BALTIC SEA ENVIRONMENT PROCEEDINGS

No. 61

RADIOACTIVITY IN THE BALTIC SEA 1984 - 1991

HELSINKI COMMISSION
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7. RADIONUCLIDES IN BIOTA

Günter Kanisch [1], Georg Neumann [2] and Erkki Ilus [3]

1) Federal Fisheries Research Centre, Institute of Fisheries Ecology, Germany
2) Swedish University of Agricultural Sciences, Department of Radioecology, Sweden
3) Finnish Centre for Radiation and Nuclear Safety, Finland

7.1. Introduction

Studies on the transfer of radionuclides between organisms as well as between organisms and their non-living environment are the basis to prepare dose assessments for human exposure to radionuclides due to consumption of different food items. Also, these studies help to get a more profound knowledge of the element transport within ecosystems.

It is well known that organisms form food chains in nature. These are seldom of a simple form, but are linked in very complicated food webs.

In general many radionuclides have a tendency to be enriched while being transferred upwards in the food web, i.e. from primary producers at the lower level of an ecosystem to the consumers (predators). Man is one of the top consumers in marine food webs.

There are many differences between radionuclides concerning their ability to accumulate in aquatic organisms. E.g. the caesium isotopes have a tendency to be enriched in fish flesh, whereas strontium mainly accumulates in bones.

The brackish water character of the Baltic Sea results in special radioecological properties. The salinity of the surface water decreases from around 25 ‰ in the Kattegat to almost fresh water in the inner parts of the Gulfs of Finland and Bothnia. The biota of the Baltic Sea consists of marine and fresh water organisms. The number of original endemic species is very small. The size of many marine organisms decreases considerably when going from higher to lower salinity. At the same time the decreasing salinity results in an increasing accumulation of some radionuclides.

The organisms collected by the different laboratories can be divided into three categories:

1) Organisms directly of importance for human consumption. This category includes a number of species of fish, crab, crayfish and mussels.

2) Organisms of importance in food webs ultimately leading to human consumption. To this category belong species serving as prey, including many kinds of fish and of benthic invertebrates. Other important species to be included here are plankton organisms and macro algae.

3) Organisms useful as bioindicators for radionuclides. Here we have to consider in the first place ***Fucus vesiculosus*** (bladder wrack), which has proved to be an excellent indicator especially used in monitoring programs at nuclear power plants in the different

areas. Also, many kinds of mussels, e.g. ***Macoma baltica*** and ***Mytilus edulis*** might be considered as good indicators, especially for radionuclides in suspended particulate matter.

The areas from where various species of fish were collected are indicated in Figure 3.1 .5. Sampling stations for algae and benthic invertebrates are given in Figure 3.1.4.

7.1.1. Some Important **Biota** in the Baltic Sea

Below a short description is given about the economical and ecological importance of some major species studied within MORS.

Herring is economically the most important fish species in the world. Its main distribution area is the northern part of the Atlantic Ocean and the southern part of the Arctic Ocean. The Baltic herring is a slow-growing and smaller form of herring and has the same economic importance in the Baltic Sea as herring in the oceans. Its importance is greatest in the northern areas of the Baltic Sea. The annual catch of herring in the Baltic Sea is about 400,000 tons and i.e. in Finland the share of herring in the total catch is about 80%. In the Northern Baltic the full-grown herring is only 16 to 19 cm long, but the size increases with increasing salinity. The nutriment consists mainly of planktonic crustaceans.

Cod is the second most important commercial fish species in the world. Its main distribution area ranges from New Foundland to the **Lofoten** Islands and the French coast. Compared with other important fish species of the Baltic Sea cod requires the most marine conditions. Thus it appears dwarfed in the Baltic Sea and is missing from the innermost parts of the Gulf of Bothnia and Gulf of Finland. In the northern parts of the Baltic Sea the appearance of cod depends on fluctuations of water salinity. The spawning does not succeed north of **Gotland,** because the salinity should be at least 10 to 12 **‰.** During the period 1984 to 1991 the annual catch of cod in the Baltic Sea decreased from 440,000 tons (exceptionally high) to 125,000 tons. ***Saduria** entomon* forms a marked share of cod’s nutriment in the northern Baltic Sea.

Flounder, plaice and dab have the main distribution areas in the northern Atlantic region, as well. From these species flounder has best adapted to the brackish water conditions of the Baltic Sea. It is missing only from the innermost parts of the Gulf of Bothnia and Gulf of Finland, but has significant economical importance only in the southern Baltic Sea. Plaice and dab have a more marine distribution. The annual catch of flounder in the Baltic Sea is about 10,000 tons. Molluscs and crustaceans are main constituents in the nutriment of these three species.

Pike, perch and roach are originally fresh water species, but are able to live in the coastal areas of almost the whole Baltic Sea, at least in shallow bays with low salinity. The premises of spawning are weakening with increasing salinity. Especially pike has economical importance in the Archipelago Sea and the coastal areas of the Gulf of Finland and Gulf of Bothnia. The annual catch of pike from the coastal areas of Finland is about 1,000 to 2,000 tons. Roach is an important prey for full-grown pike and perch. The nutriment of roach consists of small aquatic animals, sometimes merely plants. The young pike and perch eat small crustaceans and insect larvas. Pike is known as a very local fish living in a small area all its life.

The mussels *Mytilus edulis* and *Macoma baltica* live in the North Atlantic region and the Baltic Sea. In the Baltic Sea the size of the mussels decreases with decreasing salinity. *Macoma* stands low salinities better and is missing only in the northernmost part of the Bothnian Bay. The distribution of *Mytilus* ranges up to the middle parts of the Gulf of Bothnia and Gulf of Finland. In these areas the mussels are very small (l-2 cm). *Mytilus* filters nutriments from water, *Macoma* also from the surface layers of sediments. Both species are important prey, especially for flounder. The economical importance of *Mytilus* is restricted in the southernmost areas of the Baltic Sea.

Saduria entomon is originally an inhabitant of the Arctic Ocean, but lives as a glacial relict in the Baltic Sea and its gulfs down to Bornholm. In the Bothnian Sea it is together with *Monoporeia affinis* the only constituent of benthic fauna in wide areas. *Saduria* eats dead fish and other organic material existing in the bottom sediments. The full-grown animal is 5-6 cm long. *Saduria* is an important prey organism especially for cod, eel and perch.

The bladder-wrack *Fucus vesiculosus* is a tall brown alga growing in the littoral zones of the Baltic Sea and most of the northern North Atlantic region. *Fucus* communities form a significant part of the ecosystems, especially in the northern Baltic Sea area, where the littoral vegetation in general is poor in species owing to the low salinity of water. *Fucus* belts provide shelter and source of nourishment for fish of different stadia and for other aquatic organisms. The value of *Fucus* for human use is negligible. The distribution of *Fucus* corresponds to that of *Mytilus*. Similarly, the size of the plant decreases with decreasing salinity. In the southern Baltic Sea the thalli can be 70-80 cm high, but only 10 cm in the Quark (Gulf of Bothnia).

7.1.2. **Species Investigated**

The species sampled are listed below. The total number of measured samples (including various tissues from the same organism) was 1138.

A. Invertebrates

	Number of samples:		
	Animal whole	Shells	Soft parts
Arctica islandica		1	5
Asterias rubens	3		
Cardium edule		2	5
Crangon crangon	22		
Macoma baltica	20	2	2
Mya arenaria		1	2
Mytilus edulis	15	13	46
Saduria entomon	25		

B. Algae (whole plant)

	Number of samples:
Fucus vesiculosus	80
Laminaria saccharina	2

C. Fish

	Number of samples:							
	Fish whole	Fish whole without head and entrails	Flesh	Skin	Bones	Entrails	Liver	ovary
Abrumis brama (Bream)			9		6	6		
Clupea hurengus (Herring)	4	40	110		33	10	2	2
Cyprinus carpio (Carp)			3		2	2		
Enchelyopus cimbrius (Four-bearded rockling)	1		1					
Esox lucius (Pike)			44		5	5		
Gadus morhua (Cod)	1		195	14	23	2	101	
Limanda limanda (Dab)			13		3	2		
Merlangius merlangus (whiting)			5					
Myoxocephalus scorpius (Bull rout)			1		1			
Osmerus eperlanus (Smelt)			1		1			
Perca fluviatilis (Perch)			15		11	11		
Platichthys flesus (Flounder)			29		13	2		
Pleuronectes platessa (Plaice)			37		21			
Psettu maxima (Turbot)			1					
Rutilus rutilus (Roach)			11		10	10		
Spruttus sprattus (Sprat)	10		7		4			
Stizostedion lucioperca (Perch-pike)			7		6	6		

D. Others (whole sample)

	Number of samples:
Fish larvae	1
Fry	1
Plankton	24

7.1.3. Sampling Methods

Generally, fish samples were collected by the use of smaller nets, demersal fish by bottom trawls and by utilising commercial fish catches.

For benthic animals usually one of the following sampling methods was used. *Saduria entomon* was caught with bait-nets, e.g. baited with commercial herring, whereas *Mytilus edulis* was collected by divers. For the sampling of *Macoma baltica* Ekman-Birge grabs, and coarse sieves as well as specially designed trawls were used.

Aquatic plants, especially *Fucus vesiculosus* were sampled by diving or collected from the water surface near to the shore.

7.1.4. Radionuclides Studied

Totally, 35 different radionuclides were determined in the biota samples. Also, a number of beta-measurements on Cs-134 + Cs-137 were reported.

The total number of determinations of various nuclides was 3930, including those of Cs-134 + Cs-137. The number of values for radionuclides detected in the four most common organisms can be seen in Table 7.1.1. It may be noted that the number of nuclides detected in *Fucus vesiculosus* is higher than in others. This is mainly due to the fact that most *Fucus* samples were collected at coastal sites at the Archipelago Sea, the Åland Sea, the Gulf of Finland and the Bothnian Sea near to Swedish or Finnish nuclear power plants where discharge of nuclides from the plants is monitored by *Fucus*. Also, these sites received the highest Chernobyl fallout deposition within the Baltic region, thus resulting in an increase of nuclides originating from that accident.

For studying trends in concentrations of nuclides in biota the sub-areas of the Baltic Sea shown in Figure 1.1 (Chapter 1) were used.

Only for a few nuclides of regional occurrence there were enough data to make graphical presentation meaningful, namely Cs-137, Cs-134, Sr-90, Co-60, Ru-106 and Ag-110m. Cs-134 could generally not be detected in the samples before Chernobyl. After that accident its concentration showed an almost constant fraction of that of Cs-137 (after physical decay correction back to the time of the accident). For this reason, the behaviour of Cs-134 in the samples during the period 1984 to 1991 will not be discussed further.

