 31)	0.94 ± 0.02 (n = 45)	2.15 ± 0.15 (n = 41)	2.06 ± 0.17 (n = 46)	2.02 ± 0.14 (n = 45)	0.99 ± 0.05 (n = 33)	3.38 ± 0.64 (n = 4)	2.56 ± 0.33 (n = 3)	1.37 ± 0.19 (n = 15)	1.96 ± 0.17 (n = 10)	1.94 ± 0.12 (n = 45)

Table 3.2.5.6. Gamma-emitting radionuclides in Fucus vesiculosus transplanted from Store Näss, Varberg (57°07'N 12°11'E) to the northern cooling-water intake channel at Ringhals in 1987 one month before sampling. (Unit: Bq kg^{-1} dry weight)

Period of accumulation	2/1-2/2	2/2-2/3	2/4-2/5	2/5-1/6	1/6-1/7
% dry matter	23.4	37.0	16.9	14.9	14.2
^{54}Mn			8.0	7.5	6.3 A
^{58}Co			58	62	97
^{60}Co	13.9	17.3	48	39	30
^{106}Ru			55 A		
^{110m}Ag	5.7		6.0 A		
^{134}Cs	5.6	6.2	7.4	7.2	7.5
^{137}Cs	14.7	23	19.7	23	27

Table 3.2.5.7. Fucus vesiculosus. Transfer factors obtained during one month of accumulation after transplantation to Ringhals in 1987. (Unit: Bq kg^{-1} dry Fucus/GBq discharged) (cf. Tables 3.2.5.1 and 3.2.5.5)

	Jan	Feb	April	May	June	$\bar{x}$	S.E.	N
^{54}Mn			16.6	31.3	9.13	19.0	6.5	3
^{58}Co			8.66	15.1	4.04	9.3	3.2	3
^{60}Co	3.76	13.3	3.00	15.6	2.72	7.9	2.9	5
^{110m}Ag	518		545			527	19	2

Table 3.2.5.8. Gamma-emitting radionuclides in Fucus vesiculosus (Fu.ve.) and Fucus serratus (Fu.se.) collected at Stora Näss, Varberg (57°07'N 12°11'E) in 1987. (Unit: Bq kg^{-1} dry weight)

Date	2/1	2/4	1/5	1/6	1/7	1/8	1/9	1/10	1/10	2/11	1/12
% dry matter	19.9	23.3	15.8	13.8	18.2	20.6	18.4	24.3	14.2	22.2	22.1
Species	Fu.se.	Fu.se.	Fu.ve.	Fu.ve.	Fu.ve.	Fu.se.	Fu.ve.	Fu.se.	Fu.ve.	Fu.ve.	Fu.ve.
^{54}Mn	1.4 A	-	-	-	-	0.8 A	-	-	-	1.1 B	-
^{60}Co	9.4	11.0	6.0	6.5	4.3	4.6	4.7	4.4	7.4	6.2	5.7
^{106}Ru	12.5 A	18.4 A	-	-	-	-	-	-	-	-	-
^{110m}Ag	3.9	3.6 A	-	-	-	-	-	-	-	-	-
^{134}Cs	6.7	6.7	4.7	8.6	4.9	5.3	6.2	3.3	6.1	4.5	4.2
^{137}Cs	19.9	24	20	26	18.1	19.9	23	15.5	21	18.5	17.2

The experimental translocations of low-active Fucus vesiculosus plants from Varberg to the cooling water intake channel at Ringhals one month prior to sampling was discontinued in 1987. Tables 3.2.5.6 and 3.2.5.7 show the last results. It was not possible to extract a clear seasonal effect on the accumulation of radionuclides by Fucus. The background activity at Varberg is shown in Table 3.2.5.8.

Transfer factors from the Ringhals discharge (Table 3.2.5.1) to Fucus vesiculosus from location 98 (Table 3.2.5.3) calculated as the ratio of Bq kg^{-1} dry Fucus to the monthly discharge (GBq) averaged over the previous 6 months were given in the previous report as Figs. 3.2.1.3-3.2.1.7 including 1987. The results are rather variable. However, it appears clearly that ^{110m}Ag increased above what could be explained by power plant discharges after the Chernobyl accident.

Barsebäck Results

Tables 3.2.5.9-3.2.5.12 give the Barsebäck data. Table 3.2.5.12 and Fig. 3.2.5.1 give the last results from the transplantation studies from Barsebäck. Table 3.2.5.13 shows the background activity in Fucus from Limhamn south of Barsebäck.

Table 3.2.5.9 shows a single value for ^{110m}Ag in Fucus vesiculosus from Barsebäck. The gamma spectra of Fucus from Barsebäck location 25 from 1986 have been recalculated with the aim of finding ^{110m}Ag. This gave the following results in Bq ^{110m}Ag kg^{-1} dry Fucus (± 1 S.D.): 2/6-86: 12.3 ± 27%; 1/10-86: 11.7 ± 24% and 2/1-87: 3.3 ± 42%. These values should be included in the previous report.

Transfer factors from Barsebäck discharge (Table 3.2.5.9) to Fucus vesiculosus from location 25 (Table 3.2.5.11) calculated as the ratio of Bq kg^{-1} dry Fucus to the monthly discharge (GBq) averaged over the previous 6 months were reported in the previous report as Figs. 3.2.1.8-3.2.1.11.

Table 3.2.5.9. Reported monthly liquid discharges from Barsebäck in 1987, reference 36 (Unit: Bq month^{-1})

Isotope	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
^{51}Cr	1.7×10^{9}	9.8×10^{8}	3.1×10^{9}	6.3×10^{8}	1.2×10^{9}	8.8×10^{8}	3.5×10^{9}	1.4×10^{9}	5.3×10^{8}	4.2×10^{8}	2.3×10^{8}	0
^{54}Mn	3.8×10^{8}	3.7×10^{8}	1.6×10^{8}	1.2×10^{8}	1.7×10^{8}	1.1×10^{8}	1.4×10^{9}	6.0×10^{8}	1.1×10^{9}	3.5×10^{8}	1.0×10^{8}	8.7×10^{7}
^{58}Co	2.0×10^{8}	1.7×10^{8}	5.4×10^{8}	1.5×10^{8}	1.4×10^{8}	1.1×10^{8}	3.4×10^{9}	1.4×10^{9}	1.9×10^{9}	3.9×10^{8}	1.3×10^{8}	6.9×10^{7}
^{59}Fe	0	0	0	0	0	0	9.6×10^{7}	1.2×20^{7}	0	0	0	0
^{60}Co	3.4×10^{9}	2.0×10^{9}	2.4×10^{9}	6.3×10^{8}	4.3×10^{9}	1.3×10^{9}	9.5×10^{9}	2.1×10^{9}	3.8×10^{9}	1.3×10^{9}	4.8×10^{8}	7.2×10^{8}
^{65}Zn	4.1×10^{7}	2.2×10^{7}	0	0	6.8×10^{7}	1.1×10^{7}	1.0×10^{8}	0	0	1.6×10^{7}	0	0
^{110m}Ag	0	9.4×10^{8}	0	0	0	0	0	0	0	0	0	0
^{131}I	7.5×10^{7}	0	0	0	0	0	0	0	0	0	0	0
^{134}Cs	0	0	0	1.3×10^{7}	7.2×10^{7}	1.7×10^{7}	0	0	5.4×10^{7}	0	0	4.8×10^{6}
^{137}Cs	3.1×10^{7}	0	0	3.1×10^{7}	1.6×10^{8}	5.0×10^{7}	1.8×10^{7}	3.9×10^{7}	4.9×10^{7}	5.3×10^{7}	2.0×10^{7}	1.2×10^{7}

Table 3.2.5.10. Reported annual liquid discharges from Barsebäck 1975-1987, reference 36 (Unit: Bq year^{-1})

Isotope	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
^{51}Cr	1.2×10^{10}	1.7×10^{10}	1.3×10^{11}	3.2×10^{10}	1.7×10^{10}	4.2×10^{9}	2.7×10^{10}	6.7×10^{9}	7.2×10^{9}	4.7×10^{9}	6.6×10^{9}	1.8×10^{10}	1.5×10^{10}
^{54}Mn	5.6×10^{7}	2.0×10^{9}	2.1×10^{9}	3.9×10^{9}	2.0×10^{9}	1.7×10^{9}	2.0×10^{9}	3.3×10^{9}	2.7×10^{9}	3.7×10^{9}	3.7×10^{9}	1.5×10^{10}	5.0×10^{9}
^{58}Co	6.6×10^{9}	2.6×10^{10}	1.3×10^{10}	3.4×10^{10}	7.8×10^{9}	7.2×10^{9}	6.3×10^{9}	4.0×10^{9}	1.8×10^{9}	4.9×10^{9}	2.6×10^{9}	9.0×10^{9}	8.6×10^{9}
^{59}Fe					2.4×10^{8}	5.3×10^{7}	1.5×10^{8}	1.2×10^{8}	1.3×10^{8}	5.5×10^{8}	7.8×10^{7}	1.1×10^{9}	1.1×10^{9}
^{60}Co	2.6×10^{9}	1.4×10^{10}	2.8×10^{10}	5.4×10^{10}	2.2×10^{10}	3.7×10^{10}	4.3×10^{10}	2.3×10^{10}	4.9×10^{10}	5.0×10^{10}	4.2×10^{10}	9.6×10^{10}	3.2×10^{10}
^{65}Zn	3.7×10^{7}	3.1×10^{9}	7.0×10^{9}	1.0×10^{10}	5.5×10^{9}	5.8×10^{9}	5.5×10^{9}	7.7×10^{9}	2.6×10^{9}	1.2×10^{9}	7.5×10^{9}	2.2×10^{9}	2.6×10^{9}
^{110m}Ag	0	2.2×10^{9}	1.8×10^{9}	3.6×10^{9}	8.6×10^{8}	2.9×10^{9}	2.4×10^{9}	1.3×10^{9}	3.8×10^{7}	5.7×10^{7}	0	1.3×10^{7}	9.4×10^{8}
^{131}I									7.5×10^{8}	2.2×10^{8}	3.7×10^{7}	1.2×10^{8}	7.5×10^{7}
^{134}Cs					0	0	4.6×10^{9}	1.9×10^{10}	6.5×10^{9}	4.0×10^{9}	4.7×10^{9}	1.2×10^{9}	1.6×10^{9}
^{137}Cs	0	0	6.5×10^{9}	1.9×10^{7}	0	0	6.1×10^{9}	2.6×10^{10}	1.2×10^{10}	9.2×10^{9}	1.9×10^{9}	5.1×10^{9}	4.6×10^{9}

Table 3.2.5.11. Gamma-emitting radionuclides in Fucus vesiculosus collected at Barsebäck, location 25 (55°48'30N 12°54'45E) in 1987. (Unit: Bq kg^{-1} dry weight)

Sampling date	1/4	1/5	1/6	1/7	1/8	1/9	2/10	3/11	2/12
% dry matter	14.9	25.5	8.9	13.2	17.3	16.8	20.5	18.3	18.1
^{54}Mn	70	53	43	46	58	107	142	119	104
^{57}Co							0.7A		
^{58}Co	14.7	13.7		7 B	86	139	172	108	77
^{60}Co	1110	640	510	560	600	480	600	420	403
^{65}Zn	46	21			14.5			10.7	
^{110m}Ag				5.4 A					
^{134}Cs	13.4	21	21	16.1	13.7	15.3	12.5	11.7	11.3
^{137}Cs	37	60	59	44	39	45	40	38	34

Table 3.2.5.12. Gamma-emitting radionuclides in Fucus vesiculosus transplanted from Barsebäck (Table 3.2.5.10) to Limhamn (55°35'N 12°55'E) in 1987. (Unit: Bq kg^{-1} dry weight)

Transplanting date	1 May			
Sampling date	1/5	1/6	1/7	1/8
% dry matter	25.5	9.9	11.6	13.1
^{54}Mn	53	21	28	17
^{58}Co	13.7			5.7 A
^{60}Co	640	360	290	230
^{65}Zn	21			
^{134}Cs	21	18.7	19.5	15.8
^{137}Cs	60	54	58	46

Fig. 3.2.5.1. Concentration of ^{60}Co in Fucus vesiculosus translocated from Barsebäck to Limhamn (low activity). Data from Table 3.2.5.12 and previous reports.

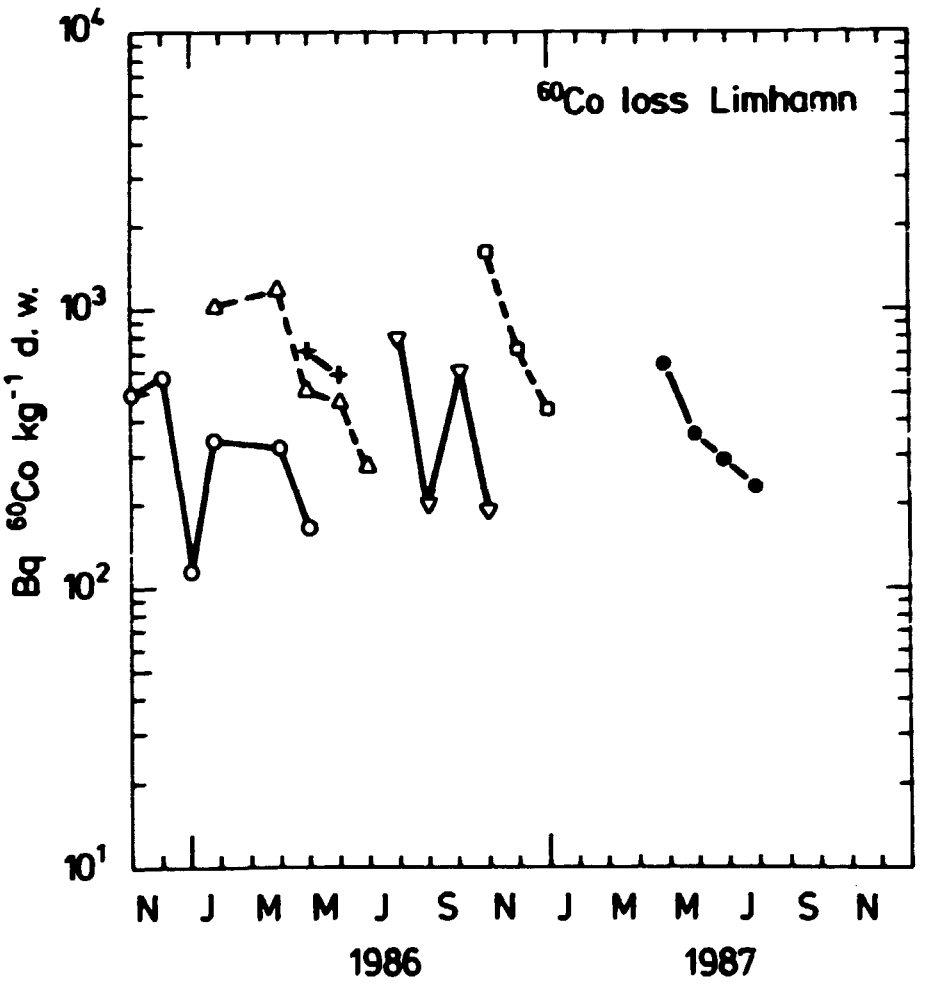


Table 3.2.5.13. Gamma-emitting radionuclides in Fucus vesiculosus collected at Limhamn (55°35'N 12°55'E) in 1987. (Unit: Bq kg^{-1} dry weight)

Date	2/1	1/5	1/6	1/7	1/8	1/9	2/10	3/11	2/12
% dry matter	17.7	16.3	11.7	12.6	13.4	16.8	18.0	18.6	17.7
^{54}Mn	1.5 A	-	-	-	1.9 A	1.6 B	-	-	-
^{58}Co	-	-	-	-	2.5 A	-	-	-	-
^{60}Co	9.6	5.1	-	3.4	6.6	4.6	5.3	3.8	6.8
^{110m}Ag	2 B	-	-	-	-	-	-	-	-
^{134}Cs	5.8	15.9	24	18.2	13.5	14.2	9.3	11.9	10.3
^{137}Cs	17.0	44	70	55	42	37	32	41	34

Forsmark Results

Tables 3.2.5.14-3.2.5.17 show data on radionuclides in water from the Biotest area, discharge from Forsmark and calculated transfer factor from discharge to water. The time-integrated water sampling procedure was described in the 1983-report[1].

The calculation of the transfer factors to water (Table 3.2.5.17) is less exact than wanted, as samplings did not follow the calendar months used in reporting discharges. The extreme outlier for ^{65}Zn may be caused by that reason, and it is excluded from the means. The water sampling from Forsmark was discontinued during 1987.

The water samplings at Forsmark were performed by the National Swedish Environmental Protection Board, and the results should be compared with their measurements on biota and sediments. A map of the location is shown in Fig. 3.2.5.3.

Table 3.2.5.14. Reported monthly liquid discharges from Forsmark I and II in 1987, reference 36 (Unit: Bq month^{-1})

Isotope	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
^{51}Cr	3.3×10^{8}	1.9×10^{8}	6.1×10^{7}	7.7×10^{8}	5.4×10^{8}	4.0×10^{8}	6.0×10^{8}	5.6×10^{8}	0	2.5×10^{8}	7.3×10^{8}	$3.3\times$
^{54}Mn	3.6×10^{8}	6.7×10^{8}	1.3×10^{8}	2.5×10^{8}	3.3×10^{8}	9.2×10^{8}	5.8×10^{8}	5.2×10^{8}	2.7×10^{7}	7.2×10^{7}	1.3×10^{8}	$1.1\times$
^{57}Co	8.3×10^{8}	2.6×10^{7}	0	1.4×10^{7}	0	2.5×10^{7}	6.8×10^{8}	0	0	0	0	0
^{58}Co	1.1×10^{9}	2.7×10^{9}	2.3×10^{8}	8.4×10^{8}	7.6×10^{8}	3.2×10^{9}	2.0×10^{8}	2.3×10^{8}	2.4×10^{8}	2.4×10^{8}	3.9×10^{8}	$3.8\times$
^{59}Fe	0	0	0	0	0	0	0	0	0	0	0	0
^{60}Co	2.6×10^{10}	4.1×10^{10}	7.9×10^{8}	1.2×10^{10}	1.8×10^{10}	2.2×10^{10}	2.1×10^{10}	2.5×10^{10}	3.6×10^{8}	2.9×10^{8}	6.8×10^{8}	$5.3\times$
^{65}Zn	1.4×10^{9}	2.8×10^{8}	2.6×10^{7}	8.6×10^{8}	9.8×10^{8}	1.2×10^{9}	9.4×10^{8}	1.6×10^{8}	4.6×10^{8}	2.8×10^{8}	4.3×10^{8}	$3.3\times$
^{95}Zr	0	0	0	0	0	0	0	0	0	0	0	0
^{95}NB	0	0	0	0	2.2×10^{7}	0	0	0	0	0	0	0
^{103}Ru	0	0	0	0	0	0	0	0	0	0	0	0
^{110m}Ag	3.4×10^{8}	1.4×10^{8}	6.1×10^{7}	4.8×10^{8}	2.4×10^{8}	6.5×10^{8}	3.9×10^{8}	5.7×10^{8}	7.4×10^{7}	9.7×10^{7}	0	$1.3\times$
^{124}Sb	0	0	5.7×10^{7}	1.1×10^{8}	5.2×10^{8}	4.8×10^{8}	9.0×10^{8}	1.8×10^{8}	3.3×10^{8}	3.1×10^{8}	2.6×10^{8}	$2.0\times$
^{125}Sb	0	0	0	0	2.2×10^{8}	0	0	5.5×10^{8}	0	0	0	0
^{131}I	3.4×10^{8}	1.6×10^{8}	1.0×10^{8}	1.1×10^{8}	0	1.3×10^{8}	0	0	0	0	0	0
^{134}Cs	0	0	0	0	0	2.3×10^{8}	4.4×10^{8}	0	0	2.9×10^{7}	8.6×10^{7}	0
^{137}Cs	0	0	0	2.4×10^{7}	0	2.4×10^{8}	4.5×10^{8}	1.9×10^{8}	0	3.3×10^{7}	7.8×10^{7}	$5.2\times$
^{140}Ba	0	0	0	0	0	0	0	0	0	0	0	0
^{140}La	0	0	0	0	0	0	0	0	0	0	0	0
^{141}Ce	0	3.8×10^{7}	0	0	0	0	0	0	0	0	0	0

Table 3.2.5.15. Reported annual liquid discharges from Forsmark I and II in 1984-1987, from reference 36

Isotope	1984	1985	1986	1987
^{51}Cr	4.9 ± 10^{11}	3.3 ± 10^{10}	1.9 ± 10^{10}	1.0 ± 10^{10}
^{54}Mn	4.7 ± 10^{9}	6.1 ± 10^{9}	7.8 ± 10^{9}	4.1 ± 10^{9}
^{57}Co	9.0 ± 10^{8}	4.1 ± 10^{7}	9.4 ± 10^{7}	8.0 ± 10^{7}
^{58}Co	3.8 ± 10^{10}	5.2 ± 10^{10}	2.8 ± 10^{10}	1.4 ± 10^{10}
^{59}Fe	4.7 ± 10^{7}	0	0	0
^{60}Co	9.2 ± 10^{10}	2.0 ± 10^{11}	3.5 ± 10^{11}	1.9 ± 10^{11}
^{65}Zn	2.4 ± 10^{10}	3.1 ± 10^{10}	3.5 ± 10^{10}	1.1 ± 10^{10}
^{95}Zr	1.8 ± 10^{8}	0	0	0
^{95}Nb	5.3 ± 10^{8}	0	0	2.2 ± 10^{7}
^{103}Ru	2.9 ± 10^{8}	0	0	0
^{110m}Ag	5.6 ± 10^{9}	4.8 ± 10^{9}	7.6 ± 10^{9}	4.4 ± 10^{9}
^{124}Sb	8.1 ± 10^{9}	2.2 ± 10^{10}	5.2 ± 10^{9}	5.0 ± 10^{9}
^{125}Sb	1.4 ± 10^{9}	6.4 ± 10^{8}	1.2 ± 10^{9}	7.7 ± 10^{8}
^{131}I	1.7 ± 10^{10}	4.4 ± 10^{9}	1.5 ± 10^{9}	8.4 ± 10^{8}
^{134}Cs	8.6 ± 10^{7}	3.6 ± 10^{9}	2.6 ± 10^{8}	7.8 ± 10^{8}
^{137}Cs	3.7 ± 10^{8}	4.4 ± 10^{9}	6.5 ± 10^{8}	1.1 ± 10^{9}
^{140}Ba	5.2 ± 10^{9}	0	0	0
^{140}La	2.8 ± 10^{9}	6.1 ± 10^{7}	2.4 ± 10^{8}	0
^{141}Ce	1.6 ± 10^{12}	1.6 ± 10^{8}	4.7 ± 10^{8}	3.8 ± 10^{7}

Table 3.2.5.16. Radiocobalt and Zn-65 in time-integrated water samples collected at the outlet from the biotest areas, Forsmark in 1987. (Unit: Bq m^{-3})

Isotope	8/1-3/2	5/2-9/3	16/3-7/4	22/4-18/5
^{58}Co	-	-	-	-
^{60}Co	111	110	71	35
^{65}Zn	11 A	9.3 A	6.2 A	4.2 A

Table 3.2.5.17. Transfer factor from reported monthly discharge (GBq) to monthly time-integrated mean water concentration (Bq m^{-3}) at the outlet from the biotest-area, Forsmark in 1987 (Bq m^{-3}/GBq $month^{-1}$ or 10^{-9} × $month^{-3}$)

Isotope	Jan	Feb	March	May	$\bar{x}$	S.E.	N
^{60}Co	4.27	2.68	9.0	1.94	4.5	1.6	4
^{65}Zn	7.85	3.32	(238)	4.28	5.2	1.4	3

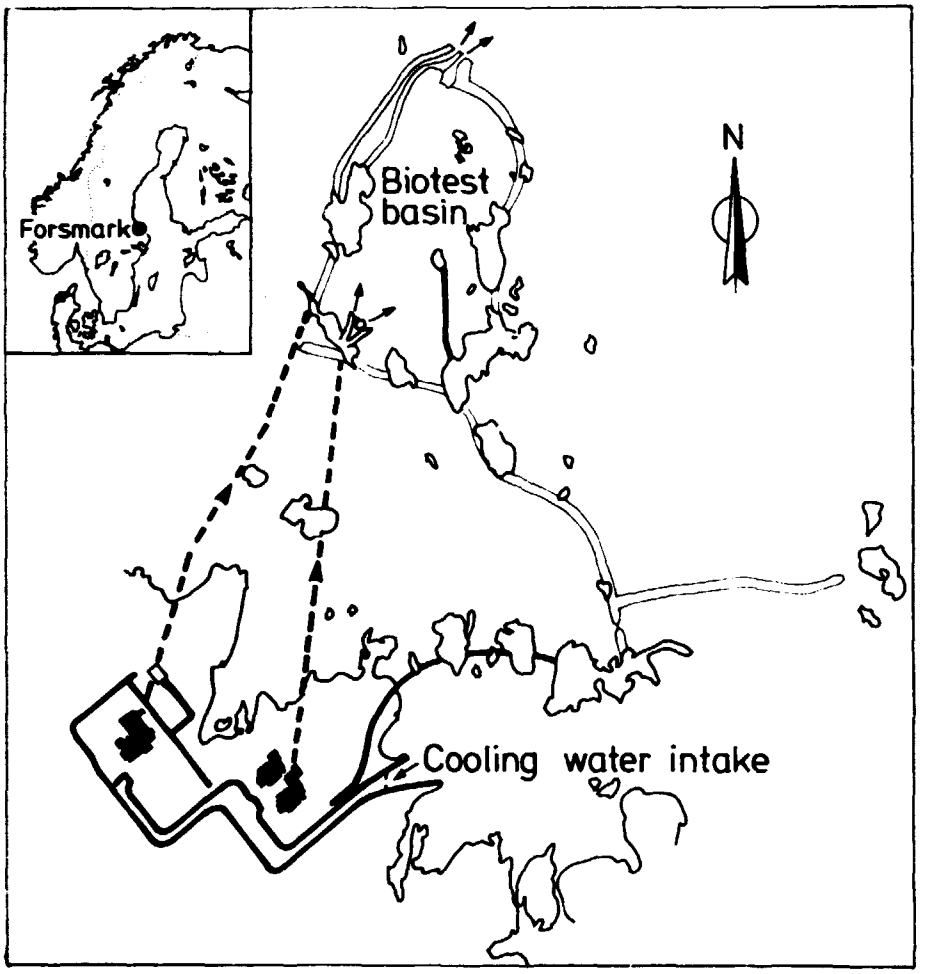


Fig. 3.2.5.3. The biotest basin at Forsmark. The water samples were taken at the outlet from the basin.

4. Fallout Nuclides in the Abiotic Environment

by A. Aarkrog and Heinz Hansen

4.1. Air

4.1.1. Strontium-90 in Air

The mean air activity for 1987 was 0.37 μBq ^{90}Sr m^{-3}, mean of big and small air samplers and glass fibre filters. This is a decrease by a factor of 70 since last year. The ^{90}Sr disappeared more rapidly from the air than the radiocesium. Compared to 1985 the ^{90}Sr levels in 1987 were 20% higher. There may thus still be a small ^{90}Sr contribution in the air from the Chernobyl accident, probably due to resuspension.

At Bornholm (Table 4.1.1.2) the mean concentration was 0.22 μBq ^{90}Sr m^{-3} in 1987.

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

Table 4.1.1.1. Strontium-90 in air collected at Risø in 1987. (Unit: μBq m^{-3})

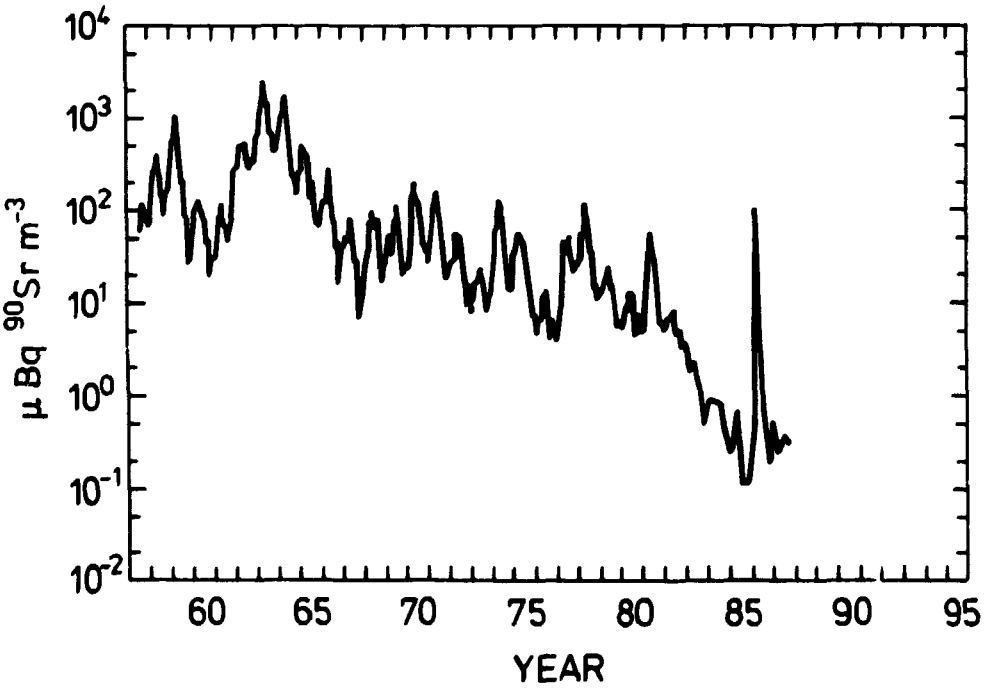
Period	Big air sampler	Small air sampler
Jan-March	0.52±0.15	0.55
April-June	0.22	0.30 A
July-Sept	0.52 B	0.19 B
Oct-Dec	0.24±0.01	0.40 A
1987	0.38	0.36

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

Table 4.1.1.2. Strontium-90 in air collected at Bornholm 1987. (Unit: μBq m^{-3})

Period	Big sampler, glass fibre filter, shunt
Jan-March	0.31
April-June	0.23
July-Sept	0.08 B
Oct-Dec	0.25
1987	0.22

Fig. 4.1.1. Strontium-90 in ground level air at Risø, 1957-1987.



4.1.2. Radiocesium in Air

The mean concentration of ^{137}Cs in air in 1987 decreased by a factor of approximately 200 compared to 1986. The mean concentration at Risø (Table 4.1.2.1) was 6.0 μBq ^{137}Cs m^{-3}. At Bornholm (Table 4.1.2.2) we measured 8.4 μBq m^{-3}. Hence the air at Bornholm showed a $^{137}Cs/^{90}Sr$ ratio (38) two times higher than that at Risø (18).

Figures 4.1.2.1-4.1.2.2 show the concentrations of ^{137}Cs in air collected at Risø and Bornholm in 1987.

As already mentioned in the previous report (Risø-R-549)[1], the air concentrations did not decrease so rapidly as would be expected from a tropospheric event.

Table 4.1.2.1. Radiocesium in air collected in glass-fibre filters by the large air sampler at Risø in 1987. (Unit: μBq m^{-3}) (The error term is 1 S.D.)

Month	^{137}Cs	$^{134}Cs/^{137}Cs$	(N)
January	10.7	0.42 ± 0.05	(9)
February	6.8	0.43 ± 0.04	(7)
March	11.0	0.41 ± 0.04	(8)
April	14.7	0.43 ± 0.08	(9)
May	5.0	0.40 ± 0.04	(4)
June	2.1	0.47 ± 0.01	(3)
July	3.0	0.40 ± 0.04	(5)
August	2.1	0.42 ± 0.10	(6)
September	1.65	0.53 ± 0.24	(2)
October	6.7	0.32 ± 0.02	(5)
November	1.77	0.41 ± 0.11	(5)
December	6.8	0.32 ± 0.03	(4)
1987	6.0		

Table 4.1.2.2. Radiocesium in air collected at the large air sampler in Bornholm in 1987. (Unit: μBq m^{-3}) (The error term is 1 S.D.)

Month	^{137}Cs	$^{134}Cs/^{137}Cs$	(N)
January	19.1	0.42 ± 0.01	(5)
February	10.5	0.44 ± 0.04	(4)
March	10.0	0.39 ± 0.04	(4)
April	25.3	0.42 ± 0.02	(4)
May	8.4	0.38 ± 0.02	(5)
June	3.2	0.34 ± 0.06	(3)
July	4.4	0.40 ± 0.04	(3)
August	2.9	0.36 ± 0.07	(4)
September	2.9	0.28 ± 0.00	(3)
October	8.2	0.32 ± 0.04	(5)
November	2.6	0.32 ± 0.05	(2)
December	2.8	0.37 ± 0.07	(3)
1987	8.4		

Table 4.1.2.3. Cesium-137 in air collected at Risø 1958-1987

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
1984	0.036	1.35
1985	0.0184	0.68
1986	36	1340
1987	0.161	6.0

Table 4.1.2.4. Resuspension factors for ^{137}Cs m^{-1} calculated for 1986-1988. (Quarterly means)

	Risø m^{-1}	Bornholm m^{-1}
July-Sep 1986	$4.75 \cdot 10^{-8}$	$2.95 \cdot 10^{-8}$
Oct-Dec 1986	$2.39 \cdot 10^{-8}$	$2.23 \cdot 10^{-8}$
Jan-March 1987	$1.19 \cdot 10^{-8}$	$2.13 \cdot 10^{-8}$
April-June 1987	$9.08 \cdot 10^{-9}$	$1.98 \cdot 10^{-8}$
July-Sep 1987	$2.81 \cdot 10^{-9}$	$5.48 \cdot 10^{-9}$
Oct-Dec 1987	$6.36 \cdot 10^{-9}$	$7.31 \cdot 10^{-9}$
Jan-March 1988	$4.68 \cdot 10^{-9}$	$7.44 \cdot 10^{-9}$
April-June 1988	$4.41 \cdot 10^{-9}$	$8.40 \cdot 10^{-9}$
July-Sep 1988	$1.26 \cdot 10^{-9}$	$2.41 \cdot 10^{-9}$

Chernobyl has shown us that after the deposition of the debris there is a period with resuspension which may last more than a year after the deposition.

At Risø the resuspension factor became $6.0 \cdot 10^{-6}/800 = 7.5 \cdot 10^{-9}$ m^{-1}, and at Bornholm we found $8.4 \cdot 10^{-6}/620 = 1.35 \cdot 10^{-8}$ m^{-1} in 1987. (Cf. also Table 4.1.2.4 and Fig. 4.1.2.3).

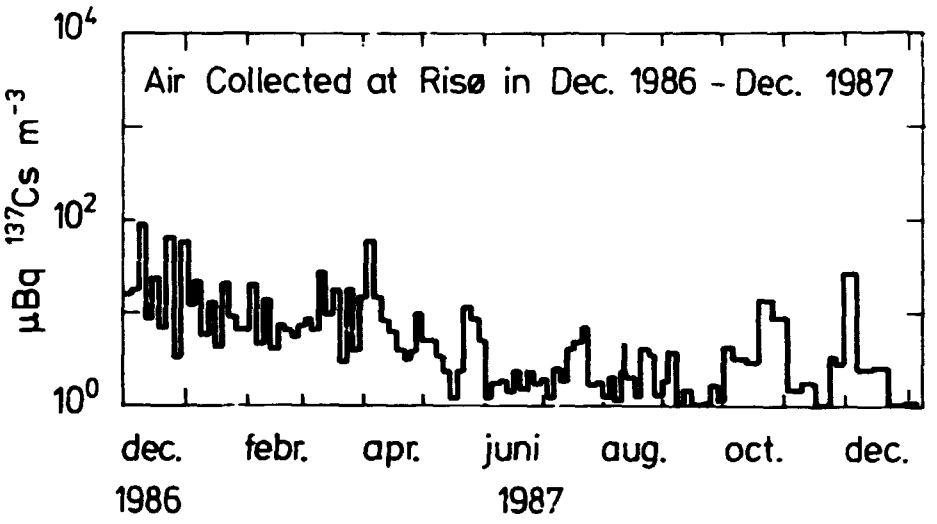
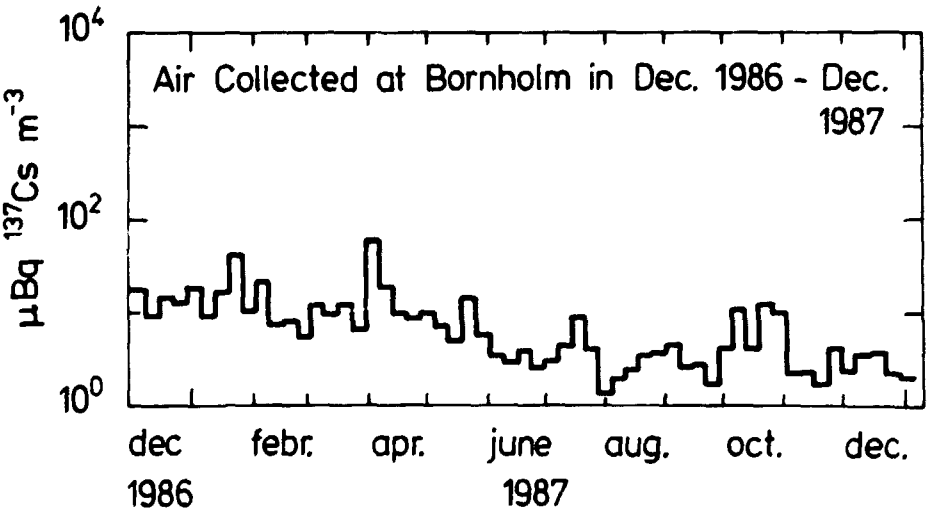


Fig. 4.1.2.1. Cesium-137 in air collected at Risø, Denmark in the period December 1, 1986 - December 31, 1987.

Fig. 4.1.2.2. Cesium-137 in air collected at Bornholm, Denmark in the period December 1, 1986 - December 31, 1987.



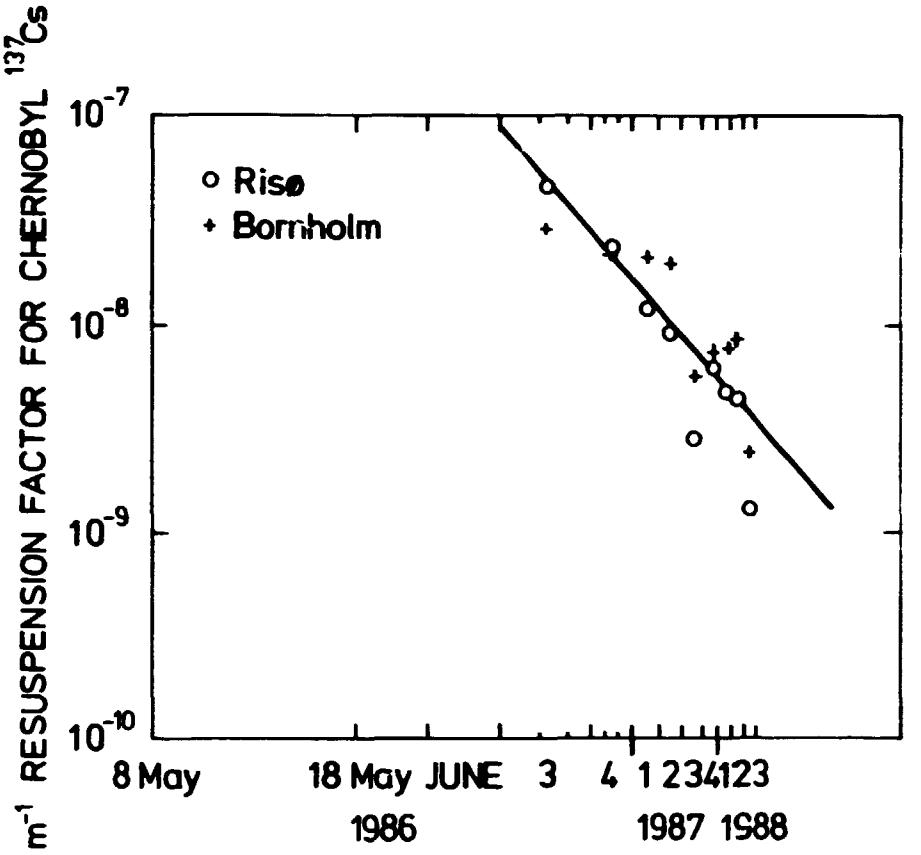


Fig. 4.1.2.3. Resuspension factor for Chernobyl cesium-137.

4.1.3. Iodine-131 in Air

In March and August 1987 we saw ^{131}I in air samples from Risø as well as from Bornholm (Table 4.1.3). In March the integrated levels were 0.54 mBq ^{131}I $m^{-3}d$ at Risø and 0.39 mBq $m^{-3}d$ at Bornholm. In August the levels were 0.35 and 0.092, respectively. Other countries in northern Europe have made similar observations. The source of the ^{131}I in August was identified to be a leaking underground nuclear test explosion at Novaya Zemlya[14].

Table 4.1.3. Iodine-131 in air collected on glass-fibre filters in Denmark in 1987. (Unit: μBq m^{-3})

Period	Risø	Bornholm
March 2-5	0	19.4
March 5-9	70	
March 9-12	70	36
March 12-16	12	
Aug 10-11	57	13.1
Aug 11-12	152	
Aug 12-13	88	
Aug 13-14	29	
Aug 14-17	6.4	

4.2. Precipitation

4.2.1. Strontium-90 in Precipitation

Samples of rain water were collected in 1987 from the State experimental farms (cf. Fig. 4.2) in accordance with the principles laid down in Risø Report No. 63, p. 51[1]).

Tables 4.2.1.1 and 4.2.1.2 show the results of the ^{90}Sr determinations and Tables 4.2.1.3 and 4.2.1.4 the analysis of variance of the results.

The mean levels for ten State experimental farms were 1.44 Bq ^{90}Sr m^{-2} and 2.2 Bq ^{90}Sr m^{-3}. The fallout rate in 1987 was 26 times less than that observed in 1986. The ^{90}Sr mean deposition in 1987 was the same in Jutland as in the Islands.

Compared with 1985 the ^{90}Sr fallout in 1987 was 80% higher indicating that there was still a significant contribution from the Chernobyl accident. However, there was no relation between the ^{90}Sr deposition in 1987 and that from Chernobyl in 1986 (cf. Fig. 4.2.2). We thus found no indication of local resuspension of ^{90}Sr. But as observed earlier, we saw significantly higher ^{90}Sr concentrations in the precipitation from Bornholm than from other parts of

Fig. 4.2. State experimental farms in Denmark.

