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Nordisk kerne-sikkerheds-forskning

Nordisk kärn-säkerhets-forskning

Pohjoismainen ydin-turvallisuus-tutkimus

Nordic nuclear safety research

RAD-programmet

NKS RAD-2(91)2

Algae as Bioindicators for Radionuclides in Nordic Coastal Waters

A miniseminar held at Forsmark, Sweden Oct. 16-17 1990 under the sponsorship of NKS

Summary of discussions and abstracts of papers

Edited by Georg Neumann and Manuela Notter,
Swedish Envorinmental Protection Agency

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Purpose of the seminar

a) To give a survey of current Nordic activity in the field of research on the uptake of radionuclides in algae.

b) To discuss future Nordic work in the field of marine radioecology.

c) To get a survey of data on radionuclides in algae samples collected by Nordic institutions or scientists.

Introduction

During the later part of the 1970's NKS decided to introduce the bladder wrack (*Fucus vesiculosus*) as a suitable organism for monitoring radionuclides in Nordic coastal waters. During the past few years studies on this subject have been going on to a varying extent in the different Nordic countries. At this miniseminar the participants described different ongoing studies and projects. The lectures are summarized in the abstracts in the appendix, in which the speakers themselves are responsible for their contributions.

Survey of present Nordic activities in marine radioecology

Denmark:

Ongoing and planned activities:
a) Monthly samples of *Fucus* from 6 locations around Zealand. Analyses of ^{137}Cs, ^{134}Cs and ^{99}Tc.

b) Annual fish samples from Denmark, Faroe Islands and Greenland. Analyses were carried out on radiocesium.

c) Two annual water samplings around Zealand, surface and bottom. 16 stations. Analyses were carried out on radiocesium and -strontium.
-Monthly samples from the German Bight and the Kattegat: part of EEC/MAST Marine Tracer Programme in collaboration with France, United Kingdom, Holland and Germany. Analyses of ^{99}Tc.
-Greenland Sea Project: Anthropogenic Oceanographic Tracers in Greenland Sea and Denmark Strait. Analyses of ^{99}Tc, radiocesium and -strontium. Samplings were made in 1988 and 1990.

Finland:

a) A permanent Baltic program is conducted comprising water, sediments, sedimenting material, fish and different indicator organisms. Numbers of stations and collected items: 16 stations for water, 6 stations for sediments, 3 stations for sedimenting material, 6 stations for two fish species and 2 stations for 3 indicator organisms. All samples will be collected annually.

b) Extensive environmental monitoring programs around the nuclear power plants.

c) *Fucus*-sampling is planned for 1991 all around the coast (25-30 stations). The stations are the same as those employed during 1980 and 1987.

Iceland:

a) A program to measure and monitor marine radioactivity in the ocean areas around Iceland is being conducted during 1990-1992, comprising seawater, sediments, fish and *Fucus*. This program is a part of a larger program to measure and monitor marine pollution in the exclusive economic zone of Iceland.

b) Samples of *Fucus* from six locations around Iceland are taken every three months. Analyses of gamma emitters are carried out at the National Institute of Radiation Protection and analyses of ^{99}Tc in a few samples are carried out at Risoe National Laboratory, Denmark.

c) Several fish samples, especially cod, plaice, capelin and herring as well as mussels from the ocean areas around Iceland are collected every year.

d) Some seawater sampling is carried out around Iceland every year, both from the surface and as profiles.

Norway:

a) There is a yearly sampling of *Fucus* from 10 stations along the Norwegian coast and also a monthly sampling program of *Fucus* and water from 1 station (Utsira, see station 10A in Figure 1).

b) *Fucus* samples are collected once a year from 5 stations in the Hardanger Fjord.

The items a) and b) above are carried out by the Institute for Energy Technology (IFE), Kjeller.

c) *Fucus* samples and/or other species of algae will be collected from 5-10 stations at Svalbard in 1991.

d) In 1991, sampling series are planned for Barents Sea (algae, water, fish, sediments etc.). These samples will be collected and analysed in a cooperative effort by the Institute of Marine Research (Bergen), the IFE, the National Institute of Radiation Hygiene (SIS) and the Agricultural Institute of Norway.

Sweden:

a) Sören Mattson, Lund University, is collecting *Fucus* from one station at the

Swedish south coast 4-6 times a year.

b) Environmental monitoring at the Swedish nuclear power plants comprises fish, *Mytilus edulis*, different species of algae (including *Fucus*) and sediments.

c) Algae, especially diatoms and *Cladophora*, spp will be collected around the Bay of Bothnia during the summer 1991 by Pauli Snoeijs, Uppsala University. However it is not yet decided how many of these samples will be analysed for radionuclides.

d) An investigation of sediments and bottom fauna from one site in the Bay of Gävle is being conducted during autumn 1988 by Sverker Evans, Swedish Environmental Protection Agency. The sampling is planned to be repeated in June 1991.

Future tasks

During the concluding discussion the following possible fields for future radioecological activities within the NKS were identified.

-A Chernobyl Data Base

A relatively extensive and resource-demanding work has been carried out in creating a Nordic Chernobyl Data Base, NCDB, in which all relevant analyses from after the Chernobyl accident are planned to be collected. This data base has already been delivered to the relevant authorities in the Nordic Countries, but investigators have not yet been utilizing this data base to any larger extent.

In order make the NCDB more effective for registration of Nordic radioecological data concerning the Chernobyl fallout it would be necessary to let one person work at least half-time on the task. Routines for input and output as well as for different calculations are needed and a detailed manual should also be worked out.

The group agreed upon the necessity of developing the NCDB but could not see any possibility to reserve resources for this within the marine part of RAD-2.

-Development of a Fucus model

Since questions on *Fucus* constituted an important task at the seminar, there were relatively thorough discussions on *Fucus*-data from later years. It was considered worthwhile to start further refinements of the SENSI model introduced by Henning Dahlgaard. Investigations during recent years render material for a summary report on the matter and also provide some clues for future developments of the model. More data sets should be tested and the sensitivity of different parameters within the model should be studied. It is particularly important to identify the accuracy to which, and to within which limitations, the model could be used for *checking* discharges from nuclear power plants.

-Radiation exposure by fish consumption

An important subject is the calculation of radiation doses to man from consumption of fish in the Nordic countries. This could be done after registration of available data in the NCDB. The data should also include ^{210}Po.

In order to obtain sufficient and representative ^{210}Po data it is probably necessary to reserve some resources within the Rad-2 project.

-Nordic cooperation for collection and analyses of Fucus during 1991

Finland is planning a rather extensive series of *Fucus* sampling around the Finnish coast during 1991. Also, Denmark, Norway and Iceland have launched continous *Fucus* programs. After an extra input by Sweden in 1991 we would get a more complete picture of the situation in the Nordic countries. The data could be collected in the NCDB for obtaining a simple, quick and unified way of reporting the material.

-Other items at the meeting

a) An investigation on sediments from the Baltic which has been planned by ICES[1] for the year 1993.

b) A report published by MORS[2] (within HELCOM[3]) on the content of radionuclides in water and sediment samples from the Baltic before and after the Chernobyl accident.

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1) The International Council for the Exploration of the Sea.

2) The Group of Experts on the Monitoring of Radioactive Substances in the Baltic Sea.

3) The Baltic Marine Environment Protection Commission. (The Helsinki Commission)

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Appendix

Abstracts of lectures given at the miniseminar: "Algae as bioindicators for radionuclides in Nordic coastal waters"

Effects of biotic and abiotic factors on the accumulation of radionuclides in *Fucus vesiculosus* L.

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Fucus vesiculosus has been used as an indicator for the occurrence of radionuclides in the marine environment. A prerequisite in using biological organisms as indicators is that the autecology of the organism in question be well known. Growth, reproduction and individual biomass changes of tissues of different ages were studied in a *F. vesiculosus* population from The Sound, southern Sweden. The new vegetative fronds grown during the year accounted for about 80 % of the total plant biomass in the autumn and this could affect the total activity concentration of long-lived radionuclides measured in whole plants of *F. vesiculosus*. Thus, a discharge of long-lived radionuclides during winter or spring gives a higher increase than a discharge during autumn.