The concentrations of various nuclides in the samples are shown in Figures 7.2.1 to 7.4.1. All of them have been detected in varying quantities in global fallout, normal discharges from the nuclear power and reprocessing plants as well as from the Chernobyl accident. It should be remembered that many sampling sites are situated in the close vicinity of nuclear power plants (marked on Figure 1.1, Chapter 1) from which small amounts of these nuclides are always discharged, also under normal conditions. If data of samples from not more than one or two stations within a Baltic Sea subarea were used, this is indicated in the head line of each single plot within Figures 7.2.1 to 7.3.3 by adding an abbreviated station code (in brackets) to the subarea name.

Table 7.1.1. Number of values for radionuclides detected in the four most common organisms within the MORS **biota** data 1984 to 1991.

Species	**part**	**Ac-228**	**Ag-108m**	**Ag-110m**	Ba-140	Be-7	Bi-214	Ce-141	Ce-144
Clupea harengus	fillets	0	7	12	0	0	0	0	0
Fucus vesiculosus	whole	5	1	28	1	13	3	3	5
Gadus morhua	fillets	0	8	10	0	1	0	0	0
Gadus morhua	liver	0	31	100	0	0	0	0	0

Species	part	co-57	Co-58	Co-60	cs-134	**Cs-134 +137**	cs-137	1-131	K-40
Clupea harengus	fillets	0	0	10	***96***	***0***	***108***	***0***	***98***
Fucus vesiculosus	whole	5	29	69	60	0	83	1	44
Gadus morhua	fillets	0	0	11	176	5	191	0	174
Gadus morhua	liver	0	0	26	101	0	101	0	101

Species	part	La-140	Mn-54	Nb-95	Pb-212	Pb-214	**Pu-238**	**Pu-239 , 240**	Ra-224
Clupea harengus	fillets	0	8	1	0	0	0	4	0
Fucus vesiculosus	whole	2	37	5	1	5	2	3	3
Gadus morhua	fillets	0	2	0	0	0	1	7	0
Gadus morhua	liver	0	0	0	0	0	0	1	0

Species	part	Ra-226	Ra-228	Ru-103	Ru-106	Sb- 124	Sb-125	Sr-89	Sr-90
Clupea harengus	fillets	0	0	0	2	0	0	0	26
Fucus vesiculosus	whole	9	1	6	10	2	10	2	22
Gadus morhua	fillets	2	0	0	1	0	0	1	94
Gadus morhua	liver	0	0	0	0	0	0	0	8

Species	part	Tc-99	**Te-**129m	Tl-228	Zn-65	Zr-95
Clupea harengus	**fillets**	0	0	0	0	1
Fucus vesiculosus	whole	21	2	1	23	3
Gadus morhua	fillets	0	0	0	1	0
Gadus morhua	liver	0	0	0	0	0

At many sampling locations, especially those representing subareas where the main fallout from Chernobyl occurred, only one sample was reported every year. This might lead to doubts concerning the significance of the obtained radioactivity values for a single sample. Certainly in many cases it would be very desirable to have access to a greater number of analyses. However, it should also be kept in mind that most of the measurements, especially from the subareas just mentioned, were made on pooled samples from a number of specimen, the minimum number being generally 10 for Baltic herring, 3 to 5 for pike and cod and around 100 for most invertebrates. In the case of bladder wrack (***Fucus vesiculosus***) a sample is usually made from several plants. Furthermore, it should be kept in mind that in many cases the values reported to the database are representative for the whole discharge areas of nuclear power plants, where several samples are taken annually, but not reported to the database.

7.2. Fish

In the following some comments will be made on the occurrence and time-trends for Cs-137 and for some other nuclides.

7.2.1. Cs-137 in Fish

The level of Cs-137 in fish samples at specific sites is largely explained by the varying amounts of initial fallout from Chernobyl in different regions of the Baltic Sea area (Figure 5.2.2, Chapter 5). Thus, the pattern varies considerably if one compares subareas with a high fallout level with those with a lower level. Also, the slow counter clockwise circulation of surface water in the Gulf of Bothnia, as well as in the Baltic Proper and the net southward water transport along the Swedish coast, have a great importance for the time-trends shown by samples from some subareas.

Subareas with a relatively high level of fallout from Chernobyl are the Bothnian Sea, the Gulf of Finland and the Northern Baltic, the Åland and the Archipelago Seas. These subareas are all characterised by maximum Cs-137 levels for most species in 1986 or 1987, followed by a monotonous decrease during the following years. This pattern is recognised e.g. for Baltic herring from the Northern Baltic Proper (Figure 7.2.2g) and cod from the Bothnian Sea (Figure 7.2.1a) as well as in herring from the Bothnian Sea (Figure 7.2.2c) and the Gulf of Finland (Figure 7.2.2f).

The trends for Cs-137 activities in pike from the Archipelago Sea, the Bothnian Sea, and the Gulf of Finland seem to develop differently compared to cod and Baltic herring, showing a more slow increase after Chernobyl and reaching a maximum only in 1988 to 1990 (Figures 7.2.4a, 7.2.4b and 7.2.4d). This observation shows up clearly when comparing pike from the Vaasa region (Bothnian Sea, Figure 7.2.4b) with herring from the same area (Figure 7.2.2c). The trend is interpreted as due to the position of pike as a top predator, thus reaching a maximum for Cs-137 later by consuming fish having reached its maximum of radiocaesium earlier.

Herring from the Bothnian Bay (Figure 7.2.2b) shows a slower increase in caesium levels reaching a maximum around the years 1989-1990. This seems to be the result of riverine inflow of caesium from drainage areas as well as of a slow transport of caesium in more contaminated waters from the south.

In the subareas Gotland East and Southern Baltic Proper the Chernobyl deposition was lower than within the Archipelago Sea and adjacent subareas. A distinct maximum is not observed as a function of time (Figures 7.2. lb, 7.2.2h and 7.2. lc).

Figure 7.2.1. Activities of Cs-137 in cod from different Baltic Sea areas.

Fig. 7.2.1.a: Cs-137 in **GADUS** MORHUA (fillets)
Bothnlan Sea (SWF 22)

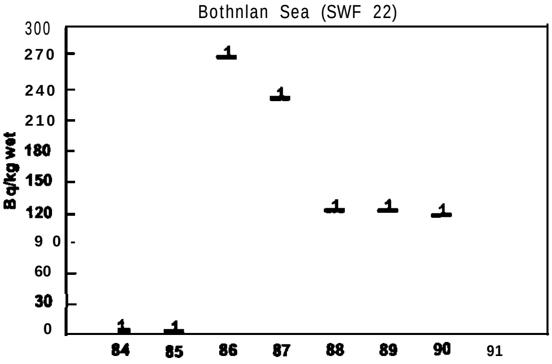


Fig. 7.2.1.b: **Cs-137** in **GADUS** MORHUA (fillets)
Gotland East

Fig. **7.2.1.c:** Cs-137 in **GADUS** MORHUA (fillets)
Southern Baltic Proper

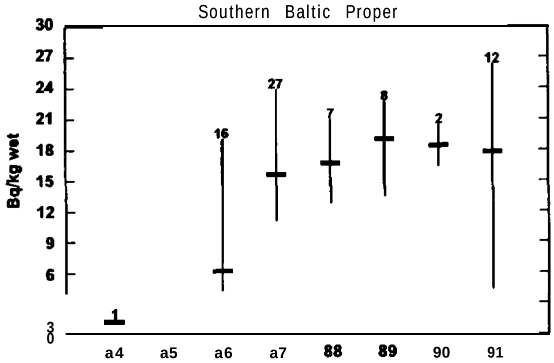
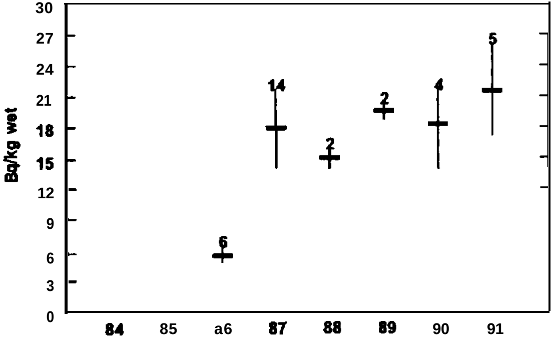


Fig. 7.2.1.d: Cs-137 in **GADUS** MORHUA (fillets)
Bomholm Sea



Fia. 7.2.1.e: Cs-137 in **GADUS** MORHUA **(fillets)**
Arkona Sea

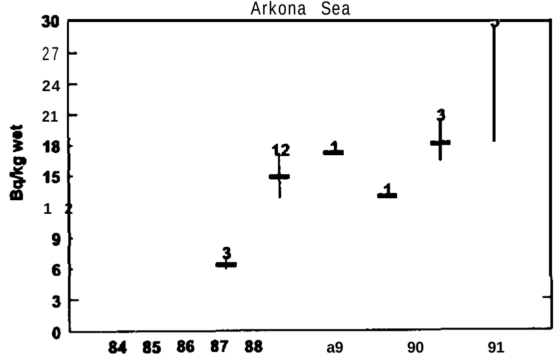


Fig. 7.2.1.f: Cs-137 in **GADUS MORHUA (fillets)**
Belt Sea

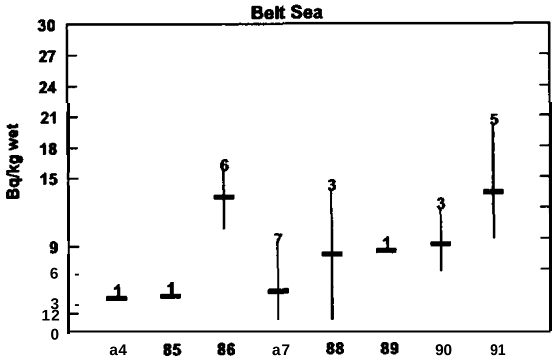
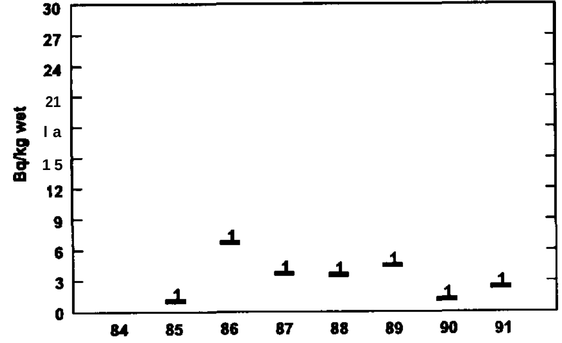