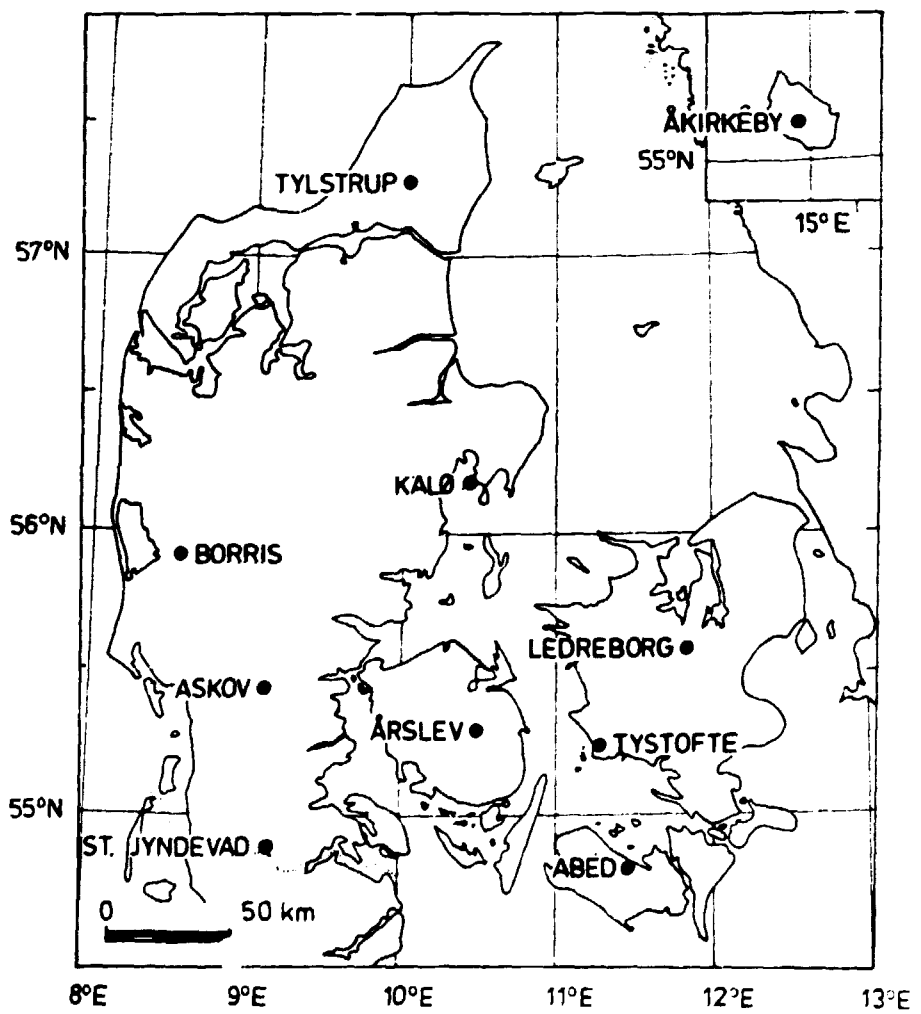


Table 4.2.1.1. Strontium-90 fallout in Denmark in 1987. (Unit: Bq m^{-3})

Location	Jan-Feb	March-April	May-June	July-Aug	Sept-Oct	Nov-Dec	Weighted mean
Tylstrup	2.6	2.2	2.8	1.74	1.07	0.20 B	1.53
Kalø	4.2	5.7	2.7	1.21	1.87	1.33	2.30
Borris	1.17	2.1 A	3.2 B	1.68	1.38	0.36	1.52
Askov	6.4	3.6	2.9	2.4	0.97	0.62	1.99
St. Jyndevad	1.94	2.3	2.3	1.05	0.59	1.24	1.36
Aarslev	7.6	3.5	2.8	2.4	2.5	1.48	2.57
Tystofte	3.0 A	1.03 B	0.51	0.37 A	0.68 A	0.25 A	0.57
Ledreborg	2.2	3.2	1.91	0.47	2.1	0.94	1.40
Abed	2.1	2.6	3.0	1.74	2.2	1.60	3.37
Bornholm	9.1	5.0	3.3	7.9 B	11.4	2.2	5.44
Weighted mean	5.5	3.2	2.6	1.75	1.95	0.96	2.11
$\bar{x}$ mm	35.7	62.2	129.8	143.8	156.1	156.2	

Table 4.2.1.2. Strontium-90 fallout in Denmark in 1987. (Unit: Bq m^{-2})

Location	Jan-Feb	March-April	May-June	July-Aug	Sept-Oct	Nov-Dec	1987	mm
Tylstrup	0.132	0.20	0.32	0.31	0.150	0.036 B	1.15	754
Kalø	0.20	0.36	0.42	0.191	0.35	0.162	1.68	730
Borris	0.059	0.139 A	0.46 B	0.198	0.41	0.079	1.35	889
Askov	0.27	0.26	0.43	0.37	0.22	0.129	1.68	845
St. Jyndevad	0.083	0.157	0.41	0.173	0.131	0.25	1.20	884
Aarslev	0.174	0.22	0.33	0.30	0.32	0.21	1.55	603
Tystofte	0.053 A	0.047 B	0.055	0.041 A	0.071 A	0.034 A	0.30	522
Ledreborg	0.049	0.120	0.195	0.099	0.20	0.103	0.77	550
Abed	0.71	0.129	0.31	0.26	0.193	0.150	1.75	519
Bornholm	0.23	0.34	0.43	0.59 B	1.00	0.35	2.94	540
Mean	0.20	0.20	0.34	0.25	0.30	0.150	1.44	684

Table 4.2.1.3. Analysis of variance of ln Bq ^{90}Sr m^{-3} precipitation, January-December 1987 (from Table 4.2.1.1)

Variation	SSD	f	s^2	v^2	P
Between months	16.99	5	3.40	12.33	> 99.95%
Between locations	18.82	9	2.09	7.59	> 99.95%
Remainder	12.40	45	0.275		

Table 4.2.1.4. Analysis of variance of ln Bq ^{90}Sr m^{-2} precipitation, January-December 1987 (from Table 4.2.1.2)

Variation	SSD	f	s^2	v^2	P
Between months	5.76	5	1.15	5.53	> 99.95%
Between locations	19.22	9	2.14	10.25	> 99.95%
Remainder	9.38	45	0.208		

Table 4.2.1.5. Strontium-90 in precipitation collected at Risø in 1987

Month	10 m^2 ion exchange sampler		Eight rain bottles total area: 0.23 m^2	
	Bq m^{-2}	Bq m^{-3}	Bq m^{-2}	Bq m^{-3}
Jan	0.097	9.6		
Feb	0.058	6.5	0.076	1.14
March	0.020	1.66		
April	0.037	1.37		
May	0.0182	0.51	0.063 A	0.38 A
June	0.031	0.43		
July	0.034	0.25		
Aug	0.0126	0.27	0.091	0.35
Sep	0.0181	0.34		
Oct	0.0115	0.78		
Nov	0.0082	0.143	0.098	0.77
Dec	0.0070	0.173		
1987	Σ0.52 (513 mm)	$\bar{x}$:1.01 (weighted mean)	Σ0.33 (619 mm)	$\bar{x}$:0.53 (weighted mean)

the country. The air concentrations at Bornholm were apparently not higher than those observed at Risø (Tables 4.1.1.1 and 4.1.1.2), but the ^{137}Cs concentrations at Bornholm were enhanced (Tables 4.1.2.1 and 4.1.2.2).

Table 4.2.1.5 shows the ^{90}Sr in precipitation collected at Risø partly by the 10 m^2 ion exchange sampler, partly in the 8 rain bottles located at Risø and elsewhere[21]. The total sampling area of these bottles is 0.23 m^2.

The mean concentrations of ^{90}Sr in the Risø rain samples were in reasonable agreement with that from the two Zealand State experimental farms. The deposition differed significantly between the two Risø sample systems; the bottles collected 0.33 Bq m^{-2} (619 mm) while the 10 m^2 ion exchange sampler gave 0.52 Bq m^{-2} (513 mm). The mean concentration found in the ion exchange sampler was two times higher than that in the rain bottles.

4.2.2. Radiocesium in Precipitation

The measurements of ^{137}Cs and ^{134}Cs in precipitation collected at the Danish State experimental farms are shown in Tables 4.2.2.1 and 4.2.2.2. The mean deposition was 28.6 Bq ^{137}Cs m^{-2} and the mean concentration was 42 Bq ^{137}Cs m^{-3}. Compared with 1986 the ^{137}Cs deposit had decreased by a factor of 37. If we assume that all ^{137}Cs deposition in 1987 came from resuspension, we concluded that 28.6/1356 = 0.021 of the Chernobyl deposit (measured in soil in September 1986[1]) was deposited once more in 1987. The ratio $^{134}Cs/^{137}Cs$ found in precipitation in 1987 shows that all radiocesium came from the Chernobyl accident.

Table 4.2.2.1. Cesium-137 (Bq m^{-3}) and $^{134}Cs/^{137}Cs$ in precipitation in Denmark in 1987

Location	Jan-Feb		March-April		May-June		July-Aug		Sept-Oct		Nov-Dec		Weighted
	^{137}Cs	$\frac{^{134}Cs}{^{137}Cs}$	^{137}Cs	$\frac{^{134}Cs}{^{137}Cs}$	^{137}Cs	$\frac{^{134}Cs}{^{137}Cs}$	^{137}Cs	$\frac{^{134}Cs}{^{137}Cs}$	^{137}Cs	$\frac{^{134}Cs}{^{137}Cs}$	^{137}Cs	$\frac{^{134}Cs}{^{137}Cs}$	mean
Tylstrup	45	0.43	48	0.41	45	0.37	31	0.34	20	0.37	4.3	0.46	28
Kalø	143	0.45	205	0.40	54	0.38	23	0.35	15.2	0.35	12.8	0.32	49
Borris	10.4	-	16.2	-	2.2	0.51	3.4	0.30	2.1	-	1.66	-	3.7
Askov	270	0.46	250	0.40	101	0.40	83	0.38	36	0.36	35	0.33	83
St. Jyndevad	103	0.44	72	0.41	34	0.44	33	0.39	15.6	0.40	18.1	0.36	32
Aarslev	270	0.45	132	0.44	85	0.42	62	0.36	36	0.41	28	0.34	70
Tystofte	94	0.55	44	0.45	21	0.45	19.5	0.34	13.8	0.40	4.2	0.35	19.5
Ledreborg	116	0.50	82	0.39	42	0.39	18.0	0.34	31	0.42	21	0.34	33
Abed	171	0.41	132	0.41	107	0.40	62	0.36	49	0.44	19.6	0.36	75
Bornholm	102	0.47	69	0.43	22	0.34	46	0.34	28	0.25	16.9	0.29	35
Weighted mean	124		104		50		38		21		15.8		42
Mean		0.46		0.42		0.41		0.35		0.38		0.35	
S.D.		0.04		0.02		0.05		0.02		0.06		0.05	
Theoretical ratio		0.43		0.40		0.38		0.36		0.34		0.33	

Table 4.2.2.2. Cesium-137 deposition with precipitation in Denmark in 1987.
(Unit: Bq m^{-2})

Location	Jan-Feb	March-April	May-June	July-Aug	Sept-Oct	Nov-Dec	1987 Σ	mm
Tylstrup	2.2	4.4	5.2	5.4	2.9	0.76	21	754
Kalø	7.0	12.9	8.3	3.7	2.8	1.55	36	730
Borris	0.53	1.05	0.31	0.39	0.63	0.36	3.3	889
Askov	11.3	15.6	14.9	12.8	8.3	7.2	70	845
St. Jyndevad	4.4	4.9	6.2	5.4	3.5	3.7	28	884
Aarslev	6.2	9.4	9.8	7.8	4.6	3.8	42	603
Tystofte	1.66	2.0	2.3	2.2	1.45	0.55	10.2	522
Ledreborg	2.6	3.1	4.3	3.8	2.2	2.2	18.2	550
Abed	5.8	6.5	11.1	9.2	4.5	1.83	39	519
Bornholm	2.6	4.7	2.8	3.5	2.4	2.7	18.7	540
$\bar{x}$	4.43	6.46	6.52	5.42	3.33	2.47	28.64	684
mm	357	622	1298	1438	1561	1562		

Table 4.2.2.3. Analysis of variance of ln Bq ^{137}Cs m^{-3} precipitation, January-December 1987 (from Table 4.2.2.1)

Variation	SSD	f	s^2	v^2	P
Between months	34.12	5	6.83	50.84	> 99.95%
Between locations	43.53	9	4.84	36.04	> 99.95%
Remainder	6.04	45	0.134		

Table 4.2.2.4. Analysis of variance of ln Bq ^{137}Cs m^{-2} precipitation, January-December 1987 (from Table 4.2.2.2)

Variation	SSD	f	s^2	v^2	P
Between months	7.38	5	1.48	13.07	> 99.95%
Between locations	40.17	9	4.46	39.54	> 99.95%
Remainder	5.08	45	0.113		

The mean $^{90}Sr/^{137}Cs$ in precipitation in 1987 was: 1.44/28.6 = 0.05. However, if we look at the individual State experimental farms, two locations were atypical: Borris and Bornholm (Tornbygaard). At Borris, the ratio was 1.35/18.7 = 0.157. In Risø air, $^{90}Sr/^{137}Cs$ was 0.062 and the air at Bornholm showed a mean ratio of 0.026 in 1987.

The resuspension at Borris seems to be very low compared with the other locations.This means that the Chernobyl contribution is relatively low here compared with the global fallout, and as the $^{90}Sr/^{137}Cs$ in global fallout is 0.625, it is reasonable to get a high ratio (0.41) at this location. At Bornholm, the high ratio is probably due to an artefact. The rain collectors at Bornholm contains relatively much soil. This soil retains ^{137}Cs more efficiently than ^{90}Sr. The soil is removed from the sample before the precipitation of the Cs with AMP, and although the sample has been treated with acid, some Cs may still be retained in the soil which is discarded. Hence the precipitation at Bornholm seems to be depleted with ^{137}Cs relative to ^{90}Sr. However, Bornholm also shows a 2-3 times higher ^{90}Sr concentration than the other Danish locations (Table 4.2.1.1) and this was also the case in 1982, 1983, 1984 and 1985[1].

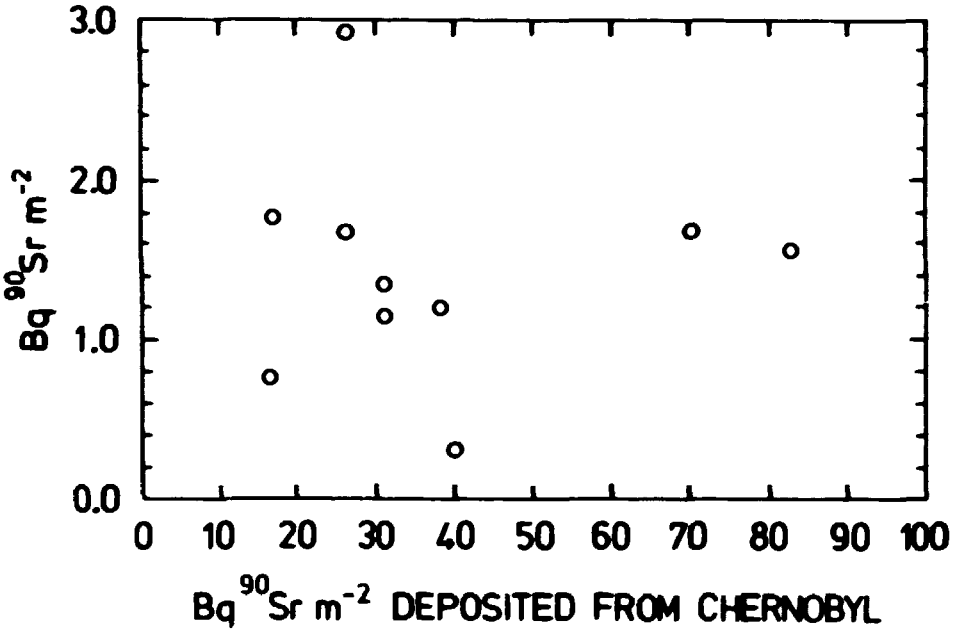
The rain collectors at Tornbygaard on the west coast of Bornholm are situated 70 metre above sea level on a slope 4 km from the Baltic sea. We have shown earlier that dry deposition increases with height[1,21]; furthermore, the nearness of Tornbygaard to the Baltic Sea may give rise to sea spray. In 1982 the global fallout decreased significantly and the relative importance of resuspension may therefore had become greater at that time. This may have resulted in higher ^{90}Sr (and ^{137}Cs) concentrations in the rain samples from Bornholm than from the other Danish locations because of the higher dry deposition at Tornbygaard, but, as mentioned above, the ^{137}Cs may partly have been removed from the samples with the impurities of soil.

The 10 m^2 ion exchange rain collector at Risø (Table 4.2.2.5) showed a ^{137}Cs deposit in 1987 of 20 Bq m^{-2} or 40 times less than in 1986. The $^{90}Sr/^{137}Cs$ was 0.026 at Risø which is half of what we found in air (0.062) and also lower than the countrywide mean for precipitation (0.05).

Table 4.2.2.5. Radiocesium in precipitation collected in the 10 m² ion exchanger at Risø in 1987

Month	Bq ^{137}Cs m^{-2}	Bq ^{137}Cs m^{-3}	$^{134}Cs/^{137}Cs$	mm precipitation
Jan	9.8	970	0.42	10.1
Feb	2.3	260	0.43	9.0
March	1.32	107	0.43	12.3
April	1.24	46	0.41	27
May	0.98	27	0.38	36
June	1.19	16.7	0.40	71
July	1.24	9.1	0.35	136
Aug	0.71	15.5	0.36	46
Sept	0.43	8.2	0.37	52
Oct	0.31	21	0.36	14.7
Nov	0.28	4.8	0.32	57
Dec	0.24	6.0	0.35	41
1987	Σ 20	39 (weighted mean)		Σ 513

Fig. 4.2.2. Strontium-90 in 1987 related to ^{90}Sr deposited from Chernobyl.



4.2.3. Shorter-lived γ-Emitters in Precipitation

At the beginning of 1987 it was still possible to measure shorter-lived γ-emitters from the Chernobyl accident in precipitation. As for radiocesium this deposition is considered to be a result of resuspension. For ^{106}Ru we estimated the resuspension in January-March 1987 to be ~ 2% of the original (decay-corrected) deposit.

The washout ratios (Bq m^3 rain/μBq m^3 air) calculated for Risø was 1.01/0.37 = 2.7 for ^{90}Sr and 39/6.0 = 6.5 for ^{137}Cs (Table 4.2.6). These values were significantly higher than the usually observed washout ratio of 1.9[21], either suggesting a more efficient washout of resuspended Chernobyl debris than of global fallout or less adherence of large resuspended particles to the air filters.

Table 4.2.3. Various γ-emitters in precipitation collected in the 10 m^2 ion exchanger at Risø in January-March 1987. (Unit: Bq m^{-2})

	Jan	Feb	March
^{95}Zr	0.58		
^{95}Nb	1.45	0.061 A	
^{103}Ru	0.37	0.06 B	
^{106}Ru	4.2	1.70	0.46
^{110m}Ag	0.187		
^{144}Ce	1.17	0.36 A	
mm precipitation	10.1	9.0	12.3

4.2.4. Tritium in Precipitation

As in previous years, the Risø rain (Table 4.2.4.1) contained higher tritium concentrations than those observed in other parts of the country.

Table 4.2.4.2 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. 2 times lower than that from Risø (1 m^2 sampler).

Table 4.2.4.1. Tritium in precipitation collected at Risø in 1987

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	0.010	1.8 ± 0.3	0.018	1.7 ± 0.3	0.017
Feb	0.009	1.3 ± 0.1	0.012	2.2 ± 0.0	0.020
March	0.012	2.3 ± 0.1	0.028	1.6 ± 0.1	0.019
April	0.027	2.5 ± 0.0	0.068	4.7 ± 0.2	0.127
May	0.036	2.0 ± 0.0	0.072	6.4 ± 0.2	0.23
June	0.071	4.6 ± 0.3	0.33	6.4 ± 0.2	0.45
July	0.136	4.8 ± 0.2	0.65	9.7 ± 0.9	1.32
Aug	0.046	4.6 ± 0.8	0.21	4.6 ± 0.3	0.21
Sept	0.053	4.8 ± 0.6	0.25	19.2 ± 0.7	1.02
Oct	0.015	2.8 ± 0.3	0.042	4.8 ± 0.0	0.072
Nov	0.057	2.2 ± 0.3	0.125	5.8 ± 0.1	0.33
Dec	0.041	2.6 ± 0.1	0.107	1.4 ± 0.1	0.057
1987	0.513	x̄ 3.1	Σ 1.612	x̄ 7.5	Σ 3.872

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

Table 4.2.4.2. Tritium in precipitation collected in Denmark in 1987. (Unit: kBq m^{-3})

Date	Tylstrup	Jyndevad	Bornholm
January	1.0±0.2	B.D.L.	1.6±0.1
February	1.6±0.4	0.9±0.0	1.2±0.0
March	1.5±0.4	1.6±0.2	1.3±0.2
April	2.8±0.1	1.7	1.3±0.2
May	3.1±0.2	1.2±0.1	1.8±0.0
June	2.2±0.0	0.9±0.1	1.2±0.1
July	3.2±0.2	1.9±0.0	2.9±0.3
August	2.6±0.2	2.0±0.0	2.4±0.3
September	2.2±0.2	0.9±0.2	1.1±0.3
October	1.3±0.2	1.0±0.2	1.3±0.1
November	1.3±0.1	1.3±0.0	2.0±0.0
December	B.D.L.	1.1±0.3	1.4±0.2
Mean	1.9	1.2	1.6

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 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 and tritium analyses.

Table 4.3.1. Radionuclides in ground water collected in 1987

Location	Date	Bq ^{90}Sr m^{-3}	kg Ca m^{-3}	kBq ^{3}H m^{-3}
Hvidsten	Feb	0.069 A	0.082	B.D.L.
Feldbak	Feb	73	0.039	2.4±0.1
Rømø	Feb	0.191	0.027	B.D.L.
Klemensker	May	0.012 B	0.055	B.D.L.
Robberdal	May	0.057 A	0.0144	2.6±0.3
Hasselø	Feb	0.0106 B	0.077	B.D.L.
Fåretofte	Feb	0.080	0.146	5.2±0.2
Kalundborg	Feb	0.124	0.089	1.6±0.6
Ravnholt	Feb	0.081 A	0.105	4.6±0.1
Fredericia	Feb	0.27	0.080	2.0±0.0
Geometric mean		0.065*	0.071**	1.8**
Median		0.063	0.078	1.8

A sample of ground water from Maglekilde in Roskilde contained 1.39 Bq ^{90}Sr m^{-3}, 4.5±0.4 kBq ^{3}H m^{-3} and 0.20 kg Ca m^{-3}.

*Feldbak was not included in the geometric mean.
**Arithmetic mean.

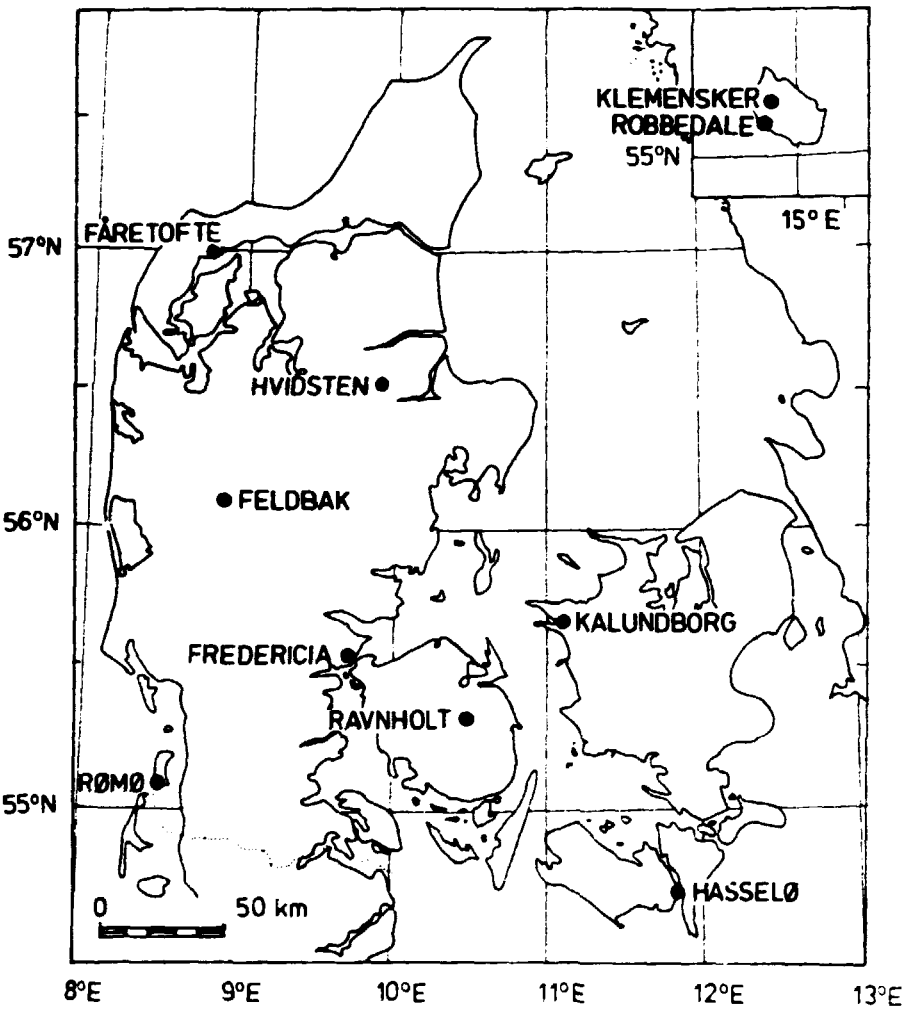
The error term is 1 S.E. of the mean of double determinations.

The median level of ^{90}Sr in 1987 was compatible with the values found since 1967 (cf. Fig. 4.3.1.2).

The tritium concentrations in 1987 were a little higher than the 1986 levels.

As appears from Fig. 4.3.1.3, the ^{90}Sr levels in ground water from Feldbak have been on the order of 50-100 Bq m^{-3} in later years. The arithmetic mean of ^{90}Sr in Danish ground water in 1987 (excluding Feldbak and including Maglekilde) was 0.23 Bq m^{-3}. The predicted mean (cf. Appendix C.1) was 0.26 Bq m^{-3}.

Fig. 4.3.1.1. Ground water sampling locations in Denmark.



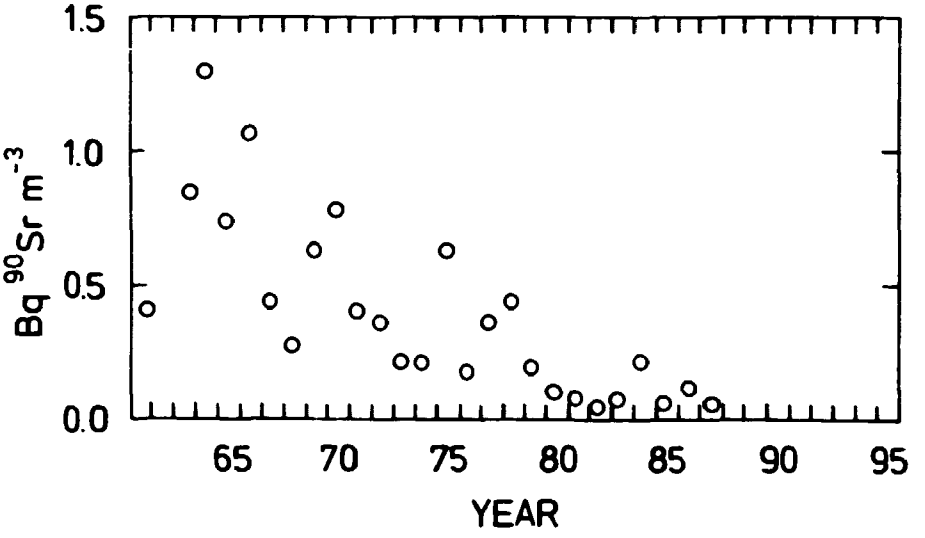
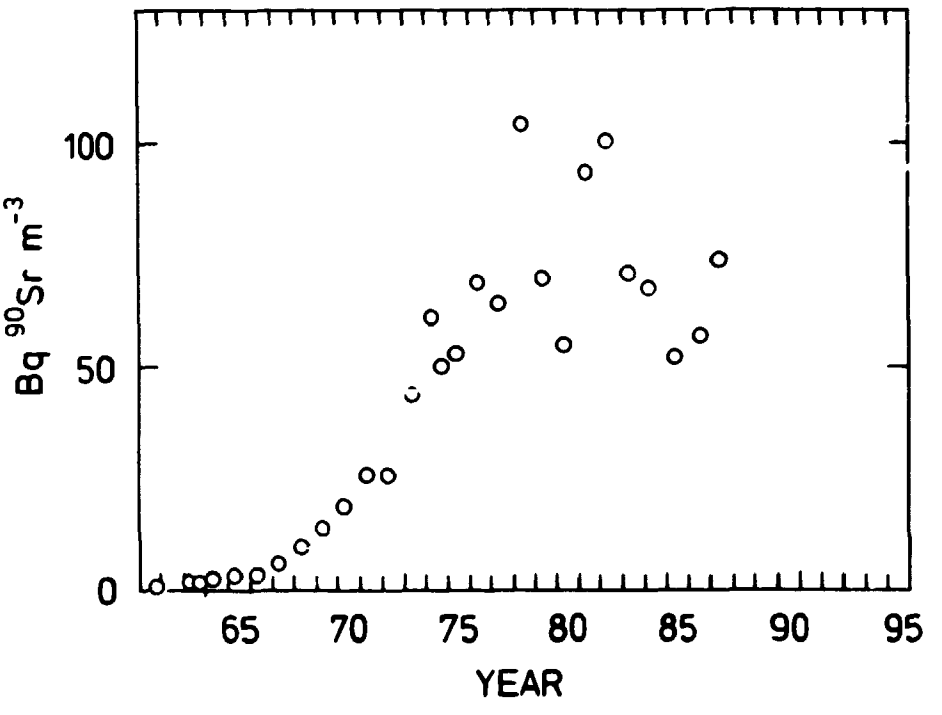


Fig. 4.3.1.2. Median ^{90}Sr levels in Danish ground water, 1961-1987.

Fig. 4.3.1.3. Strontium-90 in ground water at Feldbak 1961-1987.



4.3.2. Strontium-90, Radiocesium and Tritium in Fresh Water from Danish Lakes and Streams

The mean levels in 1987 were 9.7 Bq ^{90}Sr m^{-3} in streams and 21 Bq ^{90}Sr m^{-3} in lakes. The level in lakes in 1987 was 74% of that in 1986, and streams were unchanged (Tables 4.3.2.1 and 4.3.2.2).

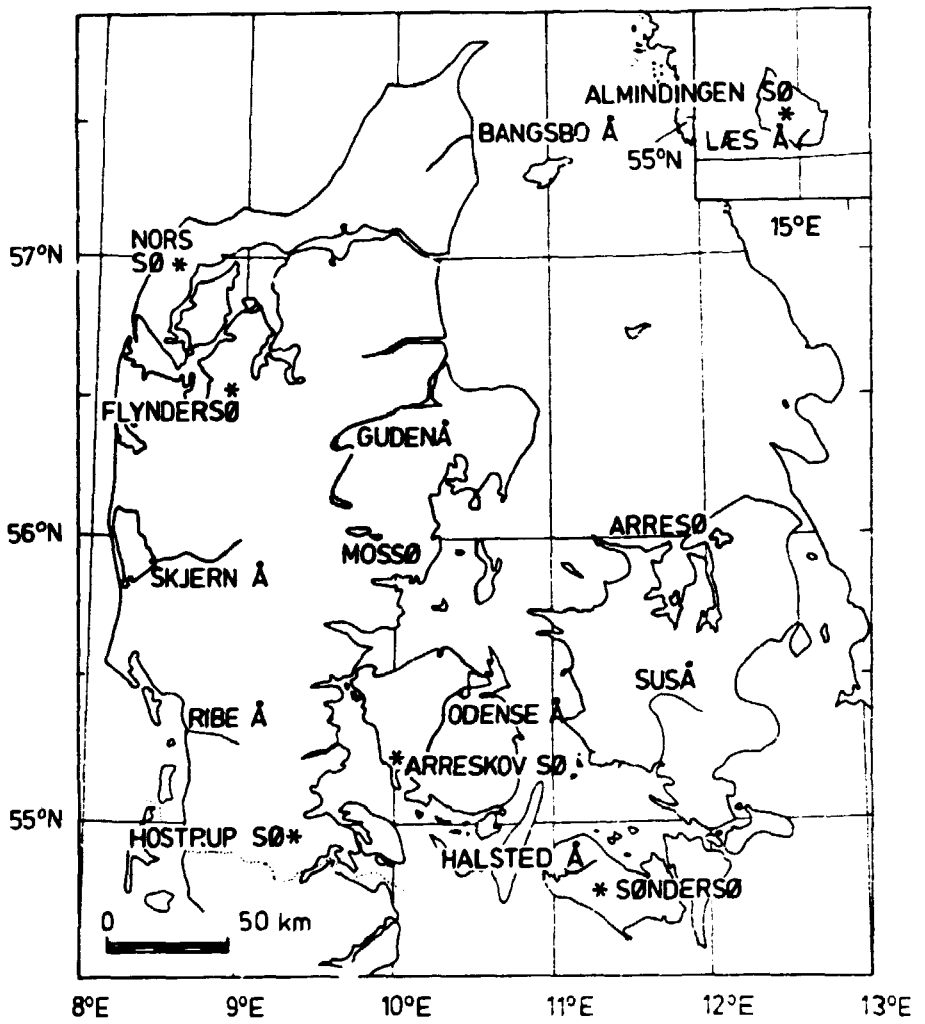


Fig. 4.3.2.1. Sample locations for fresh water from Danish streams (å) and lakes (sø).

Table 4.3.2.1. Strontium-90 in Danish stream water collected in February 1987

Stream	Bq ^{90}Sr m^{-3}	kg Ca m^{-3}
Bangsbo å	8.0	0.055
Gudenå	6.6	0.045
Skjern å	7.9	0.026
Ribe å	5.7	0.051
Odense å	9.9	0.093
Suså	11.1	0.099
Halsted å	12.4	0.172
Læs å (May)	16.2	0.031
Mean	9.7	0.072
Relative S.E.	13%	24%

Table 4.3.2.2. Strontium-90 in Danish lake water collected in February 1987

Lake	Bq ^{90}Sr m^{-3}	kg Ca m^{-3}
Norssø	19.9	0.0126
Mossø	7.9	0.021
Flyndersø	10.0	0.0197
Hostrupsø	26	0.0138
Arreskovsø	30	0.041
Arresø	20	0.062
Søndersø	25	0.054
Almindingen sø (May)	26	0.023
Mean	21	0.031
Relative S.E.	14%	22%

Table 4.3.2.3. Radiocesium in Danish stream water collected in February 1987

Stream	Bq ^{137}Cs m^{-3}	$^{134}Cs/^{137}Cs$
Bangsbo å	2.0 A	
Gudenå	6.7	0.44
Skjern å	2.3 A	
Ribe å	2.2 A	
Odense å	2.6	
Suså	3.1	
Halsted å	1.8 B	
Læs å (May)	2 B	
Mean	2.8	
Relative S.E.	20%	

Table 4.3.2.4. Radiocesium in Danish lake water collected in February 1987

Lake	Bq ^{137}Cs m^{-3}	$^{134}Cs/^{137}Cs$
Norssø	9.9	0.41
Mossø	3.3	
Flyndersø	28	0.38
Hostrupsø	35	0.41
Arreskovsø	14.8	0.36
Arresø	36	0.39
Søndersø	38	0.46
Almindingen sø (May)	1.98 A	
Mean	21	0.40
Relative S.E.	26%	3%

In the case of ^{137}Cs (Tables 4.3.2.3 and 4.3.2.4), the mean level in streams was 2.8 Bq m^{-3} and in lakes we found 21 Bq m^{-3}. The $^{134}Cs/^{137}Cs$ ratios suggest that all ^{137}Cs found in Danish streams and lakes in 1987 arose from the Chernobyl accident.

Since October 1986 the mean concentrations in streams decreased by a factor of 2.8 ± 1.54 (N = 6; ± 1 S.D.) and in lakes by a factor of 2.9 ± 3.5 (N = 7; ± 1 S.D.). Hence some lakes actually increased in ^{137}Cs activity.

Compared with rain water in January-February 1987 which showed a mean concentration of 124 Bq ^{137}Cs m^{-3}, the stream water contained 2% and the lake water 17% of this level.

The tritium contents in streams (Table 4.3.2.5) and in lakes (Table 4.3.2.6) were a little higher than those observed in 1986.

Appendix C1 shows that the observed ^{90}Sr level in streams is 1.52 times that predicted, and in the case of lake water the observed mean concentration is 5.3 times that predicted, suggesting a poor prediction model for lake water.

Table 4.3.2.5. Tritium in Danish stream water collected in February 1987

Stream	kBq ^{3}H m^{-3}
Bangsbo å	3.0 ± 0.0
Gudenå	1.5 ± 0.2
Skjern å	2.0 ± 0.0
Ribe å	2.1 ± 0.1
Odense å	1.5 ± 0.3
Suså	1.5 ± 0.0
Halsted å	B.D.L.
Læs å (May)	2.9 ± 0.3
Mean	1.81
Relative S.E.	19%

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

Table 4.3.2.6. Tritium in Danish lake water collected in February 1987

Lake	kBq ^{3}H m^{-3}
Norssø	1.3 ± 0.1
Mossø	1.4 ± 0.5
Flyndersø	1.3 ± 0.4
Hostrupsø	1.4 ± 0.0
Arreskovsø	1.8 ± 0.1
Arresø	2.0 ± 0.1
Søndersø	2.0 ± 0.2
Almindingen sø (May)	2.7 ± 0.4
Mean	1.74
Relative S.E.	10%

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

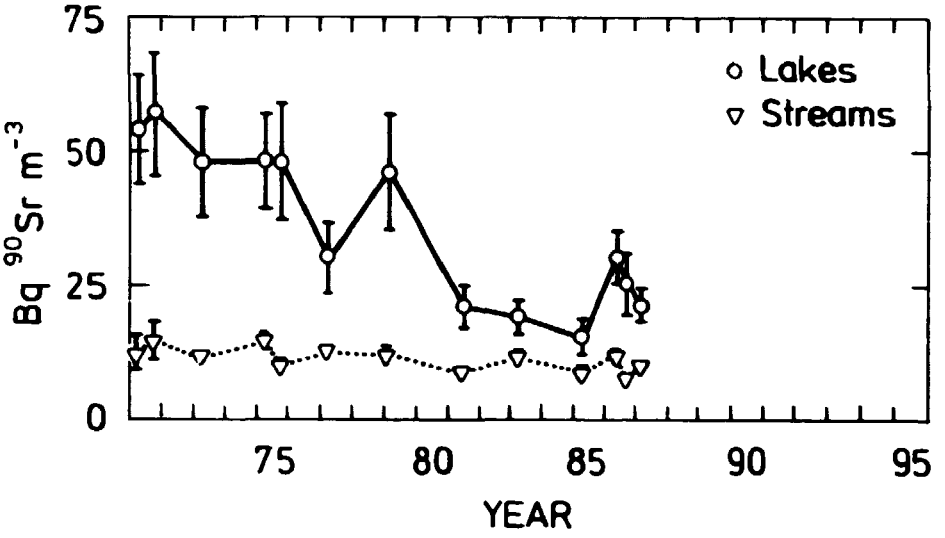


Fig. 4.3.2.2. Strontium-90 concentrations (±1 S.E.) in 8 Danish streams and 8 Danish lakes, collected since 1971.

4.3.3. Radionuclides in Danish Drinking Water

The ^{90}Sr concentrations were two times higher than those in 1986. The ^{137}Cs levels in drinking water in 1987 were an order of magnitude less than those observed last year. The concentrations were now at the limit of detection ~ 0.05 Bq m^{-3}.

The median ^{90}Sr level was 4-5 times higher in drinking water than in ground water and the arithmetic mean was 2.3 times higher. The tritium mean level in drinking water was lower than that in ground water.

Table 4.3.3. Strontium-90, cesium-137 and tritium in drinking water collected in June 1987

Zone	Bq ^{90}Sr m^{-3}	Bq ^{137}Cs m^{-3}	kBq ^{3}H m^{-3}	kg Ca m^{-3}
I: N. Jutland	0.91	0.063 A	1.9±0.3	0.039
II: E. Jutland	0.34	0.056 B	1.8±0.1	0.092
III: W. Jutland	1.72	0.069 B	1.1±0.1	0.046
IV: S. Jutland	0.086	0.050 B	0.9±0.2	0.092
V: Funen	0.139	0.069 B	B.D.L.	0.109
VI: Zealand	0.079 A	0.047 B	B.D.L.	0.109
VII: Lolland-Falster	0.21 B	0.063 B	B.D.L.	0.129
VIII: Bornholm	0.83	0.069 B	B.D.L.	0.079
Mean	0.54	0.061*	0.7	0.087
Median of zones	0.28	0.063	0.5	0.092

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

*Combined sample of all zones gave 0.047 Bq ^{137}Cs m^{-3} (A)

4.4. Radionuclides in Sea Water

As in previous years, sea water samples were collected by M/S Fyrholm from inner Danish waters (cf. Tables 4.4.1-4.4.2 and Figs. 4.4.1-4.4.6). Furthermore, sea water samples were collected at Barsebäck in the Sound, and at Ringhals in the Cattegat (Table 4.4.3). Samples were obtained from the research vessel DANA, which in 1987 has collected samples from the Danish Straits as well as from the North and the Baltic Seas (Table 4.4.3 and Figs. 4.4.4-4.4.7).

In the samples collected around Zealand in May (Table 4.4.1), ^{137}Cs from Chernobyl amounted to 87% of the total ^{137}Cs activity in the surface water, and to 62% of the ^{137}Cs found in bottom water. From November 1986 to May 1987, the surface waters ^{137}Cs-Chernobyl content increased from 46 to 69 Bq m^{-3}, while the bottom water decreased from 59 to 37 Bq ^{137}Cs m^{-3}.

In November 1987 (Table 4.4.2), 87% of the ^{137}Cs in surface water and 71% in bottom water came from Chernobyl. The Chernobyl ^{137}Cs concentrations did not change significantly from May to November in surface water (69 and 68 Bq ^{137}Cs m^{-3}, respectively, but in bottom water we saw an increase from May to November: 37 to 46 Bq m^{-3}.

From June 1986[1)] to November 1987, the Chernobyl contribution of ^{137}Cs in the central North Sea decreased from 37 ± 6 Bq m^{-3} (± 1 S.E.; N = 7) to 14 ± 2 (± 1 S.E.; N = 10) (cf. Table 4.4.3). In October 1986[1)] the mean concentration in the German Bight of Chernobyl-derived ^{137}Cs was 35 ± 11 Bq m^{-3} (± 1 S.E.; N = 8). In the calculation we corrected for the ^{134}Cs coming from La Hague estimated from a sampling in April 1986 ($\sim 1.7 \pm 0.4$ Bq ^{134}Cs m^{-3}) (± 1 S.E.; N = 10). In February 1987, the Jutland Current contained 21 ± 2 Bq ^{137}Cs m^{-3} from Chernobyl (± 1 S.E.; N = 6) and in May 1987 we found 12 ± 1 Bq m^{-3} (± 1 S.E.; N = 6).

The Chernobyl signal in the central North Sea has thus shown a rapid decrease. This may be due to in-flow of less contaminated water from the southern part of the North Sea and the English Channel which were not contaminated to any large extent by the Chernobyl accident[29)].

The main contributor to ^{137}Cs in the Danish Straits has become water from the Baltic Sea where high concentrations were observed in 1986[1)]. Figures 4.4.8 and 4.4.9 show that already between November 1986 and May 1987 the water in the western Baltic Sea began to increase in ^{137}Cs; but not until 1988 do we observe an increase in the surface water of the southern Cattegat.

Fig. 4.4.1. Strontium-90 in surface sea water from inner Danish waters, 1962-1987. (1 S.D. indicated) (from Tables 4.4.1 and 4.4.2).