Differences in uptake and release of ^{54}Mn and ^{60}Co were observed between *F. vesiculosus* and its epiphytes but also between different tissues within the *Fucus* plant. Highest uptake and release were measured for the filamentous epiphyte *Pilayella littoralis* followed by the new vegetative fronds of *F. vesiculosus* after transplantation in situ from an area outside Barsebäck nuclear power station, southern Sweden, to an area with low concentration of the radionuclides studied and vice versa.

Salinity effects on the accumulation of radionuclides in *F. vesiculosus* were studied experimentally Accumulation of ^{137}Cs, ^{54}Mn, ^{65}Zn and ^{60}Co was significantly higher in algae grown at 8 ‰ than at 15 and 24 ‰, respectively. The most pronounced salinity effects were observed for ^{137}Cs.

The impact of the Chernobyl accident was investigated in the Baltic Sea using *F. vesiculosus*. The Chernobyl accident contributed to the radioactivity in the Baltic Sea primarily concerning radiocaesium.

Radiocaesium in *Fucus vesiculosus* in the Hardanger fjord 1984-89. A preliminary report

Gordon C. Christensen, IFE, P.O. Box 40, N-2007 Kjeller, Norway

The project was initiated in order to study the variation of the content of radioactivity in bladder wrack (*Fucus vesiculosus*) along the Hardanger fjord (Hfj) compared to what was found in the open sea at Utsira. Utsira (sampling point 10A in Fig.1) is an island located about 35 km SW of the mouth of Hfj and belongs to the sampling station network for the survey of radioactivity along the Norwegian coast. This survey was initiated in 1980 as a part of a Nordic project [see report Risø-M-2517 (June 1985) "Bioindicator studies in Nordic waters"] and is still going on. At Utsira *Fucus* and sea water samples are collected monthly, and *Fucus* is collected once a year at the other locations.

The Hfj project comprises 6 sampling locations in Hfj itself (10B and 10E-10I) and 2 locations (10C and 10D) in the Åkra fjord (Åfj), which is a smaller fjord south of Hfj (see Fig 1). Samples of *Fucus* were collected in the summers of 1984, 1986, 1987 and 1989. The results of the ^{137}Cs analyses are illustrated in Table 1 and in Figure 2.

Each salinity value given is representative of the surface water at the time of sampling only. In the inner part of the fjords, the salinity varies rather much with time. Along the Hfj, the mean salinity probably decreases from about 30 ppt at Utsira to about 10 ppt at Fjæra, Odda and Sima (see Table 1 and Fig. 1)

The concentration of ^{137}Cs along the Hfj did not show any clear trend in 1984. Perhaps a possible decrease in the water concentration of ^{137}Cs inwards along the Hfj was outweighed by increased uptake of radiocaesium in the algae because of decreasing salinity. In the years 1986 and 1987 a clear Chernobyl effect is seen in the inner parts of the Hfj. But in 1989 this effect had nearly disappeared.

Samples will be collected also in 1991. The final report of the Hfj project will contain hydrographic data about e.g. salinity and water exchange, if such data are available.

Observation of the Chernobyl fallout in Tvären Bay, Baltic Proper

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The primary radioactive fallout from the Chernobyl reactor accident was early detected in Tvären Bay, Baltic Proper (Fig. 3). A second peak of ^{137}Cs in the water (Fig. 4) occurring one year after the fallout event indicated a supply of water from the highly contaminated Bothnian Sea area. Bladder wrack (*Fucus vesiculosus*) and blue mussel (*Mytilus edulis*) responded quickly to the variations in ^{137}Cs content of the water (Table 2, Figs. 5 and 6). Bladder wrack seems to be a ten times more sensitive bioindicator for radioactive Cs than the blue mussel. An apparent half-time of 29 and 21 days was observed for bladder wrack and blue mussel, respectively, at a mean temperature of 12 °C and 7 ‰ S. A long-term increase in ^{137}Cs content was observed in bottom sediment and benthic infauna.

Macroalgae as indicators of radionuclides in Finnish coastal waters

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Since the late 1960s littoral macroalgae have been used as indicators of radionuclides in Finland. The most common indicator species has been the bladder-wrack *Fucus vesiculosus*, even though the green alga *Cladophora glomerata* has later been included in the environmental monitoring programmes of the Finnish NPPs.

Fucus vesiculosus has proved to be an excellent indicator organism, because of its ability to accumulate effectively many radionuclides and because of its central position in the aquatic ecosystems of the Finnish coast, where the vegetation in general is very poor.

The first mapping of radionuclides in *Fucus* along the whole coast of Finland was carried out in 1980-1981 as a part of the panscandinavian *Fucus* project supported by the NKA. In that study the ^{137}Cs concentrations were relatively low and quite evenly distributed.

The "Monthly *Fucus* " projects carried out at Loviisa in 1983-1984 and at Olkiluoto in 1985-1986 showed how accurately the concentrations of e.g. ^{60}Co and ^{110m}Ag reflected the discharges of these radionuclides from the local NPPs.

In the first phase of the Chernobyl fallout, when only dry deposition had reached the Olkiluoto area, some rare radionuclides were detected only in *Fucus* samples, but not in other sampling objects (Table 3; April 28, 1986 at 18.00 hrs). In the study carried out in 1987 along the whole coast, the ^{137}Cs concentrations in *Fucus* indicated very clear transport of fallout nuclides by river waters and sea currents from highly contaminated areas to those with lower values of atmospheric fallout. Traces of Chernobyl-derived ^{60}Co and ^{65}Zn were also detected along the coast.

All the most important members of the aquatic food web of the Loviisa area were analysed for gamma-emitting radionuclides in 1988-1989. The study confirmed the very good indicator capacity of *Fucus vesiculosus* in radioecological monitoring of both fallout nuclides and local discharges, although the highest values of radioactive cesium were detected in flesh samples of some predatory fish and birds, as well as in seals. Compared with Cladophora, *Fucus* proved to be more sensitive in discovering of most radionuclides.

Icelandic action plan to measure and monitor marine pollution

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In accordance with proposals put forward by a task group appointed by the Minister of Communications to monitor marine pollution in the Exclusive Economic zone, the Government of Iceland has agreed to conduct a program of scientific research to measure pollutants in both marine organisms and their environment, which commenced in 1989, and will conclude in 1992.

1 *The task group's proposals*

Since special studies on marine pollution in Icelandic waters have not up to now been carried out regularly nor on a comprehensive basis it is necessary in the proposed period to acquire base-line data that can be used as a basis for further programs of research and standardized measurement activities. Furthermore, the task group's proposals assume that Iceland will participate in the Joint Monitoring Program of the Oslo and the Paris Conventions for monitoring the distribution and effects of pollutants in the North East Atlantic Ocean (convention area), to be conducted in 1990 and 1992. The task group considers it to be of primary importance that all surveys and research in this field be conducted according to internationally agreed methods so that results will be recognized by the international community as reliable and performed in a professional manner.

2.1 *The action plan*

Measurements will be conducted on the concentration of pollutants in organisms, seaweed and seawater. Analyses will be carried out on different items; the concentration of heavy metals in organisms and seawater; radionuclides (beta and gamma emittors) in organisms, and seawater; the concentration of persistent organic substances in organisms; and the concentration of nutrients in seawater. The collection of organisms and seawater samples will be made by personnel from the Marine Research Institute while the collection of seaweed will be in the hands of personnel attached to the Marine Research Institute, Icelandic Fisheries Laboratory and the State Directorate of Shipping stations around the country. The analyses of samples will be carried out as follows: The Icelandic Fisheries Laboratory will conduct analysis of heavy metals in organisms. The Marine Research Institute will determine the concentration of heavy metals as well as the concentration of nutrients in seawater samples and the National Institute of Radiation Protection will carry out gamma radiation measurements in organisms, seawater and seaweed, while the University of Iceland will be responsible for measuring beta radiation. Planned research facilities at the Fisheries Research Laboratories and the Department of Pharmacology, University of Iceland, were ready for use early in 1990 and are capable of measuring persistent organic substances which should ensure that necessary measurements for these substances can be carried out late in the year 1990.