Fig. 7.2.1.g: **Cs-137** In **GADUS** MORHUA (fillets)
Kattegat



Data shown for each year:

arithmetic mean with min-max range and the number of measurements above the min-max range

Figure 7.2.2. Activities of Cs-137 in Baltic herring from different Baltic Sea areas. (continued on next page)

Fig. 7.2.2.a: **Cs-137** in CLUPEA HARENGUS (fillets)
Bothnian Bay (SW **1)**

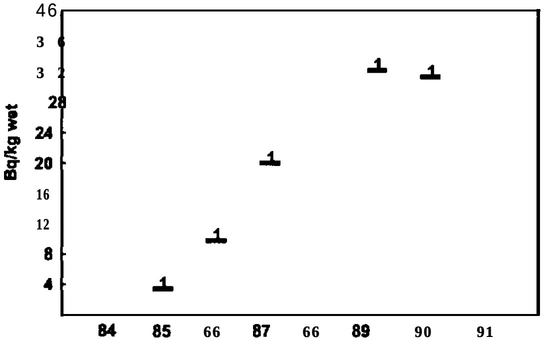


Fig. 7.2.2.b: **Cs-137** in CLUPEA HARENGUS (edible parts)
Bothnlan Bay (HAILUOTO)

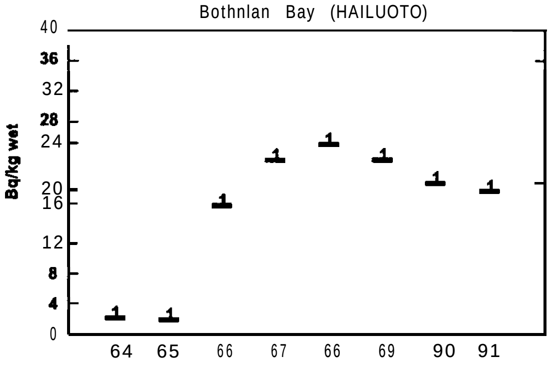


Fig. **7.2.2.c:** Cs-137 in CLUPEA HARENGUS (edible parts)
Bothnian Sea **(VAASA)**

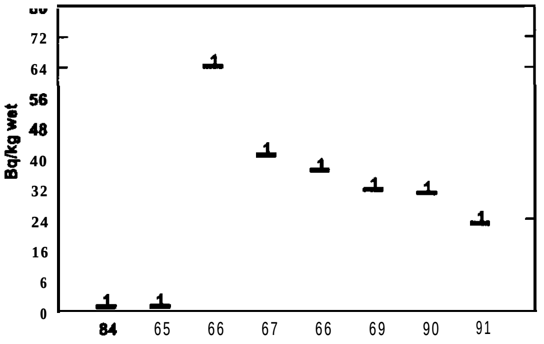


Fig. 7.2.2.d: Cs-137 **in** CLUPEA HARENGUS (fillets)
Bothnian Sea **(SW2)**

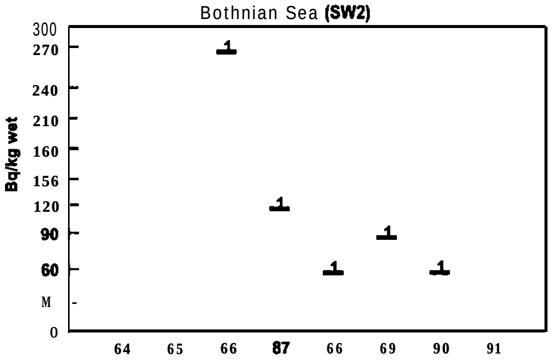


Fig. 7.2.2.e: **Cs-137** in CLUPEA HARENGUS (edible part)
Archipelago Sea **(SEILI)**

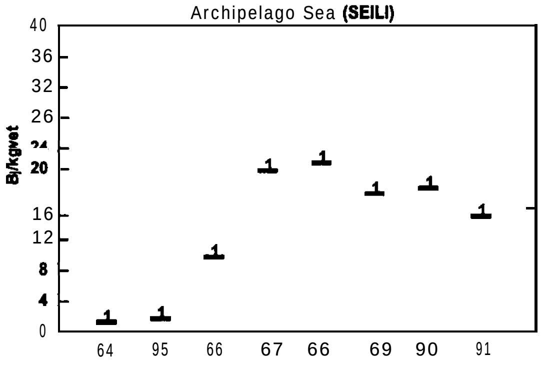


Fig. 7.2.2.f: Cs-137 in CLUPEA HARENGUS (edible parts)
Golf of Finland (LOVIISA + TVAERMINNE)

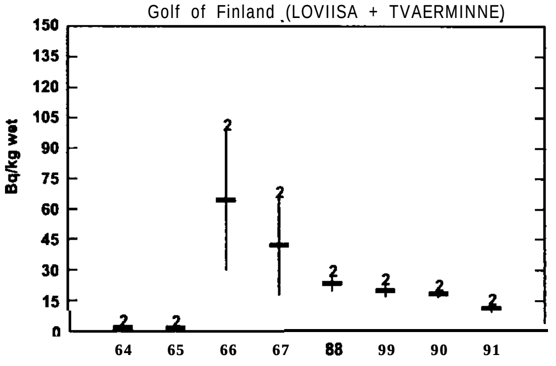


Fig. 7.2.2.g: Cs-137 in CLUPEA HARENGUS **(fillet)**
Northern **Baltic** Proper (SW 3)

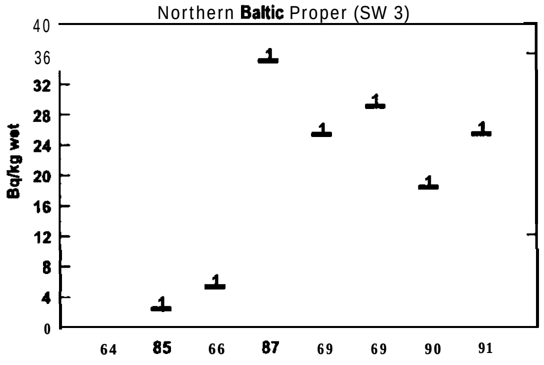


Fig. 7.2.2.h: Cs-137 in CLUPEA HARENGUS (fillet)
Southern Baltic Proper

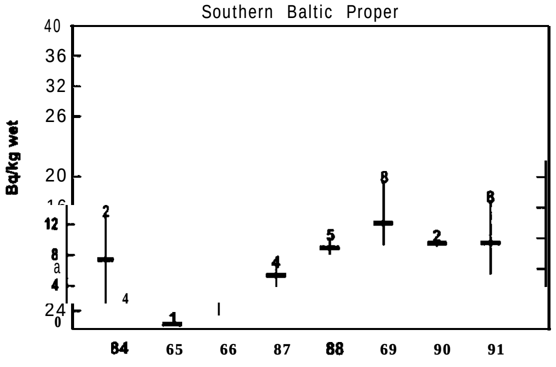


Figure 7.2.2. Activities of Cs-137 in Baltic herring from different Baltic Sea areas. (continued)

Fig. 7.2.2.i: Cs-137 in CLUPEA HARENGUS (fillets)
Bornholm Sea

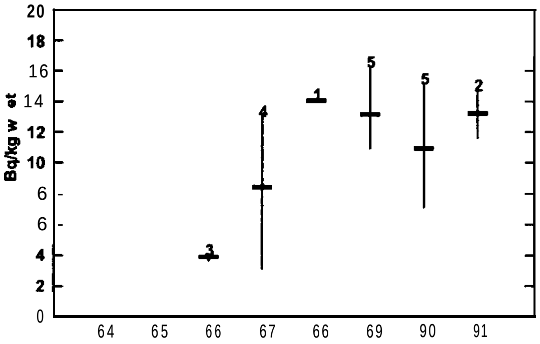


Fig. 7.2.2.j: **Cs-137 in CLUPEA HARENGUS (fillets)**
Arkona Sea

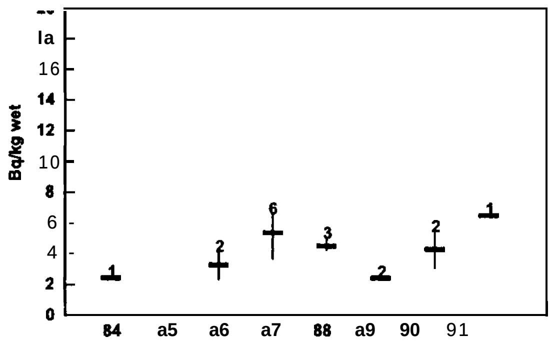


Fig. **7.2.2.k: Cs-137 in CLUPEA HARENGUS (fillets)**
Belt Sea

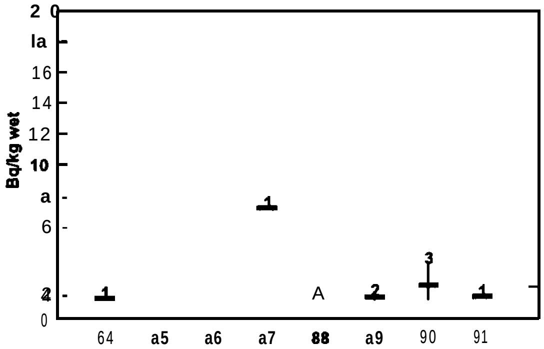


Fig. 7.2.2.1: Cs-137 in CLUPEA HARENGUS (fillets)
Kattegat

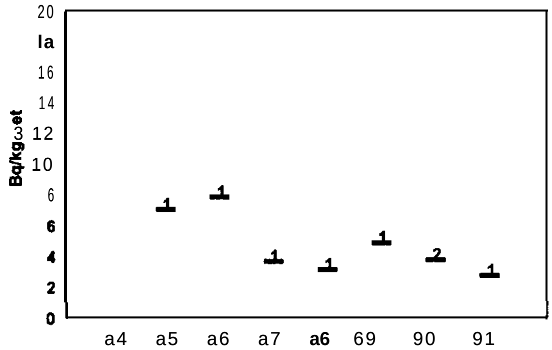
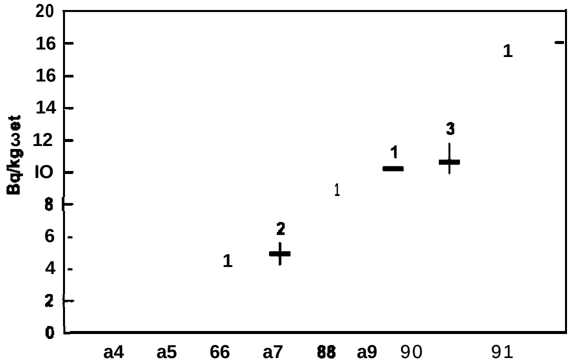


Figure 7.2.3. Activity of Cs-137 in flounder from the Arkona Sea.