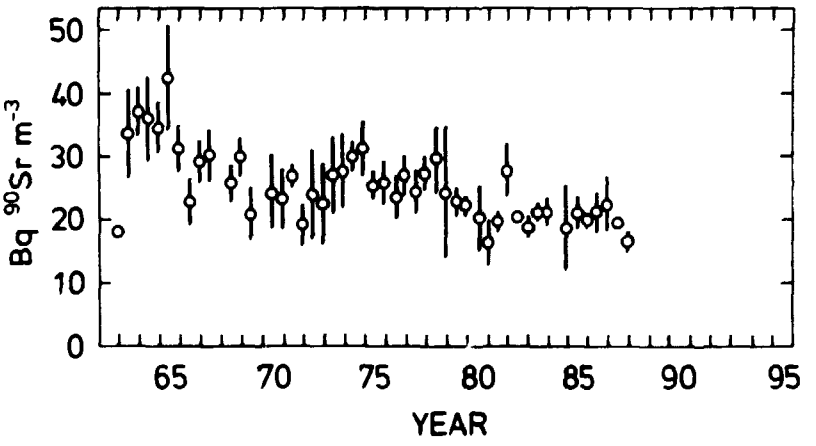


Table 4.4.1. Radionuclides in sea water collected around Zealand in May 1987

Location	Date in May	Position N	Position E	Depth in m	^{90}Sr Bq m^{-3}	^{137}Cs Bq m^{-3}	^{134}Cs / ^{137}Cs	^{3}H kBq m^{-3}	Salinity ‰
Kullen	25	56°15'	12°25'	2	-	84	0.35	3.4 ± 0.3	10.2
"				24	-	44	0.17	B.D.L.	34.6
Hesselø	25	56°10'	11°47'	2	-	62	0.26	3.2 ± 0.1	19.0
"				24	8.0	48	0.17	B.D.L.	33.2
Kattegat SW	27	56°07'	11°10'	2	-	66	0.31	2.9 ± 0.1	16.1
"				36	-	52	0.18	1.3 ± 0.2	32.3
Asnæs rev	27	55°39'	10°46'	2	-	67	0.32	3.7 ± 0.2	12.6
" "				27	-	49	0.20	B.D.L.	32.0
Halskov rev	27	55°23'	11°03'	2	19.9	72	0.33	3.4 ± 0.1	12.2
" "				25	-	55	0.20	B.D.L.	31.0
Langeland bælt	27	54°52'	10°50'	2	20.2	72	0.36	3.4 ± 0.5	11.2
" "				17	-	60	0.23	1.7 ± 0.2	24.2
Femern bælt	26	54°36'	11°04'	2	18.9	76	0.33	3.7 ± 0.3	10.2
" "				27	-	67	0.27	1.5 ± 0.1	20.2
Gedser odde	26	54°28'	11°59'	2	-	80	0.39	4.3 ± 0.6	8.5
" "				17	-	71	0.36	4.1 ± 0.1	9.9
Møen	26	54°57'	12°41'	2	-	90	0.38	3.8 ± 0.1	7.9
"				23	-	62	0.34	3.8 ± 0.8	8.1
The Sound - South	26	55°25'	12°36'	2	-	97	0.36	6.7 ± 0.1	7.8
" " "				13	-	76	0.35	4.7 ± 0.2	16.2
The Sound - North A	25	55°48'	12°44'	2	-	81	0.37	4.5 ± 0.1	8.3
" " "				19	8.6	67	0.16	1.9 ± 0.2	26.6
The Sound - North B	25	55°59'	12°42'	2	-	91	0.35	3.8 ± 0.3	8.4
" " "				29	-	56	0.23	B.D.L.	33.8
Mean				Surface	19.7	78	0.34	3.9	11.0
S.D.					0.7	11	0.03	0.99	3.5
S.E.					0.4	3	0.01	0.28	1.0
Mean				Bottom	8.3	59	0.24	1.6	25.2
S.D.					0.4	10	0.07	1.75	9.5
S.E.					0.3	3	0.02	0.51	2.8

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

Table 4.4.2. Radionuclides in sea water collected around Zealand in November-December 1987

Location	Date	Position N	Position E	Depth in m	^{90}Sr Bq m^{-3}	^{137}Cs Bq m^{-3}	$^{134}Cs/^{137}Cs$	Salinity ‰
Kullen	Dec 2	56°15'	12°25'	2	17.9	89	0.30	9.6
"				21	-	47	0.16	30.2
Hornsele	Nov 24	56°10'	11°47'	2	15.1	62	0.26	20.9
"				24	-	44	0.13	33.5
Kattegat SW	Nov 30	56°07'	11°10'	2	-	67	0.23	22.1
"				35	13.8	56	0.15	29.3
Asnæs rev	Nov 30	55°39'	10°46'	2	-	66	0.25	16.3
" "				23	13.2	57	0.21	26.4
Halskov rev	Nov 30	55°23'	11°03'	2	-	69	0.28	14.9
" "				23	-	56	0.19	27.0
Langeland bælt	Nov 30	54°52'	10°50'	2	-	72	0.29	12.7
" "				21	-	69	0.25	19.3
Femern bælt	Dec 1	54°36'	11°04'	2	-	78	0.29	13.2
" "				23	-	60	0.26	20.3
Gedser odde	Dec 1	54°28'	11°59'	2	16.9	83	0.30	10.3
" "				18	-	76	0.28	13.2
Møen	Dec 1	54°57'	12°41'	2	-	91	0.32	8.4
"				22	-	83	0.30	9.3
The Sound - South	Dec 1	55°25'	12°36'	2	-	86	0.31	8.3
" " "				12	18.5	92	0.31	8.5
The Sound - North A	Dec 2	55°48'	12°44'	2	-	88	0.30	9.2
" " "				18	-	79	0.29	10.3
The Sound - North B	Dec 2	55°59'	12°42'	2	-	83	0.30	11.5
" " "				27	11.6	51	0.14	33.1
Mean				Surface	16.6	78	0.29	13.1
S.D.					1.4	10	0.03	4.7
S.E.					0.8	3	0.01	1.3
Mean				Bottom	14.3	64	0.22	21.7
S.D.					3.0	15	0.07	9.5
S.E.					1.7	4	0.02	2.7

Table 4.4.3. Radionuclides in sea water collected in the Danish Straits, North Sea, and Baltic Sea in 1987

Location/cruise	Date	Position N	Position E or W	Depth in m	^{90}Sr Bq m^{-3}	^{137}Cs Bq m^{-3}	$\frac{^{134}Cs}{^{137}Cs}$	^{3}H kBq m^{-3}	Salinity ‰
North Sea/Dana 1a	Feb 3	56°15'	7°40'E	0	14.7	69	0.12	B.D.L.	30.4
-"-	Feb 3	55°47'	7°15'E	0	15.4	62	0.13	B.D.L.	33.7
-"-	Feb 4	55°02'	8°02'E	0	16.1	42	0.31	1.6±0	31.1
-"-	Feb 4	55°17'	8°11'E	0	16.5	54	0.14	0.9±0.1	33.4
-"-	Feb 5	54°43'	7°39'E	0	14.5	33	0.35	1.4±0.1	34.9
-"-	Feb 5	54°56'	7°26'E	0	14.5	32	0.20	1.2±0.1	31.8
-"-	Feb 9	55°56'	4°49'E	0	14.2	31	-		
-"-	Feb 11	54°42'	0°38'E	0	10.5	75	0.16	B.D.L.	34.9
-"-	Feb 17	58°12'	3°32'E	0	3.2	16.5	0.29	B.D.L.	35.1
-"-	Feb 19	57°24'	7°54'E	0	11.2	66	0.14	B.D.L.	34.7
Baltic Sea/Dana 2a	Mar 15	55°49'	18°22'E	0	18.2	57	0.35	4.3±0.2	7.8
-"-	Mar 20	55°40'	15°58'E	0		113	0.39	4.4±0.3	7.7
-"-	Mar 21	55°31'	15°53'E	0		97	0.39	4.3±0.1	7.7
North Sea/Dana 4	May 14	56°36'	7°53'E	0	9.8	40	0.12		33.1
-"-	May 4	56°59'	7°08'E	0	13.1	68	0.15		32.6
-"-	May 18	55°23'	7°27'E	0	14.2	30	0.12		31.9
-"-	May 18	55°43'	7°39'E	0	14.6	31	0.13		32.1
-"-	May 18	56°06'	8°04'E	0	14.4	27	0.24		30.8
-"-	May 19	56°11'	8°01'E	0	13.8	31	0.15		32.3
Skagerak/Dana 4	May 20	57°07'	8°24'E	0	13.7	50	0.11		33.2
-"-	May 21	57°42'	9°42'E	0	11.3	54	0.13		31.8
-"-	May 21	57°30'	9°04'E	0	11.7	48	0.18		32.4
Cattegat/Dana 4	May 23	56°48'	10°47'E	0	12.0	61	0.27		21.3
-"-	May 24	57°40'	10°49'E	0	13.7	60	0.24		23.2
-"-	May 24	56°51'	11°28'E	0	12.9	59	0.26		21.2
North Sea/Dana 9	Nov 22	54°13'	2°29'E	0		58	0.13		34.5
-"-	Nov 22	54°15'	0°30'E	0		49	0.13		34.4
-"-	Nov 25	55°15'	0°30'E	0	3.8	37	0.16		34.6
-"-	Nov 28	57°15'	0°03'W	0		35	0.10		34.8
-"-	Nov 28	56°14'	0°30'E	0		28	0.11 A		34.9
-"-	Dec 2	57°15'	1°30'E	0		29	0.14		34.7
-"-	Dec 3	56°18'	2°28'E	0		35	0.13		34.8
-"-	Dec 4	58°14'	0°25'W	0	3.7	30	0.12		34.7
-"-	Dec 4	58°16'	1°29'E	0		27	0.10		34.8
-"-	Dec 5	58°15'	3°30'E	0		41	0.12		34.4
Klint	Apr 10	55°58'	11°35'E	0		52	0.21	1.4±0.1	26.9
-"-	May 21	55°58'	11°35'E	0		65	0.28	2.6±0.1	18.9
-"-	June 22	55°58'	11°35'E	0		70	0.28	2.4±0.2	16.7
-"-	July 15	55°58'	11°35'E	0		63	0.29		17.9
-"-	Aug 13	55°58'	11°35'E	0		63	0.28	5.9±0.3	17.5
-"-	Sep 15	55°58'	11°35'E	0		61	0.26	1.7±0.3	18.5
-"-	Oct 15	55°58'	11°35'E	0		62	0.27		18.2
-"-	Nov 13	55°58'	11°35'E	0		59	0.26		20.8
-"-	Dec 17	55°58'	11°35'E	0		64	0.25		17.8

Table 4.4.3. (continued)

Location/cruise	Date	Position N	Position E or W	Depth in m	^{90}Sr Bq m^{-3}	^{137}Cs Bq m^{-3}	^{134}Cs / ^{137}Cs	^{3}H kBq m^{-3}	Salinity ‰
Hessele	May 25	56°10'	11°43'E	0		57	0.27	2.4 ± 0.6	19.3
-"-	May 25	56°13'	12°05'E	0		66	0.27	2.5 ± 0.1	18.8
-"-	May 25	56°13'	12°05'E	24	8.0	47	0.20	B.D.L.	34.0
-"-	Nov 24	56°13'	12°05'E	0		63	0.24		21.4
-"-	Nov 24	56°13'	12°05'E	23	12.3	48	0.11		32.3
-"-	Dec 14	56°12'	11°43'E	0		65	0.24		19.0
Ringhals	May 13	57°15'	12°03'E	0		57	0.27	2.6 ± 0.2	20.3
-"-	May 13	57°15'	12°03'E	23		48	0.20	3.5 ± 0.1	27.7
-"-	July 1	57°16'	12°06'E	0		61	0.25		17.8
-"-	Aug 1	57°16'	12°06'E	0		65	0.28		19.2
-"-	Sep 1	57°16'	12°06'E	0		60	0.28		18.0
-"-	Oct 1	57°16'	12°06'E	0		60	0.24	2.3 ± 0.1	31.5
-"-	Nov 2	57°16'	12°06'E	0		63	0.22		20.7
-"-	Dec 1	57°16'	12°06'E	0		56	0.22		22.1
-"-	Dec 16	57°15'	12°03'E	0		60	0.22		23.3
-"-	Dec 16	57°15'	12°03'E	21		47	0.13		31.2
Anholt	May 14	56°43'	11°30'E	0	16.6	63	0.25	2.0 ± 0.1	20.0
-"-	Dec 14	56°43'	11°30'E	0		60	0.27		19.5
Læsø	May 13	57°18'	10°56'E	0	14.0	59	0.23	2.1 ± 0.4	24.2
-"-	May 13	57°19'	11°07'E	0		59	0.23	1.8 ± 0.2	25.1
Barsebäck	May 26	55°45'	12°52'E	0		84	0.38	5.5 ± 0.4	8.0
-"-	May 26	55°45'	12°52'E	22		52	0.24	B.D.L.	29.7
-"-	July 1	55°44'	12°56'E	0		81	0.34		9.5
-"-	Aug 1	55°44'	12°56'E	0		80	0.34		11.9
-"-	Sep 1	55°44'	12°56'E	0		76	0.33		10.8
-"-	Dec 2	55°45'	12°56'E	0		90	0.30		8.6
-"-	Dec 2	55°45'	12°56'E	18		50	0.19		29.5
Stevns-Møen	May 26	55°11'	12°36'E	0	20.7	94	0.38	4.2 ± 0.3	7.8
-"-	May 26	55°11'	12°36'E	23		75	0.37	4.3 ± 0.1	8.3
-"-	Dec 1	55°11'	12°36'E	0		91	0.31		8.2
-"-	Dec 1	55°11'	12°36'E	23		86	0.32		8.5
Møen-Gedser	May 26	54°42'	12°14'E	0	21.2	88	0.37	3.6 ± 0.3	8.1
-"-	May 26	54°42'	12°14'E	18		70	0.35	4.2 ± 0.1	10.6
-"-	Dec 1	54°42'	12°21'E	0		91	0.30		8.9
-"-	Dec 1	54°42'	12°21'E	16		65	0.25		18.3
Lund	Sep 14	55°15'	12°18'E	0		81	0.32		9.3
-"-	Oct 14	55°15'	12°18'E	0		79	0.33		9.3
-"-	Nov 11	55°15'	12°18'E	0		86	0.32		8.3
-"-	Dec 16	55°15'	12°18'E	0		78	0.31		9.0
Klintholm	Nov 11	54°57'	12°28'E	0		88	0.32		8.3
-"-	Dec 17	54°57'	12°28'E	0		87	0.31		8.4

Table 4.4.3. (continued)

Location/cruise	Date	Position N	Position E or W	Depth in m	^{90}Sr Bq m^{-3}	^{137}Cs Bq m^{-3}	^{134}Cs / ^{137}Cs	^{3}H kBq m^{-3}	Salinity ‰
Hals[illegible]ov	Nov 13	55°21'	11°07'E	0		77	0.30		12.2
-"-	Dec 17	55°21'	11°07'E	0		73	0.26		17.7
Bolund	May 7	55°42'	12°05'E	0		63	0.34	9.6 ± 0.2	12.4
Bornholm	May 19	55°05'	15°09'E	0		92	0.38	3.7 ± 0.8	7.7
-"-	Nov 17	54°59'	14°48'E	0		98	0.33		7.6
-"-	Dec 13	55°05'	15°09'E	0		104	0.32		7.7

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

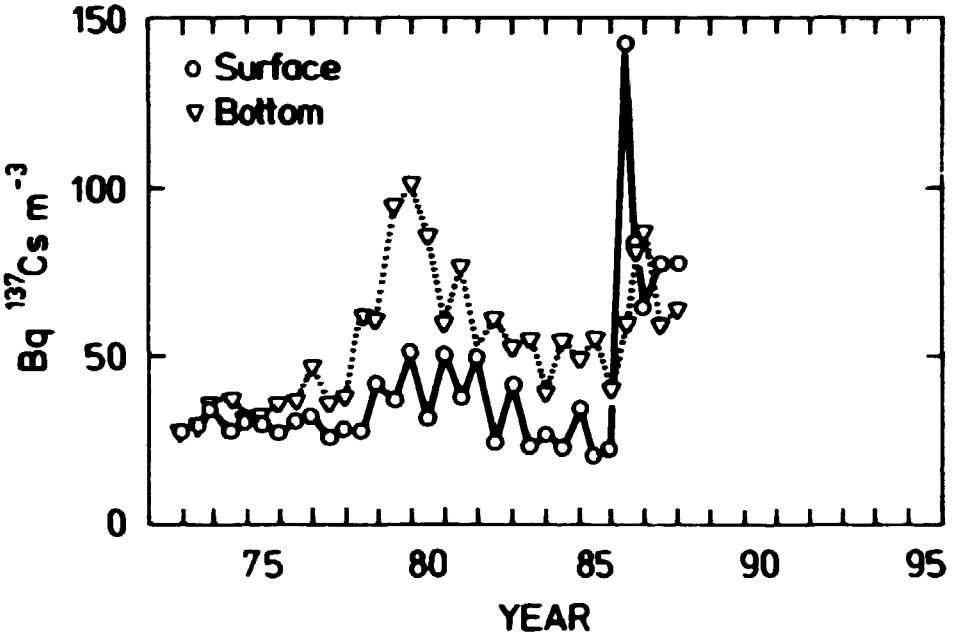


Fig. 4.4.2. Cesium-137 in surface and bottom water collected in inner Danish waters 1972-1987.

During most of 1987, the surface water concentrations in the southern Cattegat remained constant in Chernobyl ^{137}Cs. This was because the Baltic water was diluted with low-activity North Sea water. But in 1988 the "Baltic signal" had become so strong that it could overrule the dilution from the North Sea, and the surface water in southern Cattegat began to show an increase.

If we calculate the regressions between salinity and ^{134}Cs concentrations in sea water from the Danish Straits collected between 10 and 13° E we get the following equations:

May-June 1987: Bq ^{134}Cs m^{-3} = 36.0 - 0.855·salinity in ‰

Nov-Dec 1987: Bq ^{134}Cs m^{-3} = 33.9 - 0.868·salinity in ‰

May-June 1988: Bq ^{134}Cs m^{-3} = 35.6 - 0.947·salinity in ‰

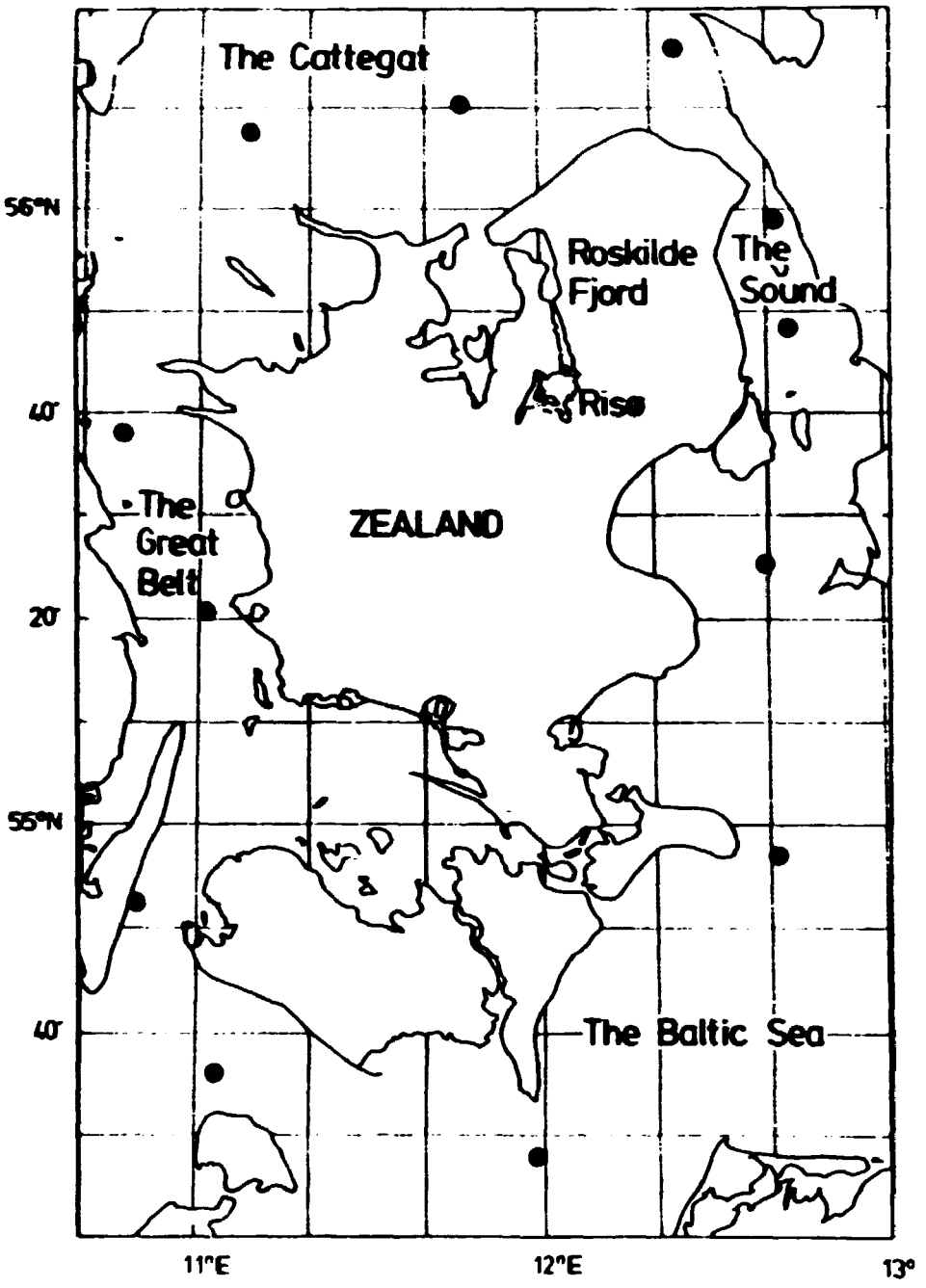


Fig. 4.4.3. Sea water locations around Zealand.

The mean salinity in Danish sea water in 1987 was 18‰ (cf. Table. 4.1 and 4.4.2). Hence the calculated mean concentrations of ^{134}Cs in the Danish Straits become: 20.6 Bq m^{-3} in May-June 1987; 18.3 in Nov-Dec 1987 and 18.6 in May-June 1988. If all data were decay-corrected to May-June 1987 we get: 20.6, 21.5, and 26.0, respectively. This means that the decay-corrected radiocesium from Chernobyl in the Danish Straits increased from May-June 1987

to Nov-Dec 1987 by a factor of 1.04 and from Nov-Dec 1987 to May-June 1988 by a factor of 1.21.

The monthly samples collected at Klint (Table 4.4.3 and Fig. 4.4.9) represent surface water in the southern Cattegat (cf. also Fig. 4.4.8). From April to May the concentration of Chernobyl ^{137}Cs increased by a factor of nearly 2 and since then the concentrations of Cherbobyl ^{137}Cs has been rather constant at Klint. However, in 1988 the levels increase again due to the appearance of contaminated water from the Baltic Sea.

Fig. 4.4.4. Strontium-90 in surface sea water collected in 1987. (Unit: Bq m^{-3}).

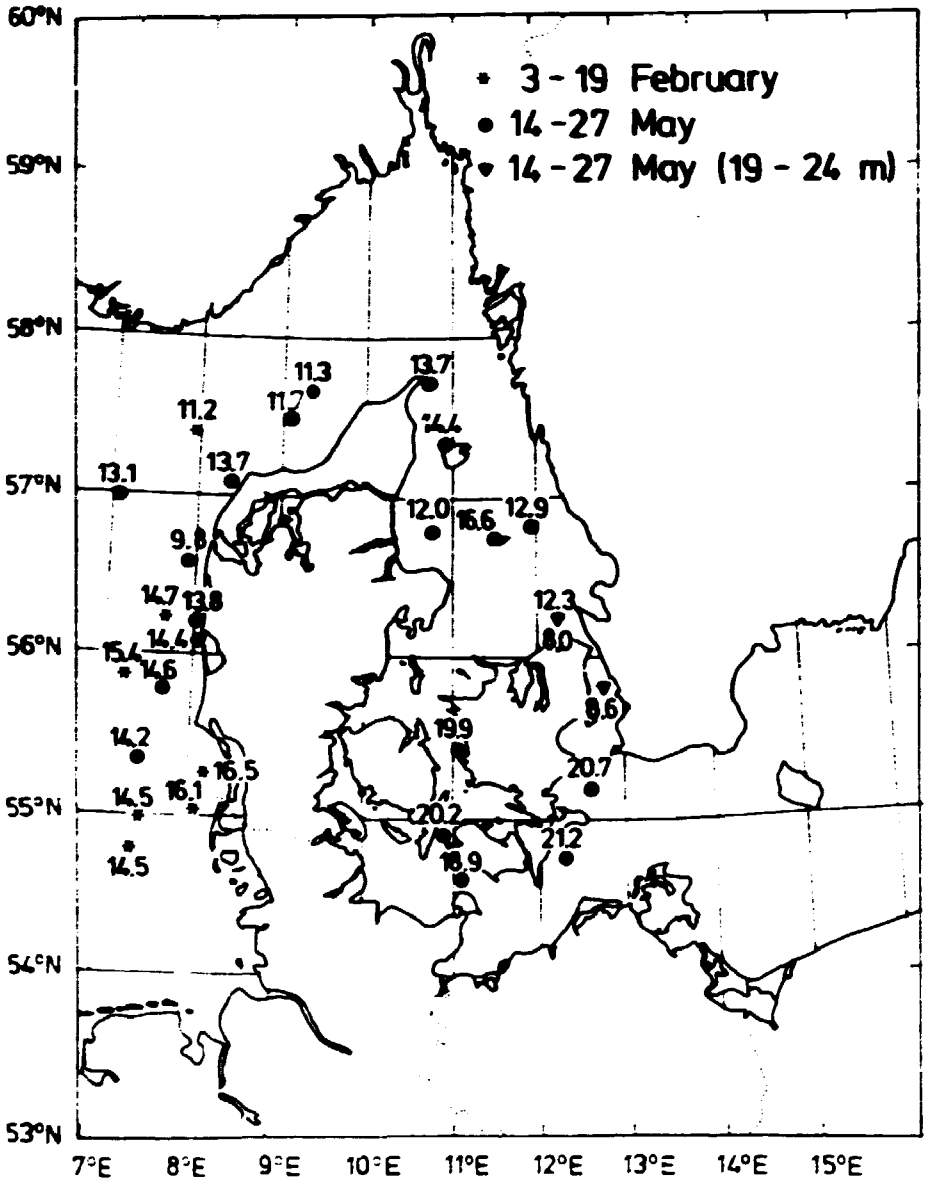


Table 4.4.4. Tritium in surface sea water in the Danish Straits in 1987

Location	Position N	Position E	Date	Salinity in ‰	^3H kBq m^{-3}
Barsebäck 25*			Jan 2	11.6	3.5 ± 0.2
"			Apr 1	5.1	3.0 ± 0.1
"			May 1	8.0	4.2 ± 0.4
"			June 1	7.9	4.7 ± 0.1
"			July 1	9.5	
"			Aug 1	11.9	
"			Sep 1	10.8	
"			Oct 2	10.0	3.8 ± 0.2
"			Nov 3	9.6	
"			Dec 2	8.7	
Ringhals 95**			Jan 2	21.8	3.5 ± 0.0
"			Feb 2	20.6	3.2 ± 0.0
"			Mar 2	15.7	3.3 ± 0.2
"			Apr 2	16.4	
"			May 1	17.6	5.4 ± 0.4
"			June 1	14.9	2.8 ± 0.1
"			July 1	18.5	
"			Aug 1	19.4	
"			Sep 1	18.2	
"			Oct 1	21.4	2.7 ± 0.1
"			Nov 2	20.8	
"			Dec 1	22.5	
Gilleleje	56°07'	12°19'	Apr 24	17.3	3.0 ± 0.1
"	56°07'	12°19'	May 20	17.2	3.1 ± 0.3
"	56°07'	12°19'	June 22	16.8	2.4 ± 0.1
"	56°07'	12°19'	July 16	20.2	
"	56°07'	12°19'	Aug 14	19.8	
"	56°07'	12°19'	Sep 14	16.7	
"	56°07'	12°19'	Oct 16	24.4	
"	56°07'	12°19'	Nov 12	20.8	
"	56°07'	12°19'	Dec 16	18.7	
Strøbyegede	55°25'	12°15'	Apr 29	8.5	4.5 ± 0.1
"	55°25'	12°15'	May 20	9.1	3.4 ± 0.2
"	55°25'	12°15'	June 17	8.1	3.8 ± 0.6
"	55°25'	12°15'	July 16	10.6	
"	55°25'	12°15'	Aug 12	9.8	
"	55°25'	12°15'	Sep 14	11.8	
"	55°25'	12°15'	Oct 14	9.6	
"	55°25'	12°15'	Nov 11	11.1	
"	55°25'	12°15'	Dec 16	12.8	
Mullerup havn	55°30'	11°30'	Apr 30	15.3	2.5 ± .0.2
"	55°30'	11°10'	May 21	17.8	2.2 ± 0.6
"	55°30'	11°10'	June 22	18.7	2.2 ± 0.1
"	55°30'	11°10'	July 15	16.7	
"	55°30'	11°10'	Aug 13	17.3	
"	55°30'	11°10'	Sep 15	13.4	2.7 ± 0.4
"	55°30'	11°10'	Oct 15	12.6	
"	55°30'	11°10'	Dec 17	16.6	

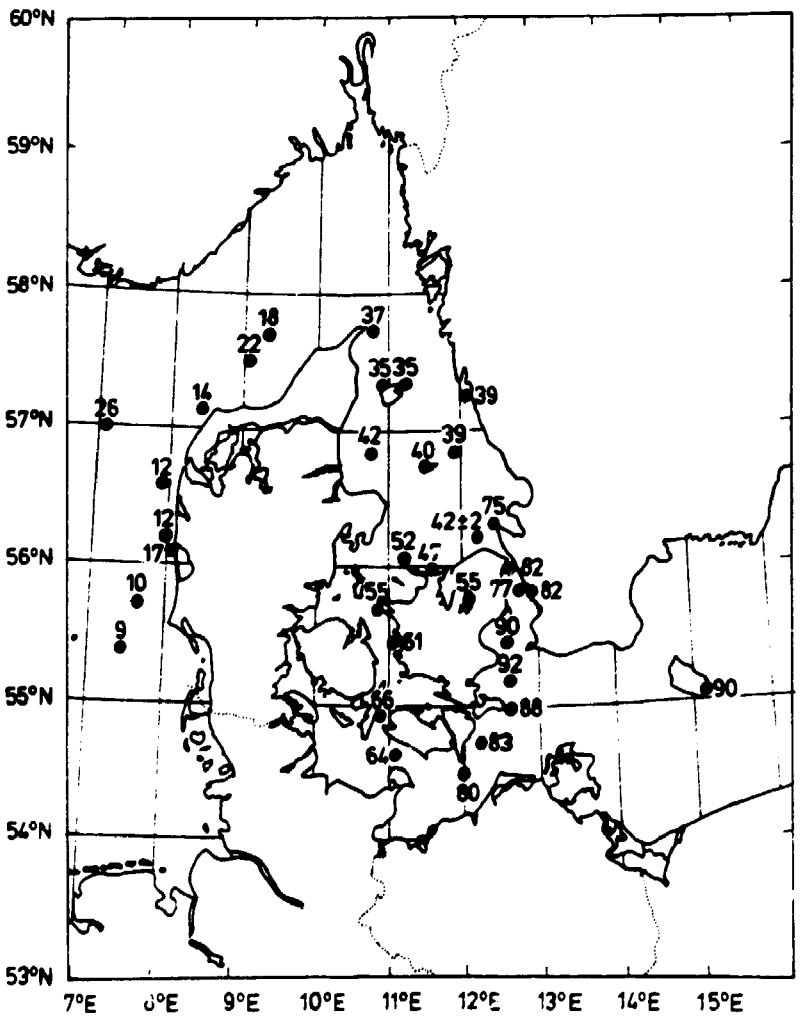
Table 4.4.4. (continued)

Location	Position N	Position E	Date	Salinity in ‰	^3H kBq m^{-3}
Nysted	54°40'	11°44'	May 20	10.4	3.7 ± 0.8
"	54°40'	11°44'	June 23	10.6	
"	54°40'	11°44'	July 16	11.0	
"	54°40'	11°44'	Aug 12	13.6	
"	54°40'	11°44'	Sep 14	10.5	
"	54°40'	11°44'	Oct 14	10.8	
"	54°40'	11°44'	Nov 11	9.9	
"	54°40'	11°44'	Dec 18	11.3	
Roskilde fjord	55°51'	12°02'	May 4	15.6	2.6 ± .0.4
"	55°45'	12°04'	May 4	13.6	5.6 ± .0.5

*Cf. Fig. 3.2.1.1.
**Cf. Fig. 3.2.1.2.

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

Fig. 4.4.5. Chernobyl cesium-137 in surface sea water collected in May 1987. (Unit: Bq m^{-3}).



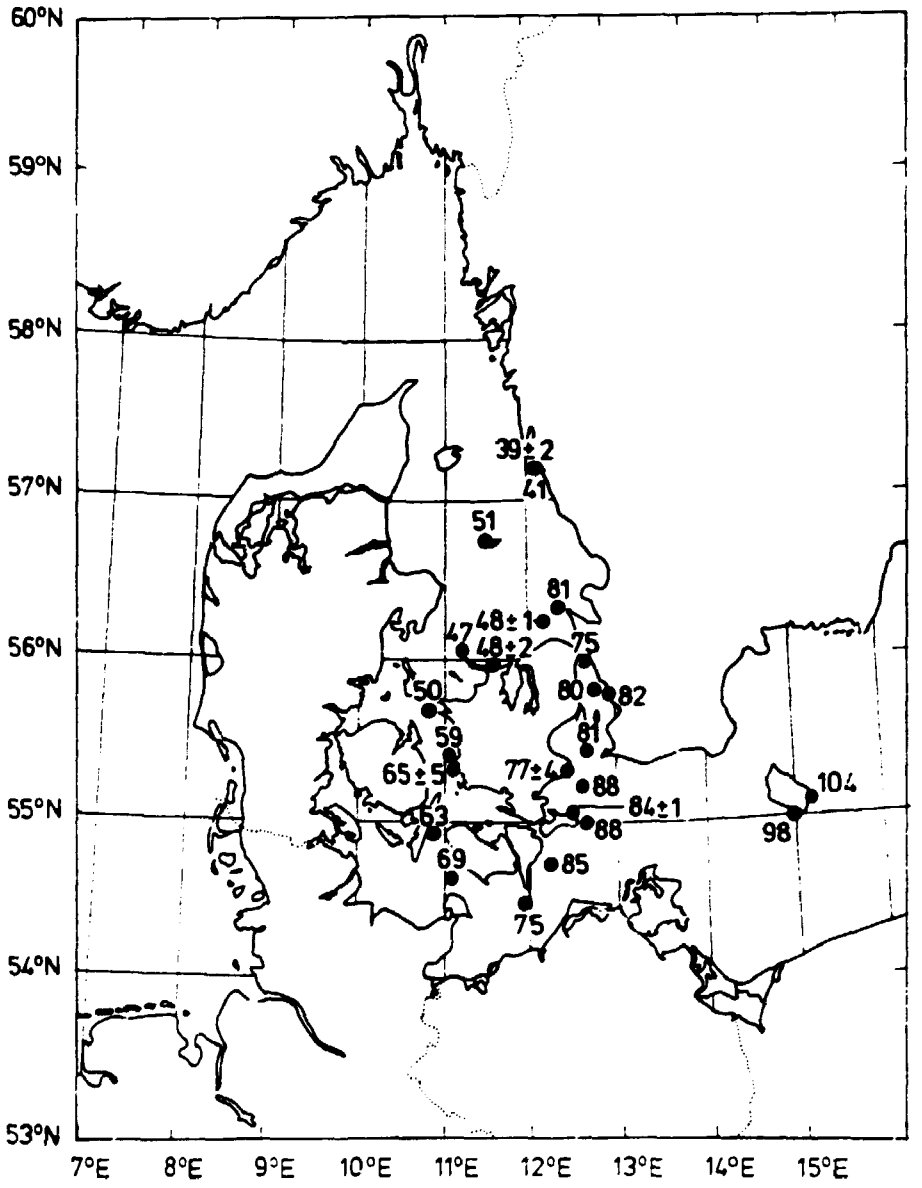


Fig. 4.4.6. Chernobyl cesium-137 in surface sea water collected in November-December 1987. (Unit: Bq m^{-3}).

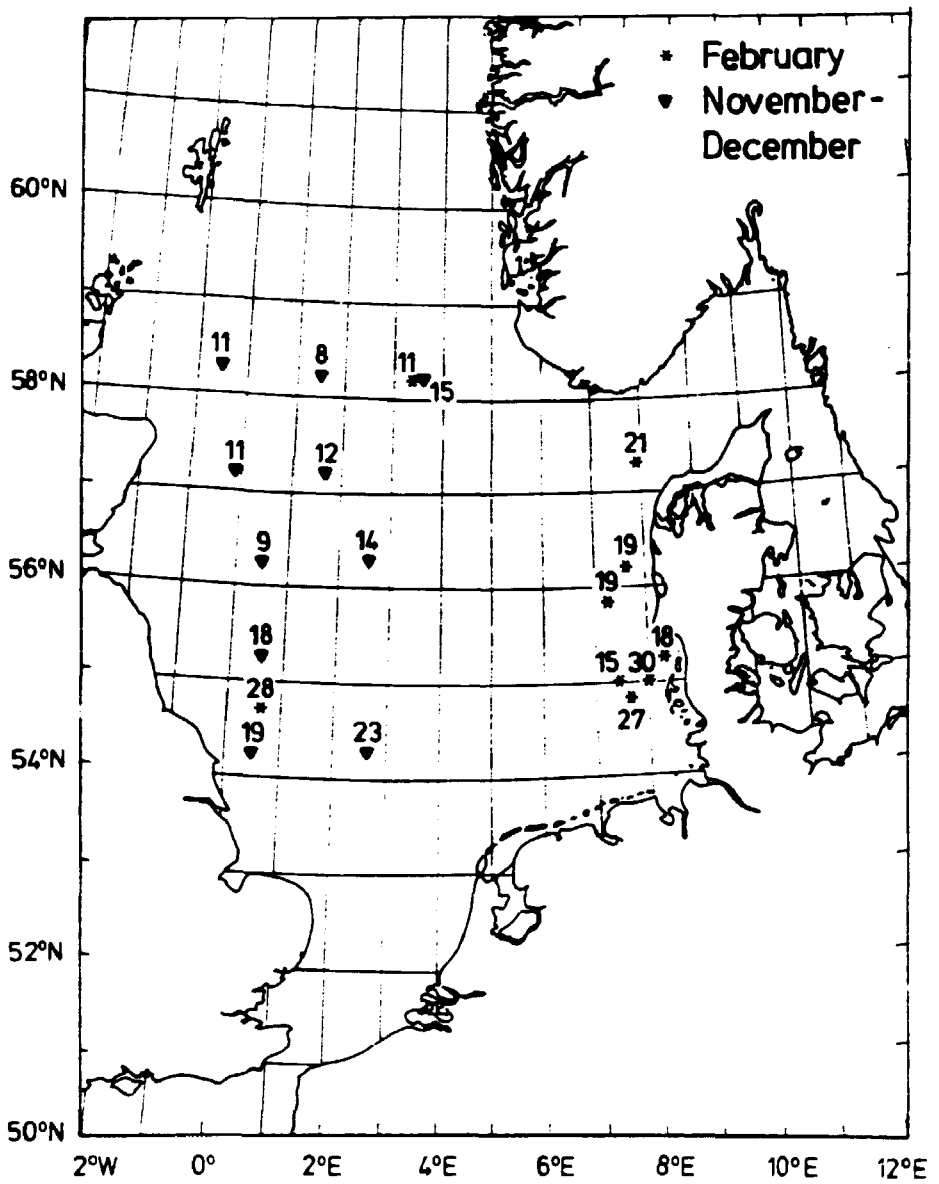


Fig. 4.4.7. Chernobyl cesium-137 in surface sea water collected in 1987. (Unit: Bq m^{-3}).

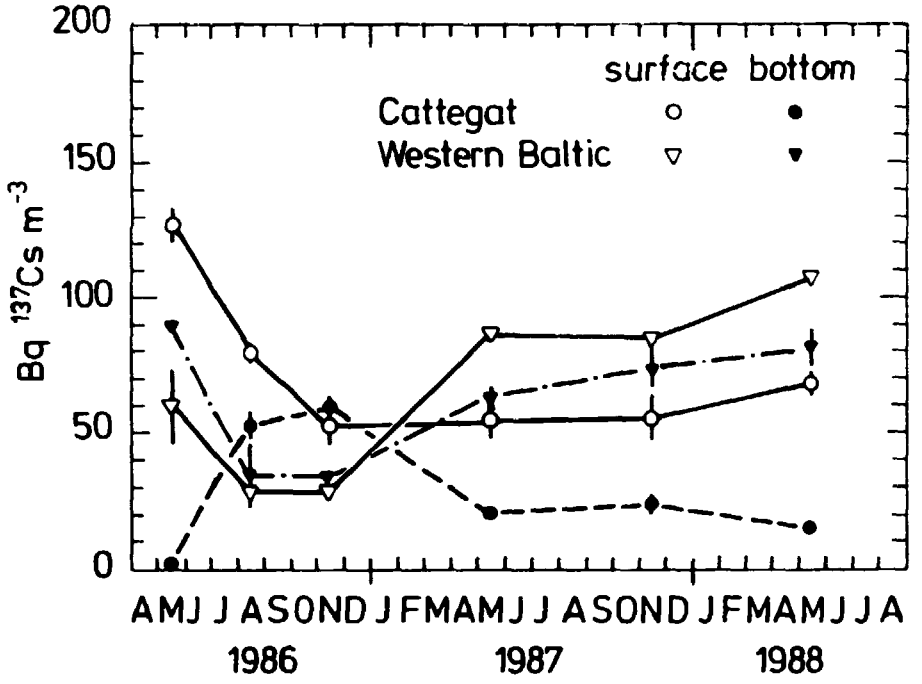
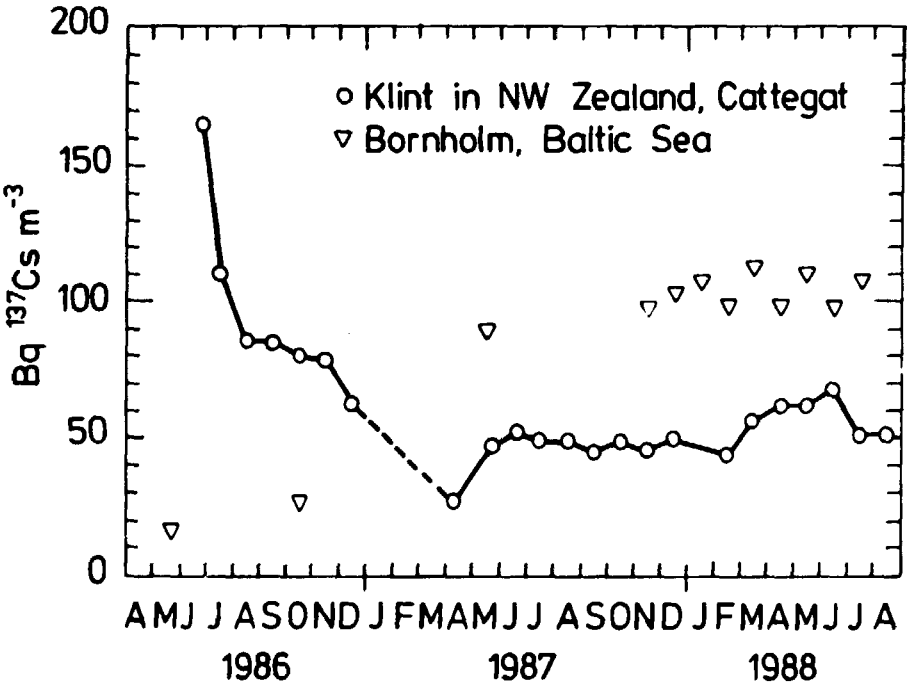


Fig. 4.4.8. Chernobyl cesium-137 in southern Cattegat and western Baltic Sea 1986-1988. (Unit: Bq m^{-3}).

Fig. 4.4.9. Chernobyl cesium-137 in surface sea water from two coastal stations 1986-1988.



4.5. Strontium-90 and Radiocesium in Soil Samples

Soil was collected from uncultivated fields in September 1987 at the 10 State experimental farms (Fig. 4.2 and Tables 4.5.1 and 4.5.2). Furthermore, we analysed soil samples collected in 1983 (Table 4.5.3) from cultivated soils.

The last time a countrywide sampling of both cultivated and uncultivated soils took place was in 1975[1]. From this sampling and from the deposition of global fallout since then, we can calculate the expected levels in uncultivated soils in 1987 and in cultivated soils in 1983. These calculated levels may then be compared with those actually observed. Table 4.5.4 shows the ratios between observed and calculated levels. Furthermore, we have compared the observed September 1987 levels of Chernobyl ^{137}Cs with those found in September 1986 (corrected for decay to 1987 and for Chernobyl fallout for the period September 1986 to August 1987).

It is evident that the observed ^{137}Cs levels in soil in general are lower than those calculated from previous measurements. This shows that ^{137}Cs disappears from the soil not only by radioactive decay, but also by other processes,

Table 4.5.1. Radiocesium in uncultivated soil collected at the 10 State experimental farms in Denmark and at two locations at Risø in August-September 1987. (Unit: Bq m^{-2}). ($^{134}Cs/^{137}Cs$)

	0-5 cm	5-10 cm	10-20 cm	20-30 cm	30-50 cm	Σ 0-50 cm	Chernobyl ^{137}Cs* 0-5 cm	5-10 cm	0-10 cm
Tylstrup	1440 (0.140)	940 (0.033)	410	64	94	2950	556	86	640
Kalø	1840 (0.178)	600 (0.037)	176	140	62	2820	903	61	960
Borris	1240 (0.216)	450 (0.053)	1470	290	176	3630	739	66	800
Askov	3300 (0.294)	300 (0.053)	790	136	43 B	4590	2680	44	2700
St. Jyndevad	1270 (0.259)	460 (0.043)	1180	580	79 A	3570	908	55	960
Årslev	1940 (0.302)	560 (0.119)	630	320	31 B	3480	1627	185	1810
Tystofte	1180 (0.188)	590 -	850	290	41 A	2950	623	-	620
Ledreborg	960 (0.210)	290 (0.065)	700	430	60	2440	566	53	620
Abed	820 (0.213)	700 (0.064)	430	200	66 A	2220	484	124	610
Tornbygård	960 (0.213)	380 -	660	310	100	2410	519	-	520
Mean	1495	527	730	276	75	3106	960	67	1027
relative S.D.	49%	37%	52%	55%	56%	23%	72%	82%	68%
Skydebanen(Risø)	1570 (0.140)	430 (0.013)	360	85	26 B	2500	617	16	630
Bolund (Risø)	1370 (0.198)	860 (0.039)	620	100	112	3060	773	96	870

*Calculated from $^{134}Cs/^{137}Cs$ assuming that this ratio was 0.55 in pure Chernobyl debris on April 26, 1986.