The procedures for collection samples, their preparation, and the analysis of pollutants will be conducted according to standard methods approved by pertinent international institutions.

2.1.1 *Sampling*

The following marine organisms will be collected:

Cod, plaice, mussel, capelin and herring and bladder wrack (*Fucus vesiculosus*).

These species will be sampled once annually, and in the case of fish, prior to each species' spawning season, in the years 1990, 1991 and 1992. A sampling schedule was already approved in 1989 for measuring pollutants in plaice and capelin. The samples are collected in the primary fishing grounds of the species concerned. In contrast, mussels are collected annually at four locations around Iceland, i.e. in Faxaflói Bay and off the southern, northern and eastern coasts of the country.

Seawater samples are collected at five locations within the Marine Pollution Control Zone of Iceland.

These locations are:

1 The continental shelf west of Faxaflói Bay, (The Irminger Current).
2 At 68 00'N and 12 30'W, (The East Icelandic Current).
3 In Central Faxaflói Bay, (Shore-based effects).
4 At 66 09'N and 27 15'W, (The East Greenland Current).
5 At 63 40'N and 13 40'W, (The North Atlantic Current).

Seawater samples are collected twice annually, in the period March-May and in July-August.

In the years 1990 and 1992 vertical sectional samples will be collected, i.e. samples from the surface to the bottom layers at the continental shelf locations in Faxaflói Bay and at 68 00'N and 12 30'W. Only surface samples will be taken at other locations. In the year 1991, only surface samples will be collected at the seawater sampling locations.

The collection of seaweed is being carried out every third month off the coast at the following locations:

The Westman Islands, Snæfellsnes Peninsula, Bjargtangar, Straumnes, Grímsey, Stokksnes Peninsula and Dyrhólaey (Portland).

An overview of the sampling sites is displayed in Figures 7 and 8.

2.1.2 *Pollutants analysed*

Organisms are analysed for concentrations of heavy metals, i.e. mercury (Hg), cadmium (Cd), lead (Pb) and zinc (Zn); the concentration of persistent organic substances PCB and DDT, and the concentration of radioactive substances, e.g. radiocesium and -strontium.

Seawater is analysed for heavy metal concentrations, i.e. mercury (Hg), cadmium (Cd), zinc (Zn) and copper (Cu), as well as levels of radioactive substances.

The concentration of radioactive substances in seaweed samples is also analysed.

2.2 *Research and measurement in response to accidental pollution.*

It is proposed to set up an emergency plan for monitoring pollution in cases of conceivable pollution accidents which can be foreseen to occur and cause pollution within the Marine Pollution Control Zone (Exclusive Economic Zone), e.g. concerning the passage of vessels and aircraft carrying hazardous substances through the Zone. It is vital that such emergency plans are ready if and when such accidents occur, thus reinforcing the effectiveness of the decisions to be made in response to pollution hazards. Under the present circumstances the danger of pollution accidents involving the transportation of oil and radioactive substances are the main sources for concern.

According to the task group it would be most practical for such emergency plans to be developed by the appropriate professional agencies i.e. the Directorate of Shipping and the National Institute of Radiation Protection.

2.3 *International cooperative ventures*

It is essential that Iceland actively participates in the international cooperation which is being conducted on monitoring marine pollutants. By carrying out this plan of action, conditions for such participation will be established. It is proposed that the Marine Research Institute participates in the cooperative committees of the Oslo and the Paris Conventions on marine pollution monitoring in close cooperation with the State Directorate of Shipping as being responsible for implementation of international conventions for the prevention of marine pollution.

2.4 *Proposed costs*

The estimated total costs of the plan according to current price levels is ISK 18,280,000 and is distributed each year of the time plan as follows:

1989 ISK 1,500,000
1990 ISK 6,010,000
1991 ISK 4,760,000
1992 ISK 6,010.000

2.5 *The management of the action plan*

In order to secure a purposeful execution of the plan the Minister of Communications has appointed a three-member project management team, consisting of the following members:

> Magnús Jóhannesson, State Directorate of Shipping, chairman
> Jón Ólafsson, Head of Division, Marine Research Institute
> Sigurdur Magnússon, Director, the National Institute of Radiation Protection

The role of the project management team, responsible to the Minister of Communications, is as follows:

> To administer the distribution of funds budgeted to the project.
>
> To administrate the relationship between participants (surveys, problem solving).
>
> To monitor and manage the progress of the project (comparative measurements, progress reports).
>
> To collect and interpret the results and present them to appropriate groups, both internationally and in Iceland (annual reports, final reports).

3 *Results*

A limited number of results are presently available.

The analyses of cesium in fish and *Fucus* in 1990 show very low values. Traces of cesium-137 can be found in *Fucus vesiculosus*. less than 1.0 Bq/kg dw in all samples, see Table 4. Traces of cesium-134 are not found in any of these samples. Analysis of Technetium-99 will be carried out at Risø to determine Sellafield traces. Values of cesium-137 in fish in 1990 are low, ranging from 0.2 Bq/kg in haddock to 0.5 Bq/kg in halibut. Cs-134 was not found in any of these samples. Analyses of sea water have not been carried out in 1990. Several seawater samples were collected and will be analysed in 1991.

Benthic diatoms as monitoring organisms for radionuclides in a brackish-water coastal environment

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Natural benthic diatom communities react fast to different types of radioactive discharge. Concentrations in diatoms were significantly related to the continuous discharge from the Forsmark nuclear power plant; the level of radionuclides was related to distance from the discharge point and to hydrographic factors. Concentrations in diatoms after the Chernobyl fallout showed that the radionuclides disappeared faster with more flushing of the site and shorter physical half lives.

A relatively large part of the radionuclides is recycling within diatom communities. The radionuclides are continuously built in to next generations of cells by cell division in which one valve is given to each of two daughter cells.

Uptake of ^{137} Cs was faster (double) and recycling less (half) in a site with 10 °C higher water temperature compared with the unheated reference site.

Concentration factors for diatom communities were calculated to be ca. 8 300 for ^{137}Cs, 140 000 for ^{65}Zn, 190 000 for ^{60}Co, 240 000 for ^{54}Mn and 330 000 for ^{110m}Ag (on dry weight basis for a site with fast flowing water, so they are even higher in stagnant water). The differences between the different radionuclides were larger in macroalgae, which may indicate that adsorption by ion-bonds is more important in diatoms.

Diatoms have higher surface/volume ratios and faster growth rates throughout the year compared with macroalgae, and thus provide a larger cell surface area for adsorption and absorption of radionuclides. Diatoms have higher radionuclide concentrations than macroalgae under the same discharge load and low discharges can still be detected in diatoms when they are under the detection limit for macroalgae.

Diatoms are important food sources for macro-, meio- and microfaunal filter feeders and grazers, and give measures of the direct dose to higher trophic levels.

Growth factors and physiological state are of minor importance for radionuclide concentrations in diatoms throughout the year. Diatoms have a large species-pool (400-500 in Forsmark) and a variety of growth forms and life-history strategies, so there are diatoms for all environmental conditions.

Disadvantages of using diatoms as monitoring organisms for radioactive discharges are in the field of gathering samples. It might be difficult to obtain enough diatom material in certain environments. At Forsmark diatoms are promoted by the heated water (no ice cover) and low salinity (5 ppt.).

Radionuclide concentrations in macroalgal samples may be strongly influenced by epiphytes with high surface/volume ratios (e.g. diatoms), depending on the season and the degree of cleaning the macroalgae from epiphytes.

"SENSI": A model describing the accumulation and time-integration of radioactive discharges in bioindicators exemplified by *Fucus*

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Fucus vesiculosus is widely used as a bioindicator for radioactive discharges in coastal waters.

The effects of salinity, temperature and light on the initial rate of uptake of several radionuclides and long-term loss rates have been studied under laboratory and semi-field conditions.

Some of these results are utilized in the model "SENSI", which describes the accumulation and loss of several radionuclides as a function of month of discharge and month of sampling.