Fig. 7.2.3.: Cs-137 In PLATICHTHYS FLESUS (fillets)
Arkona Sea



The most southern subareas (the Bornholm Sea and west of it) are influenced by the counter clockwise movements of surface water in the Baltic Sea area and the outflow to the North Sea via the Danish straits. This results in a southward directed stream along the Swedish east coast transporting Cs-137 from the areas of initial maximum of Chernobyl disposal to the southern subareas. For this reason the Cs-137 level in fish samples from these subareas generally shows an increasing trend in the period after 1986, the values for that year still being rather low. This is illustrated by Figures 7.2.2j, 7.2. le, 7.2.3 and 7.2. 1f.

Figure 7.2.4. Activities of Cs-137 in pike from different Baltic Sea areas.

Fig. 7.2.4.a: Cs-137 in ESOX LUCIUS (fillets)
Archipelago Sea **(SEILI)**

Fig. 7.2.4.b: Cs-137 In ESOX LUCIUS (fillets)
Bothnlan Sea (VAASA)

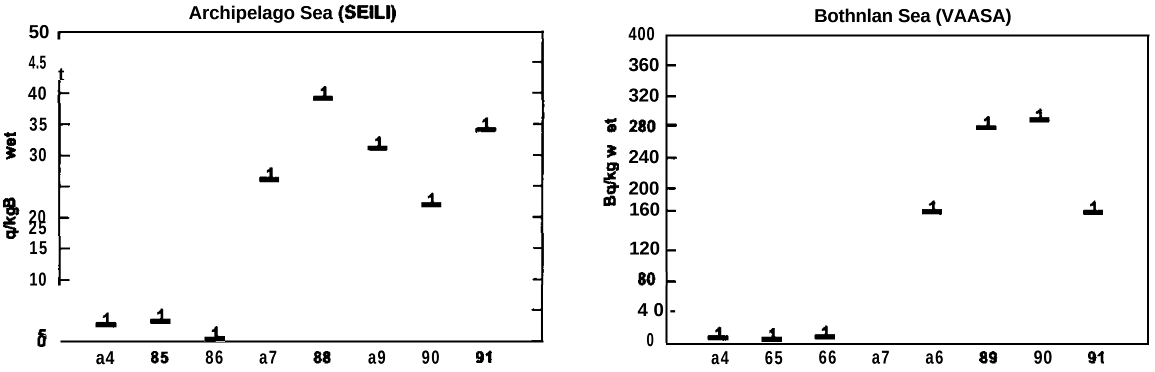
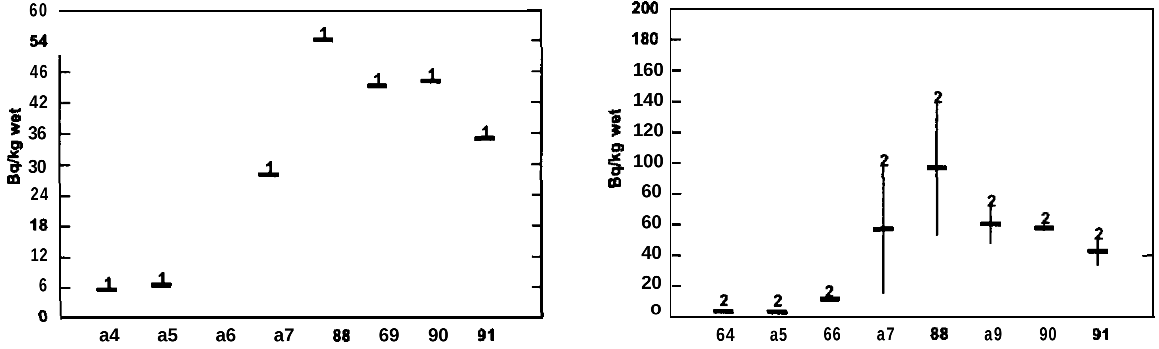


Fig. **7.2.4.c**: Cs-137 in ESOX LUCIUS (fillets)
Bothnlan Bay (HAILUOTO)

Fig. 7.2.4.d: Cs-137 in ESOX LUCIUS **(fillets)**
Gulf of Finland (LOVIISA + TVAERMINNE)



In the Kattegat the levels of Cs-137 are, on the average, much lower than in the subareas discussed earlier. In this region a relatively low direct fallout from Chernobyl resulted in an increase during 1986 followed by a decrease thereafter (Figures 7.2.2.1 and 7.2. lg).

7.2.2. **Other Radionuclides in Fish**

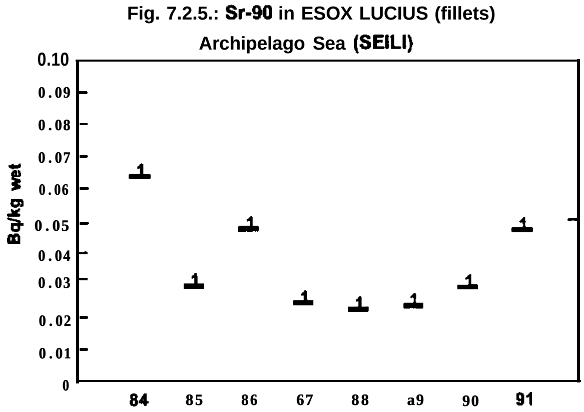
Activity concentrations of Sr-90 in fish do not show any pronounced temporal trends. Indications of a Chernobyl influence, at least in 1986, are in most cases not apparent or only very weak. Figure 7.2.5 gives one representative example of a temporal development with a small enhancement in 1986. Annual averages for three species from different subareas have been used to estimate overall Sr-90 mean values for the period 1984 to 1991. These values as well as minima and maxima are given in Table 7.2.1.

The Sr-90 activities in cod fillets appeared to be lower than in edible parts of Baltic herring, as well as in fillets of pike, by an order of magnitude. For herring, this results from the fact that Sr-90 is enriched mainly in bones and skin. The pike lives in waters with low salinity, for which the concentration factor for Sr-90 in flesh is assumed to be higher than in marine fish.

Table 7.2.1. Sr-90 activities (Bq kg^{-1} wet weight) in fish representing the period 1984 to 1991 in different Baltic Sea subareas

Subarea	fish species	tissue	mean	minimum	maximum
			Bq kg-’	Bq kg-’	Bq kg-’
Belt Sea	Cod	fillets	0.004	0.002	0.005
Bomholm Sea	Cod	fillets	0.005	0.004	0.005
Bothnian Bay	Herring	edible part	0.110	0.084	0.160
Bothnian Sea	Herring	edible part	0.078	0.057	0.120
Archipelago Sea	Herring	edible part	0.073	0.046	0.150
Gulf of Finland	Herring	edible part	0.090	0.038	0.230
Bothnian Bay	Pike	fillets	0.063	0.036	0.250
Bothnian Sea	Pike	fillets	0.051	0.034	0.083
Archipelago Sea	Pike	fillets	0.035	0.022	0.064
Gulf of Finland	Pike	fillets	0.036	0.017	0.059

Figure 7.2.5. Activity of Sr-90 in pike (Archipelago Sea).

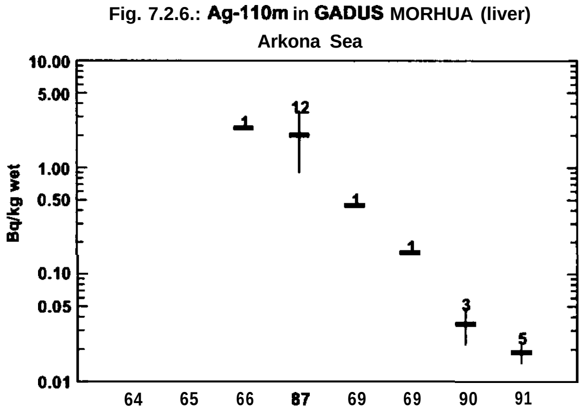


Most of the activity concentrations for plutonium isotopes in fish fillets (mainly cod and herring) were below the detection limit. Although this limit could be lowered substantially 1990 due to methodological improvements, nearly all values of Pu-239,240 obtained since 1990 were also below it. Therefore, it is concluded that the activity content of Pu-239,240 in fish flesh is at least lower than 50 μBq kg^{-1} wet weight.

Five Pu analyses of sprat samples (whole fish) from the Belt Sea, the Arkona Sea and the Bornholm Sea, which were collected in 1990 and 1991 yielded Pu-239,240 values between 0.031 and 0.72 mBq kg-’ wet weight with a mean of 0.34 mBq kg-’ wet weight. These values are at least ten-fold higher than those in cod fillets which can be explained by a higher Pu enrichment in bone and skin compared to that in fillets. The Pu-238 values were below the detection limit. Two activity ratios of **Pu-238/Pu-239,240** were less than 0.050. This indicates global fallout to be the main source for **Pu** in sprat.

After the Chernobyl accident gamma measurements of cod liver samples revealed activity contents of **Ag-110m** which were unexpectedly high. By long-term measurements the **long-lived** silver isotope Ag-108m (half-live 433 years) could also be detected. Over the years 1987 - 1991 an approximately constant and very low **Ag-108m** activity of about 0.006 Bq kg^{-1} wet weight was estimated. In each of four investigated subareas of the south-western part of the Baltic Sea a regular decrease of the **Ag-110m** activity was characterised by an effective **half-live** of about 0.60 years (15% lower than the physical half-live). This value is common to the four areas. Figure 7.2.6 shows the results for one of these areas. Obviously, **Ag-110m** originated from Chernobyl. The source of **Ag-108m** is, however, not clearly identified at present (HELCOM, 1989). Meanwhile, both isotopes have been detected also in North Sea cod liver but with different isotope activity ratios (Kanisch and Nagel, 1991).

Figure 7.2.6. Activity of **Ag-110m** in cod liver (Arkona Sea).



7.3. Invertebrates

Many invertebrates for which time-series were available are included in the regular monitoring programs at the nuclear power plants. At those sites we frequently find elevated levels of nuclides which generally are major constituents in the discharge from the plants. These are mainly activation products like Co-60, Zn-65, Mn-54, **Ag-110m** and others. Various fission products in small quantities are generally also found.

Samples of invertebrates were regularly collected in the environment of the nuclear power plants at **Barsebäck**, Forsmark, Greifswald, Loviisa, Olkiluoto, Oskarshamn and Ringhals. The position of these power plants is seen in Figure 1.1.