Table 4.5.2. Strontium-90 in uncultivated soil from the 10 State experimental farms in Denmark in August-September 1987 (0-5 cm layer)

	Bq kg^{-1}	Bq m^{-2}
Tylstrup	4.7	197
Kalø	4.5	178
Borris	1.87	110
Askov	3.8	248
St. Jyndevad	1.67	76
Årslev	3.9	190
Tystofte	2.8	141
Ledreborg	2.5	147
Abed	2.5	99
Tornbygård	1.56	105
Mean	2.98	149
relative S.D.	39%	36%

Table 4.5.3. Cesium-137 in cultivated soil from the 10 state experimental farms in Denmark in September 1983. (Unit: Bq ^{137}Cs m^{-2})

	0-20 cm	20-30 cm	30-40 cm	40-50 cm	Σ 0-50 cm
Tylstrup	1230	370	129	20	1750
Ødum	1150	590	74	30 A	1840
Borris*	1300	280	20 A	B.D.L.	1600
Askov	1600	620	47	28	2300
St. Jyndevad	1550	350	10 A	B.D.L.	1910
Blangstedgård	770	400	117	18 A	1310
Tystofte	930	610	58	B.D.L.	1600
Ledreborg	540	310	410	37	1300
Abed	820	590	B.D.L.	B.D.L.	1410
Tornbygård*	610	470	117	34 B	1230
Mean	1050	459	98	17	1620
relative S.D.	36%	29%	121%	92%	21%

*These two stations were not the same in 1975 and in 1983 (Borris was earlier Studsgård and Tornbygård was Åkirkeby).

e.g. runoff, crop removal, and wind erosion. The loss of global fallout ^{137}Cs from uncultivated soils from 1975 to 1987 corresponded to a decay factor λ of 0.017 yr^{-1} ($e^{-\lambda \cdot 12} = 0.82$; $\lambda = 0.017$) the corresponding half-life is 42 years and the effective half-life of global fallout ^{137}Cs in Danish uncultivated soils thus becomes 17.5 years.

In the case of cultivated soils, the loss rate of 137Cs is greater. The decay factor is here 0.030 yr^{-1}. ($e^{-\lambda \cdot 8} = 0.79$); $\lambda = 0.030$) and the effective half-life of global fallout ^{137}Cs in Danish cultivated soils becomes 13 years.

The last column in Table 4.5.4 shows a surprisingly high reduction in the Chernobyl ^{137}Cs in soils from 1986 to 1987, corresponding to a decay factor of 0.26 yr^{-1} or an effective half-life of 2.44 years only. In order to see whether this rapid decay continues (which is unlikely), we have planned a new soil sampling in 1989.

Table 4.5.4. Observed ^{137}Cs deposit compared with calculated levels (cf. the text)

Location	Uncultivated soil 1987 observation[a] 1975 calculation	Cultivated soil 1983 observation 1975 calculation	Uncultivated soil 1987 observation[b] 1986 calculation[b]
Tylstrup	0.74	0.55	0.96
KaløØdum	0.60[c]	0.73	0.58
Borris	1.00[d]	0.51[d]	0.92
Askov	0.52	0.85	0.70
St. Jyndevad	1.24	0.74	0.90
ÅrslevBlangstedgård	0.61[e]	0.96	0.89
Tystofte	0.89	0.64	0.76
Ledreborg	0.80	0.86	0.47
Abed	0.70	0.95	0.70
Tornbygård	0.69[f]	0.60[f]	0.81
Mean ± 1 S.E. (N)	0.82 ± 0.10 (6)	0.79 ± 0.05 (8)	0.77 ± 0.05 (10)
Risø, Bolund	1.32		
Risø, Skydebanen	0.86		
Mean ± 1 S.E. (N)	0.88 ± 0.10 (8)		

[a]Global fallout only, Chernobyl ^{137}Cs has been subtracted.
[b]Chernobyl ^{137}Cs calculated from ^{134}Cs.
[c]Kalø in 1987 but Ødum in 1975.
[d]Studsgård in 1975, Borris in 1983-1987.
[e]Blangstedgård in 1975-1983, Årslev in 1986-1987.
[f]Åkirkeby in 1975, Tornbygård 1983-1987.

4.6. Sediments

Sediments were collected from the permanent locations in Roskilde Fjord in May 1987. The mean contribution from Chernobyl was 208 ± 104 Bq ^{137}Cs m^{-2} (± 1 S.D.; N = 7). The Chernobyl radiocesium was normally found in the upper 3 to 5 cm. Compared to the deposition of Chernobyl ^{137}Cs in 1986, the sediments in Roskilde Fjord contained 20-30%. This is higher than seen in 1986, when only about 10% of the Chernobyl radiocesium had reached the sediments in the Danish Straits[1].

Table 4.6.1. Radiocesium in marine sediments collected in Roskilde Fjord on May 7, 1987 at location VI (cf. Fig. 4.6.1.)

Layer in cm	^{134}Cs Bq m^{-2}	^{134}Cs Bq kg^{-1}	^{137}Cs Bq m^{-2}	^{137}Cs Bq kg^{-1}	Chernobyl ^{137}Cs Bq m^{-2}	Chernobyl ^{137}Cs %
0-1	7.1 A	2.6 A	29	10.5	17.8	61
1-2	11.1	2.1	64	12.2	28	44
2-3	27	1.77	144	9.5	68	47
3-4	13.3 A	1.20 A	105	9.4	33	31
4-5	25 A	1.79 A	106	7.5	63	59
5-6	-	-	98	6.9	-	0
Σ 0-6	84		546		210	

Table 4.6.2. Radiocesium in marine sediments collected in Roskilde Fjord on May 7, 1987 at location V (cf. Fig. 4.6.1.)

Layer in cm	^{134}Cs Bq m^{-2}	^{134}Cs Bq kg^{-1}	^{137}Cs Bq m^{-2}	^{137}Cs Bq kg^{-1}	Chernobyl ^{137}Cs Bq m^{-2}	Chernobyl ^{137}Cs %
0-1	9.2 A	6.0 A	64	42	23	36
1-2	19.0	5.2	82	22	48	59
2-3	8.1 A	1.4 A	62	10.6	20	32
3-4	-	-	54	10.1	-	
4-5	-	-	42	7.0	-	
5-6	-	-	43	6.7	-	
Σ 0-6	36		347		91	

Table 4.6.3. Radiocesium in marine sediments collected in Roskilde Fjord on May 7, 1987 at location IV (cf. Fig. 4.6.1.)

Layer in cm	^{134}Cs Bq m^{-2}	^{134}Cs Bq kg^{-1}	^{137}Cs Bq m^{-2}	^{137}Cs Bq kg^{-1}	Chernobyl ^{137}Cs Bq m^{-2}	Chernobyl ^{137}Cs %
0-1	25	28	89	100	63	71
1-2	51	29	164	93	128	78
2-3	48	21	188	85	120	64
3-4	10.5 A	6.5 A	101	62	26	26
4-5	-	-	64	51	-	-
5-6	-	-	88	54	-	-
Σ 0-6	135		694		337	

Table 4.6.4. Radiocesium in marine sediments collected in Roskilde Fjord on May 7, 1987 at location III (cf. Fig. 4.6.1.)

Layer in cm	^{134}Cs Bq m^{-2}	^{134}Cs Bq kg^{-1}	^{137}Cs Bq m^{-2}	^{137}Cs Bq kg^{-1}	Chernobyl ^{137}Cs Bq m^{-2}	Chernobyl ^{137}Cs %
0-1	22	7.6	117	41	55	47
1-2	19.1	5.3	110	31	48	44
2-3	9.3 A	4.2 A	45	21	23	51
3-4	-	-	47	14.0	-	-
4-5	-	-	16	10.6	-	-
5-6	-	-	24	9.7	-	-
Σ 0-6	50		359		126	

Table 4.6.5. Radiocesium in marine sediments collected in Roskilde Fjord on May 7, 1987 at location X (cf. Fig. 4.6.1.)

Layer in cm	^{134}Cs Bq m^{-2}	^{134}Cs Bq kg^{-1}	^{137}Cs Bq m^{-2}	^{137}Cs Bq kg^{-1}	Chernobyl ^{137}Cs Bq m^{-2}	Chernobyl ^{137}Cs %
0-1	15.2	8.3	79	45	38	48
1-2	14.8	8.5	88	51	37	42
2-3	13.8	6.6	115	55	34	30
3-4	-	-	46	25	-	-
4-5	-	-	53	30	-	-
5-6	-	-	60	40	-	-
Σ 0-6	44		441		109	

Table 4.6.6. Radiocesium in marine sediments collected in Roskilde Fjord on May 7, 1987 at location IX (cf. Fig. 4.6.1.)

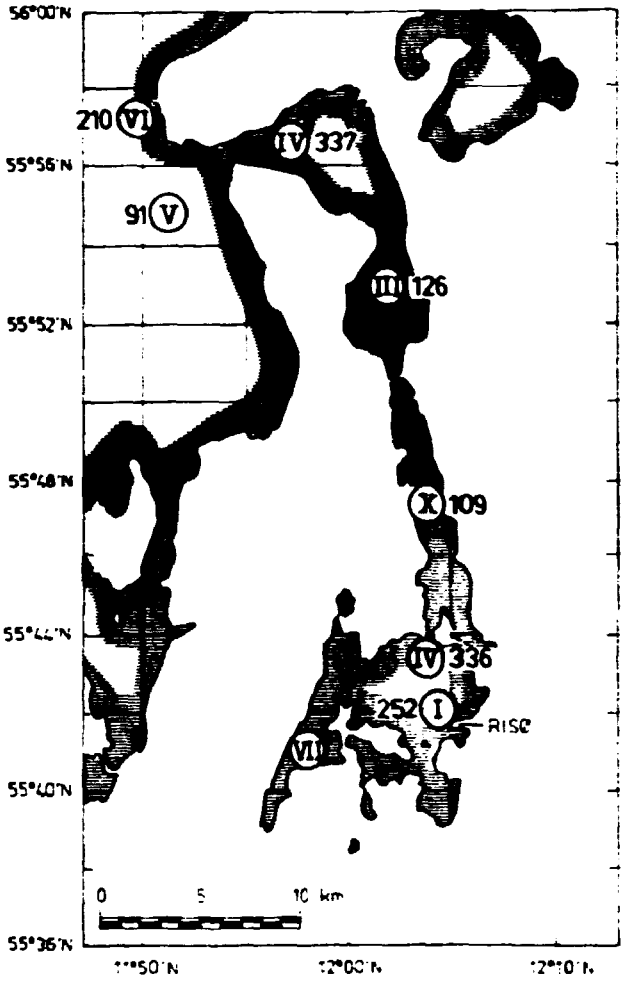
Layer in cm	^{134}Cs Bq m^{-2}	^{134}Cs Bq kg^{-1}	^{137}Cs Bq m^{-2}	^{137}Cs Bq kg^{-1}	Chernobyl ^{137}Cs Bq m^{-2}	Chernobyl ^{137}Cs %
0-1	30	12.4	109	44	75	69
1-2	49	11.7	168	41	123	73
2-3	26	5.2	126	25	65	52
3-4	15.1	2.7	122	22	38	31
4-5	14.1 A	2.4 A	105	17.5	35	33
5-6	-	-	126	21	-	-
Σ 0-6	134		756		336	

Table 4.6.7. Radiocesium in marine sediments collected in Roskilde Fjord on May 7, 1987 at location I (cf. Fig. 4.6.1.)

Layer in cm	^{134}Cs Bq m^{-2}	^{134}Cs Bq kg^{-1}	^{137}Cs Bq m^{-2}	^{137}Cs Bq kg^{-1}	Chernobyl ^{137}Cs Bq m^{-2}	Chernobyl ^{137}Cs %
0-1	21	14.2	86	59	53	61
1-2	32	9.4	166	49	80	48
2-3	31	8.4	208	56	78	37
3-4	8.2 A	2.0 A	181	44	21	11
4-5	7.8 A	2.5 A	142	46	20	14
5-6	-	-	139	46	-	-
Σ 0-6	100		922		252	
0-3	73	10.5	323	46	183	57
3-6	78	5.3	656	45	196	30
6-9	25 A	2 A	390	31	63	16
9-12	-	-	330	42	-	-
12-15	-	-	154	16.6	-	-
Σ 0-15	176		1853		442	

The double sampling from location I (Risø, cf. Table 4.6.7) showed significant variations between the two sets of samples. The set with the 3-cm layers showed 50% more Chernobyl radiocesium than that with the 1-cm layers.

Fig. 4.6.1. Chernobyl Cs-137 in sediment samples (0-6 cm layer) collected in Roskilde Fjord. (Unit: Bq m^{-2}).



5. Danish Food and Various Vegetation

by A. Aarkrog

5.1. Strontium-90 and Radiocesium in Dried Milk from the Entire Country

As compared with 1986, the countrywide mean ^{90}Sr level in dried milk decreased by 8% in 1987, which brings the ^{90}Sr levels back to pre-Chernobyl concentrations.

Tables 5.1.2 shows the anova of the ^{90}Sr data. The variation between locations was significant.

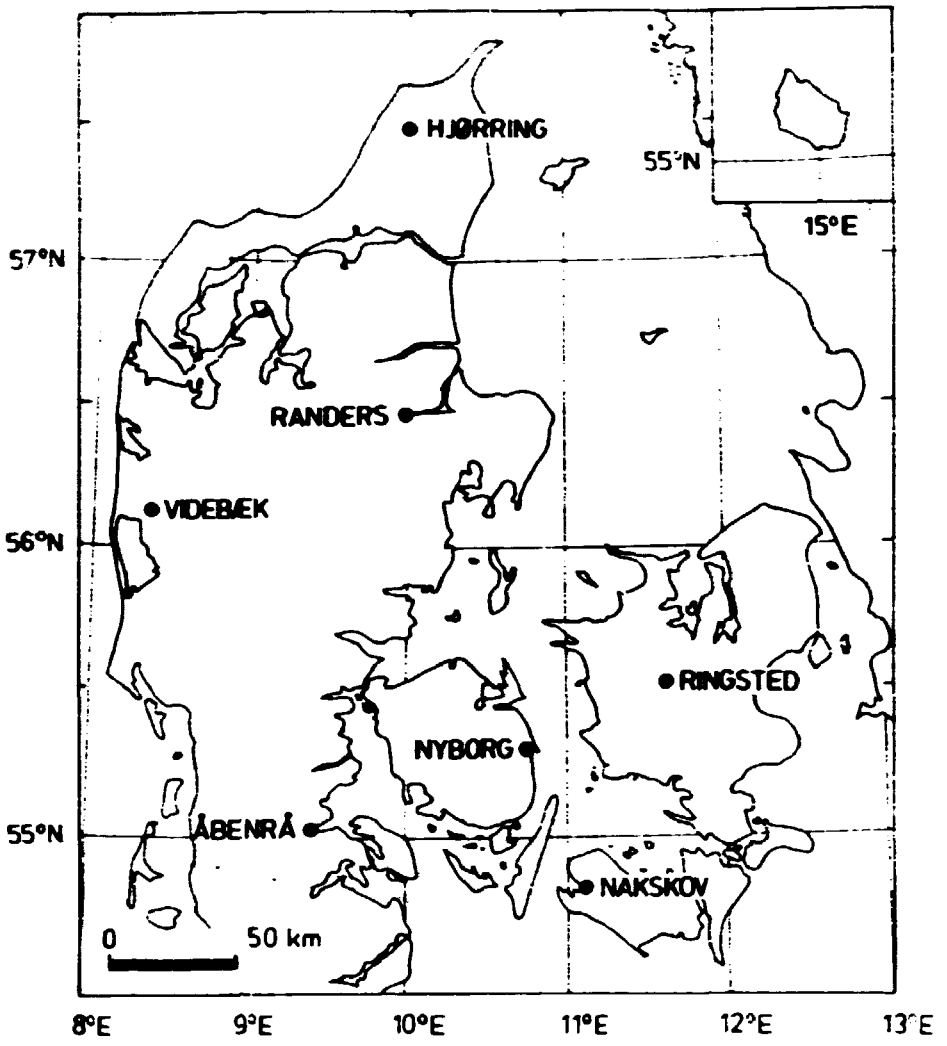


Fig. 5.1.1. Dried milk sampling locations in Denmark.

Table 5.1.1. Strontium-90 in dried milk in 1987. (Unit: Bq (kg Ca)$^{-1}$)

Month	Hjørring	Randers	Videbæk	Åbenrå	Nyborg	Ringsted	Nakskov	Mean
Jan-April	62	71	73	73	41	36	45	57
May-June	63	71	81	91	52	61	44	66
July	59	62	75	90	36	42	46	59
Aug	59	61	69	(80)	39	41	41	56
Sept	52	70	69	69	41	42	44	55
Oct	70	59	64	65	42	50	44	56
Nov-Dec	58	72	69	81	58	53	44	62
Mean*	61	69	72	78	45	46	44	59

*The data were weighted with the number of months when calculating the mean.

As 1 cubic meter of milk contains 1.2 kg Ca, the mean ^{90}Sr content in Danish milk produced in 1987 was 71 Bq m^{-3} (or 0.07 Bq ^{90}Sr l^{-1}).

Table 5.1.2. Analysis of variance of ln Bq ^{90}Sr (kg Ca)$^{-1}$ in Danish dried milk in 1987 (from Table 5.1.1) (milk year May 1987 - April 1988)

Variation	SSD	f	s^2	v^2	P
Between months*	0.138	6	0.023	1.94	-
Between locations	2.522	6	0.420	35.45	> 99.95%
Month × loc.	0.403	34	0.012	7.27	> 99%
Remainder	0.011	7	0.002		

*May-June, July, Aug, Sept,Oct, Nov-Dec (1987), Jan-April (1988).

Fig. 5.1.2. Predicted (curve) and observed $^{90}Sr/Ca$ levels in dried milk from Denmark (May 1962 - April 1987).

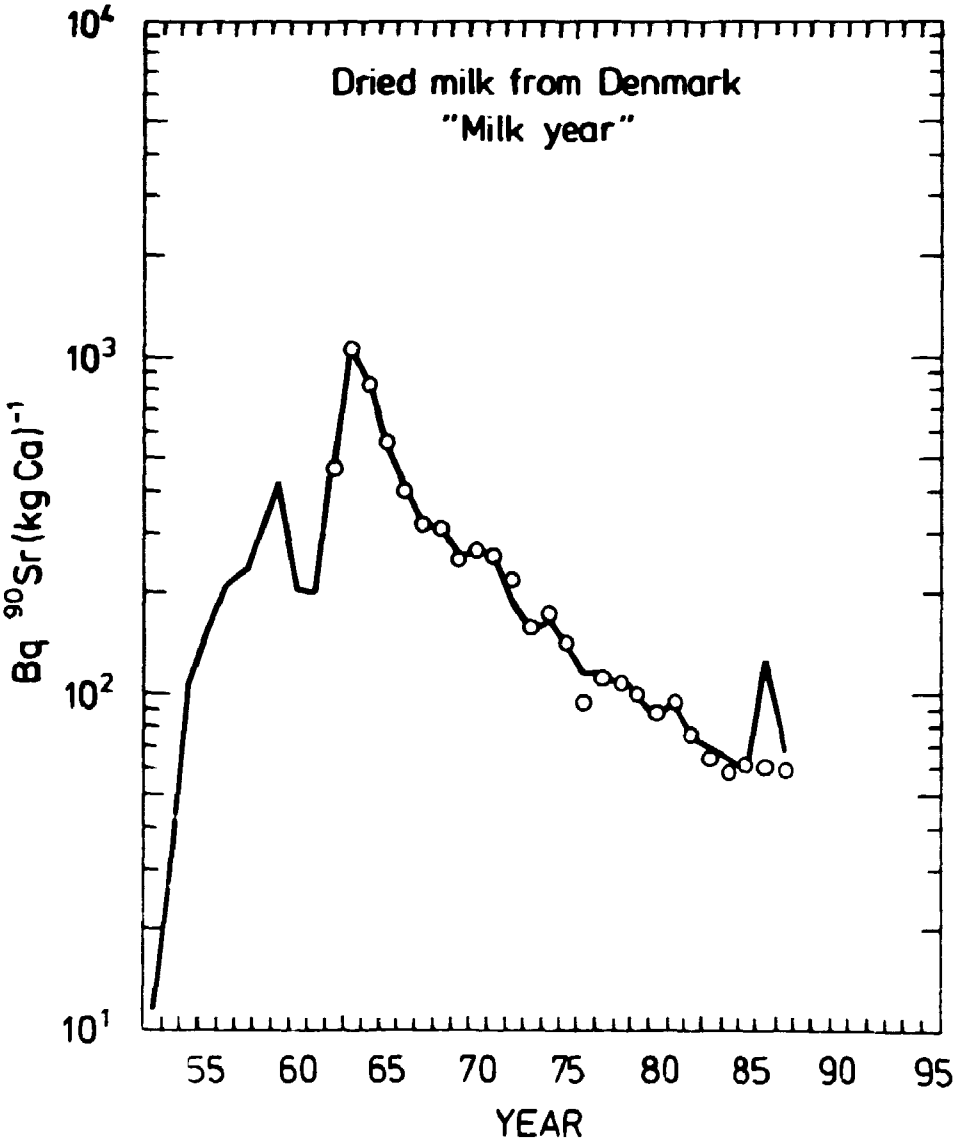


Table 5.1.3. Cesium-137 in Danish dried milk in 1987. (Unit: Bq ^{137}Cs (kg K)$^{-1}$)

Month	Hjørring	Randers	Videbæk	Åbenrå	Nyborg	Ringsted	Nakskov	Mean
Jan	350	590	810	1020	230	250	92	480
Feb	360	720	710	750	540	370	109	510
March	380	570	890	820	410	400	98	510
April	330	600	(920)	600	270	181	152	440
May	360	780	960	730	(230)	184	104	470
June	320	500	760	740	(230)	179	78	400
July	196	470	660	940	183	199	83	390
Aug	350	460	660	(680)	180	174	77	370
Sep	220	390	810	410	122	73	82	300
Oct	220	320	430	340	116	45	38	215
Nov	107	230	330	156	84	71	26	144
Dec	184	270	250	176	67	58	29	148
Mean	280	490	680	610	220	182	81	360

As 1 cubic meter of milk contains approx. 1.66 kg K, the mean ^{137}Cs content in Danish milk produced in 1987 was estimated at 600 Bq m^{-3} (or 0.60 Bq ^{137}Cs l^{-1}).

Table 5.1.4. Analysis of variance of ln Bq ^{137}Cs (kg K)$^{-1}$ in Danish dried milk in 1987 (from Table 5.1.3) (milk year May 1987 - April 1988)

Variation	SSD	f	s^2	v^2	P
Between months	13.66	11	1.242	13.89	> 99.95%
Between locations	51.93	6	8.66	96.81	> 99.95%
Remainder	5.54	62	0.089		

Table 5.1.5. Radiocesium: $^{134}Cs/^{137}Cs$ in Danish dried milk in 1987

Month	Hjørring	Randers	Videbæk	Åbenrå	Nyborg	Ringsted	Nakskov	Mean ± 1 S.D.	Theoretical $^{134}Cs/^{137}Cs$
Jan	0.39	0.41	0.40	0.41	0.40	0.42	0.49	0.42 ± 0.03	0.44
Feb	0.39	0.41	0.41	0.43	0.41	0.43	0.41	0.41 ± 0.01	0.43
March	0.40	0.40	0.38	0.42	0.42	0.41	0.38	0.40 ± 0.02	0.42
April	0.36	0.40		0.42	0.39	0.40	0.41	0.40 ± 0.01	0.41
May	0.37	0.38	0.39	0.41		0.39	0.35	0.38 ± 0.02	0.40
June	0.35	0.37	0.40	0.38		0.34	0.35	0.37 ± 0.02	0.39
July	0.35	0.36	0.36	0.37	0.36	0.35	0.35	0.36 ± 0.01	0.38
Aug	0.33	0.33	0.35		0.32	0.37	0.37	0.35 ± 0.02	0.37
Sept	0.27	0.33	0.34	0.34	0.30	0.30	0.24	0.30 ± 0.04	0.36
Oct	0.31	0.33	0.33	0.32	0.38	0.37	0.29	0.33 ± 0.03	0.35
Nov	0.29	0.31	0.31	0.30	0.26	0.26	0.38	0.30 ± 0.04	0.34
Dec	0.28	0.31	0.34	0.31	0.37	0.35	-	0.33 ± 0.03	0.33

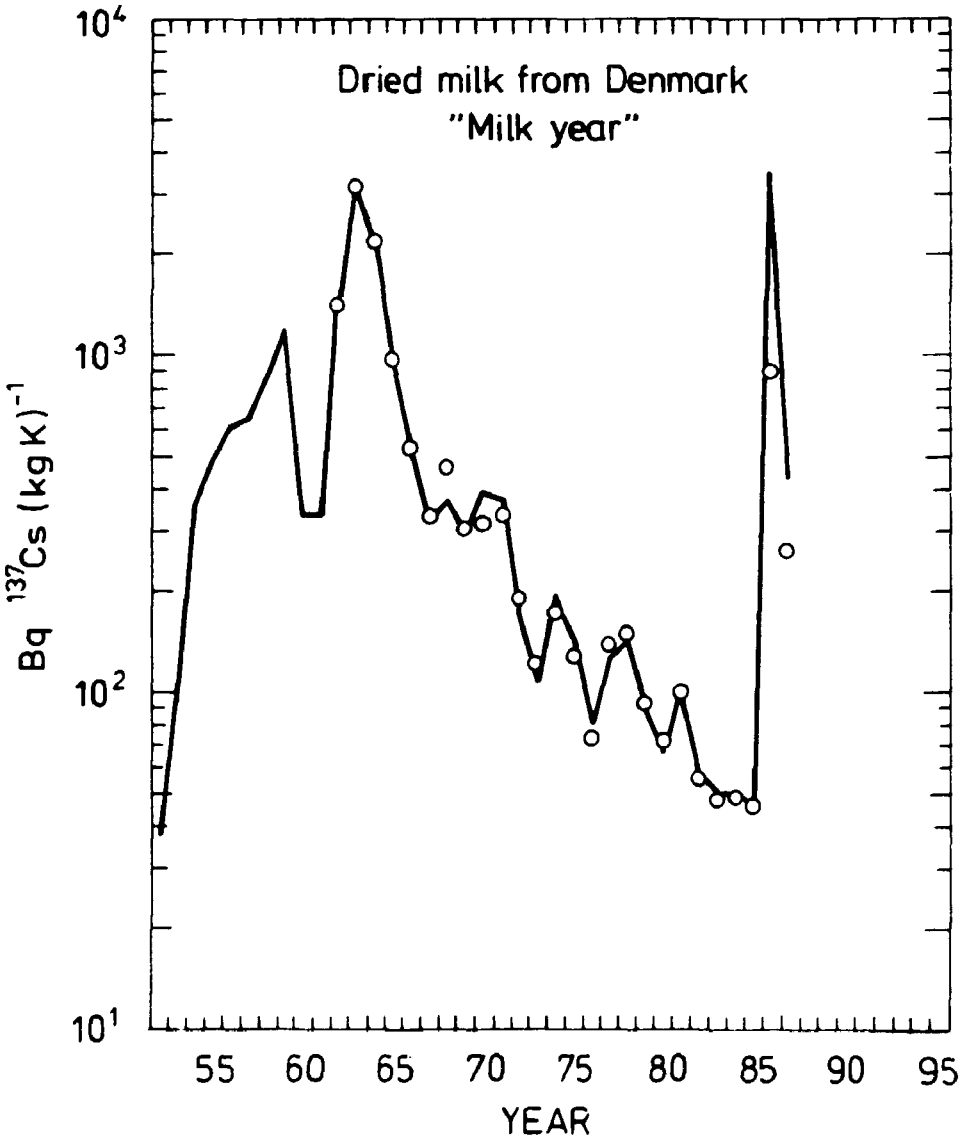
$$\frac{\text{Observed } ^{134}Cs/^{137}Cs}{\text{Theoretical } ^{134}Cs/^{137}Cs} = 0.94 \pm 0.04 \text{ (1 S.D.; N = 12)}$$

Compared with 1986, the ^{137}Cs concentrations in Danish dried milk decreased by a factor of 1.8 in 1987. It is more interesting to compare the milk years: May 1986 - April 1987 and May 1987 - April 1988, where we find that there was a decrease by a factor of 2.9 corresponding to a decay factor λ of 1.07 yr^{-1} or an effective half-life of ^{137}Cs in Danish milk of 7.75 months. We expect that this decrease rate will become less in the coming years.

The $^{134}Cs/^{137}Cs$ indicates that 94% of the ^{137}Cs in Danish milk from 1987 came from the Chernobyl accident (Table 5.1.5).

Figures 5.1.2 and 5.1.3 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 1987 were 1.11 times the predicted, while the observed ^{137}Cs levels were 0.66 times the predicted ones (means of Jutland and the Islands). Compared with 1986, the models had improved their predictions.

Fig. 5.1.3. Predicted (curve) and observed $^{137}Cs/K$ levels in dried milk from Denmark (May 1962 - April 1988).



5.2. Other Milk Products

5.2.1. Strontium-90 and Radiocesium in Consumers Milk

Milk was purchased in the 8 zones and Copenhagen (Figs. 5.4.1 and 5.4.2) in May-June and in November-December 1987. The results are shown in Table 5.2.1 and were similar to those in the dried milk samples (cf. Table 5.1.3).

Table 5.2.1. Strontium-90 and radiocesium in consumers milk collected in the 8 zones and Copenhagen in 1987 (cf. Figs. 5.4.1 and 5.4.2)

Country part	June				December			
	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs (kg K)$^{-1}$	Bq ^{137}Cs l^{-1}	$\frac{^{134}Cs}{^{137}Cs}$	Bq^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs (kg K)$^{-1}$	Bq ^{137}Cs l^{-1}	$\frac{^{134}Cs}{^{137}Cs}$
N-Jutland	60	580	0.90	0.37		182	0.29	0.30
E-Jutland	65	490	0.75	0.36		270	0.41	0.30
W-Jutland	62	540	0.86	0.36		193	0.31	0.31
S-Jutland	75	610	0.95	0.38		182	0.29	0.30
Funen	69	660	1.06	0.38		204	0.32	0.30
Zealand	46	210	0.34	0.38		52	0.081	0.29
Lolland-Falster	50	170	0.28	0.35		72	0.108	0.28
Bornholm	63	45	0.07	0.40		30	0.048	0.25
Mean	61	410	0.65	0.37	60	148	0.23	0.29

5.2.2. Strontium-90 and Radiocesium in Danish Cheese

The ^{90}Sr levels (Bq (kg Ca)$^{-1}$) in cheese in 1987 corresponded to those observed in milk in South and West Jutland in June 1986. The ^{137}Cs levels (Bq (kg K)$^{-1}$) were also similar to the milk levels observed in Jutland in the grazing season 1986.

Compared with cheese from 1986, the 1987 levels were nearly the same for ^{90}Sr, while the ^{137}Cs concentrations had decreased by a factor of 2.4. As in 1986, we must conclude that the ^{137}Cs/K in cheese was higher than that in milk.

Table 5.2.2. Strontium-90 and radiocesium in Danish cheese in 1987

Month	Bq ^{90}Sr kg^{-1}	Bq ^{90} (kg Ca)$^{-1}$	Bq^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	$\frac{^{134}Cs}{^{137}Cs}$
Jan-March	0.90	112	1.03	1440	0.48
April-June	0.84	98	1.03	1360	0.39 A
July-Sept	1.05	100	1.27	1180	0.35
Mean	0.93	103	1.11	1330	-

5.3. Strontium-90 and Radiocesium 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 and ^{134}Cs were measured on ashed samples by γ-spectrometry on a Ge(Li) detector.

Tables 5.3.1 and 5.3.2 show the measurements of ^{90}Sr in grain in 1987. 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.

The variation between species was not significant for Bq ^{90}Sr kg^{-1} (Table 5.3.3).

Table 5.3.1. Strontium-90 in Danish grain in 1987. (Unit: Bq kg^{-1})

Location	Rye	Barley		Wheat		Oats	Triticale
	Winter	Spring	Winter	Winter	Spring	Spring	
Tylstrup	0.33	0.46	1.67	0.90		1.13	-
Kalø*	0.80	0.42±0.18	0.60	0.34±0.01	0.91	0.63±0.38	-
Askov	0.84	1.22	0.76	0.56	-	0.57	-
Borris	0.95	0.87	0.90	0.92	1.80	0.55	1.17
St. Jyndevad	0.30	0.20	0.76	0.68	-	0.81	-
Årslev	0.33	0.95	0.41	0.25	-	0.57	-
Tystofte	0.29	0.47	0.27	0.32	0.63	0.43	-
Ledreborg	0.26	-	0.32	0.30	-	0.50	-
Abed	0.17	0.24	0.29	0.43	0.36	-	-
Tornbygård	0.16	0.19	0.31	0.17	0.32	0.34	-
Mean	0.44	0.56	0.63	0.49	0.80	0.61	-

*Mean of Kalø and Foulum ±1 S.E.

Table 5.3.2. Strontium-90 in Danish grain in 1987. (Unit: Bq kg Ca)$^{-1}$)

Location	Rye	Barley		Wheat		Oats	Triticale
	Winter	Spring	Winter	Winter	Spring	Spring	
Tylstrup	960	340	1500	790	-	570	-
Kalø*	2500	770±310	1190	870±210	2100	780±540	-
Askov	1440	660	920	1360	-	890	-
Borris	1630	1530	720	1450	2500	1030	1570
St. Jyndevad	670	590	1390	1500	-	1250	-
Årslev	940	1700	830	860	-	810	-
Tystofte	800	880	710	990	1180	540	-
Ledreborg	730	-	630	890	-	660	-
Abed	450	460	470	1230	720	-	
Tornbygård	480	420	510	490	800	390	-
Mean	1060	820	890	1040	1460	770	-

*Mean of Kalø and Foulum ±1 S.E.

Table 5.3.3. Analysis of variance of ln Bq ^{90}Sr kg^{-1} in grain in 1987 (from Table 5.3.1)

Variation	SSD	f	s^2	v^2	P
Between species	0.714	3	0.238	1.30	-
Between locations	9.38	9	1.04	5.69	> 99.95%
Spec. × loc.	4.76	26	0.183	0.61	-
Remainder	5.11	17	0.30		

Table 5.3.4. Analysis of variance of ln Bq ^{90}Sr (kg Ca)$^{-1}$ in grain in 1987 (from Table 5.3.2)

Variation	SSD	f	s^2	v^2	P
Between species	1.95	3	0.65	5.95	> 99.5%
Between locations	4.71	9	0.52	4.80	> 99.9%
Spec. × loc.	2.83	26	0.109	0.39	-
Remainder	4.77	17	0.281		

As in previous years, the variation with location was highly significant; the mean Bq ^{90}Sr kg^{-1} level for grain from Jutland was 2.2 ± 0.3 times that in eastern Denmark. The observed Bq ^{90}Sr kg^{-1} levels in grain from 1987 were 1.38 ± 0.52 (1 S.D., N = 8) times those predicted (cf. Appendix C).

Tables 5.3.5 and 5.3.6 show the measurements of ^{137}Cs and ^{134}Cs in grain in 1987. Compared with 1986, the ^{137}Cs levels in Danish grain had decreased significantly in 1987. However, the decrease was very unevenly distributed.

The median reduction from 1986 to 1987 was by a factor of 11 (47 paired observations). Rye showed a median factor of 73 (8 observations) and oats of 2.5 (9 observations). Barley and wheat were in between these extremes.

The ^{137}Cs fallout in May-August 1987 was a factor of 65 less than in May-August 1986. Only the rye levels followed this reduction from 1986 to 1987. But rye was also the only species which showed a significant response to the early Chernobyl fallout in May-June. Barley, wheat and oats were not so developed as rye when the bulk of the Chernobyl fallout arrived, and the response to the fallout was thus less than for rye in 1986.

The ANOVA's (Tables 5.3.7 and 5.3.8) showed significant variation between locations as well as between species.

Our prediction models (cf. Appendix C.2) which assume that the radiocesium found in grain is solely dependent upon the fallout coming in May-August, overestimated the radiocesium concentrations actually found by a factor of 4-12 except for oats from Jutland.

We do not know why also in 1987 the models overestimated the grain levels. We believe that it may be because the resuspended radiocesium does not adhere so efficiently to the crops or/and because the resuspended ^{137}Cs is less available for translocation than direct global fallout ^{137}Cs (cf. also 4.2.2 last paragraph). It is also difficult to explain the enhanced ^{137}Cs levels in the oats samples from Kalø and St. Jyndevad in 1987. We suppose that "hot" resuspended particles may be responsible.

Cesium-134 was detectable in only a few grain samples in 1987. The mean $^{134}Cs/^{137}Cs$ was 0.28 ± 0.04 (± 1 S.D.; N = 10).

Table 5.3.5. Radiocesium in Danish grain in 1987. (Unit: Bq kg^{-1})

Location	Rye Winter	Barley		Wheat		Oats Spring	Triticale
		Spring	Winter	Winter	Spring		
Tylstrup	0.182	0.26	0.093 A	0.105 A	-	0.135	-
	(0.29 A)	(0.22 A)	-	-	-	-	-
Kalø*	0.116	0.121 ± 0.022	-	0.075 ± 0.014	0.19	1.88 ± 1.72	-
	-	-	-	-	(0.25 B)	(0.29)	-
Askov	0.42	0.125	0.082 A	0.22	-	0.39	-
	(0.31)	-	-	(0.38 A)	-	(0.29)	-
Borris	0.168	0.034 B	0.076 A	0.04 B	0.065 A	0.081 A	0.099
St. Jyndevad	0.28	0.096 A	0.05 B	0.130	-	1.47	-
	-	-	-	-	-	(0.25)	-
Årslev	0.26	0.40	0.134	0.078 A	-	0.151	-
	(0.26)	(0.26)	-	-	-	-	-
Tystofte	0.06 B	0.075 A	0.049 A	0.033 B	0.079 A	0.110	-
Ledreborg	0.068 A	-	0.091	0.038 A	-	0.095	-
Abed	0.063 A	0.01 B	0.054 A	0.036 B	0.02 B	-	-
Tornbygård	0.097	0.04 B	0.07 B	0.032 A	0.03 B	0.182	-
Mean	0.17	0.13	0.078	0.079	0.077	0.50	-

*Mean of Kalø and Foulum ± 1 S.E.

In brackets the $^{134}Cs/^{137}Cs$ are shown.

Table 5.3.6. Cesium-137 in Danish grain in 1987. (Unit: Bq (kg K)$^{-1}$)

Location	Rye Winter	Barley		Wheat		Oats Spring	Triticale
		Spring	Winter	Winter	Spring		
Tylstrup	37	59	28 A	29 A	-	32	-
Kalø*	28	34 ± 6	-	22 ± 3	50	610 ± 570	-
Askov	94	26	27 A	60	-	110	-
Borris	35	9 B	17 A	11 B	15 B	23 A	16
St. Jyndevad	54	22 A	20 B	30	-	340	-
Årslev	53	76	31	19 A	-	40	-
Tystofte	12 B	17	12 A	7 B	17 A	28	-
Ledreborg	14 A	-	19	11 A	-	24	-
Abed	14 A	2 B	13 A	10 B	5 B	-	-
Tornbygård	18	11 B	12 B	11 A	7 B	41	-
Mean	36	28	20	21	19	139	-

*Mean of Kalø and Foulum ± 1 S.E.

Table 5.3.7. Analysis of variance of ln Bq ^{137}Cs kg^{-1} in grain in 1987 (from Table 5.3.5)

Variation	SSD	f	s^2	v^2	P
Between species	10.55	3	3.52	9.42	> 99.95%
Between locations	17.10	9	1.90	5.09	> 97.5%
Spec. × loc.	9.71	26	0.373	0.614	-
Remainder	9.74	16	0.608		

Table 5.3.8. Analysis of variance of ln Bq ^{137}Cs (kg K)$^{-1}$ in grain in 1987 (from Table 5.3.6)

Variation	SSD	f	s^2	v^2	P
Between species	10.12	3	3.37	10.18	> 99.95%
Between locations	19.92	9	2.21	6.68	> 99.95%
Spec. × loc.	8.61	26	0.331	0.600	-
Remainder	8.83	16	0.552		

The theoretical mean ratio in mid-September, when most of the grain was harvested, was 0.36, hence 78% of the ^{137}Cs in the Danish grain in 1987 came from Chernobyl. If so, the contribution from global fallout has been 22% of the levels in Table 5.3.5 or 0.047 Bq ^{137}Cs kg^{-1} as a mean of the 4 species. This is 60% of the mean found in 1985, which does not seem unreasonable.

In 1981 the fallout rate of ^{137}Cs was 15.4 Bq ^{137}Cs m^{-2} (Risø-R-469)[1] and in 1987 it was 29 Bq ^{137}Cs m^{-2} or two times more. But the grain levels were on the average 6 times higher in 1981 than in 1987. It is thus evident that the direct global fallout in 1981 contaminated the grain about 10 times more efficiently than the resuspended Chernobyl debris did in 1987.

5.4. Strontium-90 and Radiocesium in Bread from the Entire Country

In 1986, samples of white bread (75% extraction) and dark rye bread (100% extraction) were collected all over the country (cf. Figs. 5.4.1 and 5.4.2) in June and December, and ^{90}Sr, ^{137}Cs and ^{134}Cs were determined. Samples from Copenhagen were analysed separately. The ^{137}Cs determinations were carried out on the ash by Ge(Li) γ-spectroscopy.

Tables 5.4.1-5.4.4 show 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 1987 June bread levels with the 1986 grain levels (cf. Table 5.4.5). The above assumptions for transfer of ^{137}Cs and ^{90}Sr from grain to bread seem justified for rye but not for wheat. This has in fact been envisaged in Risø-R-437 p. 86[21] where it is predicted that the transfer from wheat to white bread will increase from 20 to 33% for ^{90}Sr. The discrepancy for ^{137}Cs on white bread/wheat may be due to the import of Chernobyl-contaminated wheat from Southern Europe, where the contamination of wheat was higher than in Denmark.

Table 5.4.1. Strontium-90 in Danish bread collected in June 1987

Location	Rye bread		White bread	
	Bq kg^{-1}	Bq (kg Ca)$^{-1}$	Bq kg^{-1}	Bq (kg Ca)$^{-1}$
I North Jutland	0.24	260	0.193	390
II East Jutland	0.30	310	0.159	77
III West Jutland	0.22	840	0.144	38
IV South Jutland	0.23	280	0.100	102
V Funen	0.27	280	0.135	290
VI Zealand	0.26	220	0.067	240
VII Lolland-Falster	0.23	52	0.103	200
VIII Bornholm	0.27	370	0.193	430
Mean	0.25	330	0.137	220
Copenhagen	0.24	750	0.170	149
Population-weighted mean	0.25	450	0.139	175

Table 5.4.2. Strontium-90 in Danish bread collected in December 1987

Location	Rye bread		White bread	
	Bq kg^{-1}	Bq (kg Ca)$^{-1}$	Bq kg^{-1}	Bq (kg Ca)$^{-1}$
Mean zones I-VIII	0.22	450	0.088	165

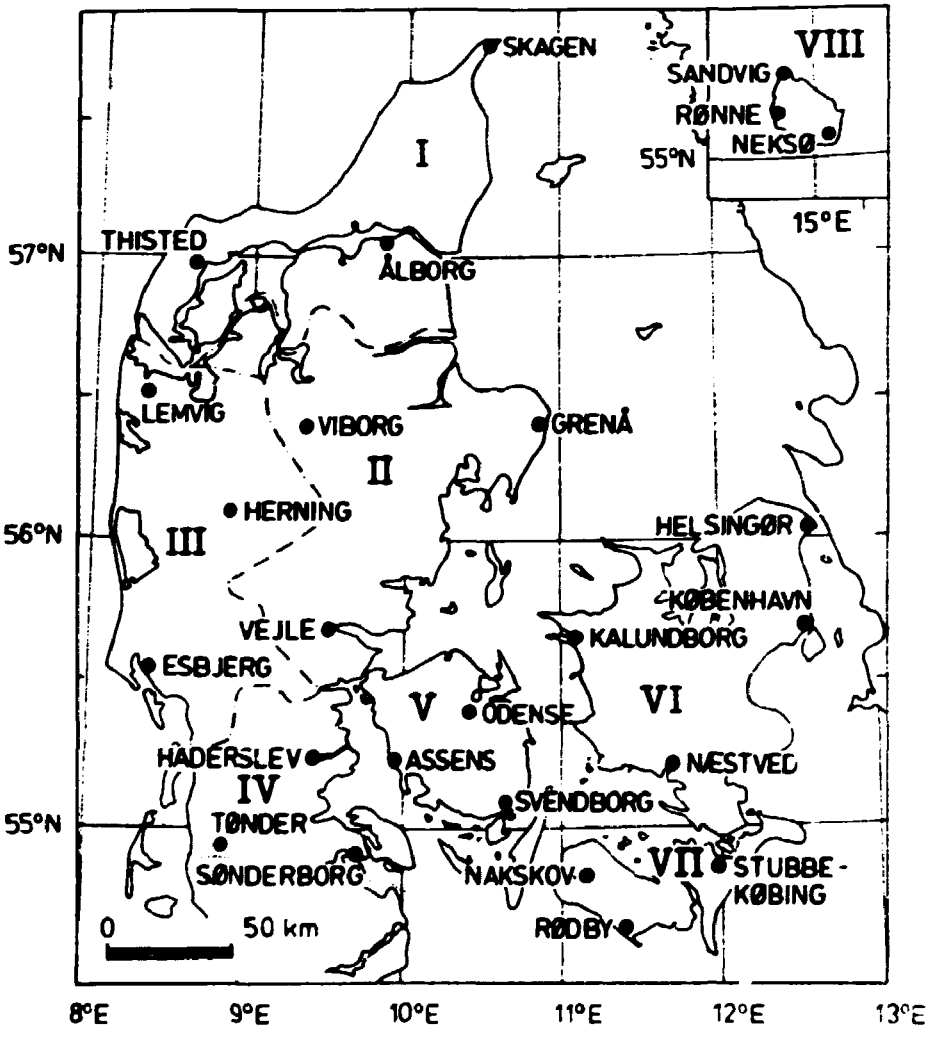
Table 5.4.3. Radiocesium in Danish bread collected in June 1987

Location	Rye bread			White bread		
	Bq kg^{-1}	Bq (kg K)$^{-1}$	$\frac{^{134}Cs}{^{137}Cs}$	Bq kg^{-1}	Bq (kg K)$^{-1}$	$\frac{^{134}Cs}{^{137}Cs}$
I North Jutland	6.8	2600	0.40	0.61	410	0.40
II East Jutland	8.1	2900	0.39	0.79	510	0.39
III West Jutland	3.8	1800	0.40	0.66	500	0.40
IV South Jutland	6.6	2000	0.39	0.50	400	0.35
V Funen	11.0	3600	0.40	0.81	680	0.40
VI Zealand	4.8	1580	0.40	0.44	340	0.39
VII Lolland-Falster	4.7	1650	0.40	0.24	168	0.35
VIII Bornholm	2.8	830	0.38	0.27	220	0.36
Mean	6.1	2100	0.40	0.54	400	0.38
Copenhagen	4.6	1610	0.39	0.34	250	0.40
Population-weighted mean	6.0	2100	0.40	0.55	410	0.39

Table 5.4.4. Radiocesium in Danish bread collected in December 1987

Location	Rye bread			White bread		
	Bq kg^{-1}	Bq (kg K)$^{-1}$	$\frac{^{134}Cs}{^{137}Cs}$	Bq kg^{-1}	Bq (kg K)$^{-1}$	$\frac{^{134}Cs}{^{137}Cs}$
I North-Jutland	1.00	370	0.38	0.128	100	0.34
II East-Jutland	0.41	160	0.24	0.120	96	0.28 A
III West-Jutland	0.30	103	-	0.35	250	0.34
IV South-Jutland	0.25	94	0.25 A	0.136	98	0.28
V Funen	0.25	88	-	0.134	107	0.30 A
VI Zealand	0.098	43	-	0.23	172	0.30
VII Lolland-Falster	0.173	50	-	0.32	270	0.35
VIII Bornholm	0.20	51	-	0.138	119	0.29 A
Mean	0.34	120	0.29	0.195	152	0.31

Fig. 5.4.1. "A"-towns in the 8 zones in Denmark used for diet, meat, bread and milk sampling (these towns were used in 1961-1972 and in 1986-1987).
I: North Jutland; II: East Jutland; III: West Jutland; IV: South Jutland; V: Funen; VI: Zealand; VII: Lolland-Falster; VIII: Bornholm.