The concepts behind "SENSI" are described and its capabilities are demonstrated by comparing calculated concentrations of ^{65}Zn, ^{60}Co, ^{58}Co and ^{54}Mn with measured values in *Fucus* sampled monthly at the Swedish nuclear power plant Ringhals.

Ref.: Dahlgaard, H., S. Boelskifte: "SENSI": a model describing the accumulation and time-integration of radioactive discharges in bioindicators (*Fucus* and *Mytilus*) including seasonal variation. Det fjerde nordiske Radioøkologiseminar, 27 februar - 1 marts 1985, Gol, Norge.

Bladder-wrack (*Fucus vesiculosus*) as an indictor for radionuclides in the environment of Swedish nuclear power plants.

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Results from gamma radiation analysis of samples of bladder-wrack (*Fucus vesiculosus*) growing in the aquatic environment of Swedish nuclear plants, are discussed. The concentrations of the main nuclides, viz. ^{60}Co, ^{58}Co, ^{65}Zn, ^{54}Mn and ^{110m}Ag are reported. Series of samples from the environment of Ringhals (at the Swedish west coast) and of Simpevarp (at the Baltic proper) were collected during the years 1979-1982 and 1981-1982, respectively. The data for ^{60}Co and ^{65}Zn were analysed using the SENSI method (Dahlgaard and Boelskifte, see abstract in this report) which is a tool for correlating the concentration of radionuclides in *Fucus* with the corresponding discharges from the power plant. Examples of the correlation between measured and calculated values for ^{60}Co and ^{65}Zn for two stations near the outlets (station 3 at Ringhals situated 400 m north from the outlet and station 2 at Simpevarp 200 m north from the outlet) are given in Figure 9 - Also, on a small series of ^{60}Co data from Simpevarp, a model was tried based on kinetic constants for uptake and elimination. The nuclide concentrations in *Fucus* as a function of the distance to the point of emission were also studied, as well as transfer factors for the different nuclides. Finally the accuracy which can be expected when using *Fucus* for checking discharges from a power plant is discussed.

Table 1
Fucus vesiculosus from the Hardanger Fjord 1984-89
Concentration of ^{137}Cs (Bq kg^{-1} d.w.)

Location	1984		1986		1987		1989	
	sal.	conc.	sal.	conc	sal.	conc	sal.	conc.
10A Utsira	27	9.7	29	20.3	32	9.5	31	4.3
10B Sveio	-	12.4	-	19.6	-	-	-	-
10E Husnes	24	8.6	-	24.1	30	7.4	20	na.
10F Str.barm	17	9.5	-	38.5	26	12.4	11	5.2
10G Ålvik	9	9.5	-	37.6	12	8.6	7	na.
10H Sima	2	7.2	-	266	10	63.1	3	12.0
10I Odda	2	11.3	-	-	-	-	-	-
10C Skånevik	23	10.8	-	-	-	-	-	-
10D Fjæra	1	12.8						

sal. = salinity in ppt. (‰)
\- = no data
na. = not analysed

Table 2. Concentration of radionuclides (Bq kg^{-1} dry weight) in bladder wrack in Tvären Bay.
Reference date = sampling date.

date	^{40}K	^{54}Mn	^{60}Co	^{95}Zr	^{95}Nb	^{103}Ru	^{106}Ru	^{131}I	^{134}Cs	^{137}Cs	^{140}Ba	^{140}La	^{141}Ce	^{144}Ce
860506	not det.		93±23	840±80	1220±80	1740±110		21600±900	162±19	300±50	2000±700	1610±170	950±130	710±230
860522	970±50	8±3	80±4	3470±50	6590±50	830±50	275±32	not det.	143±5	281±7			2990±110	2260±470
860708	853±46		114±5					not det.	18±2	54±4				
860806	752±48		52±3					not det.	17±2	42±4				
860924	780±110		57±6					not.det.	21±4	56±8				
870428	1050±60		62±4						69±3	174±6				
870604 1										246±5				
870709	804±22	3±1	60±2						82±1	225±5				
870715 3	933±34		5±2						74±2	186±5				
870811	858±35								85±2	224±5				
870921 2									74±4	212±7				
871110 2									65±2	187±5				
871214 2									68±2	200±5				
880205	1120±50		50±3						59±3	180±5				
880406 2									52±1	174±5				
880526	783±33		29±2						47±2	172±5				
880629 2									80±2	270±5				
880804	779±29		21±1						55±1	201±5				
881006	820±41		31±2						33±2	129±5				
890103	1500±56		not det.						35±1	160±10				
890522	959±42		24±2						31±2	136±5				

1 Determination of ^{137}Cs only
2 Determination of ^{134}Cs and ^{137}Cs only
3 Sample from Askö, 7 nautical miles NNW of Tvären Bay

not det. = not determined

Table 3. The radioactivity in *Fucus vesiculosus* (Bq kg^{-1} d.w.) at sampling station Olkiluoto A in 1985 and 1986.

Date	15.8.1985	28.4.1986 18.00	21.5.1986	14.8.1986
^{7}Be	46	74	0	43
^{40}K	650	590	690	690
^{54}Mn	68	18	37	57
^{58}Co	25	0	0	14
^{60}Co	100	70	110	94
^{65}Zn	21	3,3	23	26
^{89}Sr	0	-	-	25
^{90}Sr	15	-	-	14
^{95}Zr	0	690	110	4.2
^{95}Nb	0	920	220	7.6
^{95m}Nb	0	10	0	0
^{103}Ru	0	570	1900	52
^{106}Ru	0	110	590	61
^{110m}Ag	9.5	2.2	170	62
^{125}Sb	0	0	24	4.0
^{129m}Te	0	22	2800	0
^{131}I	0	410	29000	6.8
^{132}Te	0	500	300	0
^{134}Cs	0	8.3	710	140
^{136}Cs	0	3.4	150	0
^{137}Cs	7.0	25	1300	280
^{140}Ba	0	1000	4700	0
^{140}La	0	810	3700	17
^{141}Ce	0	690	94	1.7
^{144}Ce	0	360	130	7.1
^{144}Pr	0	320	65	0
^{147}Nd	0	230	0	0
^{237}U	0	38	0	0
^{239}Np	0	3500	0	0

0 = below the detection limit
\- = not analysed

Table 4. Cs -137 (Bq kg^{-1} d.w.) in bladder-wrack. The appropriate sampling sites are seen in Figure 8.

Station	Dec.1989	Sd %	Mars 1990	Sd %	June 1990	Sd %
1. Vestm.eyjar	0.5	19.5	0.3	15.7	0.4	25.8
2. Stokksnes	0.5	14.5	0.8	17.1	0.5	12.4
3. Fáskrúðsfj.	0.7	13.6	0.3	21.9	0.3	15.1
4. Grímsey	0.8	24.6	0.5	19.3	0.7	14.1
5. Arnarnes	0.8	22.4	0.3	19.8	0.5	19.6
6. Hellissandur	0.5	15.5	0.3	20.1	0.3	18.1

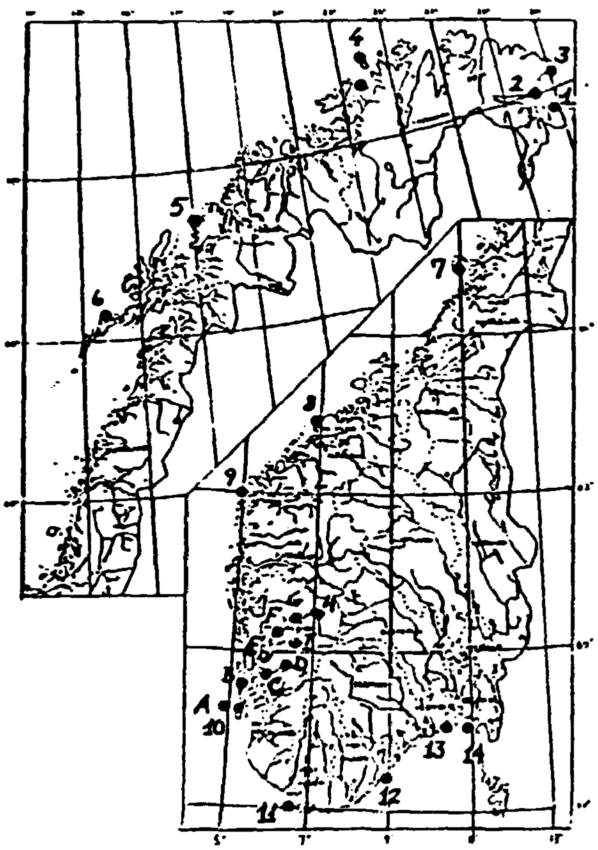


Figure 1. Sampling points for *Fucus vesiculosus* in Norway.