7.3.1. Cs-137 in Invertebrates

Samples of the mussel ***Macoma baltica*** (whole animal) collected every year at Forsmark and Olkiluoto (Figures **7.3.2a** and **7.3.2b**) showed a radiocaesium content which changed with time analogous to the results from fish. It should be noted that the data on invertebrates are reported on a dry weight basis, whereas fish data are given on a wet weight basis.

A similar analogy to fish is found for Cs-137 in the common mussel ***Mytilus edulis*** at Forsmark in the Bothnian Sea (Figure 7.3. la) and for the soft bottom isopode *Saduria entomon* at Loviisa in the Gulf of Finland (Figure 7.3.3a).

7.3.2. Other Radionuclides in Invertebrates

For Sr-90 there was not found any temporal trend in the samples. Certainly this nuclide originates mainly from global fallout. Figures 7.3.2c and 7.3.3b illustrate this for ***Macoma baltica*** from the Bothnian Sea and for *Saduria entomon* from the Gulf of Finland, respectively.

At the nuclear power plant near Loviisa samples of *Saduria entomon* were regularly collected. It has been shown that this species is an efficient accumulator of Ag-1 10m. A maximum was found in the year after Chernobyl (Figure 7.3.3d). During a cruise with R/V Gauss (FRG) in October/November 1986 Agnedal (1988) collected, inter alia, *Saduria entomon* samples showing significant activity values of Ag-110m. A value of 61 Bq kg^{-1} dry weight for a sample from the Gulf of Finland agrees very well with that shown in Figure 7.3.3d. In agreement with the distribution pattern of the Chernobyl fallout Agnedal found the highest value of 620 Bq kg-’ dry weight in a sample from the south western part of the Bothnian Sea.

At sites close to four of the nuclear power plants mussels rather regularly showed small activities of Co-60. Results for ***Mytilus edulis*** from the Forsmark area are shown in Figure 7.3.1d and those for the Kattegat in Figure 7.3.1e. In the case of ***Macoma baltica*** and for *Saduria entomon* analogous results are seen in Figures 7.3.2d, 7.3.2e, 7.3.2f and 7.3.3c. Most probably the Co-60 in these samples was of local origin.

The results of a few plutonium analyses of different invertebrate samples are shown in Table 7.3.1. Apart from 4 samples the whole organisms were analysed. Table 7.3.1 includes ratios of wet weight per dry weight to allow conversion of the activities to the wet weight base. Pu-238 could not be detected in these samples.

Figure 7.3.1. Activities of some radionuclides in blue mussels from different Baltic Sea areas.

F5.7.3.1.a: Co-137 in MYTILUS EDULIS (whole body)
Bothnian Sea **(SWF11** 1)

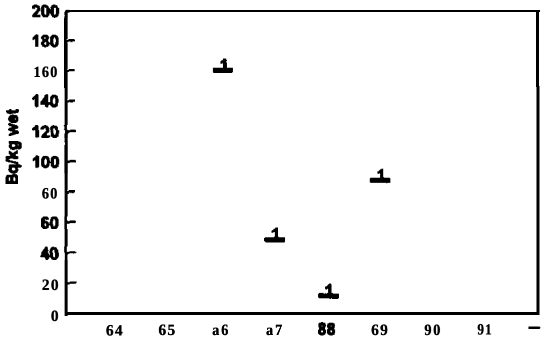


Fig. 7.3.1.b: Cs-137 in MYTILUS EDULIS (soft parts)
Bomholm Sea

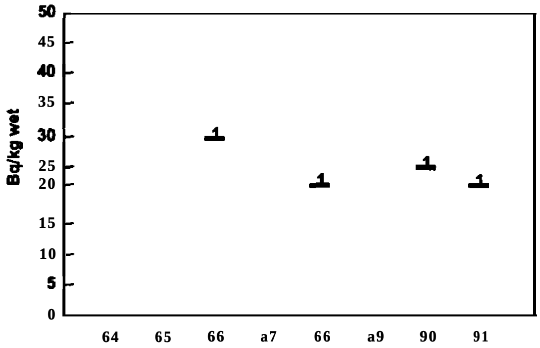


Fig. **7.3.1.c:** Cs-137 in **MYTILUS** EDULIS (soft parts)
Kattegat

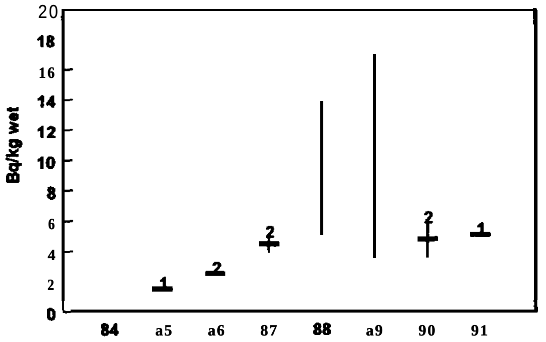


Fig. 7.3.1.d: Co-60 in MYTILUS EDULIS (whole body)
Forsmark Area **(SWF1** 11)

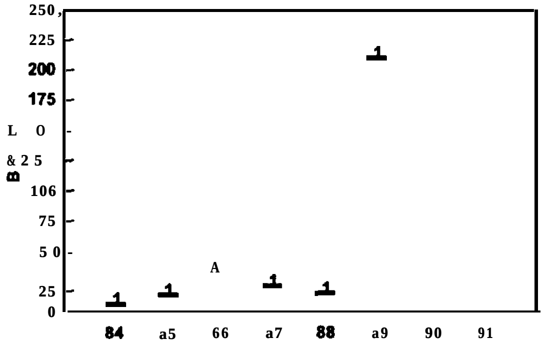
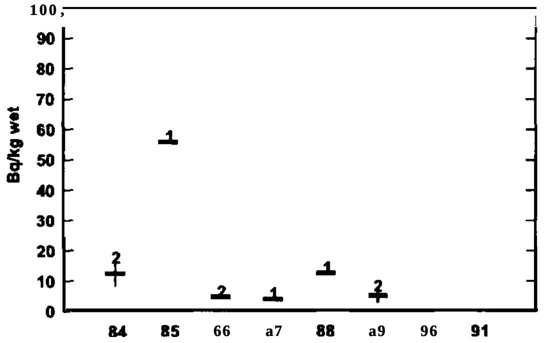


Fig. 7.3.1.e: Co-60 in MYTILUS **EDULIS** (soft parts)
Kattegat



Fii 7.3.2. Activities of some radionuclides in ***Macoma baltica*** from different Baltic Sea areas.

Fig. 7.3.2.a: Cs-137 in **MACOMA BALTICA** (whole body) Bothnian Sea **(FORSMARK)**

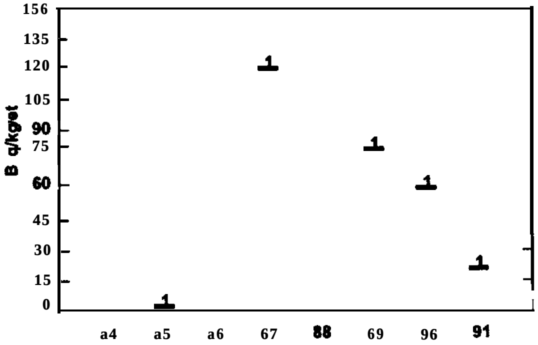


Fig. 7.3.2.b: Cs-137 in **MACOMA BALTICA** (whole body) Bothnian Sea **(OLKILUOTO)**

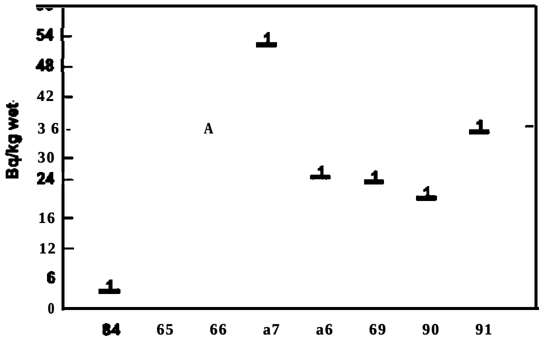


Fig. **7.3.2.c:** Sr-90 in **MACOMA BALTICA** (whole body) Bothnian **Sea** (OLKILUOTO)

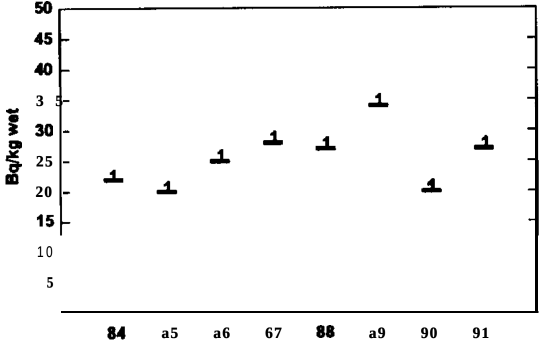


Fig. 7.3.2.d: **Co-60** in **MACOMA BALTICA** (whole body) Bothnian **Sea** (OLKILUOTO)

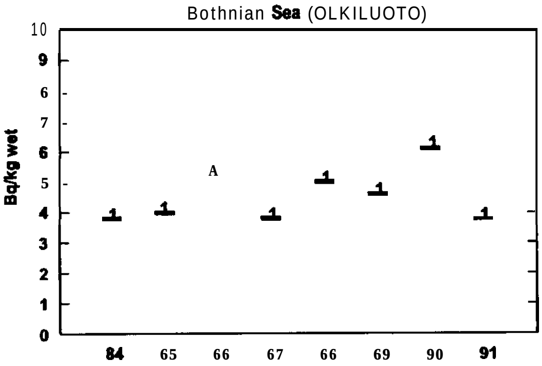


Fig. 7.3.2.e: Co-60 in **MACOMA BALTICA** (whole body) Bothnlan Sea (FORSMARK)