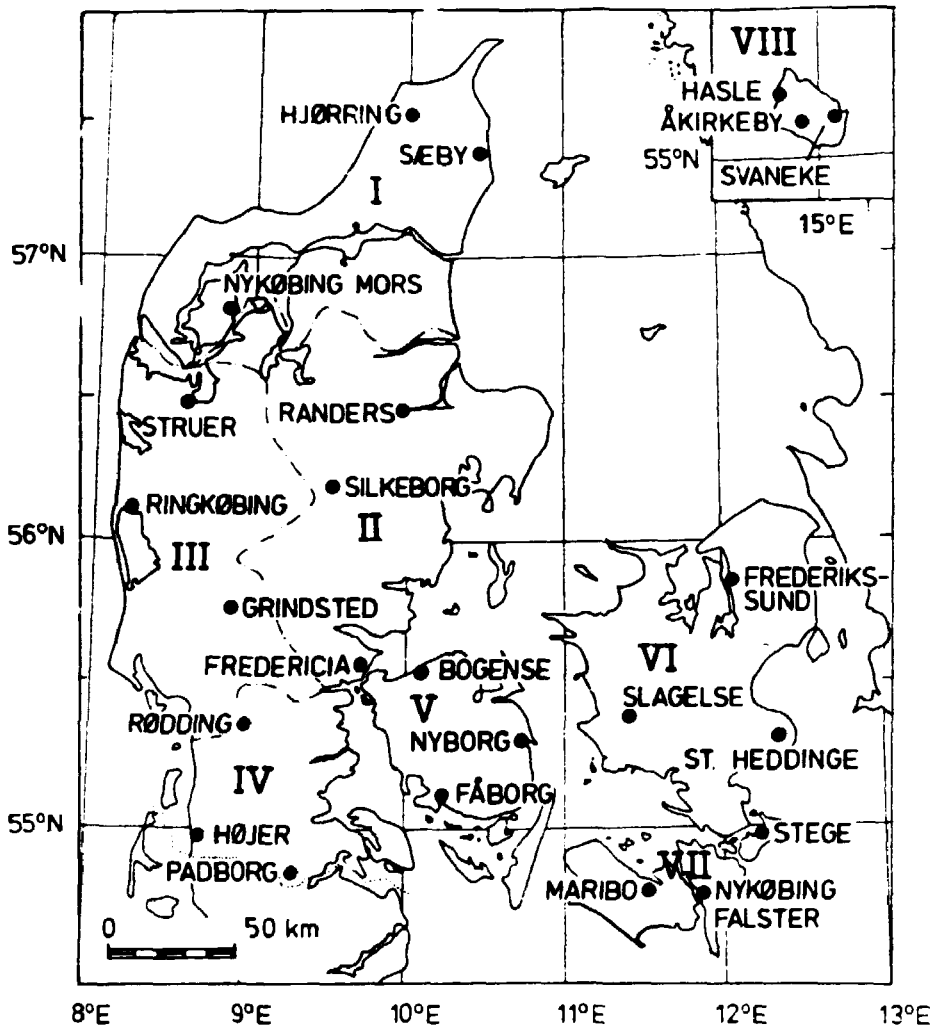


Fig. 5.4.2. "B"-towns in the 8 zones in Denmark used for diet, meat, bread and milk samplings (these towns were used in 1961-1972 and in 1986-1987).

Table 5.4.5. A comparison between ^{90}Sr and ^{137}Cs levels in bread (June) and grain 1987

Nuclide	Species	Bread activity in June 1987 calculated as grain in Bq kg^{-1} (cf. text)	Activity in grain from harvest 1986[1)] Bq kg^{-1}	"Bread"/grain ratio
^{90}Sr	Wheat	0.94	0.39	2.4
	Rye	0.34	0.43	0.8
^{137}Cs	Wheat	1.49	0.63	2.4
	Rye	8.1	11.2	0.7

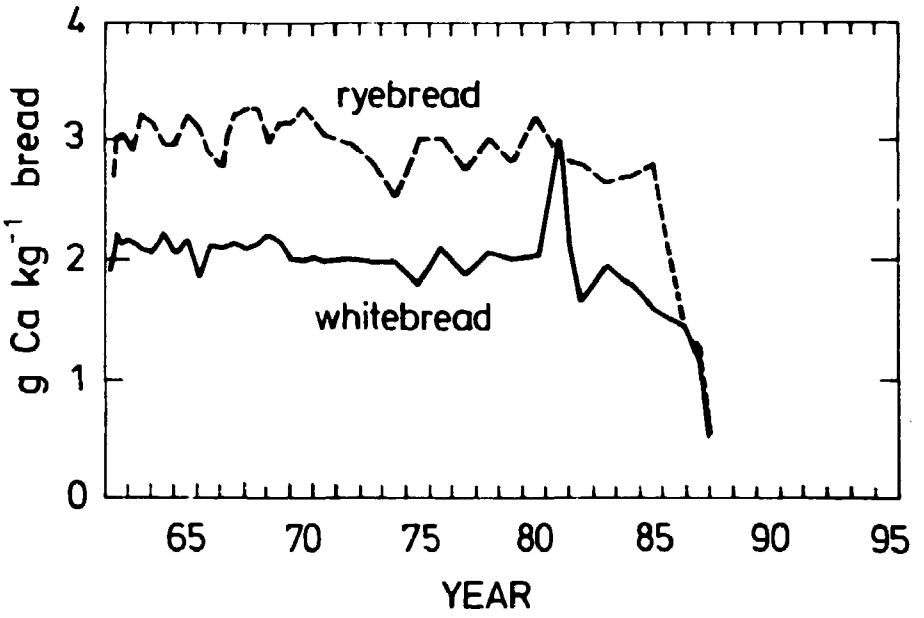


Fig. 5.4.3. Calcium in Danish bread 1962-1987. (Unit: g Ca kg^{-1} bread).

From June to December the ^{137}Cs concentrations in rye bread decreased by a factor of 18 while white bread went down by a factor of 2.8. The ^{90}Sr levels were reduced by a factor of 1.1 and 1.6, respectively.

Figure 5.4.3 shows the Ca-levels in rye bread and white bread since 1962. In 1986 a significant decrease in the levels began. This is because the Government Notice from July 29, 1957, in which it was required that creta praeparata was added to Danish cereals, has been suspended since 1986[30].

5.5. Strontium-90 and Radiocesium 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, ^{137}Cs and ^{134}Cs (γ-spectroscopy of the ash).

Table 5.5.1 shows the ^{90}Sr and radiocesium contents in potatoes. The mean contents for the country were 0.044 Bq ^{90}Sr kg^{-1}, or 970 Bq ^{90}Sr (kg Ca)$^{-1}$, and 0.134 Bq ^{137}Cs kg^{-1} or 35 Bq ^{137}Cs (kg K)$^{-1}$. The ^{90}Sr levels were 10% higher than those in 1986, and the ^{137}Cs concentrations were 0.7 times the 1986 values. About 80% of the ^{137}Cs in Danish potatoes came in 1987 from Chernobyl.

The mean ratio between observed and predicted ^{90}Sr concentrations in potatoes was 0.47 and for ^{137}Cs we found 1.26 (mean of Jutland and the Islands) (cf. Appendix C).

Table 5.5.1. Strontium-90 and radiocesium in Danish potatoes in 1987

Location	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	$\frac{^{134}Cs}{^{137}Cs}$
Tylstrup	0.046	1020	0.030 A	7.4	
Kalø	0.052	1300	0.072	15	0.32 A
Foulum	0.043	1030	0.097	28	0.25 A
Borris	0.042	870	0.176	52	0.21
Askov	0.046	1360	0.46	123	0.24
St. Jyndevad	0.034	730	0.29	69	0.33
Årslev	0.068	1090	0.21	50	0.36
Tystofte	0.029	820	0 B	0 B	
Ledreborg	0.040	630	0.05 B	14 B	
Abed	0.037	590	0.039 A	10 A	
Bornholm	0.035	1130	0.052 A	13 A	
Mean	0.044	970	0.134	35	0.29

5.6. Strontium-90 and Radiocesium in Vegetables and Fruits from the Entire Country

In 1987, as in previous years, vegetables and fruit were collected in the autumn from the 8 zones. The programme was, however, expanded considerably compared to previous years. Tables 5.6.1-5.6.13 show the results.

Table 5.6.14 shows a calculation of the mean contents of ^{90}Sr and ^{137}Cs in Danish vegetables collected in 1987. The ^{90}Sr levels were similar to the 1986 concentrations.

The ^{137}Cs concentrations in 1987 were 0.44 times those in 1986.

The ^{90}Sr concentrations in fruits in 1987 were 1.76 ± 1.50 (± 1 S.D.; N = 7) times those in 1986 and the ^{137}Cs levels in 1987 were 0.061 ± 0.034 times those in 1986. The mean $^{134}Cs/^{137}Cs$ of the 7 fruit species was 0.39 ± 0.02 (1 S.D.), and from July to October when the samples were collected the theoretical ratio in Chernobyl debris decayed from 0.38 to 0.35. Hence all radiocesium observed in Danish fruit in 1987 apparently came from Chernobyl.

Table 5.6.1. Strontium-90 and radiocesium in cabbage collected in September 1987

Zone		Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	$\frac{^{134}Cs}{^{137}Cs}$
I.	North Jutland	0.35	750	0.050	26	
II.	East Jutland	0.36	750	0.062	25	
III.	West Jutland	0.30	580	0.004 B	2 B	
IV.	South Jutland	0.31	670	0.22	69	0.35
V.	Funen	0.27	630	0.083	50	
VI.	Zealand	0.20	360	0.0124 B	6 B	
VII.	Lolland-Falster	0.173	320	0.023 A	11 A	
VIII.	Bornholm	0.156	260	0.018 B	7 B	
Mean		0.26	540	0.059	24	

Table 5.6.2. Strontium-90 and radiocesium in carrot collected in September 1987

Zone		Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	$\frac{^{134}Cs}{^{137}Cs}$
I.	North Jutland	0.195	730	0.103	65	
II.	East Jutland	0.36	1660	0.053 A	29	
III.	West Jutland	0.40	1430	0.085	30	0.35 A
IV.	South Jutland	0.45	1760	0.107	53	0.40
V.	Funen	0.54	1490	0.057 A	21 A	
VI.	Zealand	0.141	400	0.023 A	15 A	
VII.	Lolland-Falster	0.27	850	0.023 A	16 A	
VIII.	Bornholm	0.086	300	0.03 B	10 B	
Mean		0.31	1080	0.060	30	

Table 5.6.3. Strontium-90 and radiocesium in beans collected in September-October 1987

Zone		Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	$\frac{^{134}Cs}{^{137}Cs}$
I.	North Jutland	0.43	790	0.01 B	5 B	
II.	East Jutland			0.01 B	3 B	
III.	West Jutland			0.121	56	0.21 A
IV.	South Jutland			0.105	28	0.22 B
V.	Funen	0.23	730	0.30	172	0.28
VI.	Zealand			0.03 B	10	
VII.	Lolland-Falster			0.01 B	5 B	
VIII.	Bornholm			0.02 B	7 B	
Mean		0.33	760	0.076	36	

Table 5.6.4. Strontium-90 and radiocesium in total peas collected in July 1987

Zone		Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	$\frac{^{134}Cs}{^{137}Cs}$
I.	North Jutland	0.30	440	0.016 B	8 B	
II.	East Jutland	0.52	550	0.072	28	
III.	West Jutland	0.87	1070	0.24	116	0.24
IV.	South Jutland	0.35	380	0.034	15	
V.	Funen	0.47	640	0.027 A	14 A	
VI.	Zealand	0.49	730	0.056	29	
VII.	Lolland-Falster	0.31	380	0.064	29	
VIII.	Bornholm	0.42	550	0.031 A	14 A	
Mean		0.47	590	0.068	32	

Table 5.6.5. Strontium-90 and radiocesium in lettuce collected in July-August 1987

Zone		Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	$\frac{^{134}Cs}{^{137}Cs}$
I.	North Jutland	0.25	510	0.065	18	
II.	East Jutland			0.03 B	12 B	
III.	West Jutland			0.43	130	0.33
IV.	South Jutland			0.39	154	0.34
V.	Funen	0.24	420	0.082	29	
VI.	Zealand			0.081	22	
VII.	Lolland-Falster			0.016 B	6	
VIII.	Bornholm			0.045 A	10	
Mean		0.24	470	0.143	48	

Table 5.6.6. Strontium-90 and radiocesium in onions collected in September-October 1987

Zone		Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$
I.	North Jutland	0.189	940	0.004 B	2 B
II.	East Jutland			0.024 A	12 A
III.	West Jutland			0.062	29
IV.	South Jutland			0.02 B	11 B
V.	Funen	0.23	680	0.03 B	18 B
VI.	Zealand			0.01 B	7 B
VII.	Lolland-Falster			0.005 B	2 B
VIII.	Bornholm			0.02 B	7 B
Mean		0.21	810	0.022	11

Table 5.6.7. Strontium-90 and radiocesium in strawberries collected in July 1987

Zone		Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	$\frac{^{134}Cs}{^{137}Cs}$
I.	North Jutland			0.22	151	0.28
II.	East Jutland			0.02 A	15 A	
III.	West Jutland			0.31	205	0.33
IV.	South Jutland			0.117	72	0.30 A
V.	Funen			0.03 A	20 A	
VI.	Zealand			0.068	53	0.50
VII.	Lolland-Falster			0.014 B	8 B	
VIII.	Bornholm			0.043 A	25 A	
Mean		0.22	1090	0.103	69	0.35

Table 5.6.8. Strontium-90 and radiocesium in gooseberries collected in July-August 1987

Zone		Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	$\frac{^{134}Cs}{^{137}Cs}$
I.	North Jutland			0.38	179	0.43
II.	East Jutland			0.31	185	0.40
III.	West Jutland			1.39	750	0.38
IV.	South Jutland			0.34	172	0.39
V.	Funen			0.61	310	0.40
VI.	Zealand			0.015 A	10 A	-
VII.	Lolland-Falster			0.175	84	0.37
VIII.	Bornholm			0.095	50	0.44
Mean		0.23	810	0.41	220	0.40

Table 5.6.9. Strontium-90 and radiocesium in red currants collected in July 1987

Zone		Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	$\frac{^{134}Cs}{^{137}Cs}$
I.	North Jutland			0.22	124	0.43
II.	East Jutland			0.21	108	0.30
III.	West Jutland			0.92	300	0.35
IV.	South Jutland			0.90	425	0.39
V.	Funen			0.34	149	0.33
VI.	Zealand			0.20	83	0.41
VII.	Lolland-Falster			0.11	51	0.45
VIII.	Bornholm			0.085	29	-
Mean		0.26	690	0.37	159	0.38

Table 5.6.10. Strontium-90 and radiocesium in black currants collected in July-August 1987

Zone		Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	$\frac{^{134}Cs}{^{137}Cs}$
I.	North Jutland			0.26	107	0.37
II.	East Jutland			0.26	97	0.43
III.	West Jutland			1.74	730	0.35
IV.	South Jutland			1.31	440	0.40
V.	Funen			1.09	480	0.37
VI.	Zealand			0.62	240	0.39
VII.	Lolland-Falster			0.35	102	0.39
VIII.	Bornholm			1.48	450	0.45
Mean		0.36	610	0.89	330	0.39

Table 5.6.11. Strontium-90 and radiocesium in raspberries collected in July-August 1987

Zone		Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	$\frac{^{134}Cs}{^{137}Cs}$
I.	North Jutland			0.135	68	0.32
II.	East Jutland			0.046	23	0.57 A
III.	West Jutland			0.37	148	0.30
IV.	South Jutland			0.65	360	0.35
V.	Funen			0.135	61	0.44
VI.	Zealand			0.077	40	0.57 A
VII.	Lolland-Falster			0.063	27	-
VIII.	Bornholm			0.034 B	16.5	-
Mean		0.169	600	0.189	93	0.43

Table 5.6.12. Strontium-90 and radiocesium in cherries collected in July-August 1987

Zone		Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	$\frac{^{134}Cs}{^{137}Cs}$
I.	North Jutland			0.67	250	0.39
II.	East Jutland			0.21	84	0.37
III.	West Jutland			1.39	470	0.39
IV.	South Jutland			1.28	720	0.34
V.	Funen			0.29	193	0.36
VI.	Zealand			0.27	164	0.36
VII.	Lolland-Falster			0.090	38	0.46 A
VIII.	Bornholm			0.46	90	0.43 A
Mean		0.085	610	0.58	260	0.39

Table 5.6.13. Strontium-90 and radiocesium in apples collected in September-October 1987

Zone		Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	$\frac{^{134}Cs}{^{137}Cs}$
I.	North Jutland	0.032	640	0.154	149	0.45
II.	East Jutland	0.030	460	0.114	114	0.49
III.	West Jutland	0.0184	320	0.37	380	0.37
IV.	South Jutland	0.0148	270	0.23	200	0.40
V.	Funen	0.033	850	0.15	151	0.45
VI.	Zealand	0.0168	300	0.34	330	0.34
VII.	Lolland-Falster	0.0133	179	0.28	170	0.30
VIII.	Bornholm	0.045	760	0.04 A	29	-
Mean		0.025	470	0.21	190	0.40

Table 5.6.14. Calculated ^{90}Sr and ^{137}Cs mean levels in vegetables in 1987

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)	0.26	540	0.059	24
30 root vegetables (carrot)	0.31	1080	0.060	30
40 peas and beans	0.40	675	0.072	34
120 g	0.32	720	0.064	29

The 1987 levels in Danish fruit were calculated from apples (80%) and strawberries (20%). The mean levels in Danish fruit were thus 0.064 Bq ^{90}Sr kg^{-1} and 0.19 Bq ^{137}Cs kg^{-1}. The observed Bq ^{90}Sr kg^{-1} levels in vegetables and fruit in 1987 were 1.20 ± 0.55 (1 S.D.; N = 5) times those predicted (cf. Appendix C). In the case of ^{137}Cs, the observed values were 0.36 ± 0.23 times the predicted ones.

5.7. Strontium-90 and Radiocesium in Total Diet from the Entire Country

In 1987 total-food samples representing an average Danish diet according to E. Hoff-Jørgensen (cf. Appendix B in Risø Report No. 631) 9 were collected from 48 towns, 6 from each of the eight zones (cf. Figs. 5.4.1 and 5.4.2) and from Copenhagen. The samplings took place in June and December.

Tables 5.7.1-5.7.6 show the results. The ^{90}Sr levels in Jutland was 16% higher than those in the Islands in 1987. The ^{137}Cs levels in Jutland were equal to those from the Islands.

The ^{90}Sr 1987 levels (Bq ^{90}Sr day^{-1}) (mean of June and December values) in the total diet were equal to the 1986 levels, but the Bq ^{90}Sr (kg Ca)$^{-1}$ levels were nearly 20% higher in 1987 because the Danish diet contained less Ca in

Table 5.7.1. Strontium-90 in Danish total diet collected in June 1987

Zone		Bq (kg Ca)$^{-1}$	Bq day^{-1} cap^{-1}	g Ca day^{-1}
I.	North Jutland	112	0.142	1.27
II.	East Jutland	141	0.195	1.38
III.	West Jutland	124	0.138	1.11
IV.	South Jutland	152	0.180	1.18
V.	Funen	117	0.124	1.06
VI.	Zealand	158	0.180	1.14
VII.	Lolland-Falster	108	0.134	1.24
VIII.	Bornholm	102	0.152	1.49
Mean		127	0.156	1.23
Copenhagen		104	0.140	1.35
Population-weighted mean		128	0.158	1.24

Table 5.7.2. Strontium-90 in Danish total diet collected in September 1987

Zone		Bq (kg Ca)$^{-1}$	Bq day^{-1} cap^{-1}	g Ca day^{-1}
I.	North Jutland	126	0.155	1.23
II.	East Jutland	164	0.179	1.09
III.	West Jutland	133	0.161	1.21
IV.	South Jutland	127	0.153	1.22
V.	Funen	106	0.130	1.04
VI.	Zealand	141	0.153	1.09
VII.	Lolland-Falster	94	0.137	1.30
VIII.	Bornholm	108	0.117	1.08
Mean		125	0.148	1.16
Copenhagen		94	0.190	2.01
Population-weighted mean		126	0.165	1.34

Table 5.7.3. Radiocesium in Danish total diet collected in June 1987

Zone		Town group	Bq ^{137}Cs (kg K)$^{-1}$	Bq ^{137}Cs day^{-1} cap^{-1}	g K day^{-1}	$\frac{^{134}Cs}{^{137}Cs}$
I.	North Jutland	A	580	1.94	3.37	0.38
		B	610	2.33	3.83	0.37
II.	East Jutland	A	490	1.70	3.46	0.36
		B	920	3.27	3.57	0.37
III.	West Jutland	A	660	2.09	3.20	0.39
		B	670	2.12	3.17	0.37
IV.	South Jutland	A	640	2.31	3.60	0.38
		B	700	2.30	3.28	0.37
V.	Funen	A	720	2.51	3.48	0.39
		B	700	2.20	3.14	0.39
VI.	Zealand	A	720	2.41	3.34	0.38
		B	560	1.94	3.48	0.38
VII.	Lolland-Falster	A	640	1.87	2.91	0.38
		B	550	1.88	3.40	0.38
VIII	Bornholm	A	630	2.46	3.89	0.36
		B	660	2.25	3.40	0.38
Mean			650	2.22	3.41	0.38 ± 0.01
Copenhagen			640	2.17	3.40	0.38
Population-weighted mean			660	2.23	3.40	0.38

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

Table 5.7.4. Radiocesium in Danish total diet collected in December 1987

Zone		Town group	Bq ^{137}Cs (kg K)$^{-1}$	Bq ^{137}Cs day^{-1} cap^{-1}	g K day^{-1}	$\frac{^{134}Cs}{^{137}Cs}$
I.	North Jutland	A	300	1.05	3.54	0.31
		B	270	0.95	3.54	0.30
II.	East Jutland	A	260	0.88	3.34	0.38
		B	290	1.02	3.54	0.33
III.	West Jutland	A	270	1.06	4.00	0.30
		B	260	0.89	3.43	0.28
IV.	South Jutland	A	320	1.17	3.72	0.32
		B	260	0.92	3.57	0.31
V.	Funen	A	310	1.07	3.46	0.34
		B	320	1.18	3.72	0.31
VI.	Zealand	A	177	0.58	3.31	0.32
		B	182	0.58	3.20	0.32
VII.	Lolland-Falster	A	220	0.73	3.28	0.33
		B	230	0.83	3.63	0.31
VIII.	Bornholm		220	0.75	3.40	0.31
Mean			260	0.90	3.51	0.32 ± 0.02
Copenhagen			200	0.69	3.40	0.29
Population-weighted mean			240	0.84	3.47	0.31

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

1987 than previously (cf. Fig. 5.7.2). This was due to the absence of creata praeparata in the bread (cf. 5.4), while the ^{137}Cs levels in 1987 were 0.78 times those in 1986.

From the total-diet sampling it is possible to estimate the mean levels of ^{90}Sr and ^{137}Cs in the Danish diet in 1987. For the period January-March 1987, the ^{90}Sr level in the total diet is assumed to have been equal to that measured in December 1986 (Risø Report No. 549[1]). For the period April-September we assume the level to have corresponded to that measured in June 1987. In the months October-December we used the December 1987 figures. Hence the mean content in the total diet in 1987 was 121 Bq ^{90}Sr (kg Ca)$^{-1}$, or 0.16 Bq ^{90}Sr (day)$^{-1}$.

Similarly, the ^{137}Cs content in the Danish diet in 1987 was estimated to be 1.93 Bq ^{137}Cs (day)$^{-1}$ or 550 Bq ^{137}Cs (kg K)$^{-1}$ or 37% higher than in 1986. The daily mean intake of ^{134}Cs was 0.78 Bq cap^{-1} corresponding to a total intake of 285 Bq ^{134}Cs in 1987 or 24% higher than in 1986. The observed ^{137}Cs fallout level in total diet was 0.25 times that predicted (cf. Appendix C.2).

Figure 5.7.1 shows 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 0.64 times that predicted.

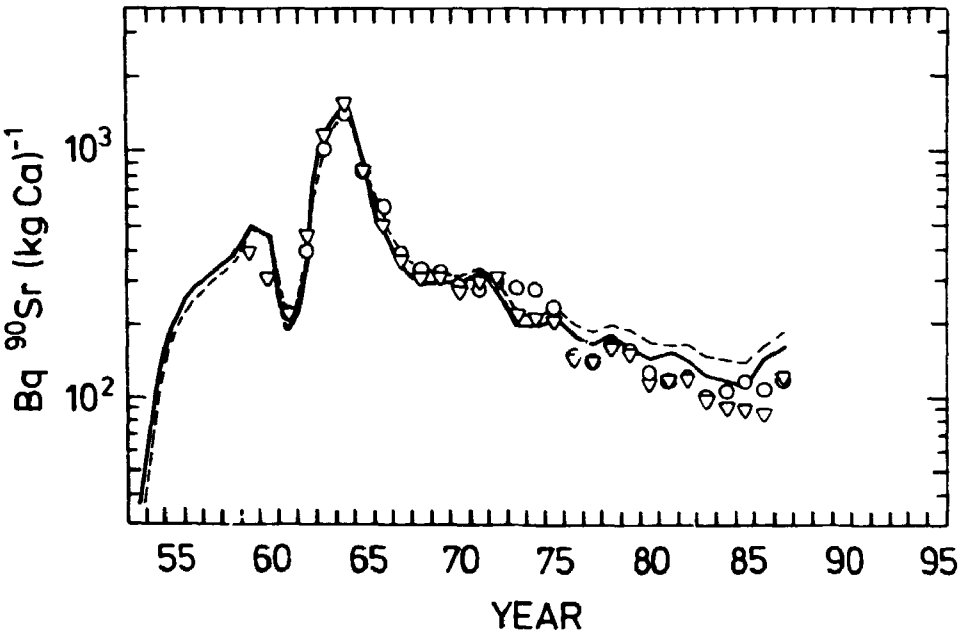
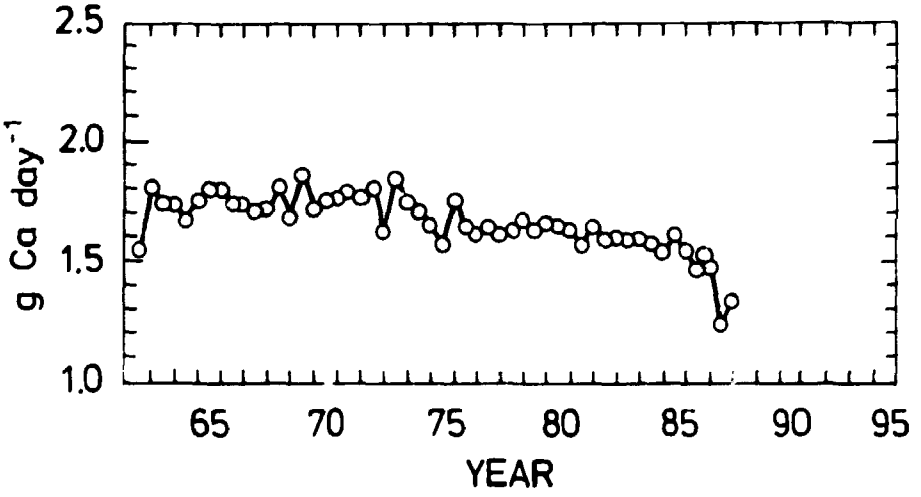


Fig. 5.7.1. Predicted and observed ^{90}Sr levels in the Danish total diet. The dotted curve represents the predicted values for "Diet C" (cf. Tables 5.7.1 and 5.7.2) and the circles are the corresponding observed values. The unbroken curve represents the predicted values for "Diet P" (cf. Table 5.9.3),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

Fig. 5.7.2. Calcium in Danish average diet 1962-1987. (Unit: g Ca day^{-1}).



5.8. Radionuclides in Meat, Fish, Eggs and Various Vegetable Foodstuffs

5.8.1. Strontium-90 and Radiocesium in Meat

Pork and beef samples were collected countrywide (cf. Figs. 5.4.1 and 5.4.2) in June and December. Tables 5.8.1.1-5.8.1.3 show the results.

In order to calculate the mean level of ^{90}Sr and radiocesium in Danish meat in 1987, we use the means of the June and December samplings.

Hence the mean ^{137}Cs content in Danish beef in 1987 becomes 5.6 Bq kg^{-1} and in pork we get 0.99 Bq ^{137}Cs kg^{-1}. It was surprising to see the high ^{137}Cs levels in beef in June 1987, because similar high concentrations were not observed in milk (cf. 5.1 and 5.2). We believe that meat has been imported from more contaminated parts of Europe. Compared to 1986 the ^{137}Cs level in beef increased by a factor of 2.7 and that in pork by a factor of 1.4. The difference between beef and pork levels reflects the differences in the contamination of grass (cow fodder) and grain (pig fodder). The Chernobyl contributions of ^{137}Cs were 95% for beef and 85% for pork. The ^{134}Cs mean concentrations were 2.1 Bq kg^{-1} beef and 0.32 Bq kg^{-1} pork. Beef contained 0.0152 Bq ^{90}Sr and pork 0.007 Bq ^{90}Sr kg^{-1} in 1987.

Table 5.8.1.1. Strontium-90 in countrywide-collected beef and pork in 1987

Month	Species	Bq kg^{-1}	Bq (kg Ca)$^{-1}$
June	Beef	0.0174	156
June	Pork	0.009 B	70 B
Dec	Beef	0.0129	115
Dec	Pork	0.0047 A	58 A

Table 5.8.1.2. Radiocesium in beef and pork collected countrywide in Denmark in June 1987

Zone		Beef			Pork		
		Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	$\frac{^{134}Cs}{^{137}Cs}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	$\frac{^{134}Cs}{^{137}Cs}$
I.	North Jutland	3.1	1170	0.35	0.47	144	0.32
II.	East Jutland	16.9	6000	0.40	2.2	710	0.35
III.	West Jutland	4.6	1650	0.38	1.26	400	0.31
IV.	South Jutland	7.0	2300	0.38	2.1	660	0.35
V.	Funen	5.4	1730	0.39	1.32	430	0.36
VI.	Zealand	7.6	2900	0.40	0.74	240	0.36
VII.	Lolland-Falster	12.6	3900	0.38	0.73	300	0.36
VIII.	Bornholm	18.6	6500	0.41	1.16	360	0.38
Mean		9.5	3300	0.39	1.25	410	0.35
Copenhagen		11.5	3300	0.40	1.68	490	0.35
Population-weighted mean		9.3	3100	0.39	1.38	430	0.34

Table 5.8.1.3. Radiocesium in beef and pork collected countrywide in Denmark in December 1987

Zone		Beef			Pork		
		Bq ^{137}Cs kg^{-1}	Bq^{137}Cs (kg K)$^{-1}$	$\frac{^{134}Cs}{^{137}Cs}$	Bq ^{137}Cs kg^{-1}	Bq^{137}Cs (kg K)$^{-1}$	$\frac{^{134}Cs}{^{137}Cs}$
I.	North Jutland	3.2	1040	0.29	0.87	280	0.26
II.	East Jutland	1.68	670	0.30	0.53	170	0.25
III.	West Jutland	1.90	670	0.31	0.67	220	0.24
IV.	South Jutland	4.0	1370	0.31	0.60	193	0.26
V.	Funen	1.30	440	0.32	0.60	200	0.28
VI.	Zealand	1.93	630	0.32	0.39	131	0.29
VII.	Lolland-Falster	1.29	440	0.29	1.04	360	0.30
VIII.	Bornholm	0.126	39	0.25	0.083	30	0.25
Mean		1.93	660	0.30	0.60	198	0.27

The mean ratio between observed and predicted (cf. Appendix C) ^{137}Cs levels in beef was 2.04 and for ^{90}Sr the mean ratio was 0.43. In pork, the ratios were 0.05 and 0.26 respectively.

5.8.2. Radionuclides in Fish and Mussels

Fish samples were collected in the North Sea and in inner Danish waters. Tables 5.8.2.1-5.8.2.2 show the results. The mean levels were 0.014 Bq ^{90}Sr kg^{-1} and 4.7 Bq ^{137}Cs kg^{-1}, i.e. unchanged from 1986.

The mean ^{137}Cs content in fish from Cattegat was 2.5 times that in fish from the North Sea; the contribution from Chernobyl was 42% in the North Sea fish while it was 64% in the fish from Cattegat. Hence the ^{137}Cs Chernobyl concentrations in Cattegat fish became 6.7 × 0.64 = 4.3 Bq kg^{-1} and in North Sea fish 2.7 × 0.42 = 1.13 Bq kg^{-1}. This implies that the mean content of non-Chernobyl ^{137}Cs in Danish fish from 1987 became 2.0 Bq kg^{-1}, which is 25% higher than the estimate for 1986.

The non-Chernobyl ^{137}Cs in fish from Danish waters has two main sources: discharges from nuclear reprocessing plants (Sellafield in U.K. and La Hague in France) and global fallout. For 1986, it was estimated that 1 Bq ^{137}Cs kg^{-1} fish came from reprocessing; a similar level is anticipated for 1987.

Table 5.8.2.1. Strontium-90 in fish collected in Danish waters in 1987 (samples were obtained from Hundested (Cattegat) and Ringkøbing (North Sea))

Month	Species	Flesh		Bone
		Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{90}Sr (kg Ca)$^{-1}$
March	Cod	0.035	41	27
March	Plaice	0.0178	21	17.4
March	Herring	0.0042 A	8.6	4.5
September	Cod	0.0080	9.8	16.4
September	Plaice	0.0063	12.3	13.9
September	Herring	0.0094	28	3.8
September	Pike (total fish)	0.46	1050	
Mean (Pike excluded)		0.0135	20	13.8

Table 5.8.2.2. Radiocesium in fish from Danish waters in 1987

Location	Month	Species	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs $(kg\ K)^{-1}$	$\frac{^{134}Cs}{^{137}Cs}$
Hundested	March	Cod	12.6	3900	0.36
(Cattegat)	March	Plaice	5.3	1860	0.27
-"-	March	Herring	4.8	1370	0.22
-"-	Sept	Cod	13.3	3400	0.28
-"-	Sept	Plaice	1.52	580	0.18
-"-	Sept	Herring	2.6	840	0.19
Mean			6.7	1990	
Ringkøbing	March	Cod	4.7	1320	0.19
(North Sea)	March	Plaice	1.10	680	0.27
-"-	March	Herring	4.4	1480	0.24
-"-	Sept	Cod	3.3	1100	0.12
-"-	Sept	Plaice	1.18	480	0.21
-"-	Sept	Herring	1.61	550	0.15
Mean			2.7	940	
Total mean			4.7	1460	

Table 5.8.2.3. Radiocesium in marine fish from various locations in 1987

Location	Date	Species	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs $(kg\ K)^{-1}$	$\frac{^{134}Cs}{^{137}Cs}$
Roskilde Fjord	Apr 26	Herring	6.1	1570	0.27
Cattegat	May 22	Garpike	6.5	2200	0.20
Ringkøbing Fjord	Sep 24	Pike	35	10700	0.36
Oscarshamn					
Baltic Sea, Sweden	Jan	Eel	4.6	1560	0.28
-"-	April	Eel	7.5	2800	0.32
-"-	May	Eel	7.2	2800	0.34
-"-	June	Eel	6.5	2400	0.33
-"-	July	Eel	8.1	2600	0.33
-"-	Aug	Eel	6.6	2200	0.32
-"-	Sept	Eel	8.4 ± 0.9	2800	0.33 ± 0.01
-"-	Oct	Eel	9.9	3400	0.30
-"-	Nov	Eel	11.4	3700	0.32
-"-	Dec	Eel	11.6	4300	0.31

Table 5.8.2.4. Radiocesium in Mytilus edulis, soft part, collected in 1987. (Unit: Bq kg^{-1} dry weight)

Location	Strøby Egede	Limhamn
Position	55°25'N 12°15'E	55°35'N 12°55'E
Date	16 July	3 November
% dry matter	10.3	8.3
^{40}K*	8.76	7.93
^{134}Cs	<8.0	<9.6
^{137}Cs	10.0	9.9

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

Table 5.8.2.5. Radiocesium in fresh water fish caught in the middle of May 1987 in Arresø and Esrumsø in Zealand

Lake	Species	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	$\frac{^{134}Cs}{^{137}Cs}$
Arresø	Eel	21	7700	0.26
-"-	Pike	64	22000	0.37
-"-	Roach	36	10200	0.30
-"-	Perch	75	-	0.36
-"-	Bleak	51	-	0.37
Esrumsø	Eel	32	14400	0.35
-"-	Pike	66	20000	0.30
-"-	Roach	45	9400	0.36
-"-	Perch	166	63000	0.35
-"-	Pike	78	19300	0.32

In Fig. 5.8.2 we have shown the radiocesium levels in eels caught at Oscarshamn, Sweden in the Baltic Sea since April 1986. Since the Chernobyl accident the total ^{137}Cs has increased by a factor of 7.7 (December 1987). The significant increases occurred from December 1986 to April 1987 and from August 1987 to November 1987. In June 1986 the Chernobyl ^{137}Cs was 40% of the total ^{137}Cs in eels; in December 1987 it had increased to 94% (cf. also Table 5.8.2.3). Table 5.8.2.4 shows the radiocesium content in blue mussels. The mean level was about 1 Bq ^{137}Cs kg^{-1} fresh weight.

In Table 5.8.2.5, analyses on fresh water fish caught in two Danish lakes in North Zealand are reported. The high concentrations are remarkable. The levels are an order of magnitude higher than those seen in marine fish. It is also remarkable that only 84±9% (±1 S.D.; N = 10) of the ^{137}Cs in fresh water fish came from Chernobyl. In other words, there is a fallout background on 9±6 (±1 S.D.; N = 10) Bq ^{137}Cs kg^{-1} fish in Esromsø and Arresø.

Although fresh water fish are among the highest contaminated food products in Denmark, this has no significant impact on the human intake of radiocesium because the consumption of fresh water fish in Denmark is insignificant.

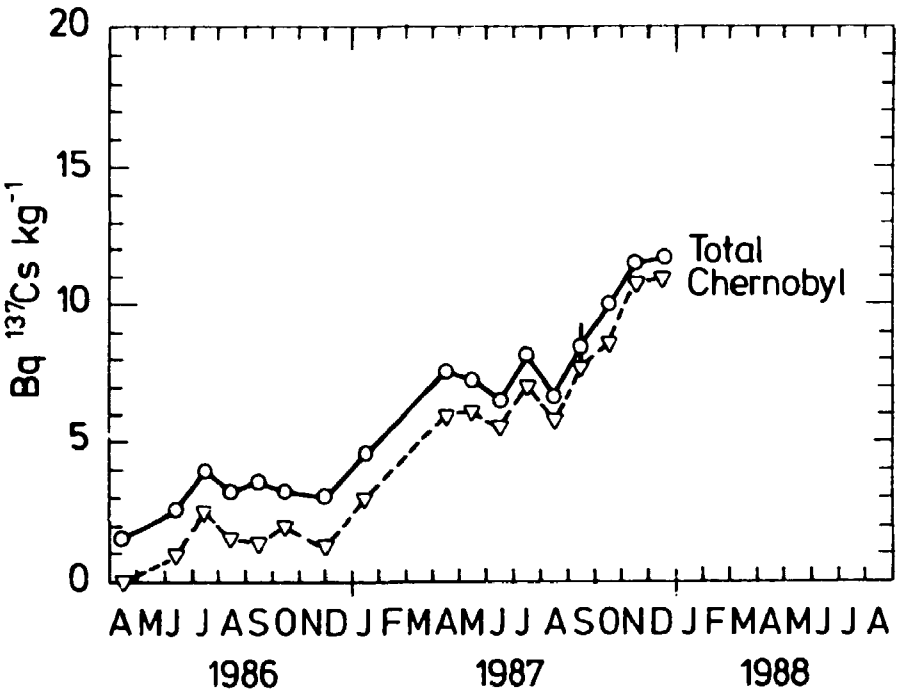


Fig. 5.8.2. Cesium-137 in eels from the Baltic Sea (Oscarshamn, Sweden) 1986-1987. (Unit: Bq ^{137}Cs kg^{-1}).

5.8.3. Strontium-90 and Radiocesium in Eggs

Eggs were collected countrywide in June 1987. The ^{90}Sr and ^{137}Cs concentrations were a little higher than in 1986.

The observed ^{90}Sr levels in eggs were (cf. Appendix C) 1.67 times those predicted. In 1986 the effect was reversed, which shows that our prediction model for ^{137}Cs in eggs has significantly underestimated the importance of the deposition of ^{137}Cs in the year when the eggs are produced and, on the other hand, overestimated the importance of the deposition in the previous year.

Table 5.8.3. Strontium-90 and radiocesium in Danish eggs collected countrywide in June 1987

	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	$\frac{^{134}Cs}{^{137}Cs}$
Denmark	0.020	36	0.185	143	0.36

5.8.4. Strontium-90 and Radiocesium in the Variety of Vegetable Food

The spring vegetables and fruits are imported from other European countries to some extent. Table 5.8.4 shows the analysis on these samples. It appears that most of the samples have been very low in radiocesium. Relatively high concentrations were observed in apples and pears from Italy and in peaches from Greece. Samples of wine were also measured; they all contained less than 1 Bq ^{137}Cs l^{-1}, but the "Chernobyl signal" was present in 2 samples of five.