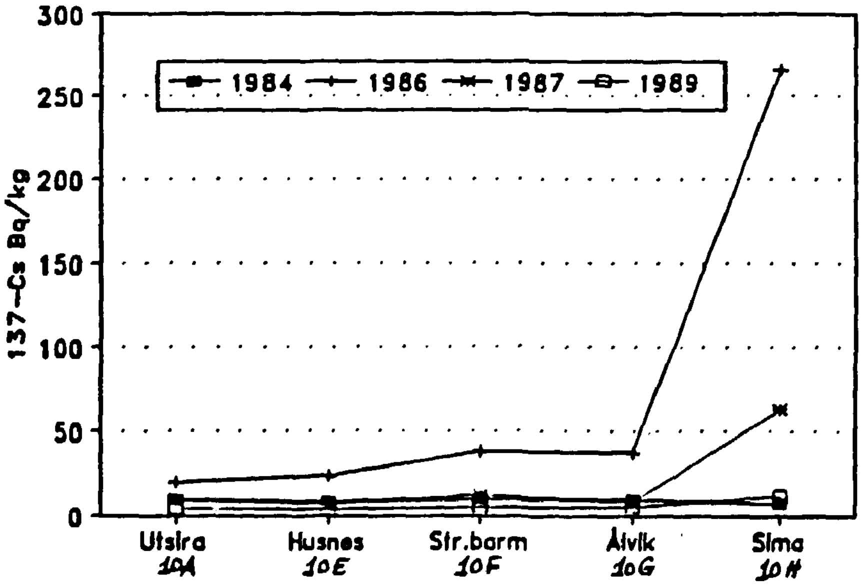


Figure 2. The concentration of ^{137}Cs in *Fucus vesiculosus* at stations in the Hardanger Fjord and outside its mouth.

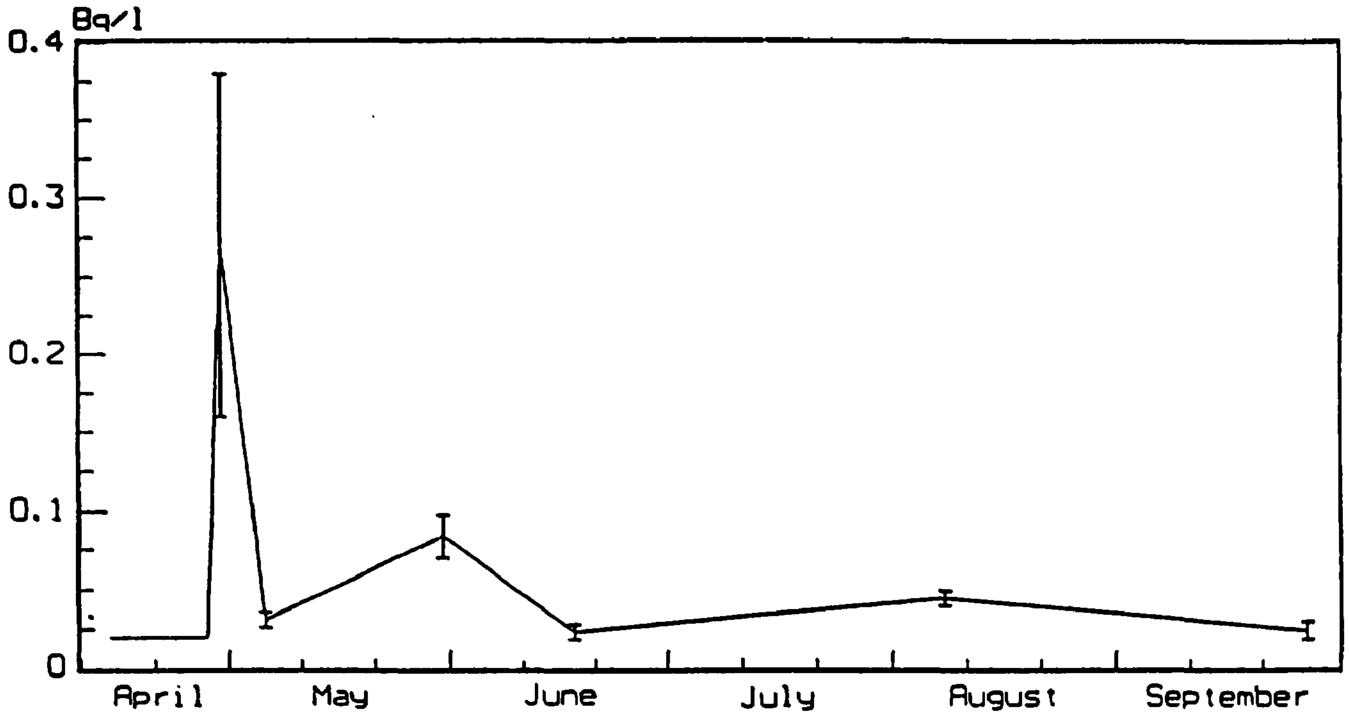


Figure 3. Concentration of ^{137}Cs in surface water in Tvären Bay following the two pulse-releases from the Chernbyl site.