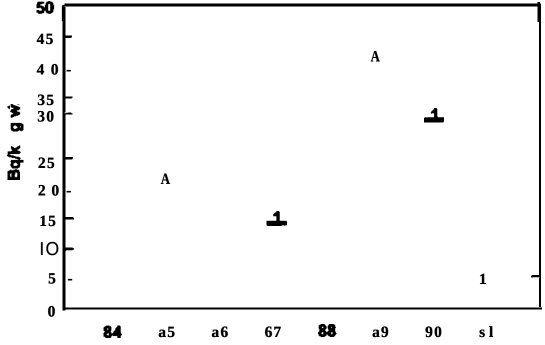
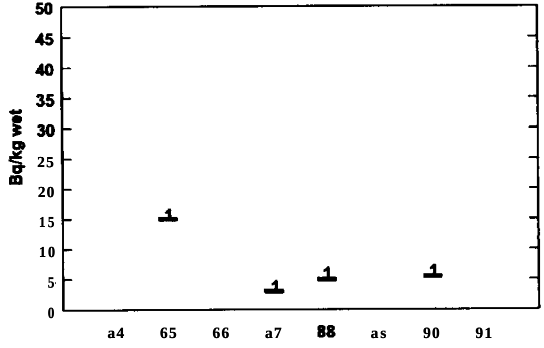


Fig. 7.3.2.f: Co-60 in **MACOMA BALTICA** (whole body) **Gotland** West (OKG)



These data can be compared with results obtained by investigations within the Polish Economic Zone after the Chernobyl accident (Skwarzec and Bojanowski, 1992). Their **Pu**-239,240 mean of 51 **mBq kg**$^{-1}$ dry weight for ***Saduria entomon*** confirms very well our mean of 55 **mBq** kg-‘. The Pu-239,240 activities in soft parts of ***Mytilus edulis,*** given in Table **7.3.1**, are within the lower part of the range given by Skwarzec and Bojanowski. However, their mean of about 92 **mBq kg**$^{-1}$ dry weight was nearly four times higher than that of the two samples of soft parts in Table 7.3.1. The only result for ***Macoma baltica***, measured here as whole animals, is lower than their **mean** of 49 **mBq kg**$^{-1}$ dry weight (range **31**- 86 **mBq** kg-‘).

Figure 7.3.3. Activities of some radionuclides in ***Saduria*** *entomon* from the Loviisa area (Gulf of Finland).

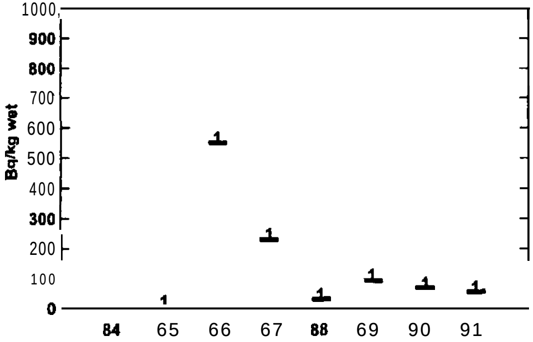


Fig. 7.3.3.a: Cs-137 **In** SADURIA ENTOMON (whole body)
Gulf of Finland (LOVIISA)

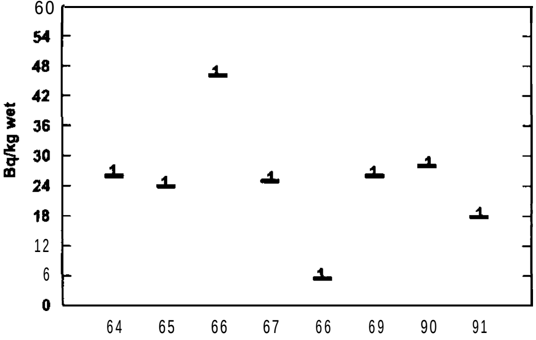


Fig. 7.3.3.b: Sr-90 In SADURIA ENTOMON (whole body)
Gulf of Finland (LOVIISA)

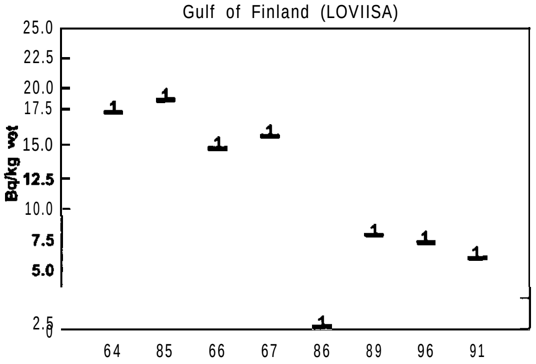


Fig. **7.3.3.c:** Co-60 In SADURIA ENTOMON (whole body)
Gulf of Finland (LOVIISA)

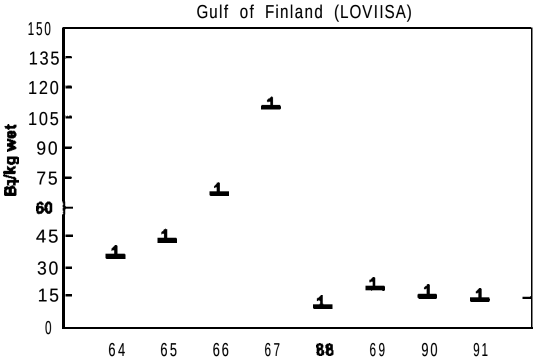


Fig. 7.3.3.d: **Ag-110m** in SADURIA ENTOMON (whole body)
Gulf of Finland (LOVIISA)

Some of the activity ratios of Pu-238/Pu-239,240 from Table 7.3.1 are lower than 0.06 or even 0.04. Neglecting the other “less than values” being significantly higher, we conclude that the Pu activity ratios seem to be consistent with values of about 0.04 being representative for the global fallout (Pentreath, 1988). Skwarzec and Bojanowski (1992) found for their samples from 1986 to 1988 slightly higher activity ratios (between 0.08 and 0.125) which they attributed to an influence by the Chernobyl deposition.

Table 7.3.1. Results for plutonium isotopes (mBq kg^{-1} dry weight, single measurements) in invertebrates from various subareas

Subarea	year	tissue	WD [a]	F’u-239,240 mBq kg” dw	Pu-238/ Pu-239,240
Saduria entomon:					
Southern Baltic Proper	1989	whole	2.9	110	< 0.072
	1989	whole	4.0	25	< 0.10
	1989	whole	4.3	39	< 0.059
	1989	whole	2.9	30	< 0.19
	1990	whole	5.9	41	< 0.078
Gulf of Finland	1989	whole	4.8	84	—
Mytilus edulis:					
Arkona Sea	1989	soft part	7.7	31	< 0.035
Belt Sea	1991	soft part	10.	19	< 0.12
	1991	whole	3.2	30	< 0.11
Macoma baltica:					
Bothnian Sea	1989	whole	2.9	14	---
Arctica islandica:					
Belt Sea	1988	soft part	11.	76	< 0.16
Arkona Sea	1991	soft part	11.	36	< 0.028
Asterias rubens:					
Belt Sea	1989	whole	4.5	22	< 0.18
	1990	whole	3.8	28	< 0.054

[a] ratio wet per dry weight

7.4. Algae

The only species regularly sampled in the area was bladder wrack, ***Fucus vesiculosus***. A relatively large number of samples was collected especially in the close environs of the Swedish and Finnish power plants. A list of the nuclides most frequently detected in ***Fucus*** is found in Table 7.1.1.

The concentration of these nuclides varies depending on the distance and direction of the sampling place in relation to the point of discharge. Some models have rather successfully described this relation, which gives a possibility to use ***Fucus*** as a semi-quantitative indicator for the discharge (Dahlgaard and Boelskifte, **1992).**

The amounts of some radionuclides in the samples were also strongly related to the deposition of the Chernobyl fallout at the different sampling sites, generally being highest at Forsmark and Olkiluoto at the Bothnian Sea. This is well illustrated in Figures 7.4. la, 7.4. lb and 7.4. lc showing Cs-137, Ag-110m and Ru-106 at the different sites.

The results of few plutonium analyses of aquatic plants are shown in Table 7.4.1. Two significant activity ratios Pu-238/Pu-239,240 of *Fucus* are, considering their measurement uncertainties, consistent with global fallout, whereas one ratio of *Laminaria saccharina (0.19)* could indicate an influence of North Sea derived plutonium.

Table 7.4.1. Results for plutonium isotopes (mBq kg^{-1} dry weight, single measurements) in aquatic plants from the Belt Sea

Subarea	year	tissue	WD [a]	Pu-239,240 mBq kg-’ dw	Pu-238/ Pu-239,240
Fucus vesiculosus:					
Belt Sea	1988	whole	5.3	190	0.050
	1989	whole	7.7	300	0.057
	1990	whole	6.3	31	< 0.15
Laminaria saccharina:					
Belt Sea	1987	whole	10.	63	0.19
	1988	whole	7.1	31	< 0.077