Table 5.8.4. Radiocesium in various imported fruits and vegetables (and wine) purchased in 1987 in a Danish supermarket

Country of origin	Month	Species	Bq ^{137}Cs kg^{-1}	Bq ^{137}Cs $(kg\ K)^{-1}$	$\frac{^{134}Cs}{^{137}Cs}$
Cyprus	May	Potatoes	0.04 B	8.5 B	-
France	May	Cauliflower	0.01 B	2 B	-
- " -	May	Onion	0.01 B	8 B	-
- " -	May	Apples	0.01 B	8 B	-
Netherlands	May	Cucumber	0.29	186	0.39
- " -	May	China cabbage	0.23	133	0.42
- " -	May	Squash	0.082 A	26 A	-
- " -	May	Tomatoes	0.31	127	0.41
- " -	May	Green pepper	0.063 A	37 A	-
Italy	May	Carrots	0.02 B	6.5 B	-
- " -	May	Spring onions	0.26	230	0.43
- " -	May	Potatoes	0.31	75	0.42
- " -	May	Apples	12.1	10400	0.42
- " -	May	Pears	39	28000	0.41
- " -	May	Peas	0.036 A	16 A	-
- " -	May	Strawberries	0.03 B	20 B	-
- " -	May	Peaches	0.128	84	0.55
- " -	July	Wine			
- " -	July	Wine	0.82	-	0.39
- " -	July	Wine	0.24 A	-	-
Greece	May	Watermelon	0.087	74	0.49
- " -	Aug	Peaches	9.0	4000	0.36
Belgium	May	Strawberries	0.01 B	3.5 B	-
Hungary	May	Asparagus	0.02 B	9 B	-
F.R.G.	May	Plums	0.73	420	0.43
Yugoslavia	Sept	Wine	0.89	-	0.47 A
- " -	Sept	Wine	0.79	-	-

5.9. Estimate of the Mean Contents of ^{90}Sr and Radiocesium in the Human Diet in Denmark in 1987

5.9.1. The Annual Quantities

The annual quantities are calculated by multiplying 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 fresh milk ~ 1 l milk, containing approximately 1.2 g Ca and 1.66 g K. Hence the mean contents in milk were 0.071 Bq ^{90}Sr kg^{-1} and 0.60 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 0.50 Bq ^{90}Sr and 0.43 Bq ^{137}Cs. These levels are lower than those reported from direct measurements of cheese (Table 5.3), but these cheese samples do not represent the countrywide mean.

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 1987. From these tables, the activity levels in grain products were estimated at 0.228 Bq ^{90}Sr kg^{-1} and 3.20 Bq ^{137}Cs kg^{-1}.

Table 5.9.1. Estimate of the ^{90}Sr content in grain products consumed pro capite in 1987

Type	Fraction from harvest 1986			Fraction from harvest 1987			Total
	kg flour	Bq kg^{-1}	Bq	kg flour	Bq kg^{-1}	Bq	Bq
Rye flour 100% extraction	21.9	0.43	9.42	7.3	0.44	3.21	12.63
Wheat flour 75% extraction	32.9	0.08	2.63	10.9	[illegible]	1.41	4.04
Grits	5.5	0.23	1.27	1.8	0.20	0.36	1.63
Total	60.3	0.22	13.32	20.0	0.25	4.98	18.30

Table 5.9.2. Estimate of the ^{137}Cs content in grain products consumed pro capite in 1987

Type	Fraction from harvest 1986			Fraction from harvest 1987			Total
	kg flour	Bq kg^{-1}	Bq	kg flour	Bq kg^{-1}	Bq	Bq
Rye flour 100% extraction	21.9	11.1	243.09	7.3	0.17	1.24	244.33
Wheat flour 75% extraction	32.9	0.29	9.54	10.9	0.04	0.44	9.98
Grits	5.5	0.37	2.04	1.8	0.25	0.45	2.49
Total	60.3	4.22	254.67	20.0	0.11	2.13	256.77

5.9.5. Potatoes

The figures in Table 5.5.1 were used, i.e. 0.044 Bq ^{90}Sr kg^{-1} and 0.134 Bq ^{137}Cs kg^{-1}.

5.9.6. Vegetables

Table 5.6.15 shows the calculation of ^{90}Sr and ^{137}Cs in Danish vegetables consumed in 1987. The mean contents were 0.32 Bq ^{90}Sr kg^{-1} and 0.064 Bq ^{137}Cs kg^{-1}.

5.9.7. Fruit

The levels in imported fruit in 1987 are assumed to be equal to the mean levels found in oranges and bananas collected in Copenhagen in 1986, i.e. 0.067 Bq ^{90}Sr kg^{-1} and 0.068 Bq ^{137}Cs kg^{-1}. The mean levels in Danish fruit (cf. 5.6) in 1987 were 0.064 Bq ^{90}Sr kg^{-1} and 0.19 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 0.065 Bq ^{90}Sr kg^{-1} and 0.16 Bq ^{137}Cs kg^{-1}.

5.9.8. Meat

The annual mean values of ^{90}Sr and ^{137}Cs in meat were calculated from 5.8.1: 0.010 Bq ^{90}Sr kg^{-1} and 2.53 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 are estimated from 5.8.2 at 0.014 Bq ^{90}Sr kg^{-1} and 4.7 Bq ^{137}Cs kg^{-1}.

5.9.10. Eggs

The contents of activity in eggs were estimated from 5.8.3. The levels were 0.020 Bq ^{90}Sr kg^{-1} and 0.185 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 1986 (5.8.4): 0.41 Bq ^{90}Sr kg^{-1} and 1.29 Bq ^{137}Cs kg^{-1} [1].

5.9.12. Drinking Water

The ^{90}Sr mean level found in drinking water collected in June 1987 (4.3.3) was used as the mean level for drinking water, i.e. $0.54 \cdot 10^{-3}$ Bq ^{90}Sr kg^{-1}. The ^{137}Cs content in drinking water was measured to be $0.06 \cdot 10^{-3}$ Bq kg^{-1}.

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 1986. 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 124 Bq (kg Ca)$^{-1}$ and 121 Bq (kg Ca)$^{-1}$, respectively, or 0.16 and 0.16 Bq ^{90}Sr $(day)^{-1}$, and the ^{137}Cs estimates were 1.62 Bq ^{137}Cs $(day)^{-1}$ and 1.93 Bq ^{137}Cs $(day)^{-1}$.

Table 5.9.3. Estimate of the mean content of ^{90}Sr in the human diet in 1987

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	0.071	11.64	19.9
Cheese	9.1	0.50	4.55	7.8
Grain products	80.3	0.228	18.30	31.3
Potatoes	73.0	0.044	3.21	5.5
Vegetables	43.8	0.32	14.02	24.0
Fruit	51.1	0.065	3.32	5.7
Meat	54.7	0.010	0.55	0.9
Eggs	10.9	0.020	0.22	0.4
Fish	10.9	0.014	0.15	0.2
Coffee and tea	5.5	0.41	2.26	3.9
Drinking water	548	0.0005	0.27	0.4
Total			58.49	

The mean Ca intake was estimated at 0.47 kg y^{-1} (approx. 0.1 kg creata praeparata). Hence the ^{90}Sr/Ca ratio in total diet was 124 Bq ^{90}Sr (kg Ca)$^{-1}$ (3.4 S.U.) in 1987.

Table 5.9.4. Estimate of the mean content of ^{137}Cs in the human diet in 1987

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	0.60	98.40	17.2
Cheese	9.1	0.43	3.91	0.7
Grain products	80.3	3.20	256.77	44.9
Potatoes	73.0	0.134	9.78	1.7
Vegetables	43.8	0.064	2.80	0.5
Fruit	51.1	0.16	8.18	1.4
Meat	54.7	2.53	138.39	24.2
Eggs	10.9	0.185	2.02	0.4
Fish	10.9	4.7	51.23	9.0
Coffee and tea	5.5	1.29	0.03	0.0
Drinking water	548	0.00006	0.03	0.0
Total			571.54	

As the approximate intake of potassium was 1.365 kg y^{-1} the ^{137}Cs/K ratios were 424 Bq ^{137}Cs (kg K)$^{-1}$ or 11.5 M.U. in 1987.

The ratio of the observed to the predicted (cf. Appendix C) diet levels was 0.75 for ^{90}Sr and 0.15 for ^{137}Cs.

The relative contribution of ^{90}Sr from milk products was 28% in 1987. The contribution from potatoes, other vegetables, and fruit was 35%, and that from cereals was 31%. The relative contribution of ^{137}Cs in the total diet changed from 1986 to 1987 as follows: milk products (37 to 17%), grain pro-

ducts increased from 18 to 43%, and meat from 13 to 24%. Fruit decreased from 14 to 1% and has thus been the diet group which was relatively most influenced by the Chernobyl debris. Fish contributed 9% to the total ^{137}Cs intake in 1987.

5.10. Grass and Fodder Samples

5.10.1. Grass Collected Around Risø

Table 5.10.1.1 shows the ^{90}Sr content in grass ash from Zealand in 1987. The mean ^{90}Sr activity was 17.8 Bq ^{90}Sr (kg ash)$^{-1}$, or 400 Bq ^{90}Sr (kg Ca)$^{-1}$, i.e. the 1987 level was approximately ¾ of the 1986 level. Figure 5.10.1 shows the ^{90}Sr concentration in grass since 1957. The ratio of the observed to the predicted (cf. Appendix C.1) ^{90}Sr levels in grass in 1987 was 0.49.

Figure 5.10.2 shows the variation of the ^{137}Cs in Risø grass since Chernobyl. In May we see a steep decrease mainly due to growth dilution. From June 1986 to March 1987, the levels were rather constant around 10 Bq ^{137}Cs kg^{-1} fresh weight; since May 1987 the levels have decreased to about 0.5-1 Bq ^{137}Cs kg^{-1} (cf. also Table 5.10.1.2).

Table 5.10.1.1. Strontium-90 in grass from Zealand, 1987

Periods	Bq ^{90}Sr (kg ash)$^{-1}$	Bq ^{90}Sr (kg Ca)$^{-1}$
Jan-March	14.6	480
April-June	16.2	320
July-Sept	21	400
Oct-Dec	19.6	390
Mean	17.8	400

Table 5.10.1.2. Radiocesium in grass collected at Risø weekly in 1987

Month	Bq ^{137}Cs kg^{-1} fresh weight		Bq ^{137}Cs m^{-2}		$\frac{^{134}Cs}{^{137}Cs}$	
Jan	1.0 A	(n=1)	0.29 A	(n=1)	-	
Feb	10.4 ±2.6	(n=3)	4.7 ±2.5	(n=3)	0.46±0.03	(n=2)
March	9.9	(n=1)	1.54	(n=1)	-	
April	7.2	(n=1)	2.2	(n=1)	0.33	(n=1)
May	1.2	(n=1)	0.94	(n=1)	-	
June	0.72±0.10	(n=4)	0.47±0.07	(n=4)	-	
July	0.84±0.12	(n=4)	0.48±0.06	(n=4)	0.52	(n=1)
Aug	0.62±0.22	(n=2)	0.28±0.05	(n=2)	-	
Sept	0.69±0.22	(n=3)	0.29±0.10	(n=3)	-	
Oct	0.99 A	(n=1)	0.39 A	(n=1)	-	
Nov	0.54±0.10		0.25±0.03		0.32	
Dec	0.53±0.11		0.20±0.05		0.32	

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

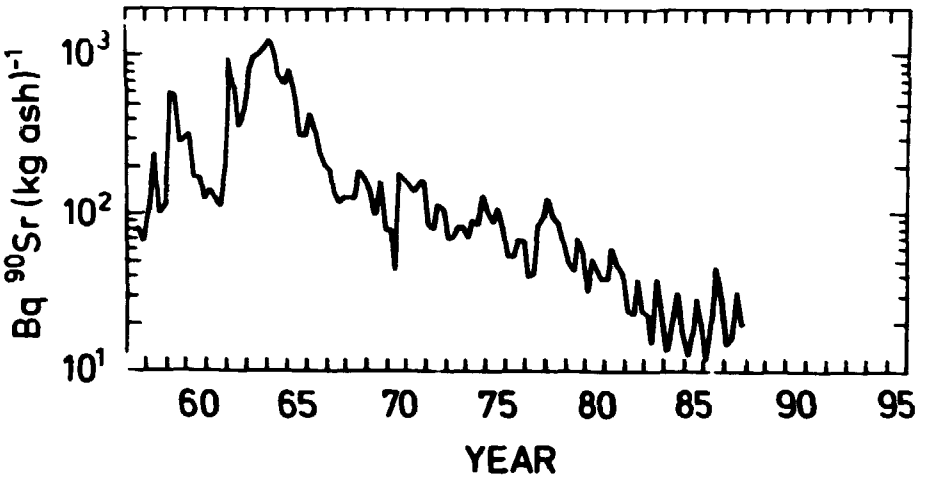


Fig. 5.10.1. Quarterly ^{90}Sr levels in grass, 1957-1987.

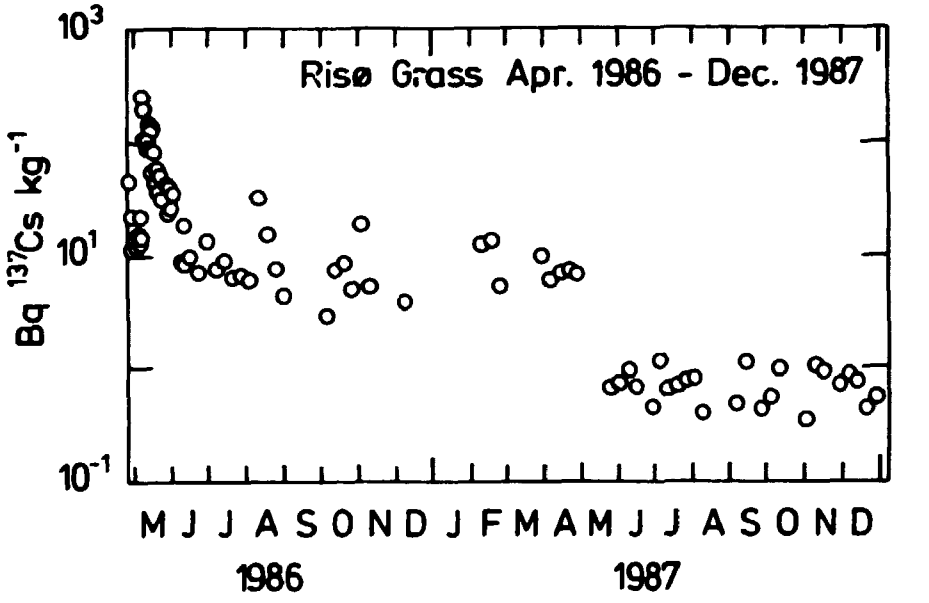


Fig. 5.10.2. Cesium-137 in grass samples collected at Risø, Denmark in the period April 1986 - December 1987.

5.10.2. Radionuclides in Grass Collected at the State Experimental Farms

Grass samples were collected countrywide in July and September 1987 at the 10 State experimental farms (Tables 5.10.2 - 5.10.3). The grass samples from the State experimental farms (Table 5.10.2) show that about 95% of ^{137}Cs came from Chernobyl. The large variations between the two samplings for the same locations suggest that some samples may have contained hot particles deposited on the grass by resuspension.

The contribution from root uptake is presumed to be of minor importance.

Figure 5.10.3 shows the median ^{137}Cs levels in Danish grass collected countrywide since the Chernobyl accident.

Table 5.10.2. Radiocesium in grass collected at the State experimental farms in 1987 (fresh weight samples)

Location	July				September			
	Bq ^{137}Cs		$^{134}Cs/^{137}Cs$	g K	Bq ^{137}Cs		$^{134}Cs/^{137}Cs$	g K
	kg^{-1}	m^{-2}		kg^{-1}	kg^{-1}	m^{-2}		kg^{-1}
Tylstrup	1.62	2.1	0.45	5.8	0.83	0.43		6.7
Kalø	0.48 A	0.24 A		4.5	1.25	0.66		5.4
Borris	5.4	3.0	0.34	4.4	0.28 A	0.18 A		5.8
Askov	4.7	5.3	0.35	4.0	2.81	1.70	0.33	5.4
St. Jyndevad	1.61	1.41	0.32	4.5	0.58	0.38	0.32 A	7.0
Årslev	0.50	0.45	0.40 A	6.0	0.78	0.78	0.38	4.6
Tystofte	0.18 A	0.23 A		4.8	0.71	0.39	0.30	5.5
Ledreborg	0.28 A	0.21 A		6.3	0.34	0.34		5.4
Abed	0.26 A	0.20 A		7.2	0.174 A	0.105 A		8.1
Tornbygård	0.19 B	0.15 B		4.4	1.47	1.10	0.34	4.2
Mean	1.52	1.33	0.37	5.2	0.92	0.61	0.33	5.8
S.D.	1.94	1.71	0.05	1.06	0.78	0.48	0.03	1.16
N	10	10	5	10	10	10	5	10

Table 5.10.3. Strontium-90 in grass collected at the State experimental farms in September 1987. (Fresh weight samples)

Location	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr m^{-2}	Bq ^{90}Sr $(kg\ Ca)^{-1}$
Tylstrup	0.94	0.49	600
Kalø	0.56	0.29	420
Borris	0.79	0.51	770
Askov	3.76	2.28	2600
St. Jyndevad	2.01	1.31	2400
Årslev	0.77	0.77	610
Tystofte	2.54	1.40	1670
Ledreborg	0.71	0.71	640
Abed	0.71	0.43	410
Tornbygård	4.29	3.21	1210
Mean	1.71	1.14	1130
S.D.	1.39	0.95	820

If we compare the grass ^{137}Cs levels in September 1987 with those in 1986 we observe a decrease by a factor of two (Fig. 5.10.3). In the same period the deposition decreased by a factor of six. This may indicate that the grass received a significant part of its ^{137}Cs through root uptake. It may, however, also be due to a higher resuspension to the grass than to the higher (1 m above ground level) situated rain collectors.

Table 5.10.3 shows the ^{90}Sr grass levels at the 10 State experimental farms. Compared with last year's results the concentrations in 1987 were 2.0 ± 0.6 (± 1 S.E.; N = 10) ($Bq\ kg^{-1}$) or 1.49 ± 0.27 ($Bq\ (kg\ Ca)^{-1}$) times higher.

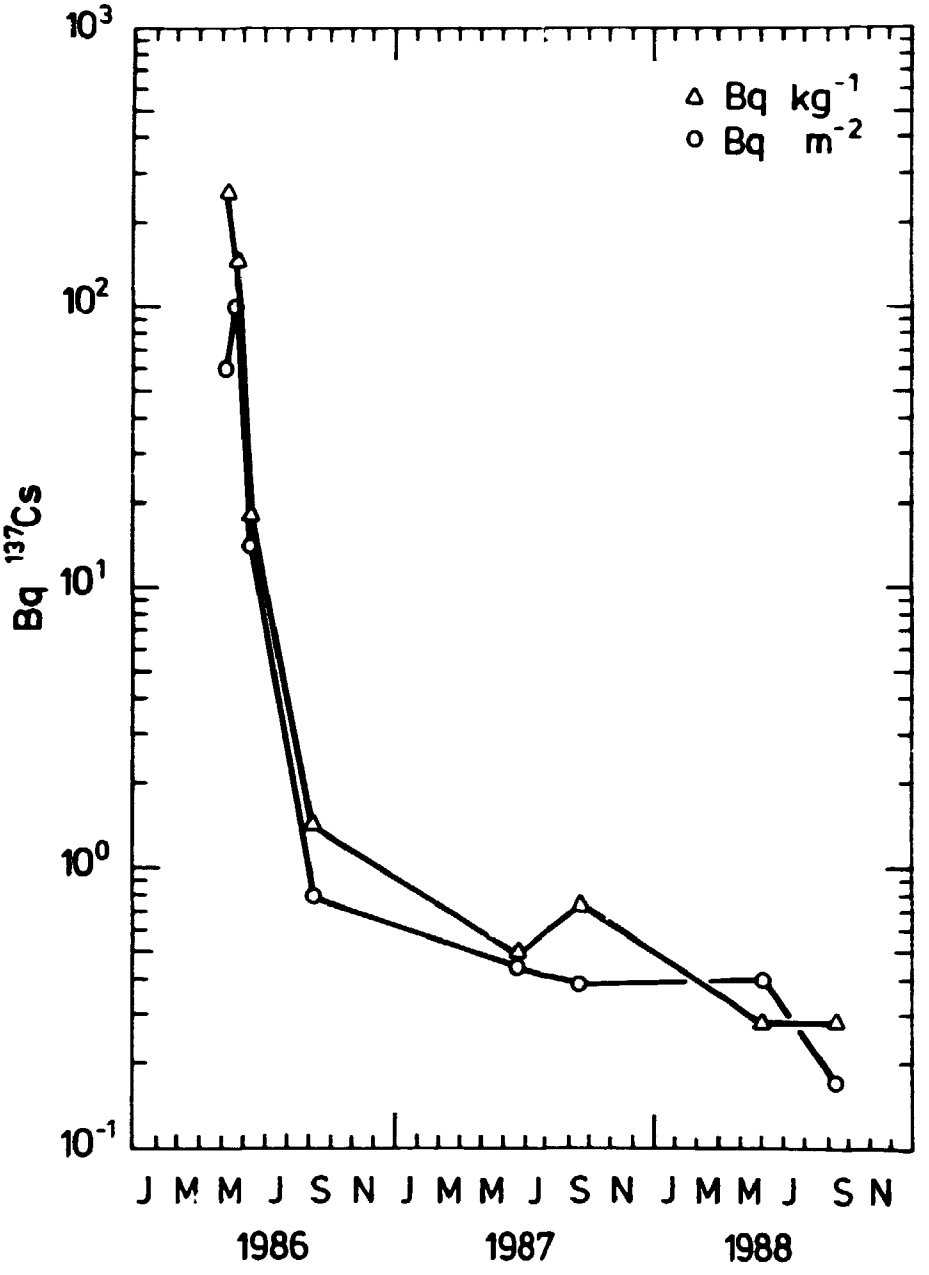


Fig. 5.10.3. Cesium-137 median values in grass from the 10 Danish State experimental farms 1986-1988.

5.10.3. Straw, Beets, and Beet Leaves in 1986 and 1987

Tables 5.10.3.1-5.10.3.3 show a general decrease in the ^{137}Cs levels from 1986 to 1987. The decrease varied from a factor of 4 in straw to a factor of 1.5 in beets.

Compared with grain (mean of all means in Table 5.3.5) the straw ^{137}Cs mean level was 2 times higher in 1986 and 7 times higher in 1987. The ^{90}Sr concentrations were 11 times higher in straw than in grain in 1986 as well as in 1987. Earlier we have assumed, based on experimental evidence, that straw contained two times higher ^{137}Cs and 10 times higher ^{90}Sr concentrations than grain. The slower decrease of the ^{137}Cs concentrations in straw compared with grain may suggest that resuspended soil particles have been responsible

for a significant part of the contamination of straw in 1987. This contamination has not been fully available for translocation to the grain, and the grains have thus contained relatively lower levels than expected from the measured deposition (cf. also the discussion in 5.3).

We may compare the radioactivity levels (Bq kg^{-1}) in beets with those in potatoes in 1986: ^{137}Cs beets/^{137}Cs potatoes = 0.99 ± 0.57 (± 1 S.D.; N = 8) and in 1987: 0.73 ± 0.52 (± 1 S.D.; N = 9). In the case of ^{90}Sr, the ratios of beets to potatoes became: 11 and 13, respectively.

In a similar way beet leaves may be compared with cabbage. For ^{137}Cs, the ratios became 2.5 in 1986 and 2.9 in 1987. For ^{90}Sr the ratios were 2.5 and 2.1, respectively. We conclude that beets may be compared with potatoes and beet leaves with cabbage as regards ^{137}Cs and ^{90}Sr contamination.

Table 5.10.3.1. Radiocesium and Strontium-90 in straw collected at the state experimental farms in September 1986 and September 1987

	1986				1987			
	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	^{134}Cs/^{137}Cs	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	^{134}Cs/^{137}Cs
Tylstrup			4.7	0.45			0.25	
Kalø			2.4	0.53			0.73	0.32
Borris			3.1	0.51	4.5	1040	0.29	0.36 A
Askov			0.86	0.51			4.8	0.33
St. Jyndevad			27	0.50			1.93	
Årslev			1.62	0.55			1.93	0.38
Tystofte			3.0	0.48			0.34	
Ledreborg			1.76	0.47	8.1	1010	0.72	
Abed			8.6	0.54			0.53	0.27 A
Tornbygård			3.7	0.56			1.13	
Mean	4.8	1060	5.7	0.51	6.3	1025	1.26	0.33
Median			3.0				0.72	

Table 5.10.3.2. Radiocesium and strontium-90 in beets collected at the State experimental farms in September 1986 and September 1987

	1986				1987			
	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	^{134}Cs/^{137}Cs	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$	Bq ^{137}Cs kg^{-1}	^{134}Cs/^{137}Cs
Tylstrup			0.03 B				0.050 A	
Kalø							0.062 A	
Borris			0.04 B		0.69	4000	0.069 A	
Askov			0.50	0.42			0.157	0.34
St. Jyndevad			0.24				0.105	0.31
Årslev			0.14 A				0.142	0.26 A
Tystofte			0.065 B				0.080	
Ledreborg			0.05 B		0.46	1500	0.02 B	
Abed							0.059 A	
Tornbygård			0.02 B				0.02 B	
Mean	0.42	1950	0.14	0.42	0.58	2750	0.076	0.30
Median			0.06				0.06	

Table 5.10.3.3. Radiocesium and strontium-90 in beet leaves collected at the State experimental farms in September 1986 and September 1987

	1986				1987			
	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr $(kg\ Ca)^{-1}$	Bq ^{137}Cs kg^{-1}	$\frac{^{134}Cs}{^{137}Cs}$	Bq ^{90}Sr kg^{-1}	Bq ^{90}Sr $(kg\ Ca)^{-1}$	Bq ^{137}Cs kg^{-1}	$\frac{^{134}Cs}{^{137}Cs}$
Tylstrup			0.23				0.033 B	
Kalø			0.38	0.51			0.136	0.32 A
Borris			0.189	0.49 A	0.76	820	0.23	0.27
Askov			2.3	0.49			0.52	0.35
St. Jyndevad			0.93				0.184	0.24
Årslev			0.35	0.46			0.44	0.26
Tystofte			0.31				0.05 B	
Ledreborg			0.24 B		0.34	340	0.03 B	
Abed			0.16				0.040 A	
Tombygård			0.10 A				0.05 B	
Mean	0.55	400	0.52	0.49	0.55	580	0.17	0.29
Median			0.28				0.09	

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 1987. The mean level in Fucus vesiculosus was 230 Bq ^{90}Sr $(kg\ Ca)^{-1}$ (5.3 Bq kg^{-1} dry weight). We got no samples of Zostera marina in 1987. The mean ratio of observed to predicted ^{90}Sr levels in fucus was 0.54 (cf. Appendix C.1).

Fucus contained 24 Bq ^{137}Cs kg^{-1} dry weight, i.e. 10% more than in 1986.

Table 5.11.1. Strontium-90 and radiocesium in Fucus vesiculosus from Roskilde Fjord in 1987

Location (cf. Fig. 4.6.1)	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	$\frac{^{134}Cs}{^{137}Cs}$
At Risø	31 Mar	23.8	300	6.5	1230	27	0.32
At Risø	11 Aug	20.2	260	5.5	860	18.2	0.27
At Risø	2 Oct	23.1	-	-	820	21	0.26
IX	4 May	13.5	194	4.7	780	29	0.31
X	4 May	14.8	150	4.6	740	27	0.30

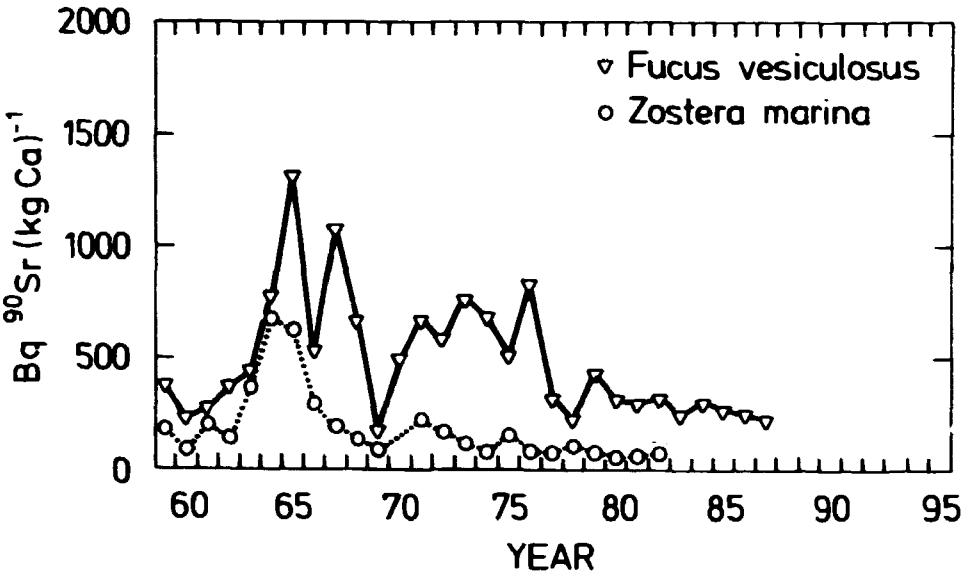


Fig. 5.11.1. Strontium-90 in sea plants from Roskilde Fjord, 1959-1987.

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 monthly 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 (Table 5.11.2).

Contrary to last year's observations, Fucus serratus did not contain significantly higher ^{60}Co concentrations than Fucus vesiculosus.

Table 5.11.2. Radionuclides in Fucus vesiculosus (Fu.ve.) and Fucus serratus (Fu.se.) collected at Klint (55°58'N, 11°35'E) in 1987. (Unit: Bq kg^{-1} dry matter)

Species	Date	^{60}Co	^{137}Cs	$\frac{^{106}Ru}{^{137}Cs}$	$\frac{^{110m}Ag}{^{137}Cs}$	$\frac{^{125}Sb}{^{137}Cs}$	$\frac{^{134}Cs}{^{137}Cs}$
Fu.ve.	April 10	4.0	14.9		0.23		0.27
Fu.se.	April 10	4.1	14.0	1.31	0.41	0.14	0.21
Fu.ve.	May 21	2.9	9.7		0.24		0.25
Fu.se.	May 21	3.0	13.3				0.27
Fu.ve.	June 22	2.5	12.6				0.25
Fu.se.	June 22	2.4	16.9				0.27
Fu.ve.	July 15	2.7	18.1		0.06 B		0.25
Fu.se.	July 15	3.4	16.8				0.24
Fu.ve.	Aug 13	2.3	14.6				0.25
Fu.se.	Aug 13	1.50	15.3				0.22
Fu.ve.	Sept 15	1.53	10.2				0.25
Fu.se.	Sept 15	1.87	13.2				0.25
Fu.ve.	Oct 15	1.74	11.2				0.25
Fu.se.	Oct 15	1.50	9.4				0.22
Fu.ve.	Nov 13	1.45	9.0				0.22
Fu.se.	Nov 13	1.54	8.8				0.21
Fu.ve.	Dec 17	2.1	12.4				0.24
Fu.se.	Dec 17	2.4	12.1				0.25

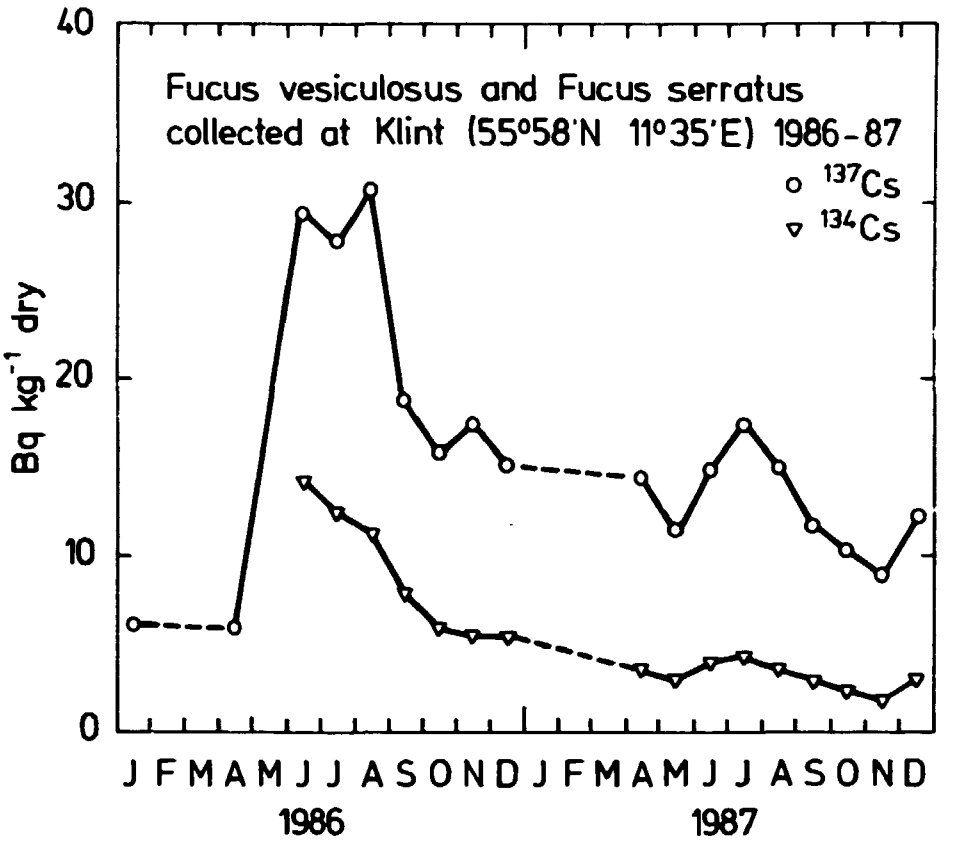


Fig. 5.11.2. Cesium-137 and cesium-134 (lower curve) in Fucus vesiculosus and Fucus serratus from April 1986 to November 1987 collected at Klint, Zealand (55°58'N, 11°35'E).

There was no significant difference between the ^{137}Cs levels in the two fucoids.

From July to December, the levels decreased again by a factor of 1.4. This is not in agreement with the constant levels in water in this period (cf. Fig. 4.4.9).

The observed ratio: Bq ^{137}Cs kg^{-1} Fucus dry weight/Bq ^{137}Cs l^{-1} sea water was 260 from June to December 1987, which concurs with observations in earlier years in southern Cattegat[18].

5.11.3. Sea Plants Collected in Danish Waters

Apart from the Klint and Roskilde Fjord collections, 7 other locations were examined in 1987 (cf. Table 5.11.3 and Fig. 5.11.3).

The Anovas (Tables 5.11.4 and 5.11.5) show no significant interaction between locations and month for ^{134}Cs, but probably for ^{60}Co. The local pattern for ^{134}Cs was compatible with the source being Baltic sea water. The highest concentrations were seen at Strøby Egede in southeast Zealand and the lowest at Klint in northwest Zealand. In case of ^{60}Co the local pattern was consistent with Barsebäck and perhaps to some extent Ringhals as sources. The highest levels were seen at Gilleleje in northeast Zealand and the lowest at Mullerup in southwest Zealand (in Lolland-Falster in Nysted, no ^{60}Co was observed).

Table 5.II.3. Radionuclides in Fucus vesiculosus (Fu.ve.) and Fucus serratus (Fu.se.) collected in Danish waters in 1987

Location	Position N	Position E	Date	Bq ^{60}Co kg^{-1} d.w.	Bq ^{137}Cs kg^{-1} d.w.	$\frac{^{110m}Ag}{^{137}Cs}$	$\frac{^{106}Ru}{^{137}Cs}$	$\frac{^{134}Cs}{^{137}Cs}$	% dry matter	Species
Nysted	54°40'	11°44'	April 29		18.0			0.30		Fu.ve.
-"-	-"-		May 20		24			0.28	13.3	Fu.ve.
-"-	-"-		June 23		37			0.29	17.9	Fu.ve.
-"-	-"-		July 16		34			0.31	19.8	Fu.ve.
-"-	-"-		Aug 12		19.0			0.29	20.8	Fu.ve.
-"-	-"-		Sept 14		35			0.31	17.2	Fu.ve.
-"-	-"-		Oct 14		34			0.25	16.5	Fu.ve.
-"-	-"-		Nov 11		24			0.28	17.6	Fu.ve.
-"-	-"-		Dec 18		30			0.26	17.7	Fu.ve.
Strøby Egede	55°25'	12°15'	April 29		28			0.33	16.5	Fu.ve.
-"-	-"-		May 20		19.5			0.36	14.1	Fu.ve.
-"-	-"-		June 17	2.1	60			0.32	10.2	Fu.ve.
-"-	-"-		July 16		42			0.32	17.2	Fu.ve.
-"-	-"-		Aug 12	1.5	31			0.34	20.8	Fu.ve.
-"-	-"-		Sept 14		44			0.29	19.1	Fu.ve.
-"-	-"-		Oct 14		36			0.28	18.1	Fu.ve.
-"-	-"-		Nov 11		24			0.29	18.2	Fu.ve.
-"-	-"-		Dec 18	2.0	33			0.30	18.8	Fu.ve.
Gilleleje	56°07'	12°19'	April 24	9.2	14.8	0.22		0.30		Fu.ve.
-"-	-"-		May 20	3.7	11.3	0.25	0.97	0.29	21.9	Fu.se.
-"-	-"-		June 22	2.0	18.6			0.28	17.3	Fu.ve.
-"-	-"-		July 17	4.6	19.5			0.24	19.5	Fu.se.
-"-	-"-		Aug 14	1.8	6.2			0.29	26.2	Fu.se.
-"-	-"-		Sept 14	5.9	17.7			0.23		Fu.se.
-"-	-"-		Oct 16	3.3	18.5			0.27	21.5	Fu.se.
-"-	-"-		Nov 12	2.8	8.4		0.58	0.31	20.7	Fu.se.
Hesselø	56°12'	11°43'	May 25	3.2	13.1	0.23		0.28	22.1	Fu.ve.
-"-	-"-		May 25	3.2	15.3			0.26	21.8	Fu.se.
-"-	-"-		Dec 14	2.8	14.7			0.25	34.3	Fu.se.
Anholt	56°43'	11°31'	May 13	2.0	22	0.13	0.56	0.25	21.6	Fu.ve.
-"-	-"-		Dec 14	1.4 A	16.8			0.24	17.9	Fu.ve.
Mullerup	55°30'	11°10'	April 30	1.6	20[a]	0.13		0.33	13.5	Fu.ve.
-"-	-"-		May 21	1.3	16.2			0.33	12.7	Fu.ve.
-"-	-"-		June 22		31			0.33	14.5	Fu.ve.
-"-	-"-		July 15	1.5	17.8[b]			0.31	25.3	Fu.ve.
-"-	-"-		Aug 13	0.8 A	12.3			0.30	21.3	Fu.ve.
-"-	-"-		Sept 15		19.7			0.27	20.5	Fu.ve.
-"-	-"-		Oct 15		19.5			0.32	22.0	Fu.se.
-"-	-"-		Oct 15		20.4			0.28	19.4	Fu.ve.
-"-	-"-		Dec 17		19.3			0.26	21.2	Fu.ve.
Læsø	57°18'	10°56'	May 13	2.4	14.6			0.24	25.4	Fu.se.
-"-	57°19'	11°08'	May 13	2.5	13.7			0.22	13.6	Fu.ve.
Sverske Havn	55°05'	15°09'	May 19		36	0.21		0.35	21.4	Fu.ve.

a) $^{125}Sb/^{137}Cs$ = 0.35
b) $^{125}Sb/^{137}Cs$ = 0.25

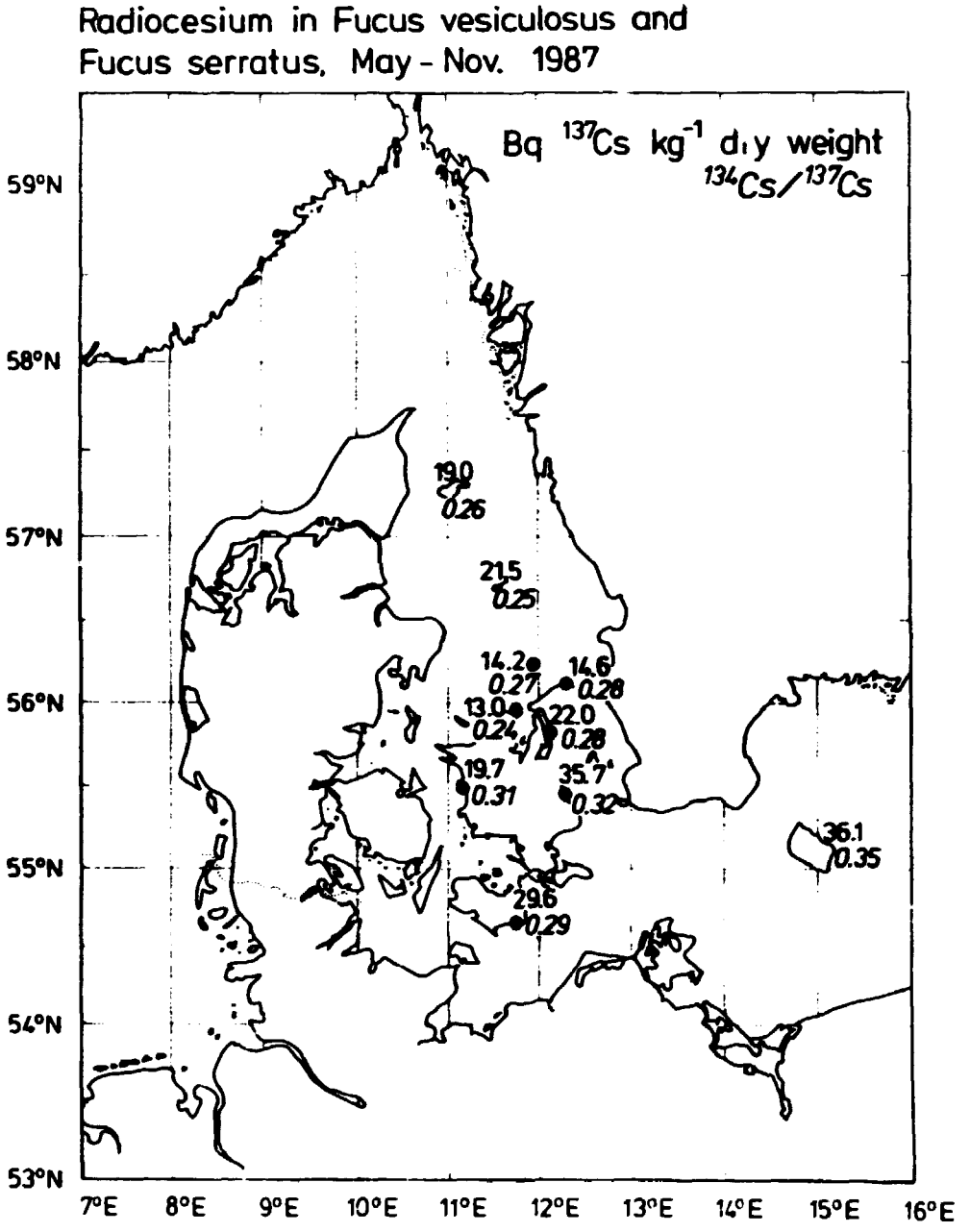


Fig. 5.II.3. Cesium-137 and $^{134}Cs/^{137}Cs$ (lower figure) in Fucus vesiculosus and Fucus serratus collected in May-November 1987 along the Danish coasts. (Unit: Bq kg^{-1} dry weight)

Table 5.II.4. Analysis of variance of ln Bq ^{134}Cs kg^{-1} d.w. fucoids (Tables 5.II.2 and 5.II.3) in 1987 (Nysted, Stroby Egede, Mullerup, Klint, Gilleleje)

Variatior	SSD	f	s^2	v^2	P
Between months	2.38	8	0.30	5.35	> 99.95%
Between locations	11.98	4	3.00	53.97	> 99.95%
Month × loc.	1.67	30	0.056	1.94	-
Remainder	0.286	10	0.029		

Table 5.11.5. Analysis of variance of ln Bq ^{60}Co kg^{-1} d.w. fucoids (Tables 5.11.2 and 5.11.3) in 1987 (Strøby Egede, Mullerup, Klint, Gilleleje)

Variation	SSD	f	s^2	v^2	P
Between months	3.18	8	0.40	4.61	> 99 %
Between locations	4.00	3	1.33	15.45	> 99.95%
Month × loc.	1.12	13	0.086	4.80	> 97.5 %
Remainder	0.162	9	0.018		

5.12. Moss and Lichens

In the total lichen layer at Oustrup Heather (Table 5.12.2) the Chernobyl ^{137}Cs decreased from 1150 Bq m^{-2} in June 1986 to 837 Bq m^{-2} (0.57·1470) in August 1987 corresponding to an effective half-life of 2.6 years. The global fallout ^{137}Cs decreased in the same period from 1150 Bq m^{-2} to 633 (1470-837) Bq m^{-2}, i.e. corresponding to an effective half-life of 1.35 years. If we considered the top layer only, the Chernobyl ^{137}Cs decreased from 1010 Bq m^{-2} to 710 Bq m^{-2} (~ effective half-life: 2.3 years) and global fallout changed from 240 to 120 (~ half-life: 1.17 years). In the bottom layer, the global fallout ^{137}Cs changed from 900 Bq m^{-2} to 560 Bq m^{-2} (~ half-life: 1.7 years). Hence the old global fallout ^{137}Cs disappeared more rapidly than the Chernobyl ^{137}Cs, which may be due to resuspension of Chernobyl ^{137}Cs, which has added extra ^{137}Cs to lichen from 1986 to 1987.