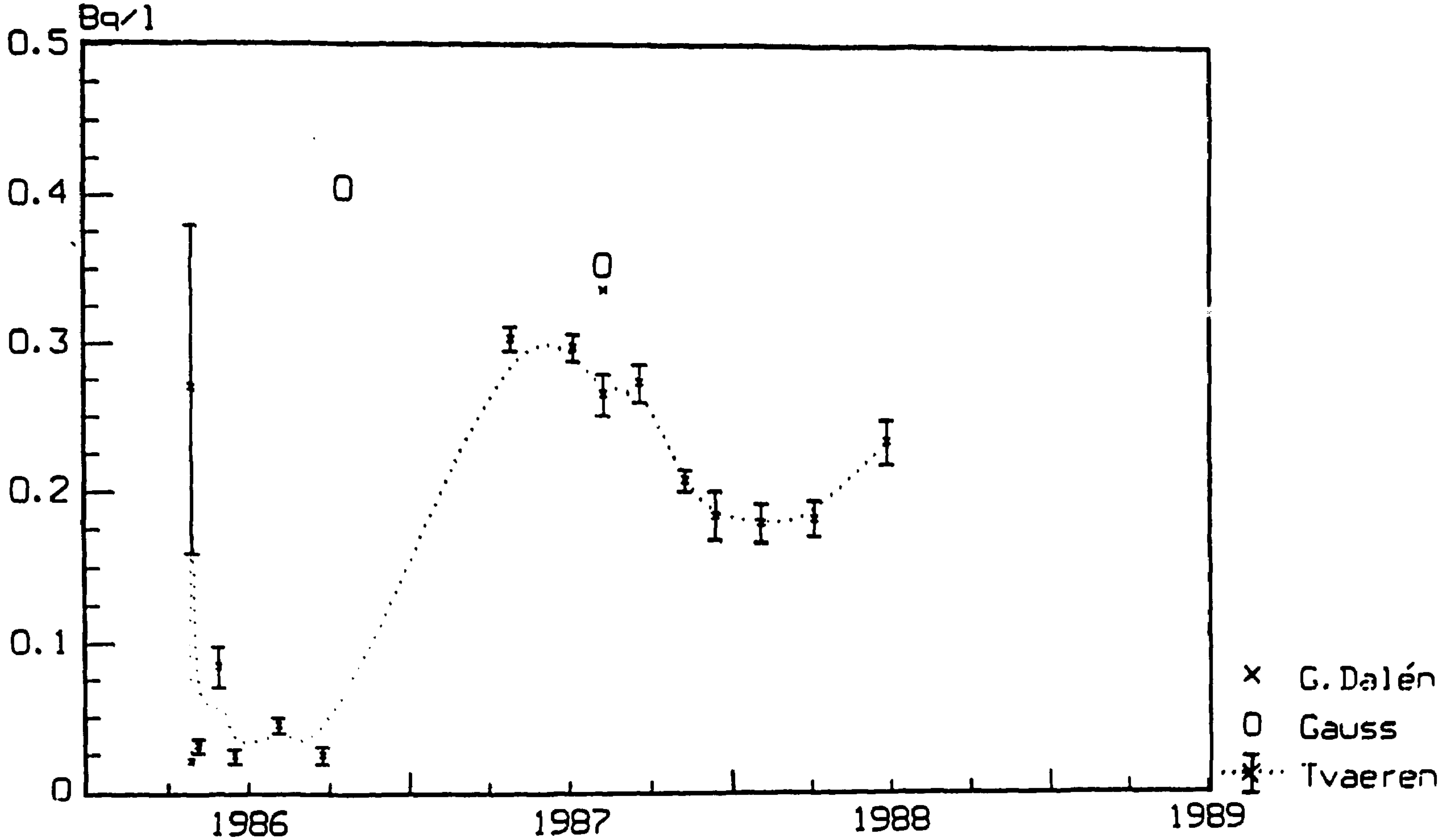


Figure 4. Concentration of ^{137}Cs in surface water in Tvären Bay 1986-1988. Values from the light-house Gustaf Dalén (N 58° 36' E 17° 29') as well as results from research vessel C.F.Gauss are also included.

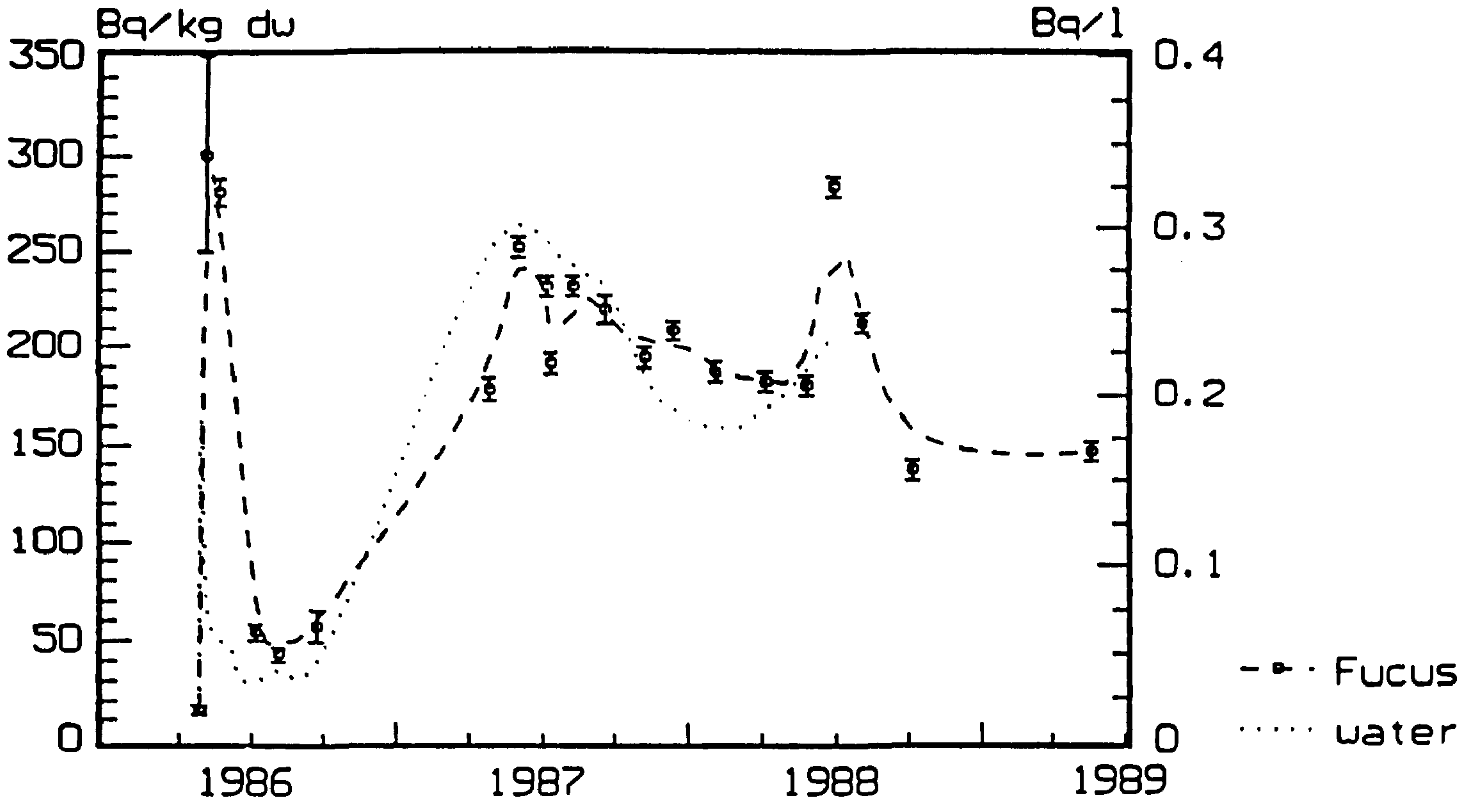


Figure 5. Concentration of ^{137}Cs in water and bladder-wrack from Tvären Bay.