[a] ratio wet per dry weight

Figure 7.4.1. Some radionuclides in *Fucus vesiculosus.*

Fig. 7.4.1 .a: Cs-137 in Fucus vesiculosus

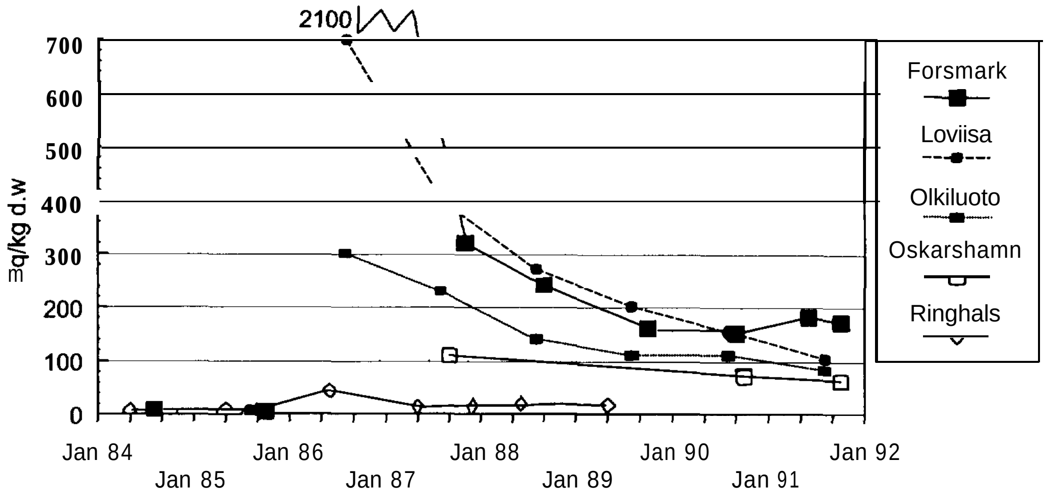


Fig. 7.4.1.b: Ag-110m in Fucus vesiculosus

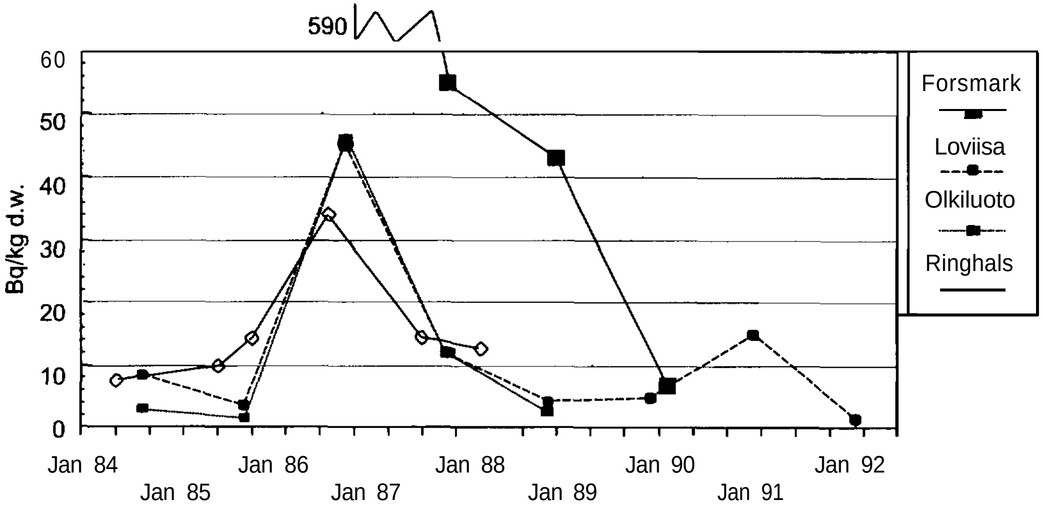
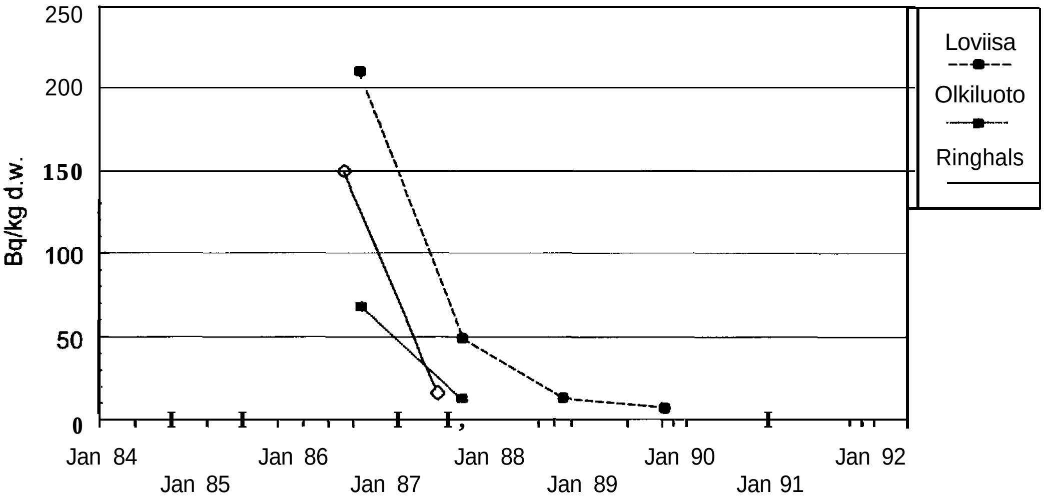


Fig. 7.4.1.c: Ru-106 in Fucus vesiculosus



7.5. Concentration Factors

The discussion of concentration factors for the radionuclides Cs-137 and Sr-90 is confined to the main marine fish, Baltic herring, cod, plaice and flounder, and the fresh water fish pike.

For the different areas of the Baltic Sea average annual concentrations of the two radionuclides in unfiltered seawater from the years 1988 to 1991 were calculated. In general, the averaging was performed using available concentrations from the whole water column. For practically all fish samples considered for the calculation of concentration factors the sampling depths were less than 80 m. Only for very few cod samples sampling depths of more than 80 m were reported. Therefore, the maximum water depth for averaging the radionuclide concentrations in water was restricted to not more than 80 m. Due to incomplete mixing after the Chernobyl deposition, especially the Cs-137 concentrations were lower in deep water than in the surface layer. This implies that an averaging over the whole water column in the three subareas 4, 6 and 9 (Southern Baltic Proper, Bornholm Sea and Gotland East, respectively) would not have been correct.

Usually, the concentration factors of biota are based on filtered seawater concentrations. For Cs-137 and Sr-90 the small error introduced by the use of unfiltered seawater is negligible for the Baltic Sea conditions. The concentration factors were obtained by division of annual means of the radionuclides in fish (Bq kg-’ wet weight) by the annual average concentrations of the same radionuclides in water (Bq 1”). The results obtained are presented in the Tables 7.5.1 to 7.5.6. Besides statistical parameters for the concentration factors, the corresponding water concentrations of each box are characterised by mean values which were averaged over the years 1988 to 1991 (4 years in total) as far as measured values were available. The standard deviation of this mean serves as a measure of the variation of the annual averages of the seawater concentrations within the 4 years. It should be emphasised, however, that the concentration factors were calculated from the individual annual averages of the seawater concentrations. Graphical presentations of the concentration factors are given in Figure 7.5.1 for different Baltic Sea areas, which have been ordered by going from west to east and then to north, thereby following the decreasing salinity in the Baltic Sea.

Undoubtedly, the increase of the concentration factors observed by going from west to east and then to north (see Figure 75.1) can be due to several factors, but first of all the well-documented increase when salinity decreases.

A mean Cs-137 concentration factor of 181 was obtained for cod in the areas 2, 6, 4 and 9 (southern part of the Baltic Sea) with a very low standard deviation of 3 between these areas (Table 7.5.1, Figure 7.5. la). In the same areas the averaged Cs-137 concentration factor for fillets of Baltic herring (Table 7.5.2, Figure 7.5.1c) was about half of that of cod with a larger standard deviation. However, in the northern part of the Baltic Sea (Gulf of Bothnia and Gulf of Finland, areas 7, 8 and 11) the averaged concentration factor was 169 ± 19 (±1σSD) in edible parts of Baltic herring (Table 7.5.3). In the southern part of the Baltic Sea (areas 2, 6 and 4) the averaged Cs-137 concentration factors were 122 ± 14 and 137 ± 18 for plaice and flounder, respectively (Tables 7.5.4 and 7.5.5, Figures 7.5. le and 7.5. 1f).

Figure 7.5.1. Concentration factors of Cs-137 and Sr-90 in fish from different Baltic Sea areas (see Figure 7.1.1 for the method of data presentation; number of years indicated above min-max range).

Fig. 7.5.1.a: **Cs-137** concentration factors of cod (fillets)

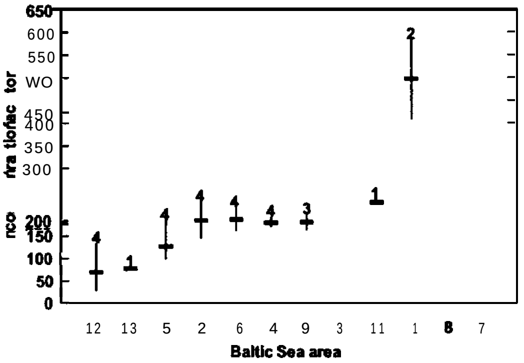


Fig. **7.5.1.b: Sr-90** concentration factors of cod (fillets)

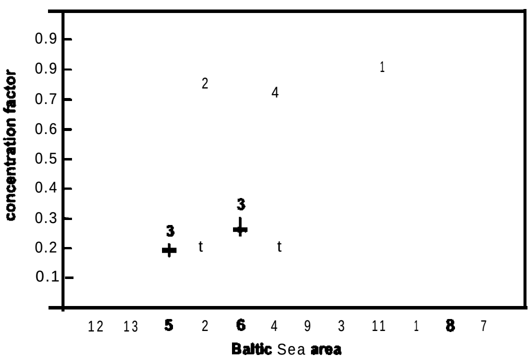


Fig. **7.5.1.c: Cs-137 concentration** factors of herring **(fillets)**

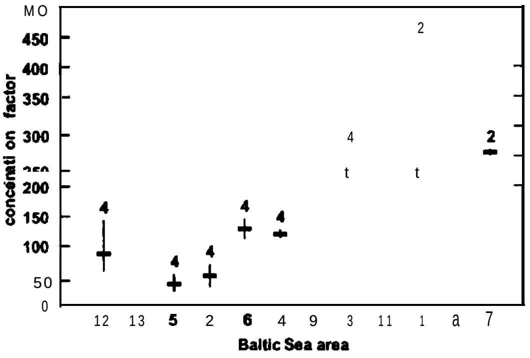


Fig. 7.5.1 **.d: Sr-90** concentration factors of herring (fillets)

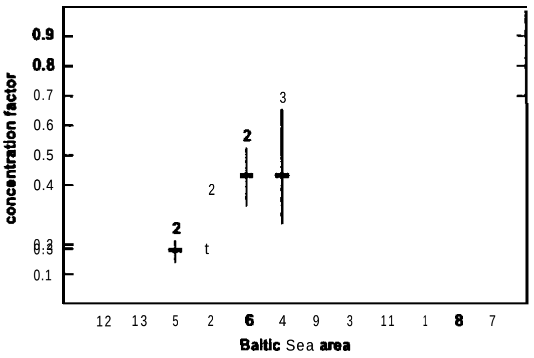


Fig. 7.5.1.e: **Cs-137** concentration factors of plaice (fillets)

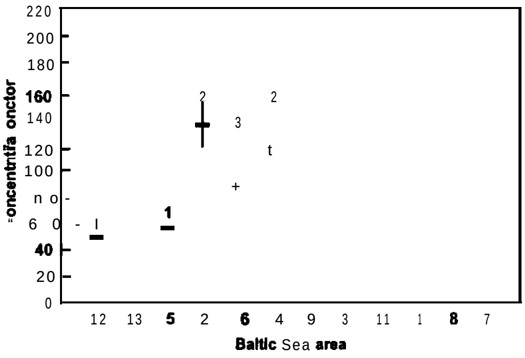


Fig. **7.5.1.f:** Cs-137 concentration factors of flounder (fillets)

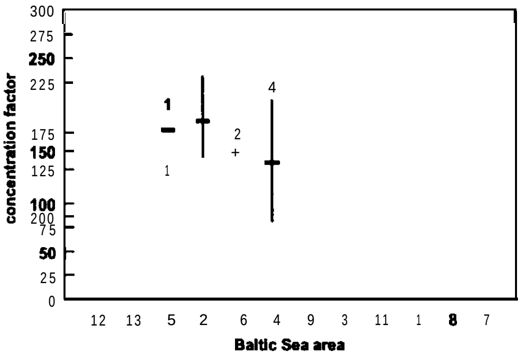


Fig. 7.5.1.g: **Cs-137** concentration factors of pike (fillets)