If we take a look at the Skagen samples, we observe an increase in Chernobyl ^{137}Cs from June 28, 1986 to September 17, 1987 (Table 5.12.1) from 380 Bq m^{-1} to 440 Bq m^{-2}. The deposit from June 1986 to September 1987 in North Jutland (Tylstrup) was ~ 85 Bq $^{-2}$. If we subtract this deposition from the observed mean in 1987 we get 355 Bq m^{-2}. The half-life corresponding to a decrease from 380 to 355 in 15 months is 12.7 years. This is in agreement with the observations of Mattsson in Lapland[26]. If we look at the global ^{137}Cs fallout in the Skagen samples, it becomes 24 Bq m^{-2} in 1986 and 26 Bq m^{-2} in 1987, i.e. no significant decrease. We are thus forced to conclude that the two sets of samples from Oustrup Heather probably have not been collected at the same location in 1987 as in 1986. Consequently, the calculated half-lives are not correct. It would also have been difficult to explain the very rapid decrease of global fallout ^{137}Cs in lichen because such a decrease would have been incompatible with the actual deposition of global fallout in Denmark.

Table 5.12.1. Radionuclides in lichen and moss collected in Denmark in 1987

Sample	Location	Date	^{90}Sr Bq m^{-2}	^{137}Cs Bq m^{-2}	$^{239,240}Pu$ Bq m^{-2}	^{95}Zr / ^{137}Cs	^{106}Ru / ^{137}Cs	^{110m}Ag / ^{137}Cs	^{125}Sb / ^{137}Cs	^{134}Cs / ^{137}Cs	^{144}Ce / ^{137}Cs	^{241}Am / $^{239,240}Pu$	^{242}Cm / $^{239,240}Pu$	kg d.w. m^{-2}
Moss	Bornholm	May 19	9.5	430	5.6	$3·10^{-3}$ B	0.16	$.9·10^{-3}$	0.023	0.175	-	0.34 A	0.010	0.54
Lichen	Bornholm	Sep 24	2.2	152	20	-	0.18	-	-	0.22	-	0.45	-	2.02
Lichen	Skagen 1	Sep 17	0.41	440	12.5	-	0.122	-	0.024	0.34	-	0.16	-	2.32
Lichen	Skagen 2	Sep 17	9.7	460	6.5	-	0.18	-	-	0.34	-	1.2	-	3.65
Lichen	Skagen 3	Sep 17	13.5	490	21	-	0.117	-	-	0.34	-	0.22	-	3.03
Lichen	Nymindegab	Oct 9	8.2	3700	6.7	-	0.149	$3.3·10^{-3}$	0.029	0.36	0.020	0.27 B	0.47	1.38
Lichen	Asserbo	Oct 19	1.54	560	-	-	0.126	$3.5·10^{-3}$ A	0.0165	0.35	-	-	-	0.21

Table 5.12.2. Radiocesium in lichen (Cladina Portentosa) collected at Oustrup Heather August 26, 1987, by Ulrik Søchting, Institute of Sporeplants, University of Copenhagen

Sample		^{137}Cs Bq kg^{-1} d.w.	^{137}Cs Bq m^{-2}	^{134}Cs Bq kg^{-1} d.w.	^{134}Cs Bq m^{-2}	$^{134}Cs/^{137}Cs$	% Chernobyl ^{137}Cs
Top layer	No. 1	640	790	197	250	0.31	
Top layer	No. 2	680	750	220	240	0.32	
Top layer	No. 3	770	790	250	260	0.33	
Top layer	No. 4	700	810	220	260	0.32	
Top layer	No. 5	670	1030	200	310	0.30	
Bottom layer	No. 1	29	450	-	-	0	
Bottom layer	No. 2	66	830	2.9	36	0.04	
Bottom layer	No. 3	54	115	2.1 A	4.6 A	0.04	
Bottom layer	No. 4	82	830	5.9	60	0.07	
Bottom layer	No. 5	54	940	2.4	41	0.04	
$\bar{x}$ Top ±1 S.D.		690±49	830±112	220±21	260±27	0.32±0.01	86
$\bar{x}$ Bottom ±1 S.D.		67±19	630±340	2.7±2.1	28±25	0.04±0.02	11
Top + Bottom ±1 S.D.		-	1470±410	-	290±42	0.21±0.05	57

The highest deposit was observed in the sample from Nymindegab collected on October 9, 1987 (Table 5.12.1). This sample also showed measurable amounts of ^{242}Cm: 3.2 Bq m^{-2}, decay corrected to April 26, 1986; this would have been 30 Bq m^{-2}. The observed $^{242}Cm/^{239,240}Pu$ in Chernobyl debris on April 26, 1986 was 10.6[20]. Hence the calculated $^{239,240}Pu$ deposit from Chernobyl at Nymindegab becomes 30/10.6 = 2.8 Bq m^{-2} or 42% of the plutonium in the lichen sample, whereas nearly 100% of the ^{137}Cs came from Chernobyl.

The ^{90}Sr in the sample may also have been entirely from Chernobyl because the $^{90}Sr/^{137}Cs$ was 0.002, which was 10 times less than in Chernobyl debris. It is well known[26] that the effective half-life of ^{90}Sr in lichen is nearly an order of magnitude less than that of ^{137}Cs. It is thus not surprising if the ^{90}Sr levels had decreased more rapidly than the ^{137}Cs levels.

The lichen (and moss) samples (Table 5.12.1) also make it possible to estimate the original Chernobyl fallout of ^{110m}Ag and ^{125}Sb relative to that of ^{137}Cs. The fallout of ^{110m}Ag becomes 1% of the ^{137}Cs fallout and that of ^{125}Sb is 3%.

6. Strontium-90 and Radiocesium in Humans in 1987

6.1. Strontium-90 in Human Bone

(by A. Aarkrog)

The collecting of human vertebrae from the institutes of forensic medicine in Copenhagen and Århus was continued in 1987. As in the total-diet survey (cf.

Table 6.1.1. Strontium-90 in vertebrae from newborn children (< 1 month old) in 1987

Zone	Age in days	Month of death	Sex	Bq (kg Ca)$^{-1}$
III	30	1	M	60
VI	0	2	M	13 B

Table 6.1.2. Strontium-90 in bone from infants (≤ 4 years) in 1987

Zone	Age in months	Month of death	Sex	Bq (kg Ca)$^{-1}$
I	2	3	M	29
I	3	1	M	38
I	7	2	M	35
I	2	2	F	18 A
II	1	1	M	8 B
II	4	8	M	16 B
II	4	8	M	11 B
II	22	3	M	20
II	2	3	F	6 A
II	3	3	F	55
II	9	3	F	11.3
II	10	3	F	28
VI	2	3	M	58 A
VI	5	2	M	51
VI	5	3	M	17 B
VI	2	4	F	33 B
VI	4	8	F	15.6
VI	2	3	M	26

Table 6.1.3. Strontium-90 in bone from children and teenagers (≤ 19 years) in 1987

Zone	Age in years	Month of death	Sex	Bq (kg Ca)$^{-1}$
II	18	8	M	15.4
VI	17	8	M	13.9

Table 6.1.4. Strontium-90 in vertebrae from adults (≤ 29 years) in 1987

Zone	Age in years	Month of death	Sex	Bq (kg Ca)$^{-1}$
II	27	9	M	15.9
VI	28	8	M	17.7

Table 6.1.5. Strontium-90 in vertebrae from adults (> 29 years) in 1987

Zone	Age in years	Month of death	Sex	Bq (kg Ca)$^{-1}$
I	38	9	F	19.4
I	63	8	F	17.1
I	30	8	M	19.9
I	55	8	M	24
II	48	9	F	31 A
II	70	8	F	15.2
II	30	8	M	14 B
II	47	8	M	18.9
II	62	9	M	16.7
II	64	9	M	17.6
II	71	8	M	15.5
VI	36	8	F	15.2
VI	48	8	F	16.8
VI	52	8	F	19.4
VI	58	4	F	30 A
VI	59	4	F	19.2
VI	60	4	F	37
VI	64	8	F	11.2 A
VI	70	3	F	19.1
VI	78	3	F	19.8
VI	32	3	M	8.4
VI	32	8	M	26 A
VI	33	8	M	35
VI	35	3	M	33 B
VI	36	8	M	45
VI	37	3	M	28
VI	39	8	M	18.6
VI	43	8	M	24
VI	58	8	M	20
VI	73	8	M	19.8
VI	80	8	M	27

Table 6.1.6. Strontium-90 in human vertebrae collected in Denmark in 1987. (Unit: Bq (kg Ca)$^{-1}$)

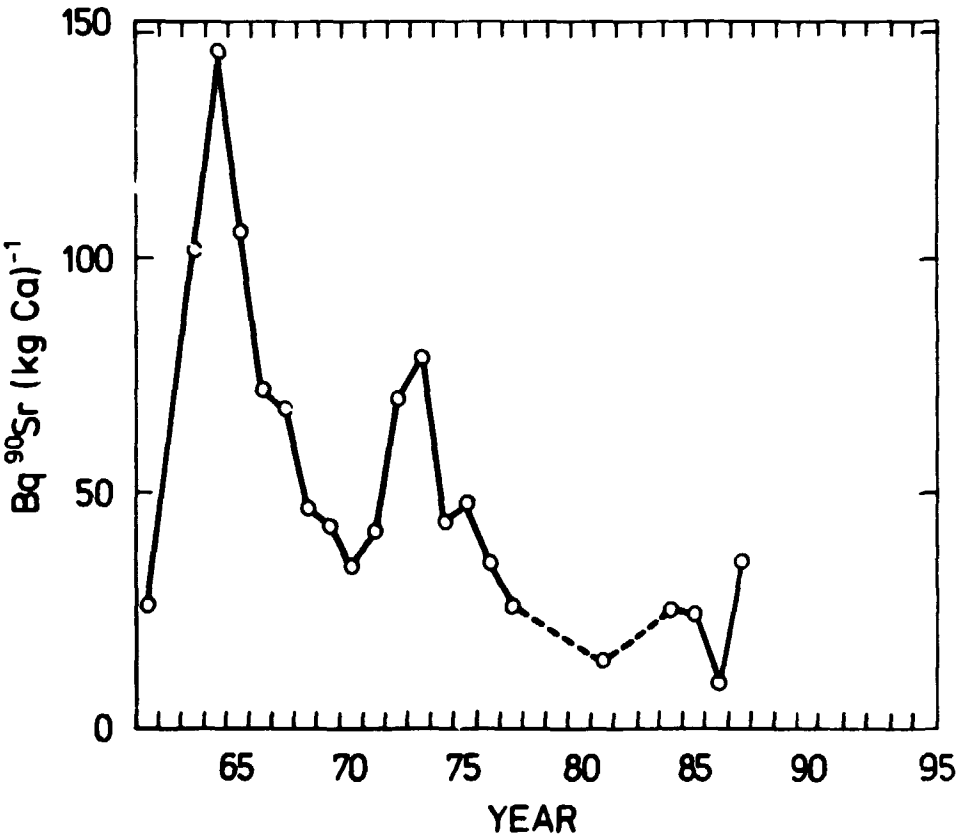
Age group	Number of samples	Min.	Max.	Median	Mean
New-born					
(					
Infants (≤ 4 years)	18	6	58	23	26
Children (≤ 19 years)	2	13.9	15.4	14.6	14.6
Adults (≤ 29 years)	2	15.9	17.7	16.8	16.8
Adults (> 29 years)	31	8.4	45	19.4	22

5.7), the country was divided into eight zones. The samples were divided into five age groups: newborn (< 1 month), 1-19 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 1987 were nearly unchanged from those observed in 1979-1987.

The observed mean concentration in adults (≥ 30 years) was 0.58 times that predicted (cf. Appendix C).

Fig. 6.1.1. Strontium-90 levels (sample number weighted mean) in bone from newborn (< 1 month) 1961-1987.



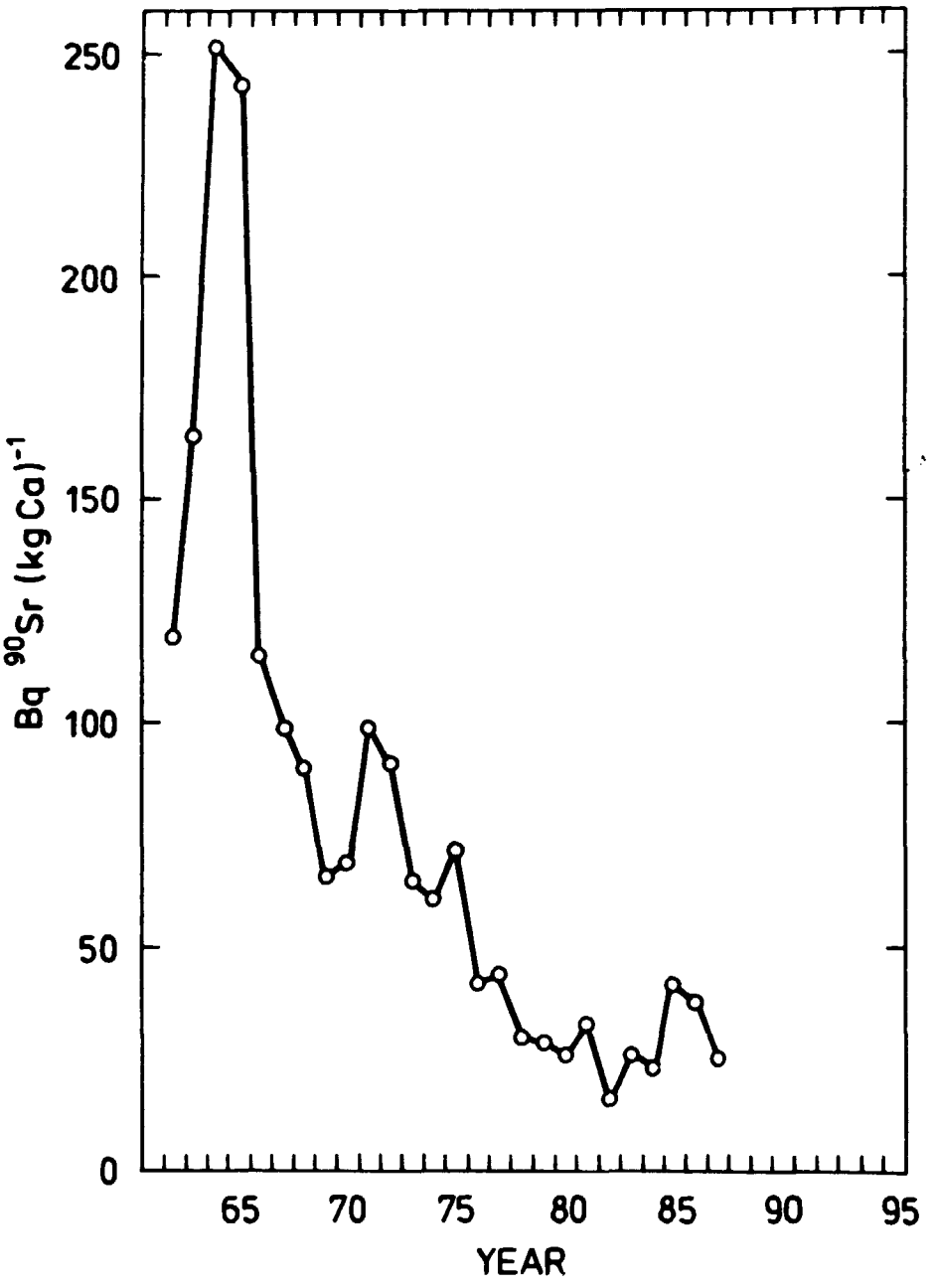


Fig. 6.1.2. Strontium-90 levels (sample number weighted mean) in bone from infants (> 1 month ≥ 4 years) 1962-1987.

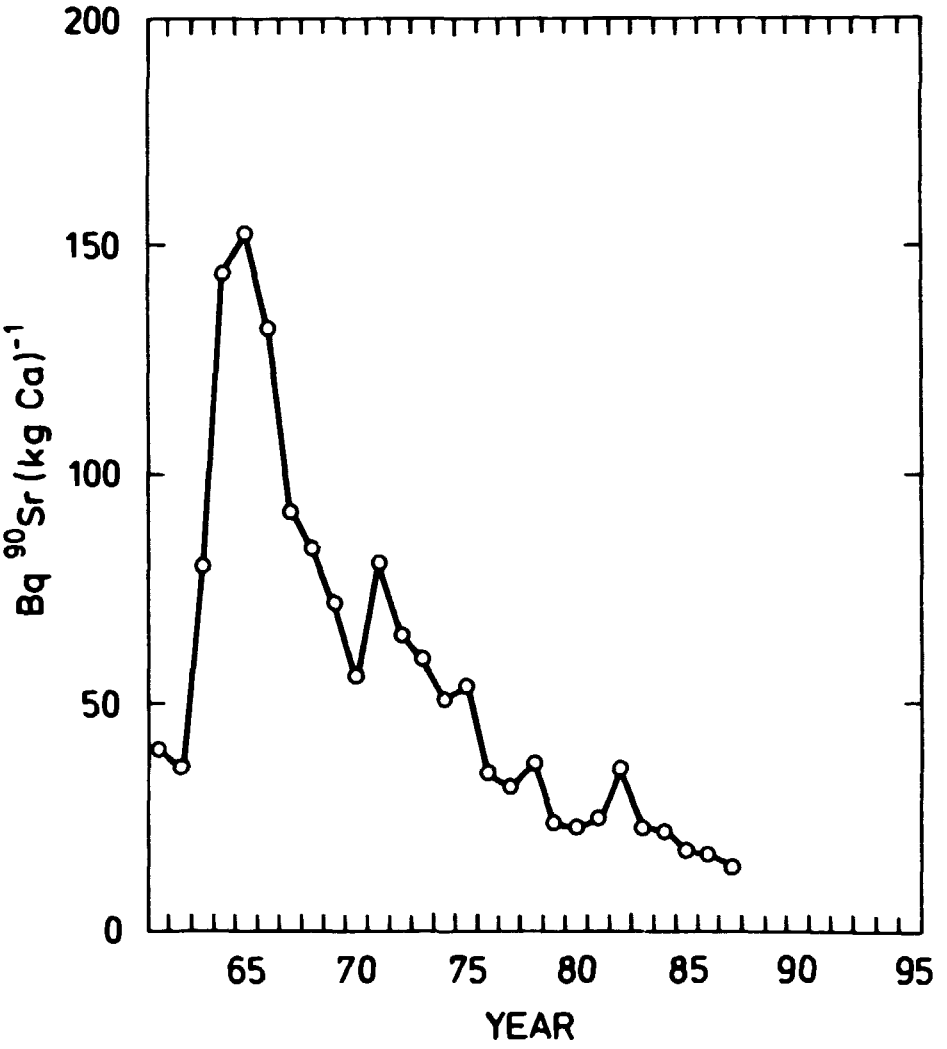


Fig. 6.1.3. Strontium-90 levels (sample number weighted mean) in bone from children (> 4 years ≤ 19 years) 1961-1987.

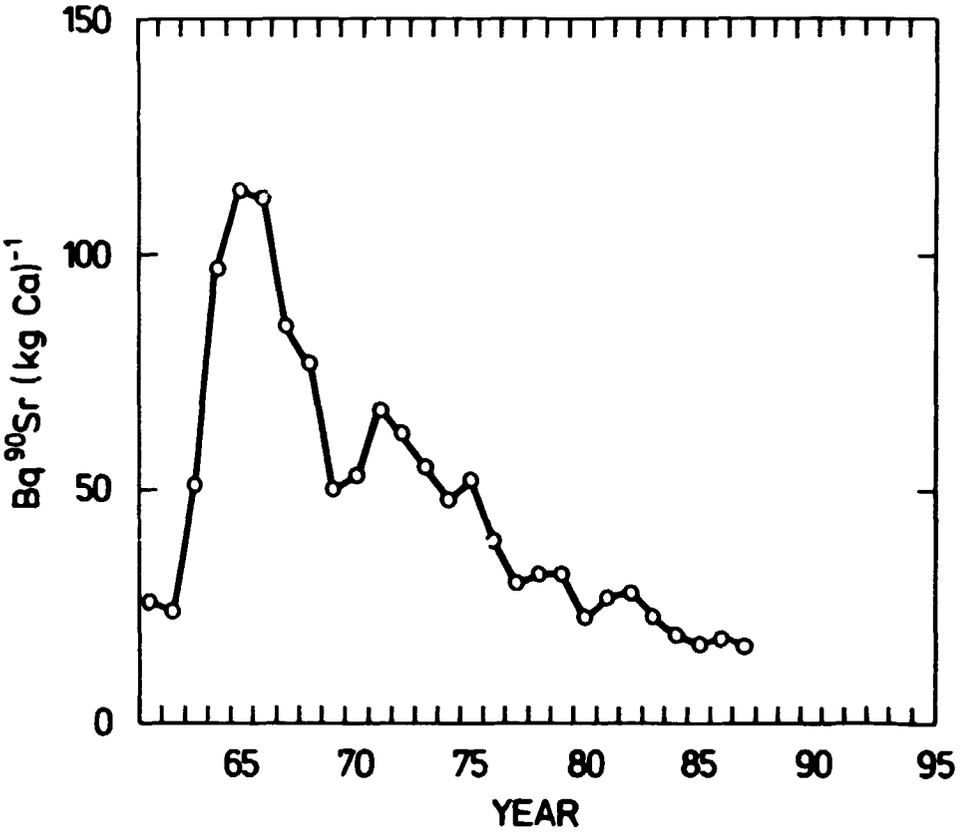
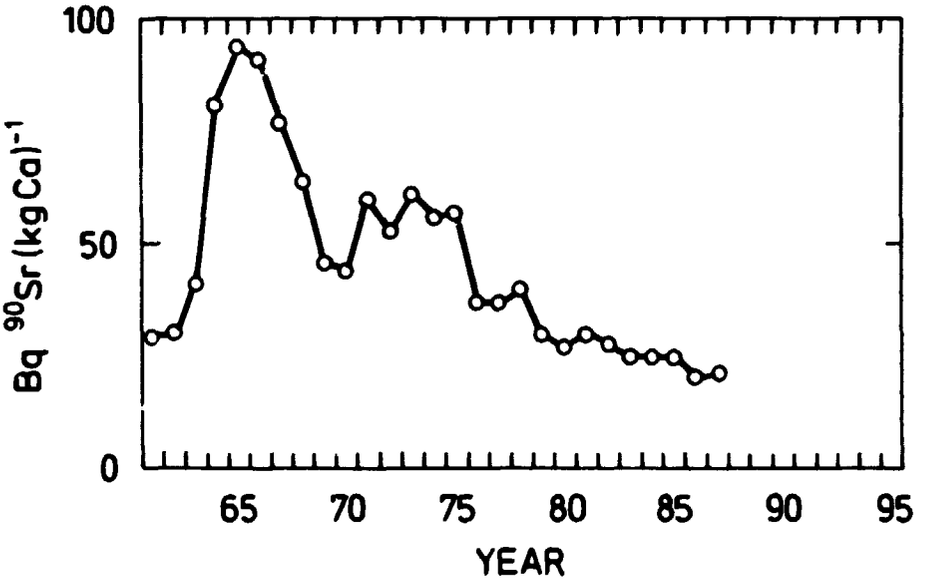


Fig. 6.1.4. Strontium-90 levels (sample number weighted mean) in bone from adults (> 19 years ≤ 29 years) 1961-1987.

Fig. 6.1.5. Strontium-90 levels (sample number weighted mean) in bone from adults (> 29 years) 1961-1987.



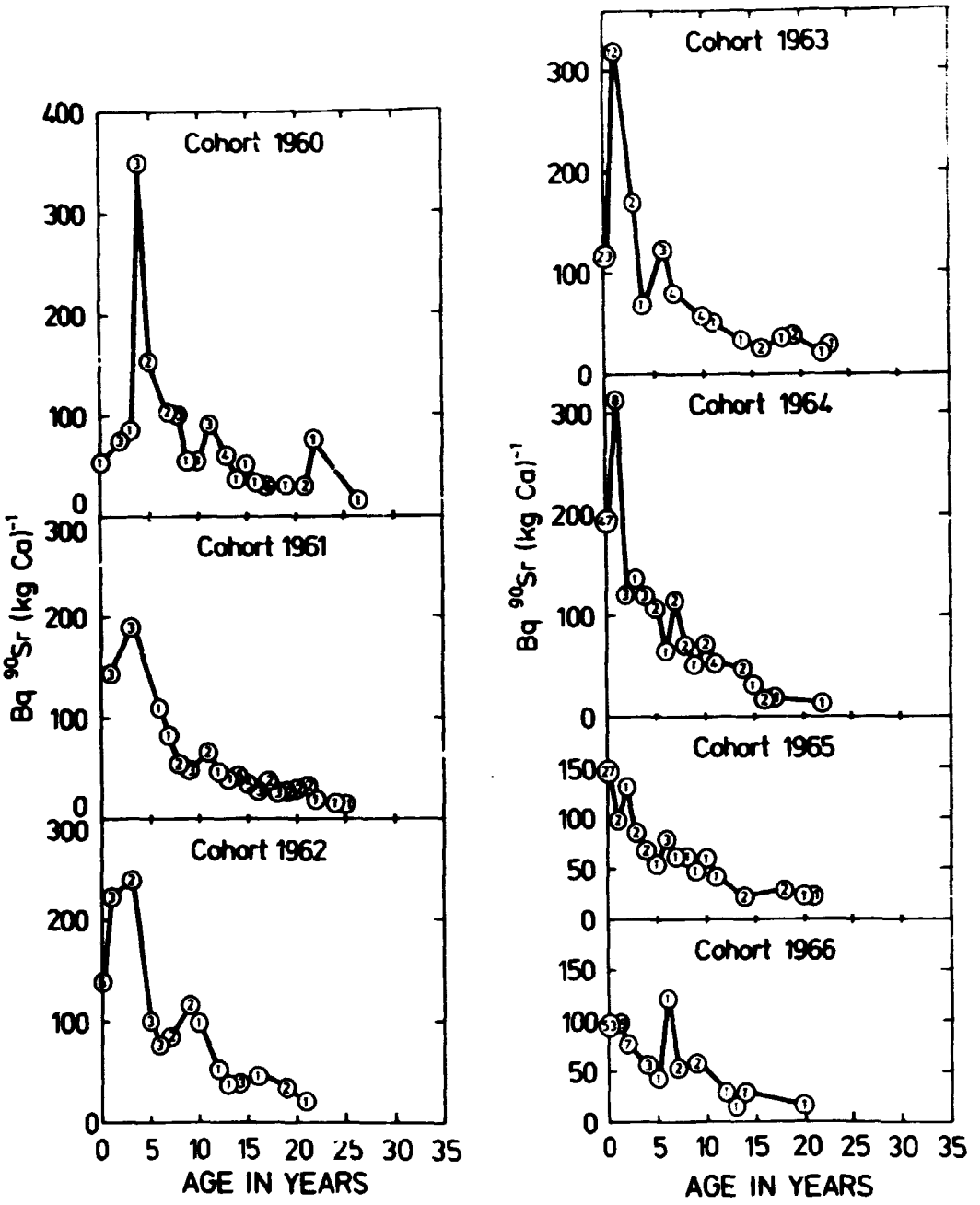


Fig. 6.1.6. Strontium-90 in human bone from Danish cohorts 1960-1966. Abscissa: age in years. Ordinate: bone level in Bq ^{90}Sr (kg Ca)$^{-1}$.

6.2. Radiocesium in the human body

by J. Søgaard-Hansen and B. Lauridsen

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 was measured 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.

After the Chernobyl accident, the whole-body measurements were resumed. The control group was essentially the old one but a few newcomers were added so that the group consisted of about 20 persons, among them a few children.

In Figure 6.2.2 the monthly mean values of ^{134}Cs + ^{137}Cs body content are shown for men, women, and children. The figure, furthermore, shows the calculated levels based upon the intake of radiocesium with food. In Figure 6.2.2, we omitted those person in the control group who had been on official travel to countries with relatively high contamination levels. It appears that the calculated levels are in good agreement with those observed. The mean concentration in the period January 1987 - December 1987 was 2210 Bq ^{134}Cs + ^{137}Cs (kg K)$^{-1}$ (relative S.D.: 7%).

Fig. 6.2.1. A comparison between observed (±1 S.E.) and calculated[21]) Bq ^{137}Cs (kg K)$^{-1}$ levels in persons from the Islands.

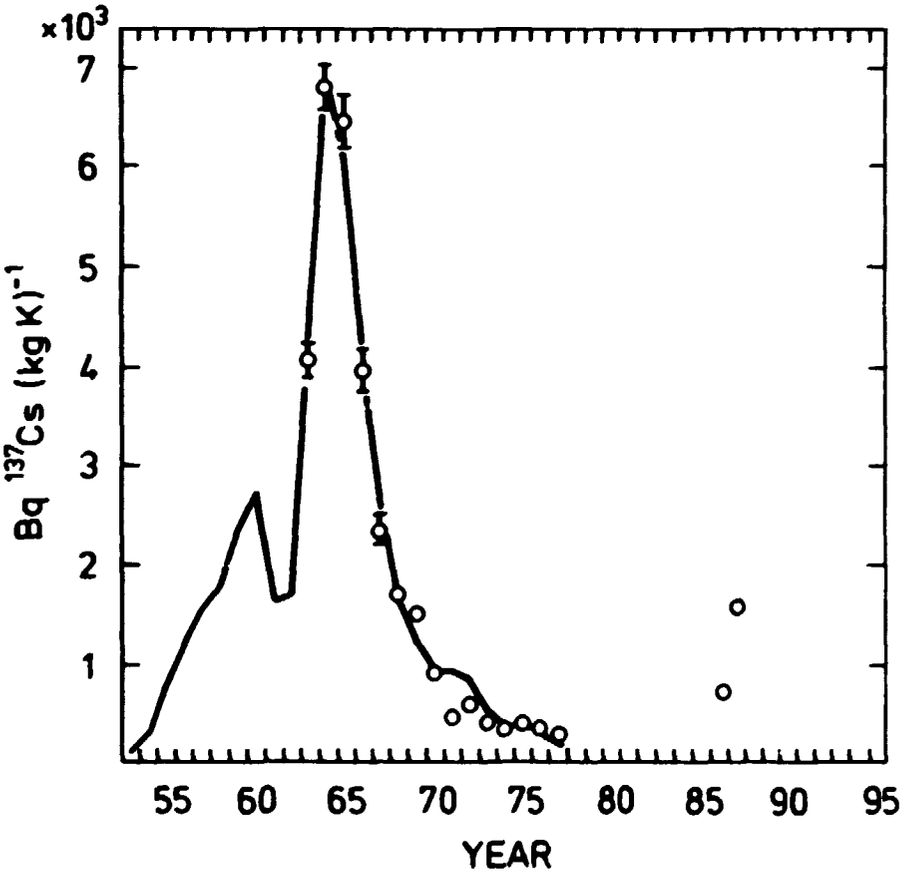


Table 6.2. Radiocesium ($^{134+137}Cs$) in humans from Risø and environment measured in 1987

No.	Date	Sex	Age	Bq Cs (kg K)$^{-1}$	g K (kg)$^{-1}$
2	20/1-87	F	43	2877	1.75
2	17/2-87	F	43	3053	1.63
2	19/3-87	F	43	2796	1.90
2	10/4-87	F	43	3003	1.59
2	22/5-87	F	43	3013	1.93
2	22/6-87	F	44	3066	2.08
2	13/7-87	F	44	2613	2.08
2	17/8-87	F	44	2675	1.83
2	14/9-87	F	44	2936	1.77
2	9/10-87	F	44	2876	1.84
2	25/11-87	F	44	2696	1.78
3	22/1-87	F	54	1664	1.77
3	18/2-87	F	54	1867	1.79
3	23/3-87	F	54	1943	1.95
3	9/4-87	F	54	1859	1.69
3	18/5-87	F	54	2014	2.09
3	22/6-87	F	54	1909	2.26
3	13/7-87	F	54	2337	1.94
3	24/8-87	F	54	2127	2.17
3	14/9-87	F	54	1989	2.16
3	8/10-87	F	54	1936	2.19
3	25/11-87	F	54	1999	1.76
4	23/1-87	M	54	2236	1.46
4	17/2-87	M	54	2236	1.63
4	27/3-87	M	54	2234	1.56
4	13/4-87	M	54	2660	1.53
4	21/5-87	M	54	2558	1.67
4	23/6-87	M	54	2720	2.08
4	17/7-87	M	54	2787	1.80
4	20/8-87	M	54	2904	1.78
4	21/9-87	M	54	2834	1.87
4	15/10-87	M	54	2674	1.51
4	20/11-87	M	55	2878	1.66
6	21/1-87	M	55	1485	1.56
6	16/2-87	M	55	1812	1.53
6	17/3-87	M	55	2316	1.27
6	14/4-87	M	55	2957	1.54
6	19/5-87	M	55	3615	1.63
6	18/6-87	M	55	4218	1.71
7	27/1-87	F	47	1534	1.49
7	19/2-87	F	47	1465	1.59
7	17/3-87	F	47	1790	1.18
7	10/4-87	F	47	1716	1.42
7	25/5-87	F	47	2030	1.36
7	18/6-87	F	47	1735	1.54
7	13/7-87	F	47	2057	1.59
7	20/8-87	F	48	2484	1.53
7	8/9-87	F	48	2194	1.44

Table 6.2. (continued)

No.	Date	Sex	Age	Bq Cs (kg K)$^{-1}$	g K (kg)$^{-1}$
7	13/10-87	F	48	2219	1.50
7	26/11-87	F	48	2123	1.63
9	22/1-87	F	58	2094	1.45
9	19/2-87	F	58	2238	1.38
9	19/3-87	F	58	1971	1.62
9	22/4-87	F	58	2229	1.39
9	21/5-87	F	58	2562	1.67
9	18/6-87	F	59	2685	1.59
9	17/7-87	F	59	2861	1.58
9	12/8-87	F	59	2879	1.80
9	8/9-87	F	59	2427	1.89
9	9/10-87	F	59	2294	1.83
9	24/11-87	F	59	2009	1.82
11	20/1-87	F	50	3025	1.32
11	18/2-87	F	50	3040	1.35
11	18/3-87	F	50	2962	1.29
11	20/5-87	F	50	2913	1.40
11	17/6-87	F	50	2830	1.50
11	12/8-87	F	50	2689	1.51
11	11/9-87	F	50	2617	1.41
11	9/10-87	F	50	2678	1.44
11	20/11-87	F	50	2466	1.41
14	21/1-87	M	44	953	2.03
14	23/2-87	M	44	1292	1.80
14	23/3-87	M	44	1225	1.69
14	13/4-87	M	44	1078	1.98
14	25/5-87	M	44	1450	1.99
14	16/6-87	M	44	1329	2.55
14	15/7-87	M	44	1471	2.27
14	17/8-87	M	44	1468	2.16
14	9/9-87	M	44	2009	2.24
14	13/10-87	M	45	2031	1.98
14	24/11-87	M	45	1852	2.20
15	21/1-87	F	45	1401	1.58
15	16/2-87	F	45	1708	1.42
15	18/3-87	F	45	1841	1.28
15	15/4-87	F	45	3125	1.30
15	25/5-87	F	46	2294	1.63
15	19/6-87	F	46	2629	1.56
15	15/7-87	F	46	3067	1.57
15	12/8-87	F	46	2924	1.56
15	14/9-87	F	46	2868	1.56
15	9/10-87	F	46	2740	1.46
15	20/11-87	F	46	2780	1.40
17	23/1-87	M	27	1820	2.03
17	18/2-87	M	27	2202	1.98
17	17/3-87	M	28	2259	1.59
17	21/4-87	M	28	1944	1.92

Table 6.2. (continued)

No.	Date	Sex	Age	Bq Cs (kg K)$^{-1}$	g K (kg)$^{-1}$
17	25/5-87	M	28	1900	2.36
17	19/6-87	M	28	1863	2.30
17	24/7-87	M	28	1437	2.31
17	21/8-87	M	28	1774	2.40
17	15/9-87	M	28	2591	2.45
17	26/11-87	M	28	1912	2.27
18	27/1-87	F	50	2071	1.51
18	23/3-87	F	51	1627	1.47
18	22/4-87	F	51	1803	1.33
18	20/5-87	F	51	2064	1.40
18	24/6-87	F	51	1617	1.88
18	19/8-87	F	51	1871	1.99
19	27/1-87	F	48	1514	1.44
19	19/3-87	F	48	1647	1.41
19	14/4-87	F	48	1733	1.47
19	22/5-87	F	48	2060	1.62
19	19/6-87	F	48	1696	1.66
19	24/7-87	F	48	1714	1.58
19	19/8-87	F	48	1582	1.68
19	18/9-87	F	48	1649	1.74
19	13/10-87	F	48	1671	1.43
19	24/11-87	F	48	1674	1.61
20	23/1-87	M	44	1656	1.62
20	24/3-87	M	44	1834	1.94
20	13/4-87	M	44	1763	1.64
20	26/5-87	M	44	2221	1.59
20	16/6-87	M	44	1307	2.42
20	18/8-87	M	44	2366	1.83
20	9/9-87	M	44	2299	1.74
20	8/10-87	M	44	2056	1.88
22	26/1-87	F	5	1007	2.21
22	24/3-87	F	5	1560	2.14
22	15/4-87	F	5	1626	2.48
22	21/5-87	F	5	1929	2.42
22	22/6-87	F	6	1619	2.66
22	22/7-87	F	6	2513	2.42
22	20/8-87	F	6	2369	2.25
22	22/9-87	F	6	1912	2.55
22	14/10-87	F	6	2192	2.27
24	21/1-87	F	12	1630	1.54
24	23/2-87	F	12	2136	1.52
24	16/3-87	F	12	2171	1.33
24	27/4-87	F	12	2441	1.43
24	18/5-87	F	12	2436	1.79
24	19/8-87	F	12	3401	2.04
24	15/9-87	F	12	3274	1.64
24	27/10-87	F	12	2765	1.68

Table 6.2. (continued)

No.	Date	Sex	Age	Bq Cs (kg K)$^{-1}$	g K (kg)$^{-1}$
25	2°/1-87	M	10	1640	1.57
25	23/2-87	M	10	2026	1.49
25	16/3-87	M	10	1999	1.25
25	27/4-87	M	10	2172	1.35
25	18/5-87	M	10	2117	1.49
25	19/8-87	M	11	3342	1.85
25	10/9-87	M	11	2987	1.83
25	14/10-87	M	11	2980	1.71
27	19/8-87	M	45	2052	1.80
27	8/9-87	M	45	2180	1.66
27	25/10-87	M	46	2207	1.65
27	20/11-87	M	46	2549	1.66

Mean*	January 1987	1890 ± 160
	February 1987	2090 ± 190
	March 1987	2035 ± 130
	April 1987	2155 ± 185
	May 1987	2360 ± 165
	June 1987	2275 ± 230
	July 1987	2260 ± 205
	August 1987	2290 ± 145
	September 1987	2385 ± 115
	October 1987	2305 ± 115
	November 1987	2265 ± 125
	December 1987	

*Monthly mean values (adults only) $^{134+137}$Cs Bq (kg K)$^{-1}$ ±1 S.E.

An approximate estimate of the ^{137}Cs content may be obtained by multiplying the Bq Cs (kg K)$^{-1}$ with 0.8

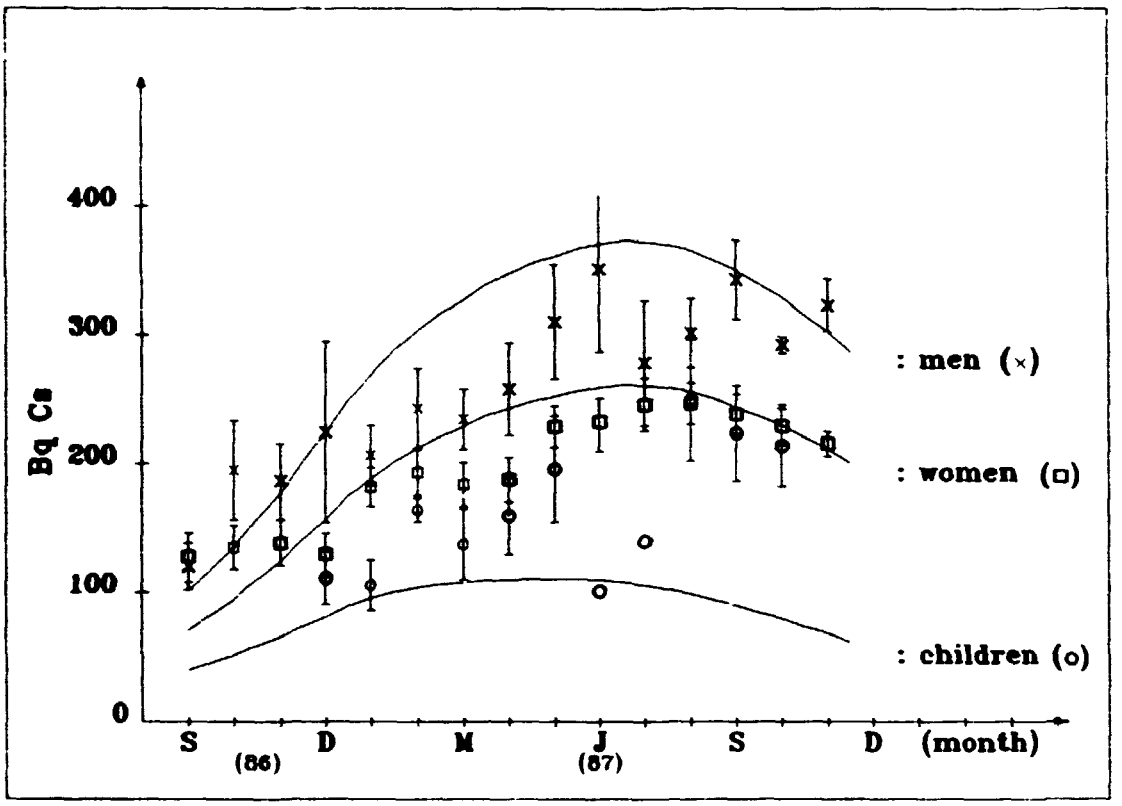


Fig. 6.2.2. Radiocesium in Danish men, women and children from Zealand in 1986-1987. The ^{137}Cs content is approx. 0.8 times the total radiocesium (^{134}Cs + ^{137}Cs). The curves represent the calculated levels based upon diet measurements (cf. Fig. 6.2.1).

6.3. Radionuclides in Human Milk

by A. Aarkrog

The mean diet ^{137}Cs and ^{90}Sr levels in Copenhagen in the first half of 1987 was estimated from the diet samplings in December 1986 (Risø-R-549)[1] and in June 1987 (cf. 5.7). The means of these two samplings were 1.87 Bq ^{137}Cs day^{-1} and 0.13 Bq ^{90}Sr day^{-1}. The means of the concentrations in human milk were 0.43 ± 0.02 Bq ^{137}Cs l^{-1} (± 1 S.E.; N = 5) and 0.0034 ± 0.0017 Bq ^{90}Sr l^{-1} (± 1 S.E.; N = 2). If we assume that the milk donors diet was represented by the diet sampling in Copenhagen, we estimate that 23% of the daily diet intake of ^{137}Cs were excreted in 1 l human milk and 2.6% of the ^{90}Sr. These figures are in agreement with earlier observations on global fallout[21]. The $^{134}Cs/^{137}Cs$ shows that all radiocesium in the human milk samples were from Chernobyl.

Table 6.3. Radiocesium and ^{90}Sr in human milk collected in Copenhagen in 1987. Donor born in May 1959, child born in December 1986

Month	Bq ^{137}Cs l^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	$\frac{^{134}Cs}{^{137}Cs}$	Bq ^{90}Sr l^{-1}	Bq ^{90}Sr (kg Ca)$^{-1}$
February	0.37	750	0.44		
March	0.39	740	0.41	0.0017 B	5.6 B
April	0.48	800	0.43		
May	0.44	930	0.37		
June-July	0.48	1010	0.34	0.005 B	18 B

6.4. Radiocesium in Urine Samples

Table 6.4. shows the radiocesium content in urine from a control group at Risø. The Chernobyl radiocesium appeared in the sample from October 1986 and has since then shown an increasing trend. Figure 6.4 shows that the radiocesium in diet has been decreasing since December 1986, but whole-body measurements show increasing levels as the urine samples Fig. 6.4 suggests that Bq ^{137}Cs (kg K)$^{-1}$ in urine samples are proportional to the body levels. The mean ratio between human and urine was 3.6 ± 0.76 (± 1 S.D.; N = 8).