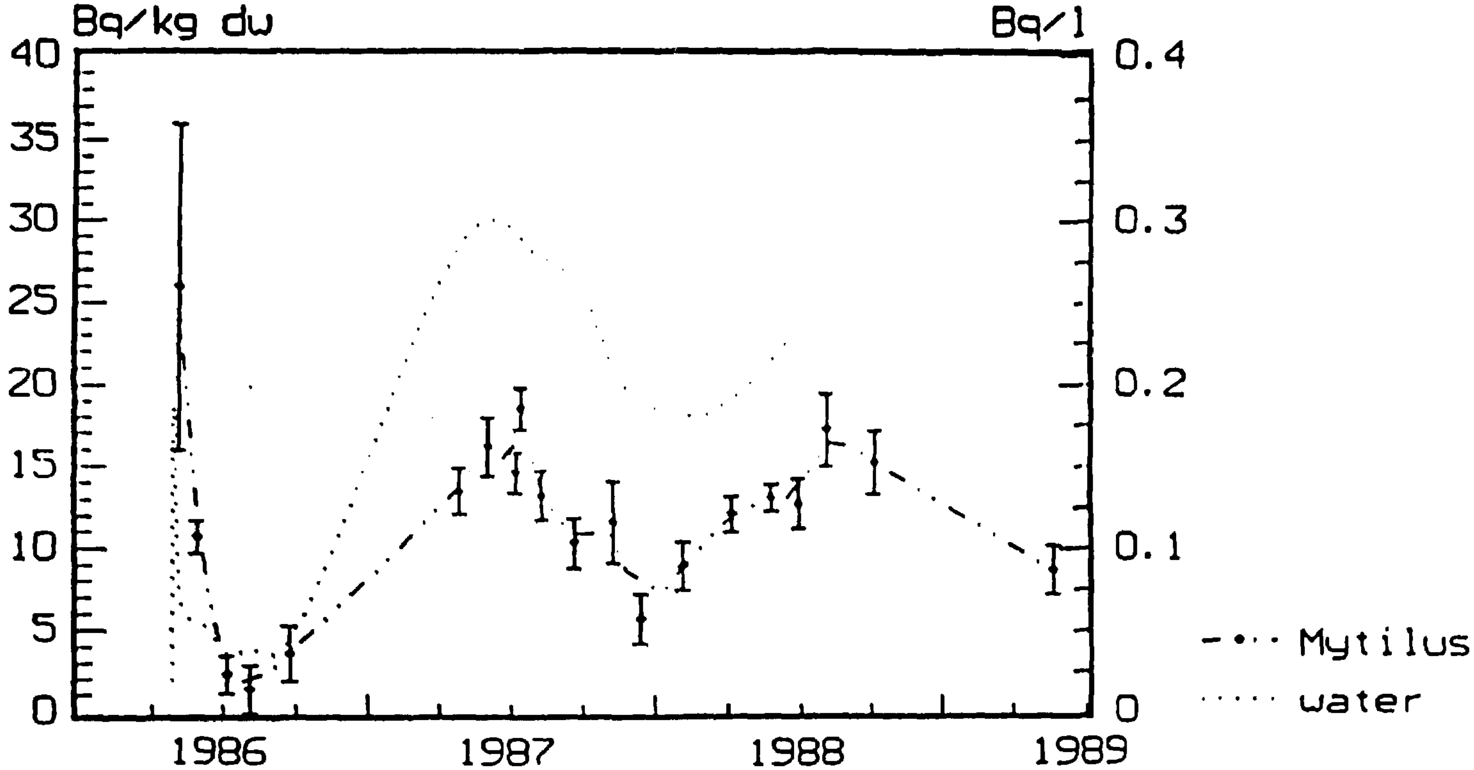


Figure 6. Concentration of ^{137}Cs in water and blue mussel from Tvären Bay.

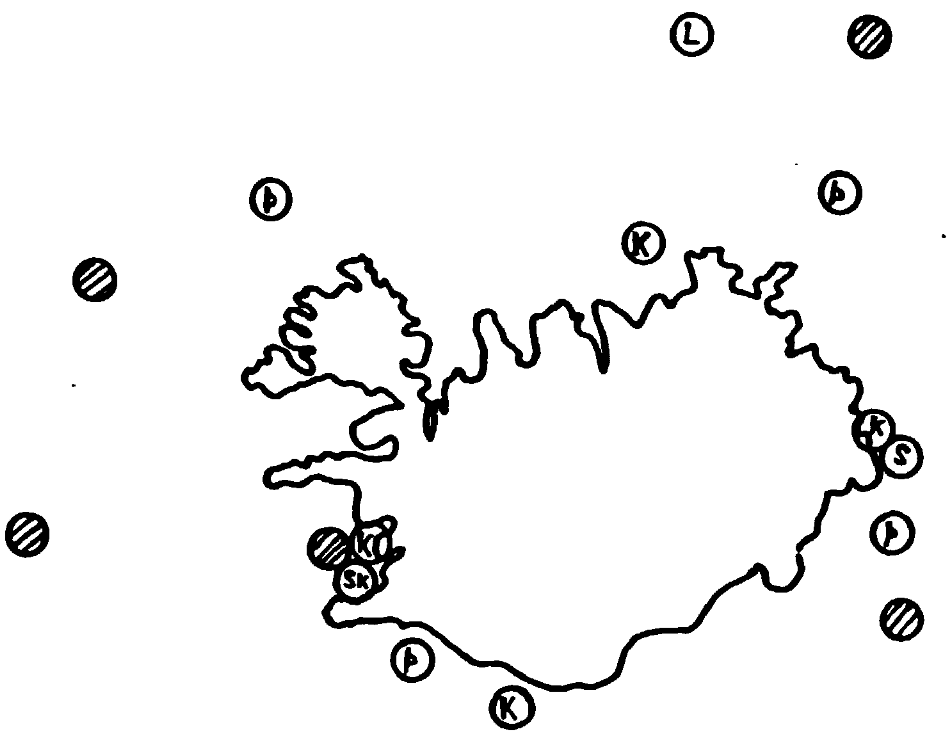


Figure 7. Sampling sites at Iceland.

Water	▨	**Mussels**	(K)	**Cod**	(Þ)
Herring	(S)	**Capelin**	(L)	**Plaice**	(SK)

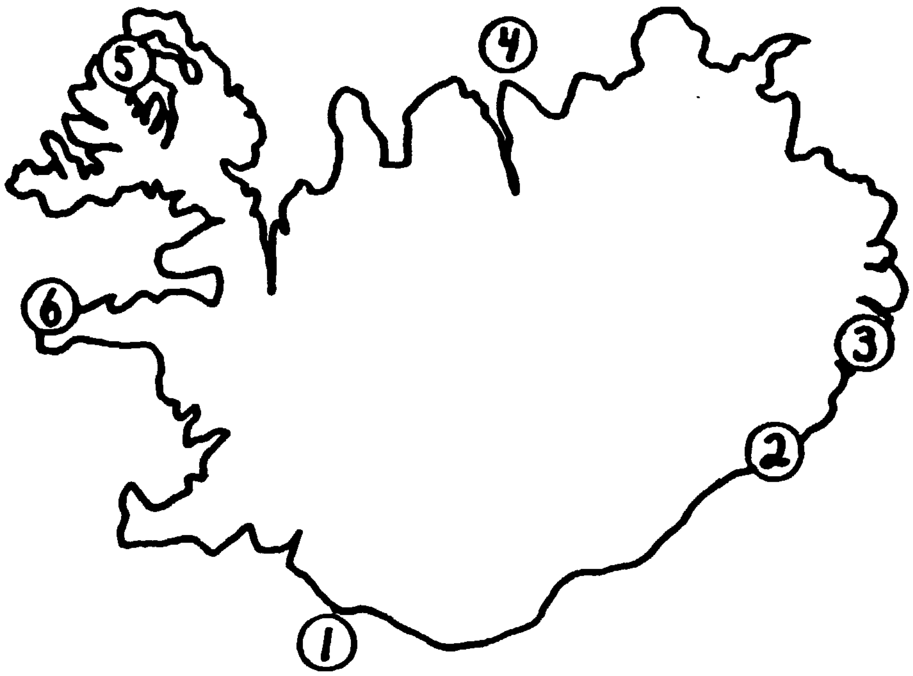
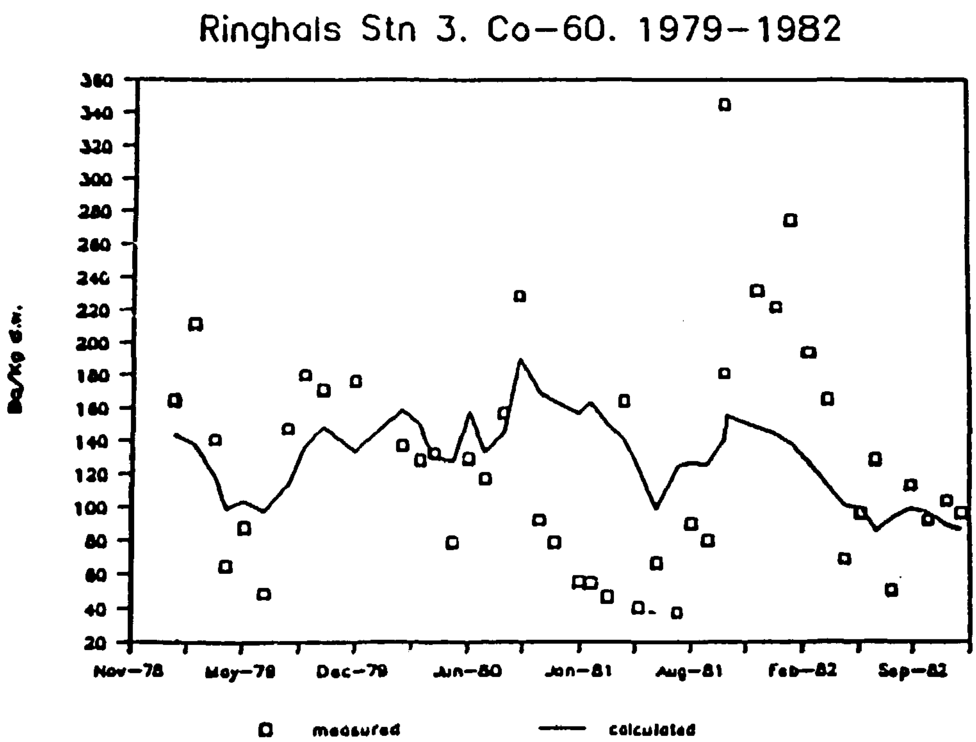


Figure 8. Sampling sites at Iceland for bladder-wrack (*F.vesiculosus*).