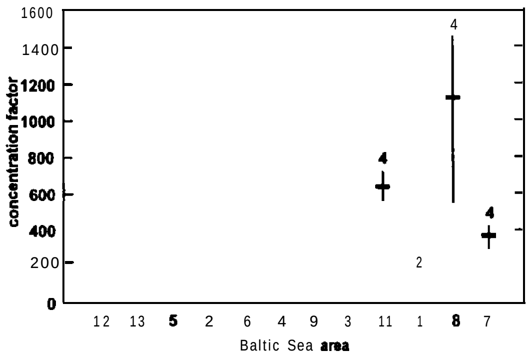
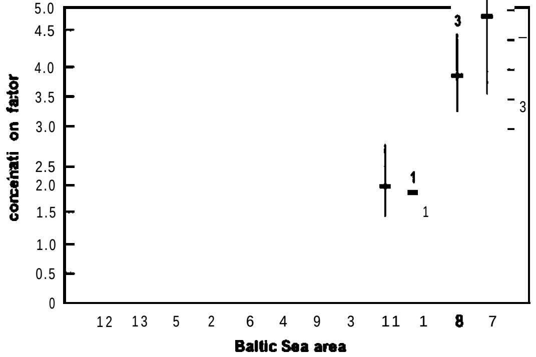


Fig. 7.5.1.h: **Sr-90** concentration factors of **pik**



Sr-90 concentration factors of cod fillets and herring fillets in the western and southern parts of the Baltic Sea were around 0.4 (Tables 75.1 and 7.5.2, Figures 7.5. lb and 7.5. 1d). The corresponding concentration factors measured in edible parts of Baltic herring from the northern parts are an order of magnitude higher, around 4 (Table 7.5.3).

High Cs-137 concentration factors were observed in fillets of pike (Table 7.5.6), which lives in waters with low salinity. In the Bothnian Sea values around 1100 were found. This is supported by results of Swedish investigations in the Biotest Basin (southern Swedish coast of the Bothnian Sea, near to the Forsmark power plant) after the Chernobyl accident. For adult pike steady state concentrations of Cs-137 resulted in a Cs-137 concentration factor of about 1000 (Evans, 1991). In fresh water systems this concentration factor was much higher. In Sweden Sundblad et al. (1991) investigated e.g. the Lake Hillesjön, which was heavily contaminated by Chernobyl fallout with about 100 kBq m^{-2} Cs-137. Their results for pike suggest a Cs-137 concentration factor of about 4000.

The Sr-90 concentration factors in pike fillets were around 2 (Table 7.5.6).

The concentration factors for Cs-137 and Sr-90 determined in the Baltic Sea before the Chernobyl accident agree quite well with those presented here. Cs-137 concentration factors for cod fillet estimated by Grimås and Holm (1983) were as follows:

		cs-137
Gotland	(area 9 and 10):	183
Öresund	(area 13):	172
Smogen	(area 12):	135

From investigations at the nuclear power plants of Olkiluoto and Loviisa in the areas 8 and 11 (Salo, 1980) the following concentration factors were estimated:

		cs-137	Sr-90
Herring	(edible parts):	200	4
Cod	(fillets):	200	1

Studies in the “Greifswalder Bodden” (Arkona Sea, area 2) before 1983 lead to a Cs-137 concentration factor of 170 for cod fillet (IAEA, 1986).

For marine fish an IAEA report (IAEA, 1985) gives a Cs-137 concentration factor of 100 (range 10-300). The Sr-90 concentration factor for the whole fish as far as it is edible is given as 2 (range 0.3-10), whereas the factor for fish flesh is stated to be less than 1.

For the central and southern parts of the North Sea (ICES areas IVB and IVC) Cs-137 concentration factors were derived among other species for fillets of cod and plaice (Steele, 1990). The mean concentration factors and the range of annual means between 1978 and 1985 were as follows:

	Mean	Range
Cod	92	66 to 120
Plaice	39	22 to 45

Our Cs-137 concentration factors of cod from the Kattegat and the Sound are similar to the mean North Sea value. For few samples of plaice from the Kattegat and the Belt Sea we found as to be expected only slightly higher concentration factors than that of 39 in the North Sea, however, they may be biased by not using local near-bottom Cs-137 concentrations in water in our calculations.

Table 7.51. Concentration factors of cod (*Gadus morhua*; fillets)

Subarea	number of years	mean water concentration	concentration factor Bq kg^{-1} per Bq l^{-1}			
		Bq l^{-1} ± 1σSD	mean	minimum	maximum	1σSD
cs-137 :						
1 Åland/Archipel.	2	0.251 ± 0.063	496	407	582	124
2 Arkona Sea	4	0.096 ± 0.005	183	144	225	34
4 South. B. Proper	4	0.101 ± 0.008	178	169	190	9
5 Belt Sea	4	0.076 ± 0.003	125	97	184	40
6 Bornholm Sea	4	0.102 ± 0.003	185	161	209	20
9 Gotland East	3	0.117 ± 0.013	179	162	195	17
11 Gulf of Finland	1	0.135	223			
12 Kattegat	4	0.046 ± 0.009	70	28	133	45
13 Sound	1	0.094	76			
Sr-90 :						
2 Arkona Sea	2	0.017 ± 0.0001	0.46	0.21	0.71	0.35
4 South. B. Proper	4	0.020 ± 0.004	0.46	0.19	0.68	0.21
5 Belt Sea	3	0.016 ± 0.002	0.19	0.17	0.21	0.02
6 Bomholm Sea	3	0.016 ± 0.001	0.26	0.30 0.24		0.03
11 Gulf of Finland	1	0.02	0.76			

Table 7.5.2. Concentration factors in Baltic herring (*Clupea harengus*, fillets)

Subarea	number of years	mean water concentration	concentration factor Bq kg^{-1} per Bq l^{-1}			
		Bq l^{-1} ± 1σSD	mean	minimum	maximum	1σSD
Cs-137 :						
1 Åland/Archipel.	2	0.251 ± 0.063	330	214	445	165
2 Arkona Sea	4	0.096 ± 0.005	46	28	65	15
3 North. B. Proper	4	0.101 ± 0.006	241	200	276	32
4 South. B. Proper	4	0.101 ± 0.008	117	112	124	5
5 Belt Sea	4	0.076 ± 0.003	32	20	48	12
6 Bornholm Sea	4	0.102 ± 0.003	126	110	142	13
7 Bothnian Bay	2	0.123 ± 0.001	256	252	260	5
12 Kattegat	4	0.046 ± 0.009	85	56	142	39
Sr-90 :						
2 Arkona Sea	2	0.017 ± 0.0001	0.26	0.17	0.34	0.12
4 South. B. Proper	3	0.021 ± 0.004	0.43	0.27	0.65	0.20
5 Belt Sea	2	0.016 ± 0.001	0.18	0.14	0.21	0.05
6 Bornholm Sea	2	0.020 ± 0.008	0.43	0.33	0.52	0.13

Table 7.5.3. Concentration factors in Baltic herring (*Clupea harengus*, edible parts)

Subarea	number of years	mean water concentration	concentration factor Bq kg^{-1} per Bq l^{-1}			
		Bq l^{-1} ± 1σSD	mean	minimum	maximum	1σSD
Cs-137 :						
1 Åland/Archipel.	2	0.251 ± 0.063	81	75	87	9
7 Bothnian Bay	4	0.123 ± 0.001	176	161	193	17
8 Bothnian Sea	4	0.213 ± 0.055	147	127	166	17
11 Gulf of Finland	4	0.100 ± 0.025	183	149	207	27
Sr-90 :						
1 Åland/Archipel.	1	0.017	3.8			
7 Bothnian Bay	4	0.016 ± 0.002	6.8	5.3	7.8	1.0
8 Bothnian Sea	3	0.019 ± 0.001	3.2	3.0	3.5	0.3
11 Gulf of Finland	4	0.021 ± 0.001	2.4	1.8	3.1	0.6

Table 7.5.4. Concentration factors of plaice (***Pleuronectes platessa***, fillets)

Subarea	number of years	mean water concentration	concentration factor Bq kg^{-1} per Bq l^{-1}			
		Bq l^{-1} ± 1σSD	mean	minimum	maximum	1σSD
Cs-137 :						
2 Arkona Sea	2	0.093 ± 0.005	133	117	150	23
4 South. B. Proper	2	0.107 ± 0.007	127	111	144	24
5 Belt Sea	1	0.073	56			
6 Bornholm Sea	3	0.103 ± 0.003	106	84	125	21
12 Kattegat	1	0.035	49			
Sr-90 :						
2 Arkona Sea	1	0.018	0.79			
6 Bornholm Sea	1	0.026	0.34			

Table 7.5.5. Concentration factors of flounder (***Platichthys flesus***, *fillets)*

Subarea	number of years	mean water concentration	concentration factor Bq kg-' per Bq l^{1}			
		Bq l^{1} ± 1σSD	mean	minimum	maximum	1σSD
Cs-137 :						
2 **Arkona Sea**	4	**0.096** ± 0.005	117	80	163	34
4 South. B. Proper	4	**0.101** ± 0.008	142	81	206	51
5 Belt **Sea**	1	0.078	108			
6 **Bornholm** Sea	2	**0.101** ± 0.002	153	148	158	7
sr-90 :						
2 Arkona Sea	3	**0.017** ± 0.0001	0.39	0.25	0.6	0.19

Table 7.5.6. Concentration factors of pike (*Esox Lucius,* fillets)

Subarea	number of years	mean water concentration	concentration factor Bq kg^{-1} per Bq l^{-1}			
		Bq l^{-1} ± 1σSD	mean	minimum	maximum	1σSD
cs-137 :						
1 Åland/Archipel.	2	0.251 ± 0.063	141	132	150	13
7 Bothnian Bay	4	0.123 ± 0.005	366	297	418	51
8 Bothnian Sea	4	0.213 ± 0.055	1119	549	1450	429
11 Gulf of Finland	4	0.100+ 0.025	635	561	716	65
Sr-90 :						
1 Åland/Archipel.	1	0.017	1.3			
7 Bothnian Bay	4	0.016 ± 0.001	3.4	2.1	4.4	1.1
8 Bothnian Sea	3	0.019 ± 0.003	2.4	1.8	3.1	0.71
11 Gulf of Finland	4	0.021 ± 0.001	1.4	0.9	2.1	0.52

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