Fig. 6.4. Radiocesium (Bq ^{137}Cs (kg K)$^{-1}$) in diet, urine, and humans from Zealand in 1986-1987. (The human data were calculated from whole-body measurements of (^{134}Cs + ^{137}Cs) by multiplication with 0.7 in 1986 and 0.8 in 1987).

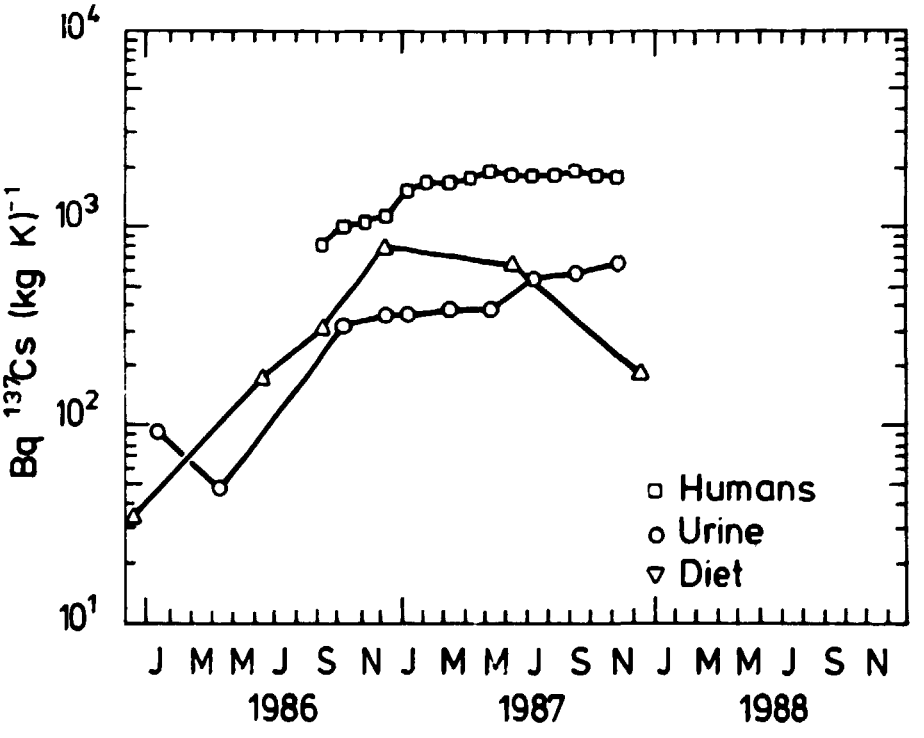


Table 6.4. Radiocesium in urine samples from a control group at Risø. January 1986 - November 1987

Date	^{40}K g l^{-1}	Bq ^{137}Cs (kg K)$^{-1}$	$\frac{^{134}Cs}{^{137}Cs}$
January 1986	1.37	94	-
April 1986	1.10	48	-
October 1986	1.26	320	0.42
December 1986	1.44	360	0.52
January 1987	1.59	360	0.47
March 1987	1.08	380	0.47
May 1987	1.09	380	0.46
July 1987	1.33	550	0.35
September 1987	1.78	580	0.35
November 1987	2.56	660	0.36

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.

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 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 (cf. Appendix E in Risø-R-527[1]).

7.3. Summary of Results

The tritium results are shown in detail in the chapters where the samples belong.

Tables 4.2.3.1 and 4.2.3.2 give the results for precipitation. The annual mean concentrations in rain in 1987 were: 5.3 kBq m^{-3} at Risø, 1.9 at Tyl-

strup, 1.2 at Jyndevad, and 1.6 at Bornholm. The concentrations at Risø were approx. 1.7 times those observed in 1986, and so were the tritium levels at the 3 experimental farms. The enhanced tritium levels at Risø were due to discharges of the DR 3 reactor at the site. We have no explanation for the higher tritium concentrations in precipitation in 1987, but laboratory contamination may not be excluded. The median concentration of tritium in Danish ground water (cf. Table 4.3.1) was 1.8 kBq ^3H m^{-3} or approximately 3 times the 1986 level.

The tritium concentrations in Danish streams and lakes were 1.8 and 1.7 kBq m^{-3}, respectively (Table 4.3.2), i.e. nearly the same as in 1986. Danish drinking water contained 0.7 kBq ^3H m^{-3} in 1987 (Table 4.3.3).

8. Measurements of Background Radiation in 1987

by L. Bøtter-Jensen and S.P. Nielsen

8.1. Instrumentation

Measurements of the background radiation were made with thermoluminescence dosimeters (TLD's), 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. At the Askov location we still see an external gamma-ray component from the Chernobyl contamination.

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 1987.

Table 8.2.1. TLD-measurements of the background radiation (integrated over 12 months and normalized to μR h^{-1}) at the State experimental farms in 1986/87

Location	Sept 1986 - Sept 1987 μR h^{-1}
Tylstrup	-
Borris	7.5
Ødum	7.6
Askov	7.7
St. Jyndevad	6.8
Blangstedgård	-
Tystofte	8.6
Abed	8.2
Mean	7.7

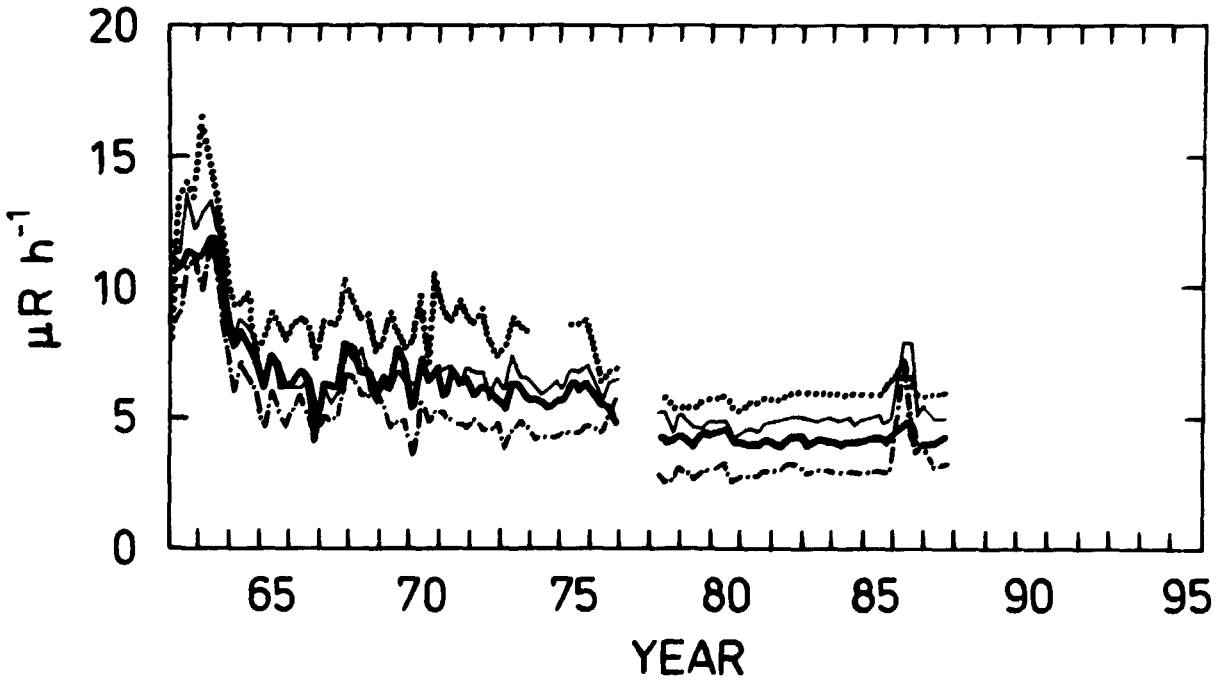
Table 8.2.2. Terrestrial exposure rates at the State experimental farms measured with the NaI(Tl) detector in 1987 (μR h⁻¹)

Location	April	September	Mean
Tylstrup	3.3	3.4	3.4
Borris	3.1	3.3	3.2
Kalø	3.9	4.6	4.2
Askov	4.5	4.2	4.4
St. Jyndevad	2.1	2.5	2.3
Årslev	5.0	5.0	5.0
Ledreborg	4.9	4.8	4.8
Tystofte	5.0	4.9	5.0
Abed	4.9	5.0	5.0
Tornbygård	5.9	(6.0)	6.0
Mean	4.3	4.4	4.3

Figures in brackets were calculated from VAR3[12].

Fig. 8.2.1. Terrestrial exposure rates at the State experimental farms in 1962-1976 and 1978-1987 measured with the NaI(Tl) detector (μR h⁻¹).

..... Åkirkeby/Tornbygård
——— Abed, Blangstedgård/Årslev, Tystofte
——— Virumgård/Ledreborg, Ødum/Kalø, Tylstrup
—·— Jyndevad, Askov, Studsgård/Borris



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.

Table 8.3.1. TLD-measurements of the background radiation (7-month integration period and normalized to μR h^{-1}) in five zones (I-V) around Risø in 1986/87

Risø zone	Location	April-Sept 1987 μR h^{-1}
I	1	8.8
I	2	10.1
I	3	20.7
I	4	9.3
I	5	11.5
Mean		12.1
II	1	7.9
II	2	8.8
II	3	7.8
II	4	7.5
Mean		8.0
III	1	9.1
III	2	8.6
III	3	8.6
Mean		8.8
IV	1	7.9
IV	2	8.5
IV	3	8.1
IV	4	7.4
IV	5	6.7
IV	6	8.2
IV	7	9.5
Mean		8,0
V	1	8.6
V	2	9.1
V	3	9.0
V	4	8.1
V	5	8.3
V	6	8.0
V	7	9.2
V	8	9.6
V	9	9.1
V	10	8.3
Mean		8.7

Table 8.3.2. Terrestrial exposure rates at the Risø zones in 1987 measured with the NaI(Tl) detector (μR h⁻¹)

Risø zone	Location	February	April	July	October
I	1	3.9	7.7	5.8	6.4
I	2	4.2	6.8	7.2	7.7
I	3	31.2	57.1	79	72
I	4	3.9	5.4	5.8	6.2
I	5	6.2	10.5	11.0	11.3
Mean		9.9	17.5	22	21
II	A	4.3	4.7	4.5	4.7
II	B	4.3	5.3	5.2	5.4
II	C	4.0	4.6	4.3	4.4
II	D	3.0	4.5	4.3	4.5
Mean		3.9	4.8	4.6	4.8
III	A		5.5		6.0
III	B		5.0		5.7
III	C		4.2		4.8
Mean			4.9		5.5
IV	A		4.2		6.7
IV	B		4.8		5.7
IV	C		4.6		5.3
IV	D		4.4		4.7
IV	E		4.0		4.0
IV	F		4.1		4.1
IV	G		4.8		5.0
Mean			4.4		5.1
V	A		4.7		5.8
V	B		5.4		7.5
V	C		5.3		5.5
V	D		5.2		5.2
V	E		5.6		5.6
V	F		4.3		4.6
V	G		4.7		4.8
V	H		4.6		4.7
V	I		5.1		5.6
V	K		4.0		5.0
Mean			4.9		5.4

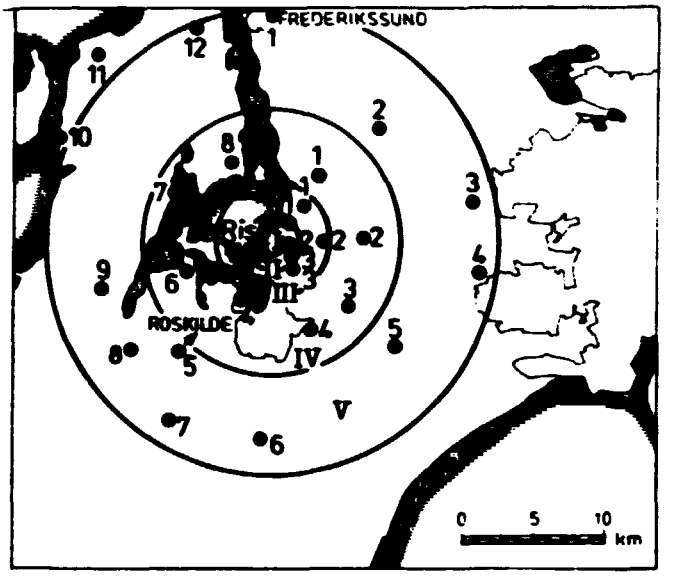


Fig. 8.3.1. The environment of Risø. Locations for measurements of the background radiation.

8.4. Gylling Næs Environment

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

Table 8.4.1. TLD-measurements of the background radiation (integrated over 12 months and normalized to μR h^{-1}) around the Gylling Næs site in 1986/87

Location	Sept 1986 - Sept 1987 μR h^{-1}
1	8.1
2	-
3	9.3
Mean	8.7

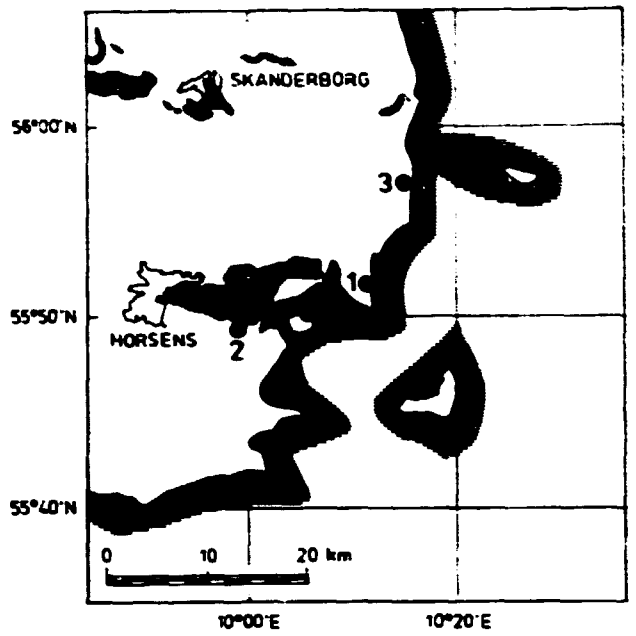


Fig. 8.4.1. The environment of Gylling Næs. Locations for measurements of the background radiation.

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 TLDs; 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 $\mu R\ h^{-1}$) along the coasts of the Great Belt and Langeland Belt in 1986/87

Location	Sept 1986 - Sept 1987 $\mu R\ h^{-1}$
Røsnæs	8.5
Reersø	9.2
Svendstrup	8.5
Vesternæs	9.9
Frederiksdal	9.3
Kelds Nor	10.6
Tranekær	10.0
Hov	9.0
Fyns Hoved	8.9
Knuds Hoved	-
Mean	9.3

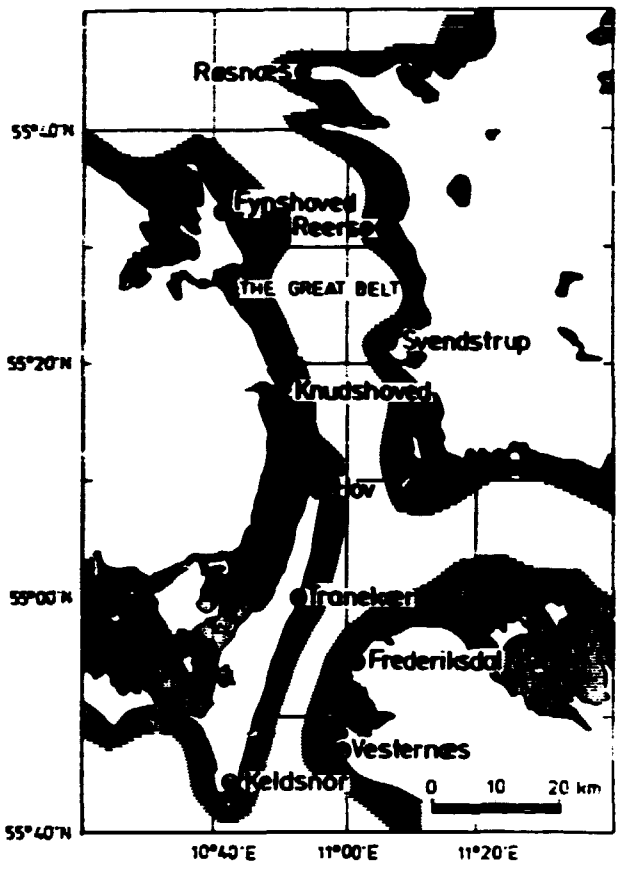


Fig. 8.5.1. The coasts of the Great Belt. Locations for measurements of the background radiation.

8.6. The Baltic Island of Bornholm

Locations on the island of Bornholm have been monitored with TLDs in the period April 1986 - May 1987. 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 14 months and normalized to μR h^{-1}) on the island of Bornholm in 198 /87

Location	April 1986 - May 1987 μR h^{-1}
1	-
2	9.6
3	8.3
4	17.4
Mean	11.8

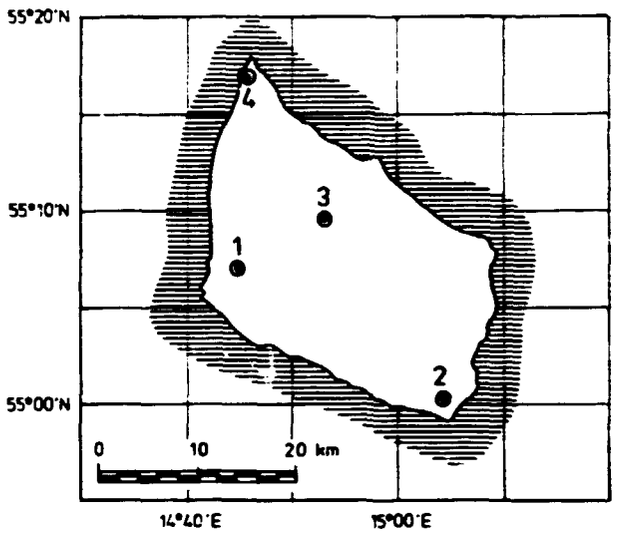


Fig. 8.6.1. Locations for measurements on Bornholm.

9. Conclusion

9.1. Environmental Monitoring at Risø, Barsebäck, and Ringhals

No radioactive contamination of the environment originating from the operation of Risø National Laboratory was ascertained outside its boundaries in 1987.

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 in doses of less than 1% of the background radiation to any individual eating 20 kg mussel and 100 kg fish per year.

9.2. Fallout in the Abiotic Environment

The mean content of ^{90}Sr in air collected in 1987 was 0.37 $\mu Bq\ m^{-3}$, i.e. 70 times less than the 1986 level. The mean concentration of ^{137}Cs in air was 6 $\mu Bq\ m^{-3}$ in 1987, i.e. 220 times less than in 1986. The average fallout at the State experimental farms in 1987 was 1.44 Bq $^{90}Sr\ m^{-2}$ or 26 times less than the 1986 figure, and the mean concentration of ^{90}Sr in rain water was 2.1 Bq $^{90}Sr\ m^{-3}$. The deposition of ^{137}Cs was 29 Bq m^{-2} or 37 times less than in 1986.

By the end of 1987 the accumulated fallout was approximately 1533 Bq ^{90}Sr m^{-2} (41 mCi $^{90}Sr\ km^{-2}$). The corresponding ^{137}Cs was estimated at 3700 Bq m^{-2}.

The median level of ^{90}Sr in Danish ground water was 0.06 Bq m^{-3}.

Inner Danish surface waters (salinity ~ 12 ‰) contained 18 Bq $^{90}Sr\ m^{-3}$ and 78 Bq $^{137}Cs\ m^{-3}$. The ^{90}Sr concentration in 1987 was 82% and the ^{137}Cs level 80% of the corresponding values in 1986.

9.3. Fallout Nuclides in the Human Diet

The mean level of ^{90}Sr in Danish milk was 59 Bq (kg Ca)$^{-1}$, and the mean content of ^{137}Cs was approximately 600 Bq m^{-3}.

The 1987 ^{90}Sr level was 0.92 times the level found in milk produced in 1986, and the ^{137}Cs was 0.57 times. The ^{90}Sr mean content in grain from the 1987 harvest was 0.57 Bq kg^{-1}. The ^{137}Cs mean content in grain was 0.21 Bq kg^{-1}. The ^{90}Sr level in grain from the 1987 harvest was 1.21 times the level found in the 1986 harvest, and ^{137}Cs was 0.06 times the 1986 level.

The mean contents of ^{90}Sr and ^{137}Cs in Danish vegetables collected in 1987 were 0.32 Bq ^{90}Sr kg^{-1} and 0.064 Bq ^{137}Cs kg^{-1}, respectively, and in fruit 0.064 Bq ^{90}Sr kg^{-1} and 0.19 ^{137}Cs kg^{-1}. Potatoes contained 0.044 Bq ^{90}Sr kg^{-1} and 0.134 Bq ^{137}Cs kg^{-1}.

The mean levels of ^{90}Sr and ^{137}Cs in the Danish total diet in 1987 were 123 Bq ^{90}Sr (kg Ca)$^{-1}$ and 490 Bq ^{137}Cs (kg K)$^{-1}$, respectively. The levels of ^{90}Sr and ^{137}Cs in the Danish total diet in 1987 were, respectively, 1.26 and 1.32. times those observed in 1986. The increase in the Bq ^{90}Sr (kg Ca)$^{-1}$ was due to lower calcium levels in the Danish diet, because Danish flour no longer is enriched artificially by calcium (creta praeparata).

Grain products contributed 31% and milk products 28% to the total ^{90}Sr intake; 44% of the ^{137}Cs in the diet originated from grain products, 24% from meat, and 17% from milk products. Fish contributed with 9% to the ^{137}Cs diet intake.

The predicted levels of ^{137}Cs in Danish food products based on global fallout models were in general higher than those actually observed in 1987, but as expected the difference was less pronounced than that observed in 1986, when the distribution in time of the fallout deviated more from global fallout than in 1987.

9.4. Strontium-90 and Cesium-137 in Humans

The ^{90}Sr mean content in human bone (vertebrae) collected in 1987 was about 23 Bq (kg Ca)$^{-1}$.

Whole-body measurements of ^{137}Cs were resumed after the Chernobyl accident. The measured mean level in 1987 was 1770 Bq ^{137}Cs (kg K)$^{-1}$.

9.5. Tritium in Environmental Samples

The tritium mean concentration in ground, stream, lake, and drinking water was approximately 1.5 kBq m^{-3} in 1987. The mean content of precipitation was 1.6 kBq m^{-3}.

9.6. Background Radiation

The average total background exposure rate measured with TLDs at the State experimental farms was 7.7 μR h^{-1}. The annual mean of the terrestrial exposure rates at the State experimental farms measured with the NaI(Tl) detector was 4.3 μR h^{-1}. The annual means in 1987 are not different from the levels prior to the Chernobyl accident.

Acknowledgements

The authors wish to thank the staff of Health Physics Department for their conscientious performance of their work of this report.

We are specially indebted to the staffs of the ten State experimental farms at Tylstrup, Kalø, Borris, Askov, St. Jyndevad, Årslev, Tystofte, Ledreborg, Abed, and Tornbygård, 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 1987.

Part of this work was supported by the CEC Radiation Protection Programme.

Appendix A

A Reinvestigation of Radiocesium in Soil Samples from S-Jutland with Emphasis on the Possible Effect of the Pretreatment of the Samples Before Measurement

In September 1986 we collected soil samples from five locations in South Jutland. These locations have been identified as having relatively high depositions of Chernobyl debris[1]).

It appeared from this study that the samples collected 0-5 cm contained contained 35% higher Chernobyl radiocesium deposit than those collected 0-10 cm. The 0-5 cm set was measured untreated, whereas the 0-10 cm set had received our normal treatment for soil samples, i.e. the soil had been dried, crushed and sieved. By this pretreatment some of the activity had apparently been lost (stones, roots etc.), and it was therefore decided to repeat the sampling and the analysis in 1988.

Table A1 shows the results. It appears that the untreated samples on the average contained 5% higher levels than the treated. This shows that e.g. stones and roots removed by the sieving process contain some radiocesium, although not so much as indicated by the 1986 sampling.

In Table A2 we have summarized the results. The distribution of Chernobyl debris differs significantly from that of global fallout. In the 0-5 cm layer we find 69% of the Chernobyl ^{137}Cs but only 17% of the global fallout (compared with that in the 0-20 cm layer). But in the 10-20 cm layer we find 9% of the Chernobyl and 53% of the global fallout.

Table A3 shows that the Chernobyl ^{137}Cs generally decreased from 1986 to 1988, but the decrease was very uneven. We conclude that the deposition from Chernobyl may have shown great local variations perhaps due to hot spots in some samples.

The mean 1988/1986 ratios in Table A3 were probably different from 1 in case of the 0-5 cm set but not for the 0-10 cm set.

Table A1. Radiocesium in soil samples collected in South Jutland 18 October 1988. (Unit: Bq m^{-2})

Location	Depth in cm	Untreated ^{137}Cs	Untreated ^{134}Cs	Treated ^{137}Cs	Treated ^{134}Cs
Hokkerup I	0-5	3800	910	3800	900
Hokkerup II	0-5	2600	570	2700	410
Hokkerup	0-10	4000	770	3600	690
Hokkerup	10-20	1470	B.D.L.	1430	29
Sønder Vilstrup I	0-5	1510	270	1450	290
Sønder Vilstrup II	0-5	1540	350	1500	320
Sønder Vilstrup	0-10	2100	360	2000	330
Sønder Vilstrup	10-20	740	B.D.L.	670	B.D.L.
Gabøl I	0-5	2200	420	1890	400
Gabøl II	0-5	1970	400	1950	370
Gabøl	0-10	4900	850	4600	800
Gabøl	10-20	1380	65 A	1300	56
Rangstrup I	0-5	1090	210	1000	159
Rangstrup II	0-5	780	138 A	730	71
Rangstrup	0-10	1760	200	1840	220
Rangstrup	10-20	1850	190	1870	200
Styding I	0-5	2200	510	2100	440
Styding II	0-5	2000	450	1900	390
Styding	0-10	2900	580	2600	470
Styding	10-20	960	B.D.L.	900	B.D.L.

I and II are duplicates.

Table A2. Chernobyl and global fallout ^{137}Cs in soil from five locations in South Jutland (cf. Table A1). (Bq ^{137}Cs m^{-2}) ± 1 S.D.

Soil layer	Chernobyl	Global fallout
0-5 cm	1600 ± 810	340 ± 80
0-10 cm	2100 ± 1030	920 ± 320
10-20 cm	220 ± 330	1040 ± 250

The Chernobyl ^{137}Cs was calculated from the ^{134}Cs data by multiplication with 4, assuming that the ^{134}Cs/^{137}Cs in fresh Chernobyl debris was 0.55[1]. The global fallout ^{137}Cs was calculated by subtracting the Chernobyl ^{137}Cs from the measured ^{137}Cs.

Table A3. Comparison of 1988 with 1986[1] Chernobyl deposition at the five locations in South Jutland. (Bq ^{137}Cs m^{-2} in 1988/Bq ^{137}Cs m^{-2} in 1986)

Location	0-5 cm (untreated)	0-10 cm (treated)
Hokkerup	0.99	0.99
Sdr. Vilstrup	0.74	0.83
Gabøl	0.32	0.84
Rangstrup	0.15	0.25
Styding	0.62	1.21
Mean ± 1 S.E.	0.56 ± 0.15	0.82 ± 0.16

Appendix B

Statistical Information on Population Density, Area of the Zones, and Milk, Grain, Vegetable, and Fruit Production in the Zones

Appendix B. Statistical information

Zone		Area in km²	Population in thousands	Annual milk production in mega-kg	Annual wheat production in mega-kg	Annual rye production in mega-kg	Annual potato production in mega-kg	Grass and green fodder production in mega-kg
		15)	28) 1985	13) 1985	13) 1985	13) 1985	13) 1985	13) 1985
I:	North Jutland	6,171	482	893				
II:	East Jutland	7,561	909	1,427	980	425	980	17,649
III:	West Jutland	12,104	711	1,326				
IV:	South Jutland	3,929	250	663				
V:	Funen	3,486	455	357				
VI:	Zealand	7,435	2,115*	306				
VII:	Lolland-Falster	1,795	141	76	992	140	120	2,536
VIII:	Bornholm	588	47	51				
Total		43,069	5,110	5,099	1,972	565	1,100	20,185

*1,170,000 people were living in Greater Copenhagen and 945,000 in the remaining part of Zealand.

Appendix C

A Comparison Between Observed and Predicted Levels in the Human Food Chain in Denmark in 1987

For the calculation of the ^{137}Cs levels before 1986 we have assumed the $^{137}Cs/^{90}Sr$ ratio equal to 1.6 because that was the ratio used in reference 21.

Table C.1. Comparison between observed and predicted ^{90}Sr levels in environmental samples collected in 1987

Sample	Location	Unit	Number observations in mean	Observed ± 1 S.E.	Predicted	Obs./pred.	Model in reference (21)
Dried milk	Jutland	Bq ^{90}Sr (kg Ca)$^{-1}$	4	68 ± 4	114	0.60	C.3.2.1 No. 1
-"-	Islands	-"-	3	45 ± 1	28	1.61	C.3.2.1 No. 3
Rye	Jutland	Bq ^{90}Sr kg^{-1}	5	0.64 ± 0.14	0.49	1.31	C.2.2.1 No. 1
"	Islands	-"-	5	0.24 ± 0.03	0.12	2.00	C.2.2.1 No. 3
Barley	Jutland	-"-	10	0.79 ± 0.13	0.63	1.25	C.2.2.1 No. 4
"	Islands	-"-	9	0.38 ± 0.08	0.25	1.52	C.2.2.1 No. 6
Wheat	Jutland	-"-	7	0.87 ± 0.17	0.46	1.89	C.2.2.1 No. 8
"	Islands	-"-	8	0.35 ± 0.05	0.20	1.75	C.2.2.1 No. 10
Oats	Jutland	-"-	5	0.74 ± 0.11	1.30	0.57	C.2.2.1 No. 12
"	Islands	-"-	4	0.46 ± 0.05	0.61	0.75	C.2.2.1 No. 13
Potatoes	Jutland	-"-	6	0.044 ± 0.002	0.097	0.45	C.2.5.1 No. 8
"	Islands	-"-	5	0.042 ± 0.007	0.088	0.48	C.2.5.1 No. 10
Cabbage	Jutland	-"-	4	0.33 ± 0.01	0.32	1.03	C.2.5.1 No. 1
"	Islands	-"-	4	0.20 ± 0.03	0.25	0.80	C.2.5.1 No. 3
Carrot	Jutland	-"-	4	0.35 ± 0.06	0.55	0.64	C.2.5.1 No. 5
"	Islands	-"-	4	0.26 ± 0.10	0.16	1.63	C.2.5.1 No. 6
Apples	Denmark	-"-	4	0.025 ± 0.004	0.013	1.92	C.2.5.1 No. 13
Pork	"	-"-		0.007	0.027	0.26	C.3.4.1 No. 3
Beef	"	-"-		0.015	0.035	0.43	C.3.4.1 No. 1
Eggs	"	-"-		0.020	0.012	1.67	C.3.6.1 No. 6
Total diet C	"	Bq ^{90}Sr (kg Ca)$^{-1}$		121	190	0.64	C.4.2.1 No. 1
Total diet P	"	-"-		124	165	0.75	C.4.2.1 No. 7
Human bone > 29 yr	"	-"-	31	22 ± 1.5	38	0.58	C.4.3.1 No. 3
Whole year grass	Islands	-"-	4	400 ± 30	820	0.49	C.2.4.1 No. 1
Fucus vesiculosus	"	-"-	4	226 ± 30	420	0.54	C.2.7.1 No. 3
Ground water**	Denmark	Bq ^{90}Sr m^{-3}	10	0.23 ± 0.13	0.26	0.88	C.1.4.1 No. 1
Stream water	"	-"-	8	9.7 ± 1.3	6.4	1.52	C.1.4.1 No. 3
Lake water	"	-"-	8	21 ± 3	4.0	5.25	C.1.4.1 No. 6

**Mean of all ground water samples except Feldbæk (cf. 4.3.1).

Table C.2. Comparison between observed and predicted ^{137}Cs levels in environmental samples collected in 1987

Sample	Location	Unit	Number observations in mean	Observed ±1 S.E.	Predicted	Obs./pred.	Model in reference (21)
Dried milk	Jutland	Bq ^{137}Cs (kg K)$^{-1}$	48	400 ±33	365	1.10	C.3.2.2 No. 1
-"-	Islands	-"-	36	97 ±10	450	0.22	C.3.2.2 No. 3
Rye	Jutland	Bq ^{137}Cs kg^{-1}		0.23	1.08	0.21	C.2.2.4 No. 1
"	Islands	-"-		0.11	0.88	0.13	C.2.2.4 No. 3
Barley	Jutland	-"-		0.11	0.80	0.14	C.2.2.4 No. 4
"	Islands	-"-		0.10	0.60	0.17	C.2.2.4 No. 5
Wheat	Jutland	-"-		0.10	0.80	0.13	C.2.2.4 No. 6
"	Islands	-"-		0.043	0.52	0.08	C.2.2.4 No. 7
Oats	Jutland	-"-		0.97	0.66	1.47	C.2.2.4 No. 8
"	Islands	-"-		0.13	0.56	0.23	C.2.2.4 No. 9
Potatoes	Jutland	-"-	6	0.19 ±0.07	0.112	1.70	C.2.5.3 No. 5
"	Islands	-"-	5	0.07 ±0.04	0.086	0.81	C.2.5.3 No. 7
Cabbage	Denmark	-"-	8	0.59 ±0.008	0.097	0.61	C.2.5.3 No. 1
Carrot	"	-"-	8	0.060 ±0.012	0.193	0.31	C.2.5.3 No. 3
Apples	"	-"-	8	0.21 ±0.04	1.43	0.15	C.2.5.3 No. 11
Pork	"	-"-		0.99	20	0.05	C.3.4.2 No. 3
Beef	"	-"-		2	0.98	2.04	C.3.4.2 No. 1
Eggs	"	-"-		0.185	1.98	0.09	C.3.6.2 No. 6
Total diet C	"	Bq ^{137}Cs (kg K)$^{-1}$		550	2200	0.25	C.4.2.2 No. 1
Total diet P	"	-"-		432	2800	0.15	C.4.2.2 No. 6

Appendix C.3. Deposition in 1987 in Bq m^{-2}

	Jutland	Islands	Denmark
^{90}Sr Jan-Dec	1.41	1.47	1.44
^{137}Cs Jan-Dec	32	26	29
^{90}Sr July-Aug	0.25	0.26	0.25
^{90}Sr May-Aug	0.66	0.52	0.59
^{137}Cs Jan-Dec	5.5	5.3	5.4
^{137}Cs May-Aug	12.5	11.4	12.0

Appendix D

Fallout Rates and Accumulated Fallout (mCi ^{90}Sr km^{-2}) in Denmark 1950-1987

d_i

Annual fallout rate in mCi ^{90}Sr km^{-2} yr^{-1} or Bq ^{90}Sr m^{-2} yr^{-1}. Accumulated fallout by the end of the year (i) assuming effective half-lives of ^{90}Sr of 28.8 y. Unit: mCi ^{90}Sr km^{-2} or Bq ^{90}Sr m^{-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} $period^{-1}$ or Bq ^{90}Sr m^{-2} $period^{-1}$. The fallout rate (d_i) was based on precipitation data collected for all Denmark in the period 1962-1984 (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 4.2[1] for the period 1962-1984. 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.

Table D.1 shows the mCi ^{90}Sr km^{-2} figures and Table D.2 gives the Bq m^{-2} values.

Appendix D.1. Fallout rates and accumulated fallout (mCi ^{90}Sr km^{-2}) in Denmark 1950-1987

	Denmark		Jutland		Islands	
Year	di	$Ai_{(28.82)}$	di	$Ai_{(28.82)}$	di	$Ai_{(28.82)}$
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	0.434	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	11.685	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	0.095	47.244	0.114	52.556	0.078	41.932
1981	0.451	46.358	0.309	51.559	0.269	41.159
1982	0.046	45.257	0.048	50.332	0.043	40.184
1983	0.036	44.174	0.036	49.123	0.037	39.227
1984	0.029	43.110	0.033	47.941	0.026	38.283
1985	0.022	42.067	0.020	46.776	0.023	37.360
1986	1.041	42.042	1.081	46.674	1.000	37.412
1987	0.039	42.022	0.038	46.649	0.040	37.396

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	2.01	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	0.590	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
0.051	0.022	0.064	0.025	0.038	0.0180
0.175	0.060	0.176	0.058	0.174	0.061
0.022	0.0071	0.024	0.0085	0.020	0.0058
0.013	0.0048	0.015	0.0055	0.0114	0.0043
0.013	0.0075	0.016	0.0090	0.0106	0.0059
0.0086	0.0054	0.0075	0.0046	0.0088	0.0062
0.74	0.052	0.78	0.055	0.70	0.048
0.0159	0.0068	0.0178	0.0068	0.0141	0.0070

Appendix D.2. Fallout rates and accumulated fallout (Bq ^{90}Sr m^{-2}) in Denmark 1950-1987

	Denmark		Jutland		Islands	
Year	di	$Ai_{(28.82)}$	di	$Ai_{(28.82)}$	di	$Ai_{(28.82)}$
1950	0.777	0.759	0.814	0.795	0.740	0.722
1951	3.737	4.389	4.218	4.894	3.256	3.884
1952	7.326	11.436	8.288	12.868	6.364	10.004
1953	18.500	29.225	20.942	33.007	16.058	25.443
1954	70.337	97.196	79.624	109.954	61.050	84.438
1955	92.537	185.224	104.747	209.599	80.327	160.849
1956	114.737	292.833	129.870	331.402	99.604	254.264
1957	114.737	397.884	129.870	450.310	99.604	345.458
1958	159.174	543.820	180.153	615.481	138.158	472.124
1959	225.774	751.306	255.596	850.377	195.989	652.236
1960	42.180	774.629	47.767	876.800	36.630	672.495
1961	54.797	809.716	62.012	916.502	47.545	702.929
1962	274.836	1058.779	295.112	1182.821	254.560	934.736
1963	617.715	1636.653	682.761	1821.249	552.669	1452.058
1964	385.244	1973.849	432.345	2200.039	338.143	1747.659
1965	146.298	2069.764	155.548	2299.609	137.048	1839.918
1966	79.365	2098.057	80.142	2323.199	78.588	1872.915
1967	38.739	2086.017	43.512	2310.468	33.966	1861.566
1968	51.911	2087.122	58.016	2312.200	45.769	1862.009
1969	38.295	2074.909	45.917	2302.078	30.673	1847.704
1970	60.939	2085.092	73.741	2319.360	48.137	1850.789
1971	55.722	2089.939	63.862	2326.587	47.582	1853.258
1972	16.095	2055.987	16.909	2287.806	15.281	1824.135
1973	7.104	2014.063	7.955	2241.204	6.216	1786.854
1974	26.270	1991.847	28.823	2216.082	23.791	1767.617
1975	15.318	1959.467	16.724	2179.746	13.912	1739.193
1976	3.811	1916.622	4.292	2132.136	3.330	1701.114
1977	14.208	1884.946	14.985	2096.097	13.394	1673.764
1978	17.131	1856.876	19.906	2065.718	14.356	1648.004
1979	6.142	1818.745	6.438	2022.914	5.772	1614.475
1980	3.504	1778.945	4.229	1979.966	2.869	1577.924
1981	10.662	1747.079	11.447	1944.499	9.967	1549.659
1982	1.691	1707.212	1.782	1900.127	1.601	1514.297
1983	1.344	1667.954	1.329	1856.433	1.359	1479.475
1984	1.094	1629.385	1.209	1813.506	0.980	1445.264
1985	0.806	1591.452	0.744	1771.286	0.868	1411.618
1986	38.5	1591.218	40	1766.622	37	1415.882
1987	1.44	1554.810	1.41	1726.017	1.47	1383 670

	Denmark		Jutland		Islands	
Year	$di_{(May-Aug)}$	$di_{(July-Aug)}$	$di_{(May-Aug)}$	$di_{(July-Aug)}$	$di_{(May-Aug)}$	$di_{(July-Aug)}$
1950	0.370	0.370	0.370	0.370	0.370	0.370
1951	1.850	0.740	2.220	1.110	1.850	0.740
1952	4.070	1.850	4.440	1.850	3.330	1.480
1953	9.990	4.440	11.470	5.180	8.510	3.700
1954	38.110	17.020	42.920	19.240	32.930	14.800
1955	49.950	22.200	56.610	25.160	43.290	19.240
1956	61.790	27.380	70.300	31.080	53.650	24.050
1957	61.790	27.380	70.300	31.080	53.650	24.050
1958	85.840	38.110	97.310	43.290	74.740	33.300
1959	92.500	25.160	102.120	27.750	82.880	22.570
1960	17.390	11.470	19.240	12.580	15.540	10.360
1961	24.420	17.390	27.010	19.240	21.830	15.540
1962	156.251	68.709	168.942	75.924	143.560	61.494
1963	368.705	208.273	397.861	219.484	339.549	197.099
1964	230.695	95.016	265.290	107.670	196.063	82.362
1965	75.073	31.450	77.478	31.524	72.668	31.376
1966	38.813	15.466	36.408	18.352	41.218	12.580
1967	13.579	5.217	14.060	4.958	13.098	5.476
1968	31.376	15.762	33.670	17.020	29.082	14.504
1969	22.718	10.212	26.751	11.803	18.685	8.621
1970	33.596	20.239	39.812	23.384	27.380	17.094
1971	36.704	14.985	42.698	19.092	30.710	10.878
1972	9.361	3.108	9.694	3.108	9.028	3.108
1973	2.775	1.221	3.441	1.443	2.109	0.999
1974	15.577	7.030	17.131	8.103	13.986	5.994
1975	5.883	2.775	6.623	3.367	5.809	2.220
1976	1.184	0.370	1.184	0.407	1.184	0.333
1977	6.586	3.959	6.068	3.145	7.030	4.773
1978	8.584	3.552	10.175	3.626	6.956	3.441
1979	3.182	1.110	3.219	1.147	3.108	1.073
1980	1.903	0.816	2.386	0.936	1.420	0.664
1981	6.464	2.205	6.494	2.144	6.433	2.265
1982	0.816	0.263	0.876	0.314	0.755	0.215
1983	0.483	0.178	0.544	0.202	0.423	0.160
1984	0.488	0.277	0.581	0.336	0.395	0.216
1985	0.318	0.200	0.276	0.169	0.326	0.230
1986	27.4	1.91	28.8	2.05	26.0	1.76
1987	0.59	0.25	0.66	0.25	0.52	0.26

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Bibliographic Data Sheet **Risø-R-563**

Title and authors

Environmental Radioactivity in Denmark in 1987

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ISBN
87-550-1532-8

ISSN
0106-2840
0106-407X

Dept. or group
Health Physics Department

Date
May 1989

Groups own reg. number(s)

Project/contract no.

Pages	Tables	Illustrations	References
142	159	58	38

Abstract (Max. 2000 characters)

Strontium-90, radiocesium, and other radionuclides were determined in samples from all over the country of air, precipitation, stream water, lake water, ground water, drinking water, sea water, soil, sediments, dried milk, fresh milk, meat, fish, cheese, eggs, grain, bread, potatoes, vegetables, fruit, grass, moss, lichen, sea plants, total diet, and humans. Estimates are given of the mean contents of radiostrontium and radiocesium in the human diet in Denmark during 1987. Tritium was determined in precipitation, ground water, other fresh waters, and sea water. 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).

The expanded programme initiated after the Cernobyl accident in 1986 was carried on in 1987 with minor reductions.

Descriptors INIS/EDB

AIR; AMERICIUM 241; ANTIMONY 125; AQUATIC ECOSYSTEMS; ATMOSPHERIC PRECIPITATIONS; BACKGROUND RADIATION; BARSEBAECK-1 REACTOR; BARSEBAECK-2 REACTOR; BONE TISSUES; CERIUM ISOTOPES; CESIUM 134; CESIUM 137; CHERNOBYLSK-4 REACTOR; COBALT ISOTOPES; CURIUM ISOTOPES; DENMARK; DIET; ENVIRONMENT; FALLOUT DEPOSITS; FISHES; FOOD; FOOD CHAINS; GLOBAL FALLOUT; GROUND WATER; IODINE 131; LANTHANUM 140; LOCAL FALLOUT; MAN; MANGANESE 54; MILK; NEPTUNIUM 239; NIOBIUM 95; NUMERICAL DATA; PLANTS; PLUTONIUM ISOTOPES; RADIOACTIVITY; REACTOR ACCIDENTS; RINGHALS-1 REACTOR; RINGHALS-2 REACTOR; RINGHALS-3 REACTOR; RISOE NATIONAL LABORATORY; RUTHENIUM ISOTOPES; SEAWATER; SEAWEEDS; SEDIMENTS; SILVER 110; STRONTIUM 90; TRITIUM; ZINC 65; ZIRCONIUM 95;

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DK-1161 Copenhagen K, Denmark

Available on exchange from:
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ISBN 87-550-1532-8
ISSN 0106-2840
ISSN 0106-407X

Notes Grafisk Service Center as