Figure 9. Measured concentrations (Bg kg[-1] d.w.) of ^{60}Co and ^{65}Zn in *Fucus* at station 3 at Ringhals and station 2 at Simpevarp compared with values calculated by means of the SENSI method.



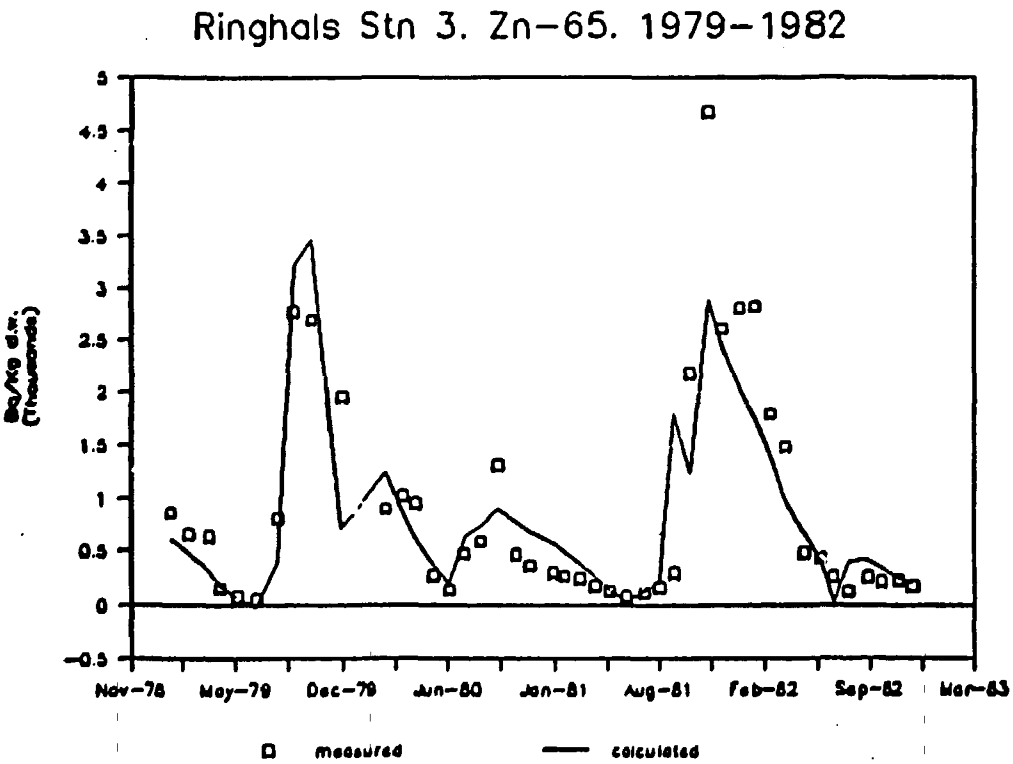
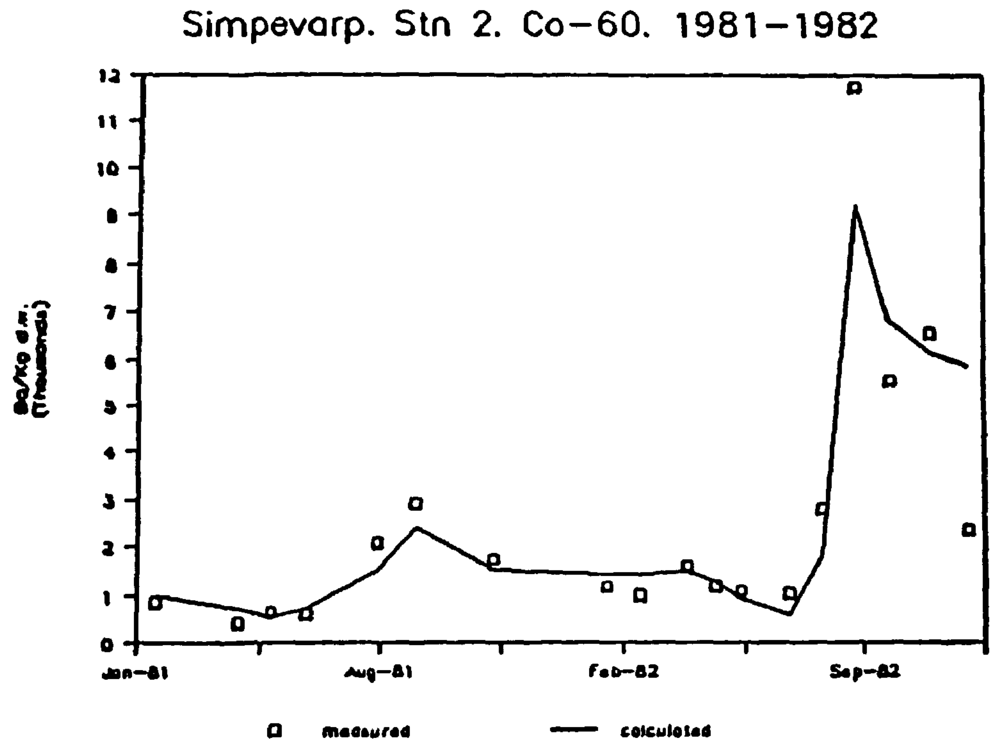
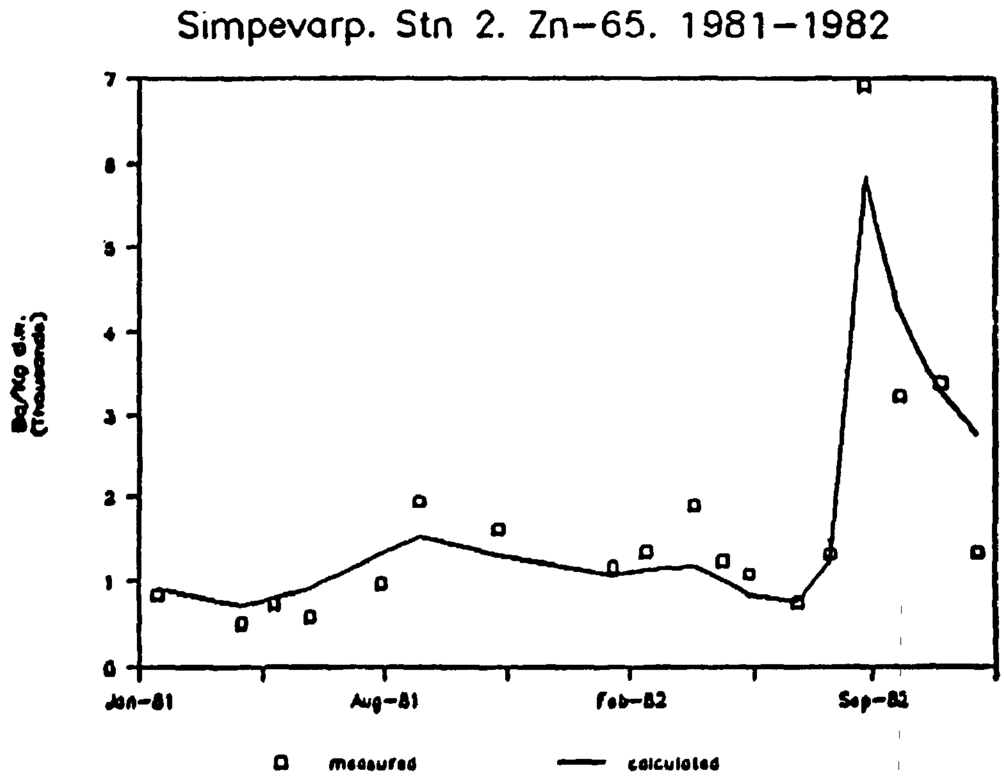


Figure 9. (Continued)





Tryk: Grafisk Service, RISØ